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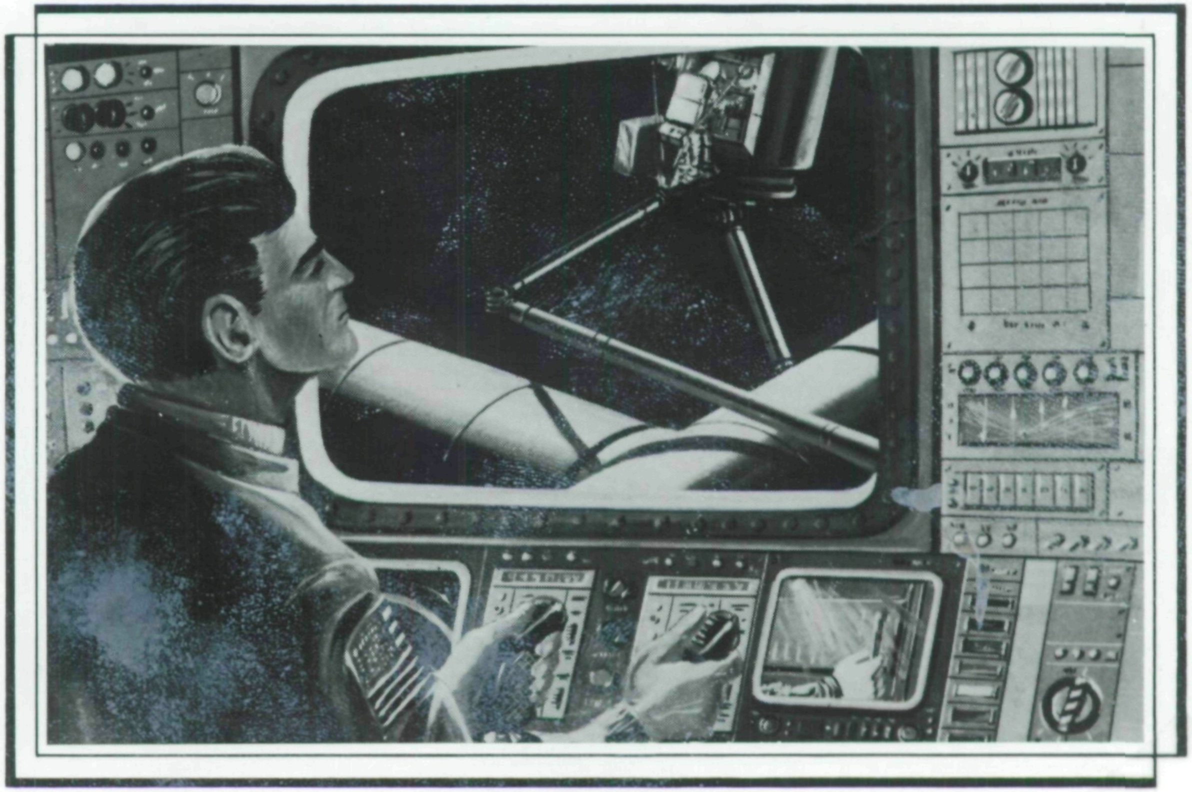
final report

SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS

volume I

executive summary



GRUMMAN

COMSAT GENERAL

GENERAL ELECTRIC

final report

SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS

volume I
executive summary

prepared for
National Aeronautics and Space Administration
Headquarters
Washington, D.C. 20546

under contract NASW-3685
Space Station Task Force
Contracting Study Project Manager — E. Brian Pritchard

by
Grumman Aerospace Corporation
Bethpage, New York 11714

report no. SA-SSP-RP007

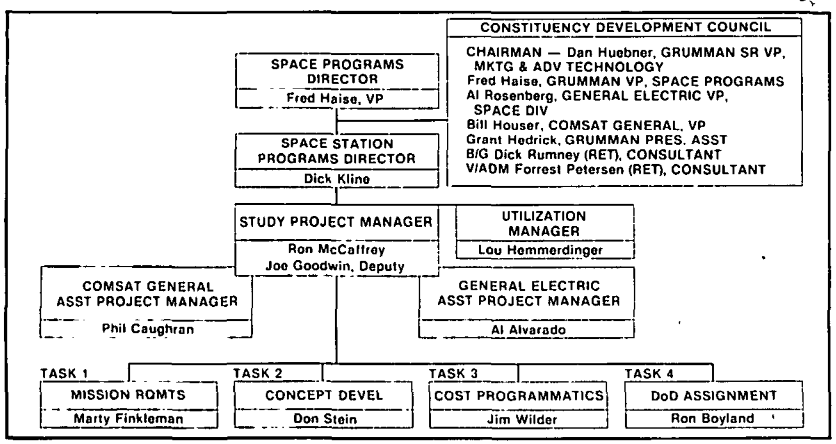
20 April 1983

PREFACE

The study of Space Station Needs, Attributes, and Architectural Options was an eight month effort, focusing on manned space activities during the 1990s that would either require or materially benefit from a manned Space Station. This study was performed by Grumman Aerospace Corporation, with General Electric and COMSAT General as teammates, under contract NASW-3685 for the National Aeronautics and Space Administration, Headquarters' Space Station Task Force.

The NASA Contracting Officer's Representative and Project Study Manager was E. Brian Pritchard. Technical monitor for the DoD Space Station Working Group was Capt. James Schiermeyer AFSD/XR, who was assisted by John Baker of the Aerospace Corporation.

This contract was performed within the Grumman Space Station Programs organization directed by Dick Kline. Grumman's Project Study Manager was Ron McCaffrey who was assisted by Deputy Project Manager Joe Goodwin, and Assistant Project Managers, Al Alvarado of General Electric and Phil Caughran of COMSAT General. Grumman's study organization is shown below:



This executive summary provides an unclassified overview of the entire study effort. Results of the overall study are described by the following Final Report documentation:

- Volume I, Executive Summary, Report No. SA-SSP-RP007, 20 April 1983
- Volume II, Technical Report, Report No. SA-SSP-RP008, 20 April 1983
  - Book 1 Mission Requirements
  - Book 2 Mission Implementation Concepts
  - Book 3 Cost and Programmatics
  - Book 4 Military Mission Assessment (Classified)
- Final Briefing, Report No. SA-SSP-RP009, 5-9 April 1983
  - Part 1 Summary
  - Part 2 Mission Requirements
  - Part 3 Commercialization
  - Part 4 Technology Development
  - Part 5 Systems
  - Part 6 Costing
  - Part 7 DoD Summary (Classified)
  - Part 8 National Security (Classified).

Significant contributions were made to the Grumman study effort by its two teammates as follows:

- COMSAT General defined Space Station requirements and benefits for commercial communication satellites and defined the on-board RF communication subsystem.
- General Electric defined Space Station requirements and benefits for selected areas of science and applications, commercial processing and remote sensing, and national security missions. In addition, they defined architectural concepts for the data management subsystem.

Technical progress was reviewed periodically during the study by a seven member intercompany Constituency Development Council (CDC).

The CDC also provided guidance to parallel corporate funded activities to develop Space Station advocates and constituents within non-aligned commercial companies.

We wish to acknowledge contributions from British Aerospace, MBB/ERNO, and Dornier Systems for information on European mission requirements and hardware definitions, for which each company is particularly competent.

Questions regarding this study should be directed to:

E. Brian Pritchard MFA-13	Ronald W. McCaffrey
Contracting Project Study Manager	Space Station Project Manager
NASA Headquarters	Grumman Aerospace Corporation
Space Station Task Force	Bethpage, N.Y. 11714
Washington, D.C. 20546	

CONTENTS

1.1 STUDY APPROACH OVERVIEW

The study of Space Station Needs, Attributes, and Architectural Options was a broad based mission analysis contract to determine key missions and benefits that justify a Space Station, develop a supporting constituency, and define a reasonable plan to implement the recommended architectural concept. Grumman's team investigated four different categories of domestic and foreign missions: science and applications, commercial, U.S. national security, and technology development. Space operations carried out on the station were considered as services to the four prime mission categories.

The study was structured with four major tasks covering mission requirements, mission implementation concepts, cost and programmatics, and a special DoD task assignment. As shown in Fig. 1-1, the first half of the study focused on the definition of potential Space Station missions including their benefits and requirements, and the development of realistic mission models. The remaining effort concentrated on desired Space Station attributes and analysis of alternate architectural concepts leading to the recommended initial/evolved Space Station concept, including its accrued benefits and costs. A special task was performed in parallel for DoD, which assessed the military utility of a manned Space Station system. As planned, NASA and DoD provided a minimum of detailed direction during this study, thereby avoiding the infusion of government ideas into those of industry. Scheduled reviews with the

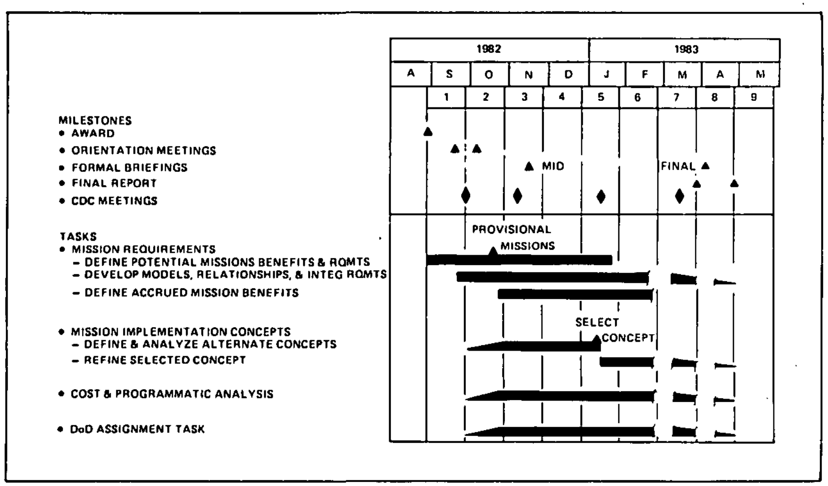


Fig. 1-1 Space Station Needs — Options Study Schedule

Grumman team Constituency Development Council were invaluable to our collective effort in obtaining executive level perspective to verify that key issues and user mission options were being addressed.

Our major thrust was in the analysis of viable Space Station missions and quantification of inherent Space Station benefits. Greater emphasis was given to the analysis of space operations, U.S. national security, and commercial space missions, since we believed these catagories offered the greatest potential payoff. Potential users of the Space Station were contacted for input on their specific mission requirements. For example, to validate their needs and assess our analysis of benefits, the Grumman team conducted a vigorous survey of future space activity directed toward the commercial sector. Each contact was keyed to the particular company background and directed toward promoting the potential value of a manned Space Station in market areas of direct interest to that company.

Grumman concentrated on material processing in space (MPS). A market analysis was made, under contract, for selected high value products such as HgCdTe and GaAs crystals. Data was obtained from various company and university contacts on these materials and used to develop alternate scenarios for analysis of incremental Space Station benefits. Under corporate funding, a special effort was also made to develop a commercial constituency among non-aerospace industries. High technology companies in metals, semiconductors, and biological separation areas were targeted to discuss the development of spaceborne experiments or processes. As a result of initial meetings with company officers and research personnel, several companies have become interested in pursuing MPS activities, although at widely varying depths of involvement. Contacts were also made at universities and institutions to assess the validity of the proposed areas of specialization. We have been quite successful in our campaign; information from the user community has been used to identify and verify our missions and we are moving forward in an effort to develop a Shuttle payload.

General Electric focused on commercial earth observations and pursued other MPS avenues. GE made a concerted effort within their own company to initiate interest in the use of space to enhance or make new commercial products. Within their Corporate Research and Development group, which cuts across all company divisions, discussions were held to seek out potential users. Some areas of particular interest were: x-ray targets, isoenzyme separation, latex spheres, and biomedical products.

The information obtained has been used to develop mission scenarios and benefits analyses. In addition, GE Corporate R&D initiated an in-house study on the utility of an industrial research facility onboard the Space Station. This facility would allow commercial and research organizations to conduct materials research and development for potential commercial products or services. Major areas of investigation include, biomaterials, electronic materials, metallurgy, and ceramics. The study will conclude in June 1983.

COMSAT General surveyed the telecommunications satellite industry and received an overall endorsement on their "Prospectus to the Year 2000." This prospectus covered future communication satellite projections and possible uses and benefits that could be derived from a Space Station. It is significant that the prospectus was mailed to 42 organizations (including satellite manufacturers, service, and insurance companies) and more than 50 percent responded. While these responses ranged from solid backing to total rejection, the general consensus was in strong support.

For each mission analyzed in this study, three Space Station functions were considered: support of mission development, mission space operation (i.e., assembly, servicing, and deployment), and resident/remote mission operations (i.e., observations). Comparative analysis of 39 missions, implemented with and without a Space Station, show that a manned Space Station could save more than $9.6B through the year 2000. The main performance advantage of the Space Station over other modes (i.e, Spacelab, platforms, and free flyers) is due to its inherent long mission duration, on-board storage capability, and the ability for man to complement automatic equipment for maximum cost effectiveness.

Based on work accomplished by the Grumman team, there are five major roles in which a Space Station has high potential payoff for the U.S. and for our society at large. These roles are listed below with their estimated gross benefits through the year 2000:

- Space Test Facility & Range = $2.44B
- Transportation Harbor = $2.55B
- Satellite Services/Assembly Station = $0.38B
- Observatory = $0.55B
- Space Industrial Park = $3.41B.

To take full advantage of these attributes, however, new methods of doing business in space must be adopted.

Our current space testing approach, for example, is limited to remote data acquisition and high confidence proof-of-concept demonstrations. A Space Test Facility and Range can provide the space equivalent of a wind tunnel for aircraft development. With manned interaction, this facility could allow greater flexibility, reduce cost, and reduce time of experimental development activities on the ground and in space.

Again, the wide body Centaur is not being developed for space basing even though these are the features needed to exploit the Space Station as a transportation mode for low cost delivery of multiple satellites to GEO. An orbiting Transport Harbor could also dispatch small proximity operations vehicles and teleoperator maneuvering systems for satellite servicing, thereby decoupling its operations from Shuttle launch constraints.

Except for the Space Telescope and Multi-Mission Spacecraft, most satellites are not designed for repair in orbit, refueling, or reconfiguration. Unless the capability to service satellites is developed and demonstrated to be available, satellites will not be made with on-orbit servicing capabilities. Satellite servicing operations are more economical from a Space Station since service equipment is stored on-board when not in use rather than being carried back and forth by the Shuttle.

The fourth high payoff item is an Observatory attached to the Space Station. The Observatory could be attached with appropriate vibration isolation, or it could operate with the Space Station as a free flyer for experiment data compaction/command.

The fifth role (Industrial Park) needs the maturity that results from more micro-g material testing before it can rank with the first four roles. MPS offers great promise for commercial development of high value/low mass products. The Space Station can provide a hands-on, interactive mode with frequent down links that would be comparable in duration to ground development. To encourage the commercial constituency to grow, a joint endeavor agreement should be negotiated with the user to minimize front end on-orbit charges, allow rapid expansion to full market production, and thereby shorten the ROI waiting period.

1.2 CONCLUSIONS

The initial Space Station should be manned, placed in 28.5^{0} orbit, and provide substantial economic, performance, and social benefits. It is clear from the work accomplished by the Grumman team that the most beneficial Space Station capabilities include: Space Test Facility, Transport Harbor, Satellite Servicing & Assembly, and Observatory. A Space Industrial Park may be added in the future, once further development effort validates the cost and expanding commercial market for space processed material. The potential accrued gross mission model benefit derived from these capabilities is $5.9B without the Industrial Park and, $9.3B with it.

The major emphasis here is on external activity, which reinforces the belief that our next Space Station must be more than just a "man-in-the-can" and surpass previous Space Station programs (i.e., Skylab and Salyut). We recommend that the U.S. establish a permanent manned presence in space that allows dramatic expansion of our capability to operate in GEO and other useful orbits. A step toward domination of orbits opens a gateway to future endeavors that could not otherwise be attempted.

As a positive step, the Space Station must blend the skills of its crew with the best features of automated equipment. Man's presence in orbit will greatly enhance mission performance in many operational activities. These activities include those requiring interactive operating such as materials processing research, life sciences, large structures/antennas/optics technology development, advanced energetics experiments, dynamic atmospheric/oceanographic observations, satellite servicing, and the assembly and check out of large complex spacecraft.

On board autonomy, on the other hand, should be used to handle repetitious tasks that are boring or dangerous. Interactive control of robotic devices and automatic equipment aboard the Space Station allows human capabilities to be used more efficiently.

Using the Space Station as a National Space Test Facility will enhance national security as well as benefit commercial and scientific interests. Adding the other capabilities (i.e., Transport Harbor, Service & Assembly) provides a focal point for high technology development and spin-off to the private sector, as shown in Fig. 1-2. These new capabilities lead to a number of benefits such as:

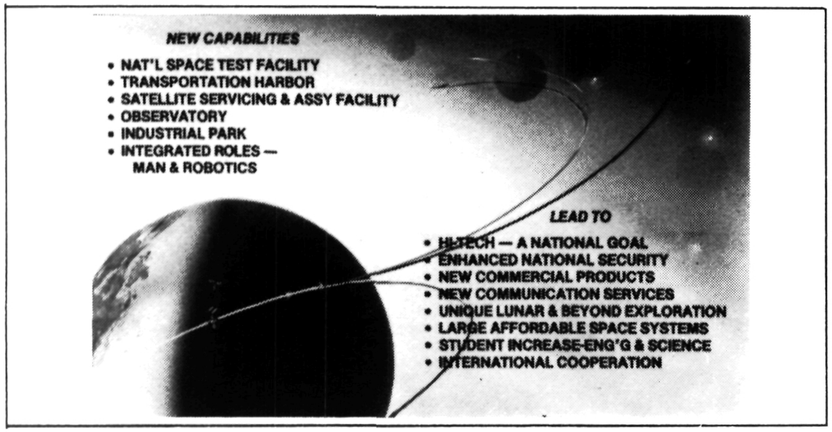


Fig. 1-2 Space Station: Gateway to the Future

- More science earlier
- Lowered cost with high performance to orbit
- Lowered acquisition cost for future NASA & DoD space assets
- Commercial development of new products (i.e., therapeutics, semiconductors, etc)
- New communication services (land mobile communication satellites)
- New energetic technologies (sun-pumped laser and plasmas)
- Unique lunar and beyond exploration.

A vigorous Space Station program will not only rekindle national interest and encourage education in science and engineering, it will also provide a basis for broadening international cooperation.

For civil purposes, our architectural studies point to the 28.5^0 inclination as the prime U.S. Space Station orbit with the possible addition of a tended platform in a sun synchronous (97^0) orbit at a later date. National Security R&D and GEO transfer missions fit naturally on the 28.5^0 station and are included in our baseline mission model.

At the configuration level of architecture, we have reached four main conclusions:

- It is cost effective to develop a limited number of building blocks for the initial station, each block to be used again in the system evolution. We have worked with four such elements
  - Command/habitation module
  - External subsystem (chiefly power supplies)
  - Surrogate payload bay
  - Observation tower
- The optimum number of such building blocks is not important; the principle of heavy emphasis on replication to hold down development costs is important
- Although MPS R&D is performed on the main station, we have elected to carry MPS production on Tended Industrial Platforms (TIPs) that fly in formation with it. Three considerations support this
  - TIPs can respond to market growth with minimum impact on the basic station, particularly its power supply
  - More exacting micro-g levels are readily met
  - Operational mode (in which TIPs return at intervals and are docked to the station) allows material throughput and production unit servicing to be a shirtsleeve activity
- We have not identified any enabling technology "show stopper."

As defined, the development, production, and launch costs of the initial station amount to $4.3B (FY '84). Investments required for any subsequent growth (when kept small by adhering to the architectural replication strategy just described) can be fully recovered within a few years from Space Station operational savings.

We believe that the initial $4.3B should be treated as a sunk cost. It should be noted that this sum is quite small when compared with Apollo, Salyut, or the Shuttle, as shown in Fig. 1-3. In addition, there are practical opportunities for NASA to reduce its initial investment by as much as $0.9B by international, commercial, and national security participation in the program.

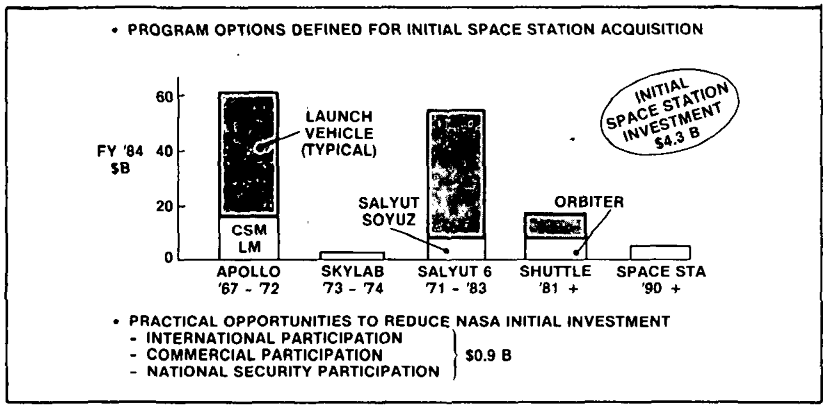


Fig. 1-3 Initial Space Station Acquisition Costs

1.3 RECOMMENDATIONS

To sustain a broad based advance toward a U.S. Space Station, there are several near term initiatives that can, and should, be pursued:

- Gathering momentum of the user community should be nurtured and stimulated; new participants should be sought. Users can profitably be drawn into development of requirements and concepts, and encouraged to explore new ways of doing business in space
- NASA and DoD can now look deeper into mixed payload missions, more detailed definitions of R&D capabilities, and operations support
- International community involvement in a U.S. Space Station's formative process should be strengthened and continued. Industry-to-industry interaction could be an effective approach
- POV & TMS development should include in-flight turnaround
- Development of the high pay-off, space-based OTV should be started
- Allow government in-house teams to exploit industry's needed expertise and avoid stop-go discouragement of corporate involvement in the formative stages. Ways should be found to continue industry participation in requirements definition and concept development
- Shuttle on-orbit capabilities that foreshadow those of the Space Station should be actively developed to augment Shuttle capabilities and demonstrate Space Station feasibility for the decision makers.

2.1 MISSION CATEGORIES & BENEFITS

Analysis of Space Station requirements encompassed the full range of possible space missions covered by U.S. national security, commercial, science and applications, and technology development. These were analyzed to identify missions that need or can gain a significant benefit from the availability of a Space Station. As shown in Fig. 2-1, major inputs to the study were derived from prior studies/plans, data provided by NASA during this study, and ideas from our Constituency Development Council.

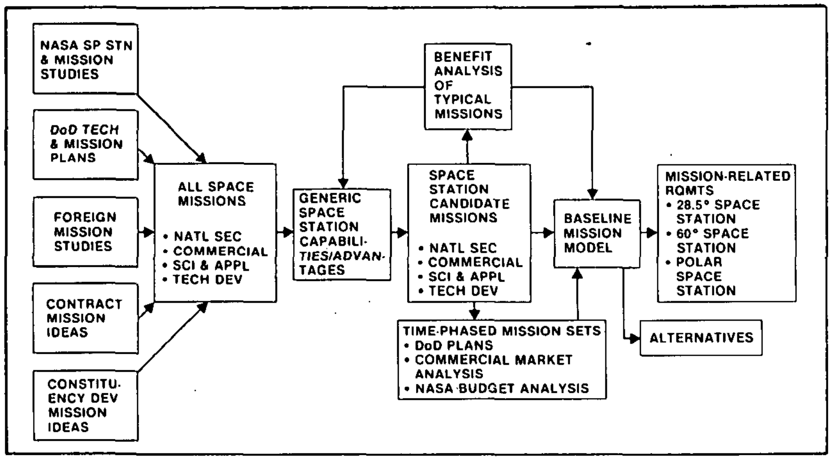


Fig. 2-1 Mission Model Logic Flow

At the start of the study, more than 100 missions were analyzed to identify which missions would most likely benefit from a Space Station if it were used in any of three roles:

- Space operations (on orbit assembly, deployment, and servicing/ retrieval)
- Mission operations (earth observations, astrophysics, etc)
- Technology development (R&D, or proof of concept).

Missions were screened against generic Space Station capabilities (long-duration, on board storage, manned attendance, ample power, etc) to identify candidate missions for further analysis and quantification of benefits. This was an iterative process. Time-phased missions sets were defined for the 1990 to 2000 timeframe for each class of missions. For example, candidate commercial missions were projected from market surveys and benefit analyses; science and application missions, in turn, were based on NASA programs/plans with schedules adjusted to meet projected budget constraints; DoD missions and schedules were based on published DoD plans and private discussions.

Major outputs of the Mission Requirements task were to:

- Establish a single baseline mission model
- Use the baseline model to develop a consistent set of Space Station mission-related requirements
- Identify and evaluate attractive alternatives to the baseline model.

The combined technical expertise and resources of Grumman and its team members, General Electric and COMSAT General, were utilized to perform the Mission Requirements task. The division of responsibilities by mission category is shown in Fig. 2-2.

MISSIONS	GRUMMAN	GENERAL ELECTRIC	COMSAT
• SPACE OPERATIONS	✓		
• NATIONAL SECURITY	✓	✓	
• COMMERCIAL			
– COMMUNICATIONS			✓
– MATERIAL PROCESSING	✓	✓	
– EARTH OBSERVATION		✓	
• SCIENCE & APPLICATION			
– ASTROPHYSICS	✓		
– LIFE SCIENCES		✓	
– SOLAR TERRESTRIAL & EARTH OBSERVATION	✓	✓	
– MATERIAL SCIENCE		✓	
– PLANETARY	✓		
TECHNOLOGY DEVELOPMENT	✓		

Fig. 2-2 Grumman Team Responsibilities

One of the key objectives of the Grumman team was to validate missions and associated requirements. As illustrated in Fig. 2-3, Grumman utilized a library of related documentation, a comprehensive data base, extensive user contacts, and vigorous user alignment activities to achieve this objective. Examples of these activities included:

- The Constituency Development Council, which includes Grumman, GE, and COMSAT corporate officers, reviewed all space station missions, military and civil. They also guided parallel corporate funded activities to develop Space Station advocates and constituents within non-aligned commercial companies
- Grumman's Space Station Utilization Office concentrated on identifying, stimulating, and developing new potential users of MPS

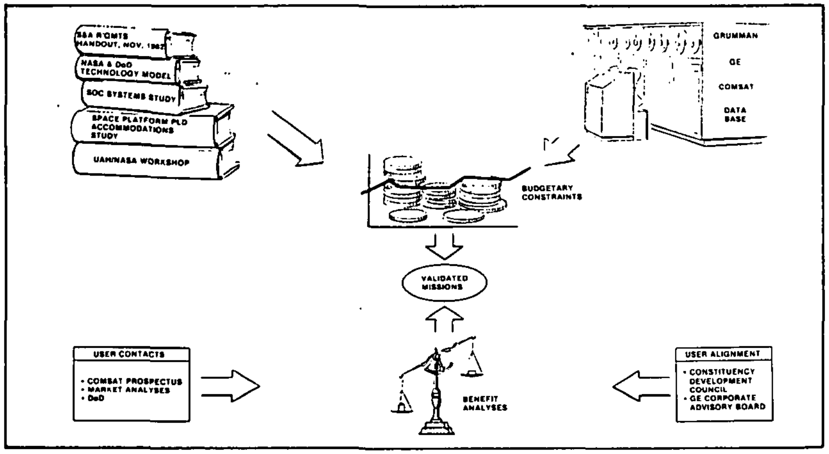


Fig. 2-3 Mission Validation

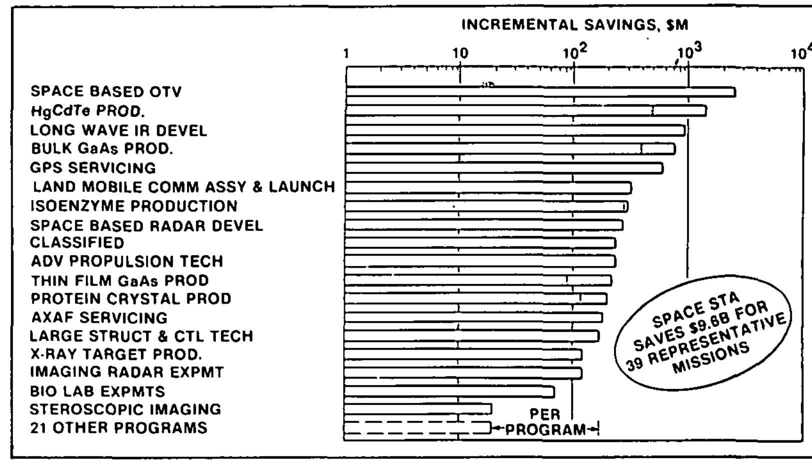


Fig. 2-4 Candidate Missions Incremental Benefits, FY '84 $M

technology within the metals, semiconductors, and pharmaceutical industries. GE, in turn, focused on commercial interests within their own company

- The GE Space Station Corporate Advisory Board is spearheading an in-house study to assess the utility of an Industrial Research Facility onboard the Space Station
- COMSAT General surveyed the telecommunications satellite industry on future growth to the year 2000 and possible uses/benefits that could be derived from a Space Station. They received a strong endorsement on their prospectus which was sent to 42 organizations in this industry. Nearly 60% of these organizations replied.

All Space Station candidate missions were subjected to an evaluation/filtering process. For example, Science and Application missions were filtered based on projected NASA budget constraints. About 17% of the candidate missions were deferred beyond the end of this century due to this constraint. Candidate commercial missions were, in turn, limited to areas with an adequate market to offset space transportation costs.

Another process used to validate candidate missions was benefit analyses. The question to be answered here was, "For a given mission, is there an economic advantage to 'flying' the mission on a Space Station rather than (for example) as a Shuttle sortie mission, or as a free flier?" The results for 39 representative missions are summarized in Fig. 2-4. About 57% of the cost savings came from commercial mission applications, 28% from national security missions, 8% from technology development missions, and 7% from science and application missions.

All activities contributed to the mission validation process and provided a sound basis to establish a Baseline Mission Model as a realistic mission set.

2.2 MISSION RELATED REQUIREMENTS & BASELINE MISSION MODEL

2.2.1 Commercial Missions

Until now, nearly all commercial space missions have been communications satellites in geostationary orbit. Very few materials processing missions have been flown and only a few will fly in the near future. The demand for communications satellites certainly will continue and materials processing, as well as all areas of commercial R&D, will inevitably expand. The commercial market for earth observations is in its infancy, but should not be disregarded.

With regard to Space Station orbits into which these missions best fit, all of these missions except earth observation may benefit from a low inclination (see Fig. 2-5). Earth observation requires a high inclination orbit for complete global coverage, and would benefit by sharing transport costs and facilities when compared to a dedicated platform. Communication missions benefit by lower transportation costs using an OTV based on the Space Station. In addition, communications satellites, particularly those with large antennas, may be assembled and checked out on the Space Station before committment to GEO transfer.

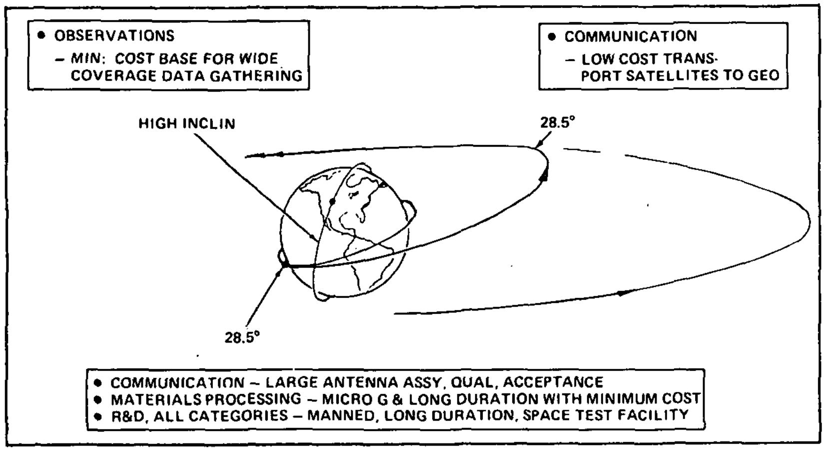


Fig. 2-5 Space Station Roles, Commercial Missions

Materials processing missions requiring micro-g levels and R&D projects will benefit from human interaction and periodic intervention over long durations; this combination is not available from present or planned spacecraft. Materials processing and the majority of R&D projects do not require any particular orbit inclination and, therefore, the lower cost transport to a 28.5° station is advantageous. Additional transport cost savings are possible by sharing the payload, rendezvous, and other STS charges for Space Station flights compared to STS charges for flights to several dedicated spacecraft.

Based on our study findings, time phased growth of activity for the set of commercial missions discussed is summarized in Fig. 2-6.

Communication activities include: component R&D, qualification of large antenna satellites, and deployment of satellites to GEO. In our baseline mission model, deployment is shown starting in 1993 when a reusable, space-based OTV is available. Before then, traffic to GEO is assumed to go direct using expendables and by passing the station. The number of communication satellites is based on a COMSAT General analysis of future activity, together with their estimate of the proportion of traffic that will use the U.S. launch system. Satellites suitable for remote servicing in GEO are expected to be launched in the late '90s.

Materials processing activities consist of continuous R&D efforts to develop new processes and new products, as well as production of developed products. Commercial R&D is accomplished onboard the station whenever possible; production (as described in the Mission Implementation Concepts Section) takes place on free flying platforms that

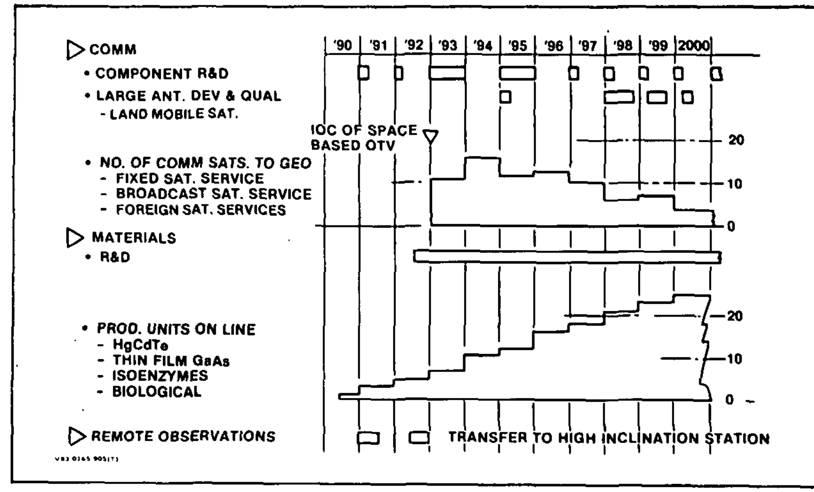


Fig. 2-6 Commercial Activities at 28.5°, Baseline Mission Model

accommodate five to ten production units, depending on the unit mix and the power required per unit. The units shown on line in Fig. 2-6 produce four of the eight products investigated: HgCdTe, thin film GaAs, isoenzymes, and biologicals. These products were selected as commercially viable based on the projected market and a reasonable payback period.

The stereoscopic imaging system is the only commercially viable remote observation mission. A high inclination orbit is required for global coverage, but partial coverage is available from a 28.5° station, which would presumably precede a high inclination station.

2.2.2 Science & Applications Missions

The role the Space Station system can play and the most appropriate orbit inclinations are summarized for this set of missions in Fig. 2-7. The 28.5° station attracts the lowest launch costs for a U.S. Shuttle. As such, it is the logical site for space-based R&D, life science work, transport of scientific payloads to GEO and beyond, celestial viewing, and even terrestrial viewing when the tropics are the area of interest.

Earth resources and meteorological payloads that should view the whole earth fit naturally on a high inclination platform. This platform can also provide support for solar and celestial viewing when high inclination is required.

Benefits from using a Space Station for Science & Application Missions include the capability to support instruments for long duration, manned intervention, and lower operational costs. Service, maintenance,

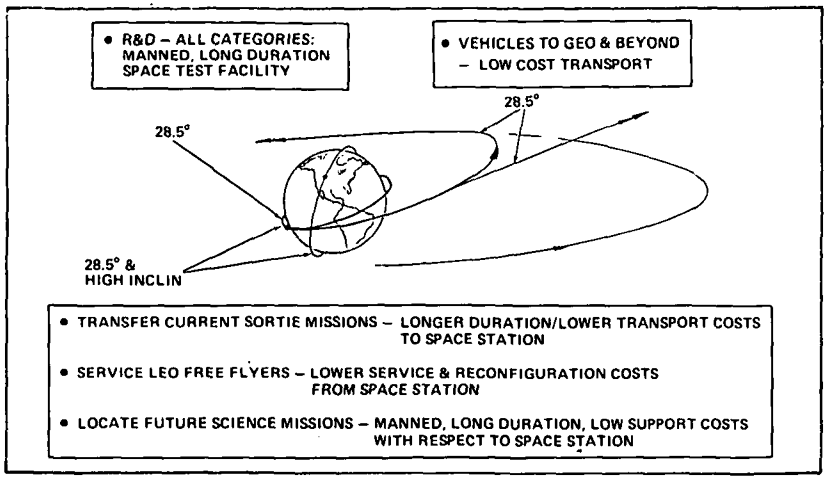


Fig. 2-7 Space Station Roles, Science & Application Missions

and refurbishment of instruments attached to the Space Station and free flyers improve data collection capability while reducing costs. Both these cost reductions permit more science. Because of the cost advantage, candidate Science and Applications missions were reviewed to determine which were suitable for direct on-station support. Major considerations were:

- Compatible orbital parameters
- Space Station/platform environment (i.e., disturbances, contamination) would not nullify data gathering
- Ability to extend useful life of payload/instruments.

Results indicate that about 85% of the orbit compatible payloads (both low and high inclination) could be attached to the station or platform. Our baseline time phased activity for the Science and Applications set of missions at 28.5° inclination is summarized in Fig. 2-8. Four mission functional groups are shown: internal laboratories, externally mounted instruments, co-orbiting free flyers, and planetary class missions that travel on departure trajectories. Material science activities commence in 1990 when the first furnace is available for experimentation; they continue throughout the decade as additional furnaces are required and higher power is provided.

Life sciences require humans in space for extended time periods; they commence with monitoring and physiological measurement of the onboard crew. Later, laboratory experiments will be conducted with animals and plants. Global environment experiments start in 1993; they will model large scale circulation of earth's atmosphere in hemispherical geometry.

Most externally mounted payloads consist of celestial pointing telescopes. In addition, there is the tropical meteorological payload that looks at earth to observe weather phenomena in the equatorial region. Because the Space Station will be gravity gradient oriented, a means of accurately pointing the telescope must be provided (i.e., the European instrument pointing system).

Co-orbiting satellites that could benefit from servicing and maintenance are periodically retrieved and serviced at the Space Station. Servicing events for three free flyers (ST, GRO, and AXAF) are also shown in Fig. 2-8.

Many externally mounted payloads on the Polar Orbit Platform (see Fig. 2-9) were originally conceived as free flyers. The majority of these payloads are earth viewing and benefit from being able to scan earth's entire surface. The initial platform consists of four science payloads, but that number increases to 11 in the year 2000. In Fig. 2-9, two free flyers are shown supported from the Space Platform; both are involved in meteorological measurements.

2.2.3 On-Orbit Technology Development Missions

Generally, technology development is not directed toward a specific product or service, but the distinction between space technology development and other R&D is rather subjective. For example, commercial communication R&D might be directed toward better land service, but the results could also benefit STS or military space applications. Many areas (e.g., propulsion, life support, electrical power generation, or system operations) seem clearly related to many applications and, therefore, are usually funded by the government.

As mentioned for other missions sets, human interaction over a long duration is an obvious contribution to all R&D activities; a Space Station is the only system that squarely fulfills these requirements.

Generally, on-orbit technology development missions (see Fig. 2-10), do not require any particular orbit inclination; the 28.5° station is once again preferred because of lower STS costs.

As for previous mission sets, time phasing of the Technology Development activities is summarized in Fig. 2-11. Enabling technology for the initial station will, by definition, be completed in the mid-'80s, but station upgrading and stations operations technology will continue throughout the '90s and some will, with advantage, be done on the Space Station itself. Mission technology has been illustrated here as falling into four broad categories that benefit from on-orbit conditions.

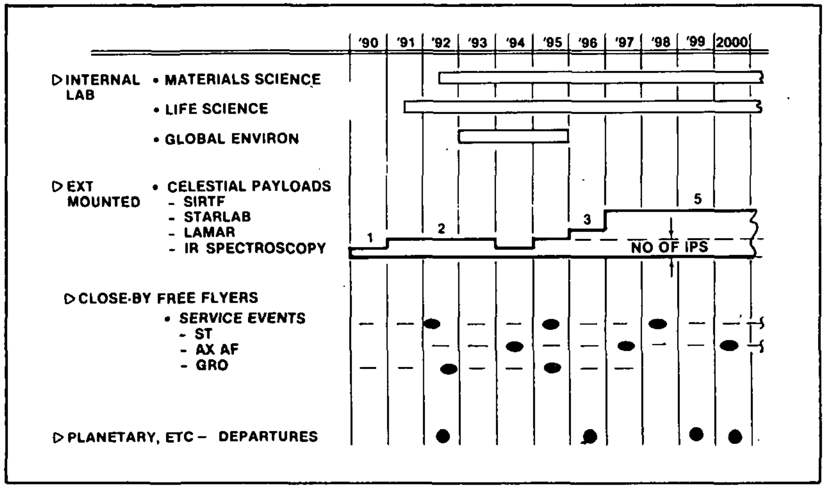


Fig. 2-8 Science & Applications Activities at 28.5°, Baseline Mission Model

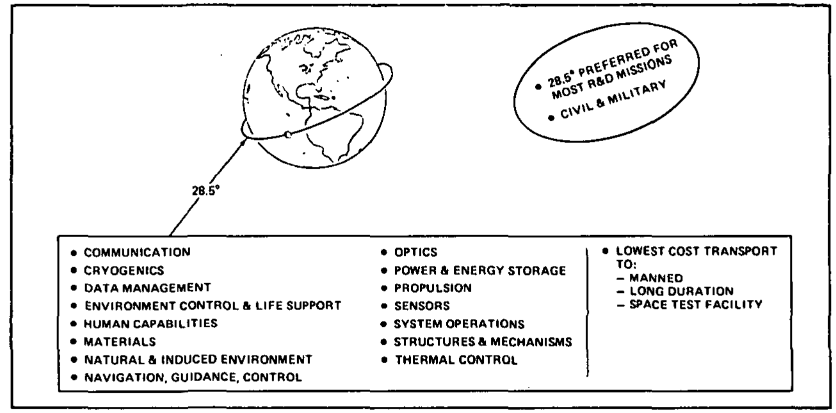


Fig. 2-10 Space Station Roles, Technology Development Missions

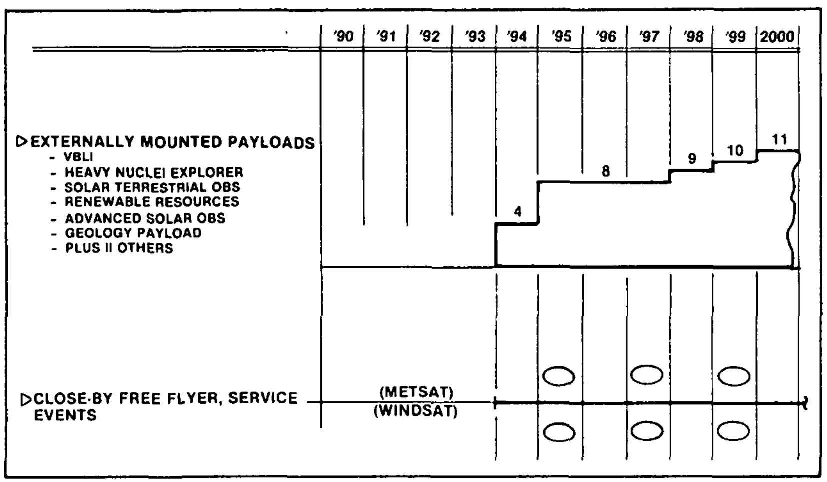


Fig. 2-9 Science & Applications Activities at 97°, Baseline Mission Model

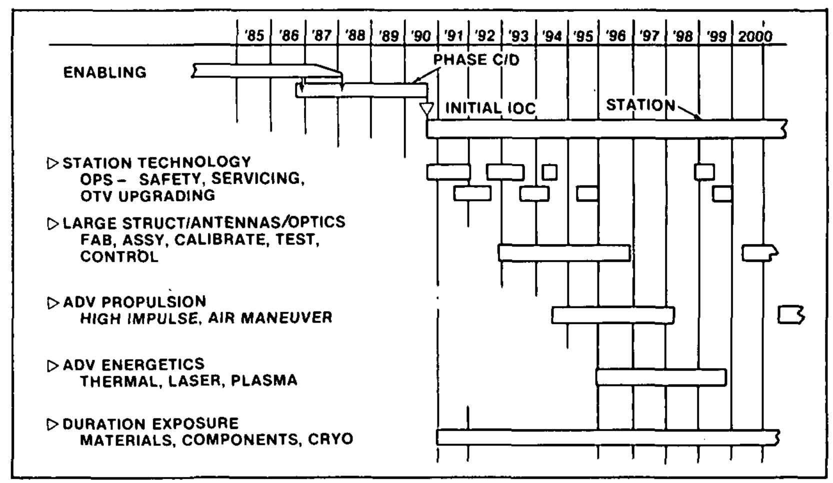


Fig. 2-11 Technology Development Activities In-Orbit at 28.5° Inclination

Large structures, antennas, and optics, for instance, involve large flexible structures, long duration tests, manned interactions, the use of much generic and specialized test gear, and the absolute need for a true micro- g environment. The lists of requirements for the advanced propulsion, advanced energetics, and long duration exposure categories differ, but each makes an equally strong case for the services of a Space Station.

While it is clear that long duration/exposure test work is an even, continuing task, the time phasing of the other three categories is less certain, and the implied three or four years duration of each borders on the notional. We believe, however, that the sequence is right.

2.2.4 DoD Activities

DoD activities involve R&D, deployment of satellites to GEO using OTVs, assembly and servicing of large systems, and servicing "current" *satellites in situ, or at the Space Station. As indicated in Fig.* 2-12, these activities could exploit three Space Station inclinations. R&D requires no particular inclination and GEO deployments should be from the lowest inclination station; these are firm activities for the Baseline Mission Model. Large military systems at 57° inclination are possible, but probably will not occur before the year 2000. If a 57° Space Station is justified for these large systems, it could be used to service "current" conventional satellites in this orbit. The major activity of a 97° station is to support the servicing of "current" conventional satellites.

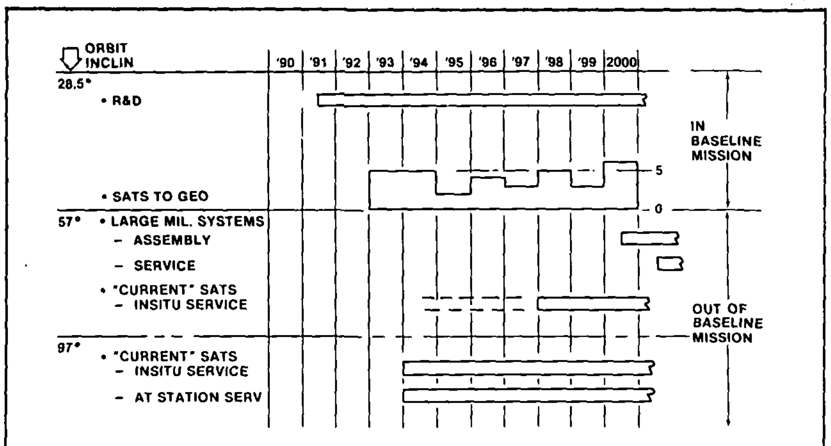


Fig. 2-12 DoD Activities

2.2.5 Integrated Requirements

A summary of the preferred Space Station orbital inclinations to support mission operational objectives of the varied military and non-military (civil) missions/payloads is presented in Fig. 2-13. All missions/payloads that either have no preferred orbital characteristics, or whose destination is geosynchronous orbit (GEO) or beyond, were placed in a 28.5° inclination orbit since this results in the lowest transportation cost to orbit. The number of STS flights/year is based on total traffic, including OTV support. Weight-to-orbit costs are based on $84.3M per flight and projected STS lift capability.

A polar orbit provides the best solar and terrestrial coverage for all civil missions. Some science and application missions would perform satisfactorily in a 57° inclination orbit, however, which represents the highest achievable inclination from ETR due to Space Shuttle launch constraints. The European community favors a 57° inclination orbit for ease of communication with the ground.

When all missions/payloads that prefer orbital inclinations greater than 28.5° are summed, total projected traffic cannot justify a permanent presence at more than one inclination. Since many payloads require polar orbit to satisfy their mission objectives, all higher inclination civil missions were integrated with the polar missions in the Baseline Mission Model. Consequently, the Baseline Mission Model identified candidate Space Station missions at two inclinations: 28.5° and polar orbit.

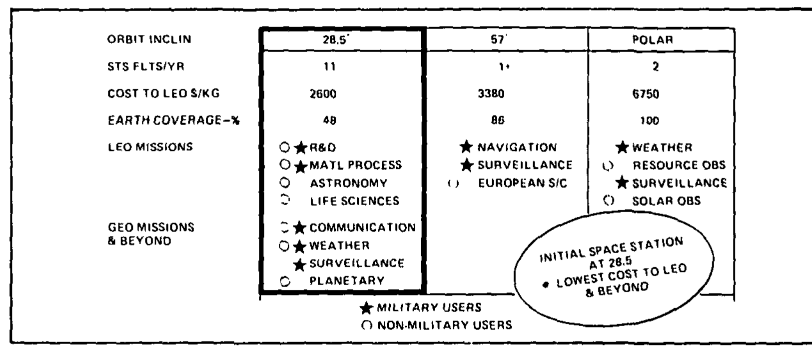


Fig. 2-13 Activities Related to LEO Space Station at 28.5°, 57°, & Polar Inclinations

Integrated requirements for the 28.5^0 Space Station are summarized in Fig. 2-14. The number of Shuttle flights, for example, indicates the breakdown of civil missions, military traffic to GEO, and the military R&D missions. Expendable upper stages are used prior to OTV IOC in 1993.

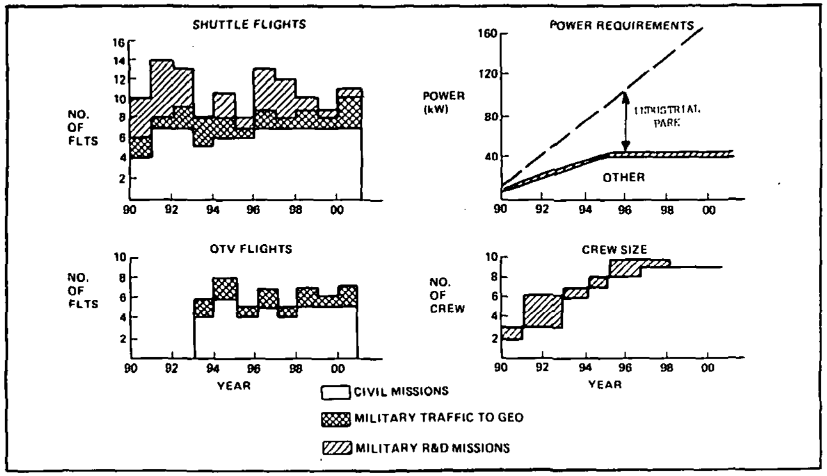


Fig. 2-14 28.5° Space Station Integrated Requirements

The average electrical power required for mission activities on the 28.5^0 Space Station is also shown in Fig. 2-14. The average electrical power requirement for military R&D missions (maximum of 3100 kWH/year) has virtually no impact. If the Space Station is required to provide power for a commercial MPS industrial park, power requirements must increase dramatically.

Integrated crew requirements show that military R&D missions require a more rapid buildup than requirements for civil missions only. Integrated (civil plus military) requirements show that starting in 1995, crew requirements build up to a total of 10. A probable crew size of nine would suffice by adjusting total integrated crew work schedules.

Integrated mission related requirements at 97^0 inclination are summarized in Fig. 2-15. The number of Shuttle flights per year strongly influences the architecture of the 97^0 station. Payloads at 97^0 would benefit (in terms of scientific value and reduced experiment/equipment complexity) with a permanent manned presence. However, since the total mass/year to polar orbit for identified civil missions requires an average of two Shuttle flights/year, providing for a continuous manned presence could require two additional Shuttle flights/year (assuming a 90 day crew changeout). Certainly, the additional cost (approximately $170M/year) for continuous manned operations would be difficult to justify. Consequently, the baseline was established to be a man-tended platform that would be visited about twice a year.

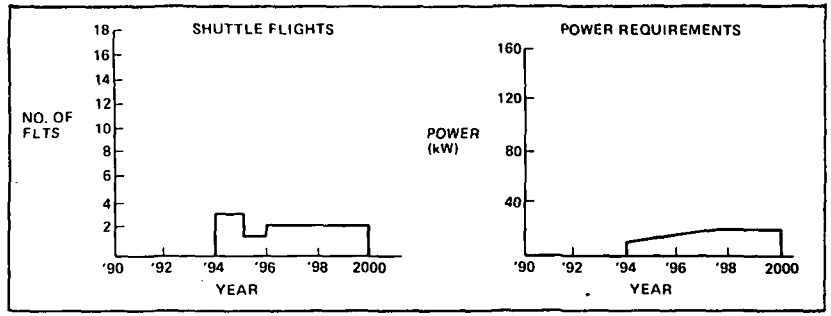


Fig. 2-15 Polar Orbit Space Station Integrated Requirements

2.3 SYSTEM REQUIREMENTS

Based on an evaluation of the wide and varied range of Space Station mission applications, it became evident that Space Station architectural development should key on the five attributes/roles shown in Fig. 2-16.

The Space Test Facility and Range provides the unique opportunity to conduct technology development and proof-of-concept in space with manned interaction in the development process. A "shirt sleeve" environment provides ideal conditions for an Industrial Research Facility

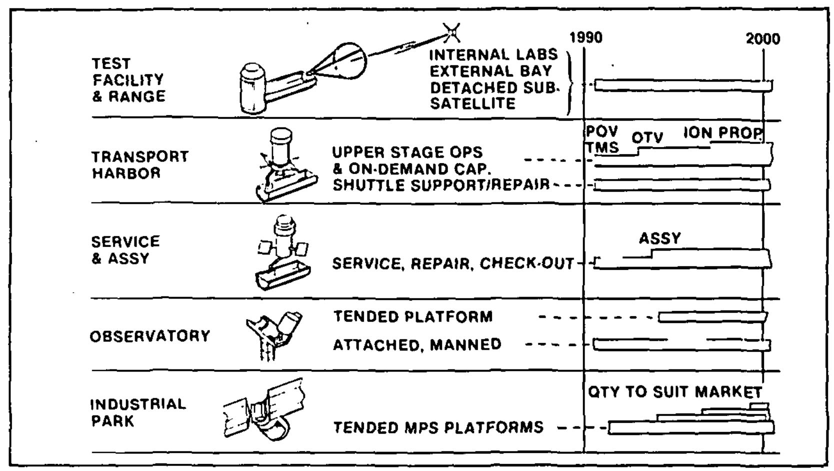


Fig. 2-16 Five Required Attributes

to conduct materials research and development relevant to commercial products and services, as well as a Life Sciences Lab. Large structures/antennas/optics deployment and testing, and heat rejection/radiator development can be performed in external bays. A Test Range would, for example, permit advanced state-of-the-art antennas to be tested with signal generators and diagnostic subsatellites that are strategically placed down-range of the Space Station so that far-field experiment results can be obtained.

A Transport Harbor has great utility and an ever expanding role. Initially, the harbor provides Shuttle support and repair in case of Shuttle malfunction. For upper stage operations, the Transport Harbor would first support small "proximity operations" vehicles used to fly from the Space Station to satellites and inspect them. Later, storable propellant upper stage vehicles such as the Teleoperator Maneuverable Systems (TMS) could be fueled on-orbit. Finally, a reusable OTV would become operational providing lower cost transportation to GEO.

Satellite Servicing and Assembly is another major area for high payoff with the Space Station. Assembly/integration and manifesting of payloads in close proximity to the Space Station represents a significant activity. Satellite Servicing pays off particularly for large observatory satellites. One illustration of this is the Advanced X-Ray Astrophysics Facility (AXAF) that NASA plans to have operational in the early 1990s. The potential exists for replacement of equipment to maintain the AXAF and to upgrade its capability at appropriate times. A $200M savings is estimated for such a satellite over a 10 year period.

The fourth major area for high payoff is an observatory attached to the Space Station with appropriate vibration isolation so that delicate instrumentation and telescopes may be pointed (earthward, or toward the heavens) with reasonably high accuracy. The observatory function can also be performed by separate platforms/satellites flying in formation with a 28.5° Space Station, or by an independent tended platform at higher inclination.

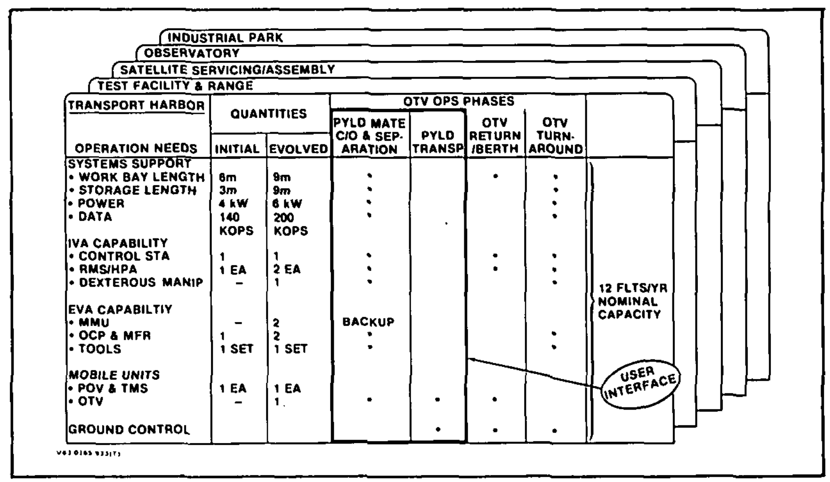
Materials processing in space offers both technical and economic advantages over earth-based manufacturing procedures. Not only are higher quality products produced in the space environment, but a significantly higher product yield also results when processing materials in a near-zero gravity field. Both of these factors, together with an expected increase in market demand for the many products identified, suggest that an Industrial Park be developed as part of the Space Station complex.

One concept utilizes a series of tended Industrial Park platforms, formation flying with the Space Station, that are incremently brought on-line as a function of evolving processing needs. Each tended platform would be identical in design and sized according to prescribed pressurized volume and power requirements.

2.3.1 Space Station Operational Requirements & Functions

Operational requirements and functions are defined for the recommended Space Station attributes. An example of these requirements is shown in Fig. 2-17 for the Transportation Harbor. This figure highlights user interfaces in terms of systems support, IVA and EVA capability, mobile units needed, and ground control. The required support equipment as well as structural, power, and data capabilities are listed. OTV operational phases that involve the user are: mating the payload (satellite) to the OTV, checkout, transportation to operational orbit, and, finally, payload separation in preparation for performing its operational role. Note that the equipment and facilities can nominally support 12 flights per year.

Similar summary sheets were prepared for other Space Station primary functions, namely: Test Facility & Range, Satellite Servicing/Assembly, Observatory, and Industrial Park.



TRANSPORT HARBOR	QUANTITIES		OTV OPS PHASES				
OPERATION NEEDS	INITIAL	EVOLVED	PYLD MATE C/O & SEPARATION	PYLD TRANSP	OTV RETURN /BERTH	OTV TURN-AROUND	
SYSTEMS SUPPORT							
• WORK BAY LENGTH	6m	9m	•		•	•	12 FLTS/YR NOMINAL CAPACITY
• STORAGE LENGTH	3m	9m	•			•	
• POWER	4 kW	6 kW	•			•	
• DATA	140 KOPS	200 KOPS	•			•	
IVA CAPABILITY							
• CONTROL STA	1	1	•		•	•	
• RMS/HPA	1 EA	2 EA	•		•	•	
• DEXTEROUS MANIP	–	1	•			•	
EVA CAPABILTIY							
• MMU	–	2	BACKUP				
• OCP & MFR	1	2	•			•	
• TOOLS	1 SET	1 SET	•			•	
MOBILE UNITS							
• POV & TMS	1 EA	1 EA					
• OTV	–	1	•	•	•		
GROUND CONTROL				•	•	•	

Fig. 2-17 Space Station Operational Requirements & Functions

2.3.2 Benefit Analysis for Transportation Harbor

MOTV studies for NASA have shown significant savings in GEO transport costs by space-basing an OTV in a 28.5° orbit. These savings result from:

- Making the OTV reusable
- Avoiding relaunch costs of the entire OTV for each mission
- Deriving higher performance from space-based vs OTV ground based designs
- Obtaining better manifesting of the Shuttle.

Any payback is highly traffic dependent, but for quite modest traffic rates, both the space-based OTV and its transport harbor can be paid back in a little as three years. A 2½-5 year payback is considered a good business investment.

The reusable space-based OTV is an efficient means of launching a spacecraft into its operational trajectory. Figure 2-18 shows the OTV inserting its attached payload spacecraft into a transfer orbit, separating from the payload, returning to perigee, and circling for subsequent Space Station berthing. Meanwhile, the spacecraft coasts to apogee and its attached propulsion is used for the circularization burn, placing the spacecraft into its operational orbit. The OTV is versatile in that it can deploy three payloads and transfer a total of 20,000 kg into GEO transfer orbit.

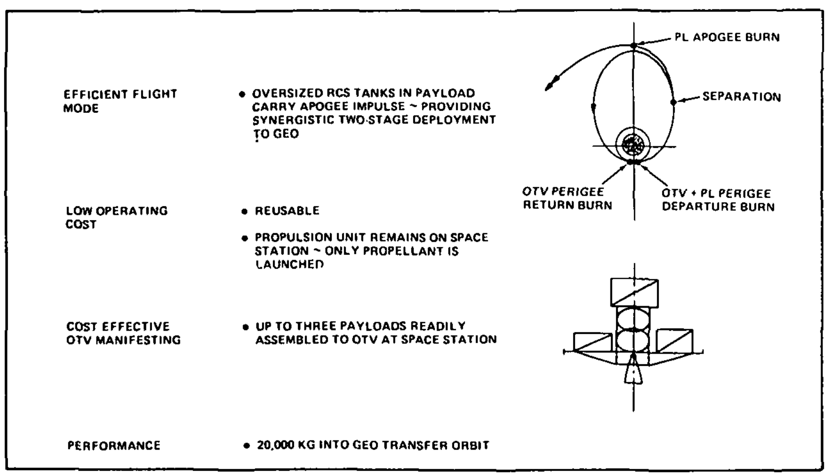


Fig. 2-18 Reusable Space Based OTV Features

Civil and DoD traffic to GEO, in terms of numbers of payloads and weight of payloads, was derived for the 1990s. To satisfy this requirement, three types of ground-based OTVs (PAM-D, Intelsat VI type, and Centaur G) and two types of space-based OTVs (storage OTV with AKS, and cryo OTV with AKS) were studied. A comparison of their performance in $/kg (assuming a Shuttle load factor of 100%) was determined. Using each of these stages, shuttle manifesting showed marked differences in efficiency for each upper stage (see Fig. 2-19). Clearly, a space-based, reusable upper stage is the most cost-effective form of transportation if the payload mass to GEO is greater than 4000 kg per OTV flight. Typically, combined payloads run in the range from 3500 to 9000 kg. Thus, by combining payloads on one OTV flight, an efficiency in scale is obtained in addition to the above mentioned STS manifesting benefits.

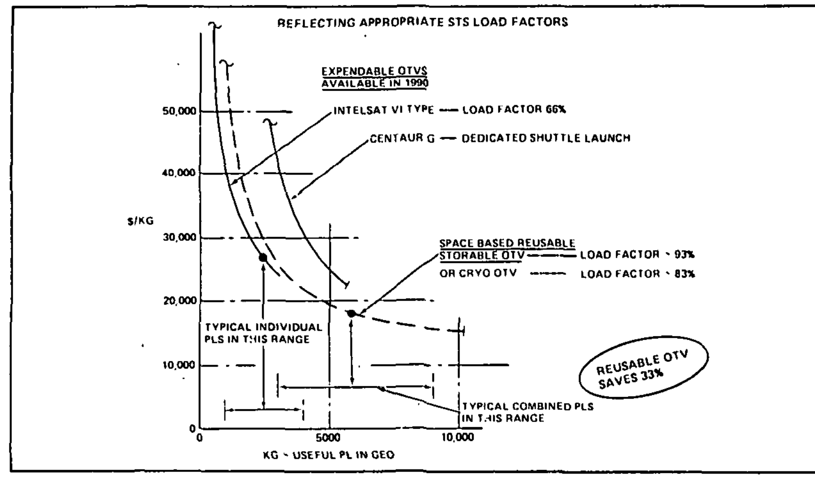


Fig. 2-19 Cost ($ '84) of Ground to GEO Transport

Figure 2-20 compares the recurring cost for GEO transport using the most cost efficient ground-based mode vs the space-based mode during a typical four year interval. If both military and civil traffic is considered, a $318M/year savings can be obtained by space-basing. However, the cost of developing both the OTV and its transport harbor must be amortized against this savings. The results are shown in Fig. 2-21, which indicates that a payback period of from 3-5 years is possible with currently projected traffic rates (approximately eight OTV flights to GEO per

• EXPENDABLE VS. REUSABLE SPACE BASED OTVS

• (ALL COSTS IN '84 $ M)

	'93	'94	'95	'96	AVG ANNUAL SAVING
• DoD TRAFFIC					
EXPENDABLE OTVS	424	258	104	273	
REUSABLE, SPACE BASED	254	184	82	191	
SAVING	170	74	22	82	87
• CIVIL TRAFFIC					
EXPENDABLE OTVS	594	822	627	690	
REUSABLE SPACE BASED	383	544	422	459	
SAVING	211	278	205	231	231

COMBINED AVERAGE SAVINGS $318 M/YR

Fig. 2-20 Cost for Transport of Satellites, Ground to GEO

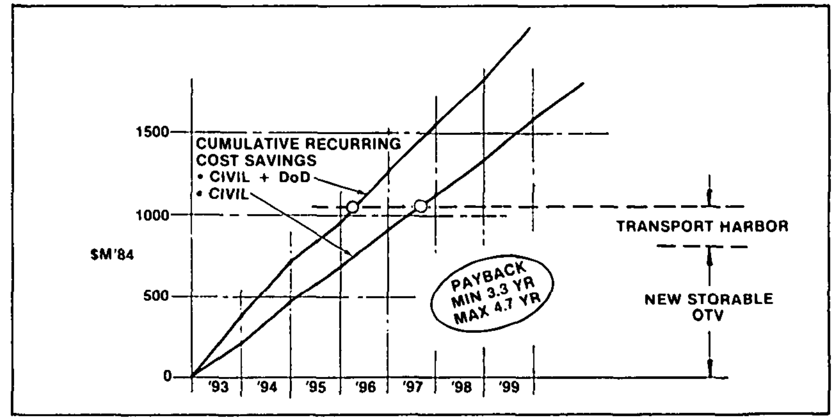


Fig. 2-21 Payback Period for New OTV & Transport Harbor

year). This would be cut by 50% with twice the projected rate. At approximately three times the traffic rate, the transport harbor must be enlarged to handle the increased traffic. Less propellant is needed with a cryo OTV, but a storable OTV permits higher Shuttle load factors, lower front end costs, and launch-on-demand.

This study indicated that a reusable OTV is, in fact, a cost effective mode of operation and the transport harbor forms an integral part of the evolutionary 28.5° Space Station.

The next U.S. Space Station will be manned, placed in low earth orbit, possess a high degree of onboard autonomy, and operate in concert with other co-orbiting elements. To go beyond previous programs such as Skylab and Salyut 6, the Space Station should be considered as a transportation node that supports operations in close proximity to itself, as well as in other orbits.

Basic elements of this orbit infrastructure are shown in Fig. 3-1. The primary operational interface of the Space Station to these elements is via communication links to ground and space-based terminals. Ground communications will be routed primarily through Tracking and Data Relay Satellite (TDRS) and the subsequent Tracking Data Acquisition Satellite (TDAS) systems. Space Station orbital control, in turn, will be based on navigation with respect to the Global Positioning Satellite (GPS). Logistic support and mission payloads will be delivered primarily by the Shuttle. Some future mission payloads may even be delivered in proximity to the Space Station by upgraded versions of Ariane. For the Space Station to be effective in the exploration and productive use of space, it must perform a variety of functions and accommodate many different types of spacecraft.

Operational services to other elements of the infrastructure include such activities as satellite servicing, payload transport to higher orbits, on-orbit testing, in-orbit formation flying, communications (command,

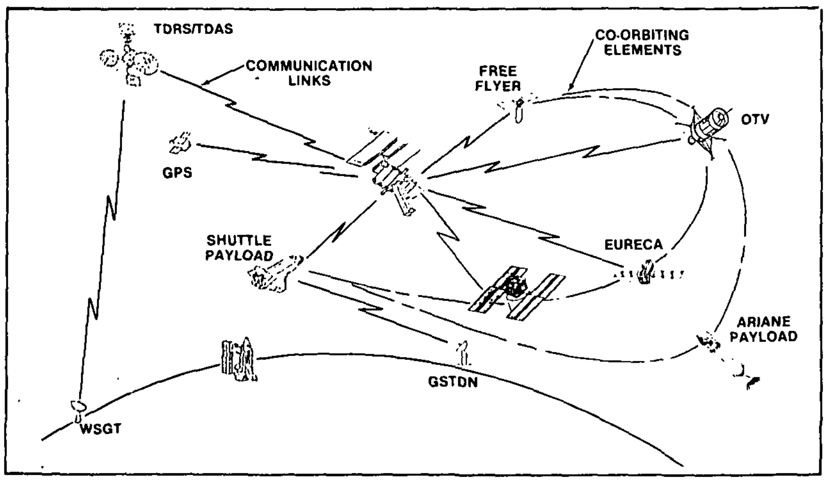


Fig. 3-1 Space Station Infrastructure

data reception), station keeping, and mission operation control. These services will be on a continuous, periodic, or intermittent basis depending on each spacecraft's requirements. Formation flying platforms, (scientific, commercial, and foreign) and attached payloads can be tended, as needed, to meet mission requirements. Space-based Orbit Transfer Vehicles (OTVs) will deliver satellites to higher orbits, perform remote servicing operations, and be clustered for unique space exploration missions.

The Space Station is a basic facility that will enhance the development, growth, and security of our country.

3.1 ARCHITECTURAL ELEMENTS

The Space Station architecture, derived from the mission requirements described above, covers two categories of elements. The first category includes basic building blocks that make up the configuration and provide essential functions/mission support facilities. The other category encompasses all mobile elements that are docked/berthed to the station for logistic support or on-orbit operations.

To arrive at a preferred system architectural configuration, commonality plays an important role. In particular, the use of common elements as replicated items is a high level cost discriminator. Our baseline system consists of a manned station and industrial park free flyers in 28.5^{0} inclination, and an observation platform in polar orbit. We optimized the basic 28.5^{0} station design, and used its components as building blocks for the free flyers and high inclination platform. We also looked for commonality in the components that make up the basic station. Figure 3-2 shows four basic building blocks (core module, external subsystems, surrogate payload bays, and an observation tower) and their replication in the Space Station system facilities.

A three man core module provides the pressure vessel used on manned stations for habitation and laboratory modules. Subsystems within these modules are also replicated, as applicable. Tended industrial platforms use the same core and many of the same subsystem elements including control, communications, data handling, and life support. The polar platform also uses the core module to house subsystems.

The external subsystems pallet, power source, and support mast combination is used on all system facilities. As indicated, the size of each array differs, but each is assembled from identical panels. Mast length

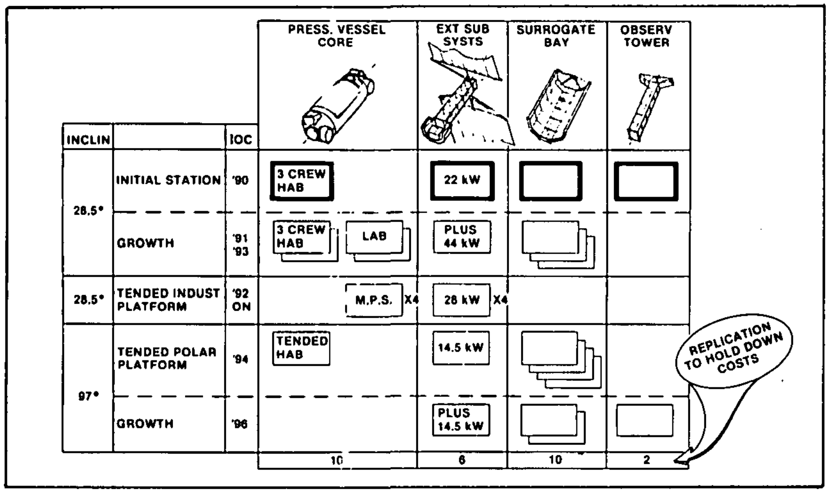


Fig. 3-2 Basic Building Blocks

also differs with each facility, but each is a multiple of standard sections. Subsystems on common pallet mounts are multiples of the same battery, the same CMG, etc.

A surrogate bay is used to mount EVA equipment such as the remote manipulator system (RMS), open cherry picker (OCP), and handling and positioning aids (HPA). In itself, the bay is a replicated structure that retains Shuttle interfaces for each application. It is used on the manned station to support satellite servicing, assembly, test range, and transportation harbor functions.

On the polar platform, it serves as an observation deck and satellite servicing facility. An observation instrument tower is used on the manned station and the polar platform. For most of its length, it uses the same standard sections as the solar array support mast.

Mobile elements used to perform Space Station missions are shown in Fig. 3-3. The space-based Proxmity Operations Vehicle (POV) and Teleoperator Maneuvering System (TMS) fetch and return free flyers to the station. A ground based logistics module contains supplies for crew and equipment. Primarily, the space-based OTV takes payloads to GEO and performs planetary missions. Beyond missions of immediate concern to this study, potential requirements include a capability such as a manned OTV. This could be an "all propulsive" or an aeromaneuvering vehicle. Probable IOC technology development requirements are given for each element.

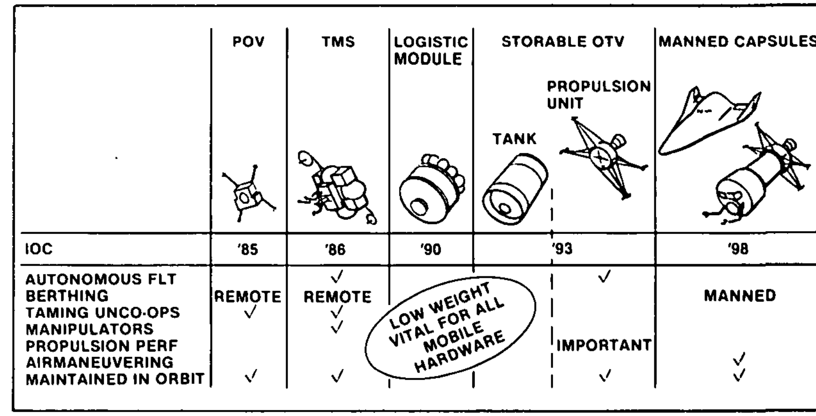


Fig. 3-3 Mobile Elements

To minimize program costs, it is vital to keep the mass of each mobile element as low as possible. For instance, refueling propellants for the space based POV, TMS, and OTV must be transported from the ground and the logistics module must be ground based. Therefore, each element demands that all Shuttle payload transport cost factors (volume and mass) be reflected in their design.

3.2 INITIAL SPACE STATION

Figure 3-4 shows the concept for an Initial Space Station (ISS) that fulfills near term requirements. Initially, the station has one pressurized

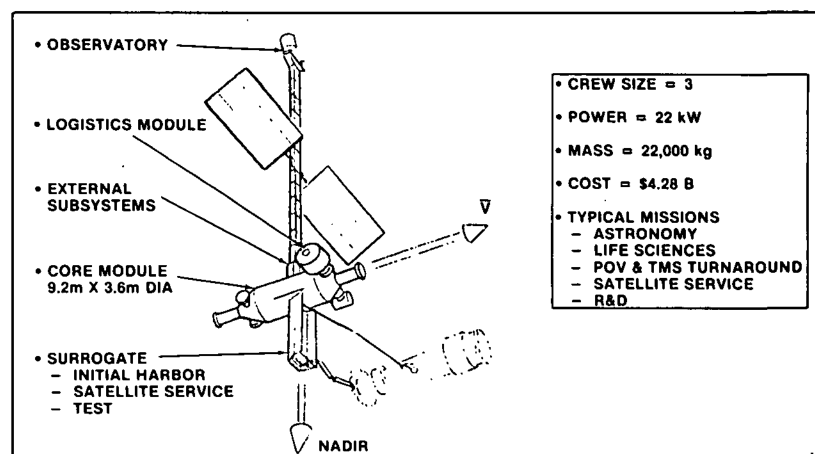


Fig. 3-4 Initial Space Station at 28.5° Inclination

core module to house three men, necessary subsystems, a life sciences laboratory area, and two EVA command post control/monitor areas. Tunnel extensions provide berthing points for a visiting Orbiter.

The EVA area on the ISS employs a cross-sectional trough to simulate the Orbiter's cargo bay. This surrogate and its equipment enable satellite servicing, space testing, and act as an initial transport harbor.

An external subsystems pallet mounts batteries for dark side power, conversion equipment, and control moment gyros for attitude control. From this pallet, a mast extends outboard to mount an astrophysics viewing instrument at its tip; this mission requires an unocculted view for 2π steradians, anti-earth. The solar array is located so as not to interfere with EVA activities, Orbiter docking, or the unloading of payloads. It provides 22 kW of continuous power and a logistics module is berthed to the pressurized module.

ISS elements can be transported to orbit in two Shuttle launches. Figure 3-5 shows the building sequence for components carried on the first launch. Main Orbiter equipment used for assembly includes the RMS, HPA, and OCP. The OCP is mounted to the RMS end effector to carry an EVA crewman. An EVA crewman with an MMU is also available to assist.

In step 1, the RMS is used to deploy the core module (and the wrapped around surrogate structure) clear of the orbiter. An EVA crewman enters the habitat module and extends the tunnels outward until they are mated to the internal surface of the module end domes. Berthing rings are mounted on the ends of these tunnels.

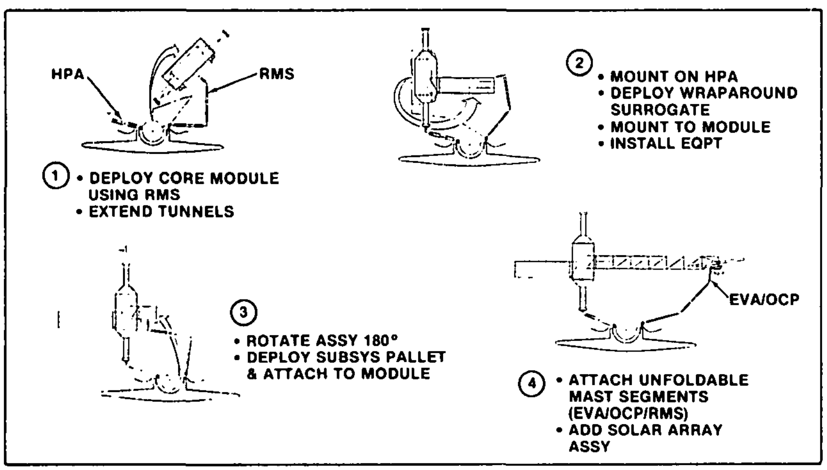


Fig. 3-5 Initial Space Station Buildup — First Launch

In step 2, the module is mounted to the HPA and the RMS removes the surrogate structure. An EVA astronaut operates the mechanism to open the surrogate structure to its full width and attach the necessary cross bracing. The surrogate structure is transferred to its position against the side of the habitat module and attached. Equipment is installed in the surrogate.

In step 3, the assembly is rotated 180° on the HPA. The RMS removes the external subsystem pallet (with its contents) from the payload bay and locates it against the opposite side of the habitat module. The EVA astronaut secures it in place.

In step 4, the solar array support tower is installed and the folded solar array wings are installed. Presently, the mast is conceived as being assembled from five compact folded segments; each is carried by a tethered EVA/MMU crewman, attached, and unfolded. Solar array panels are SEPS extensible type; they will be transferred and installed by the EVA/MMU crewman and deployed.

Figure 3-6 illustrates the operational location of Space Station elements that are brought up on the second launch. Items brought up and assembled on the first launch are shown in phantom outline. The POV, MRWS, RMS, HPA, and TMS (with its cradle assembly) are removed from the payload bay and reinstalled on identical interfaces in the surrogate structure. The logistics module is attached to a vacant berthing ring on the core module. Extension of the solar array mast is achieved by EVA/MMU crewmen who transfer the folded mast segments, unfold them individually, and attach them to the existing mast. The Orbiter

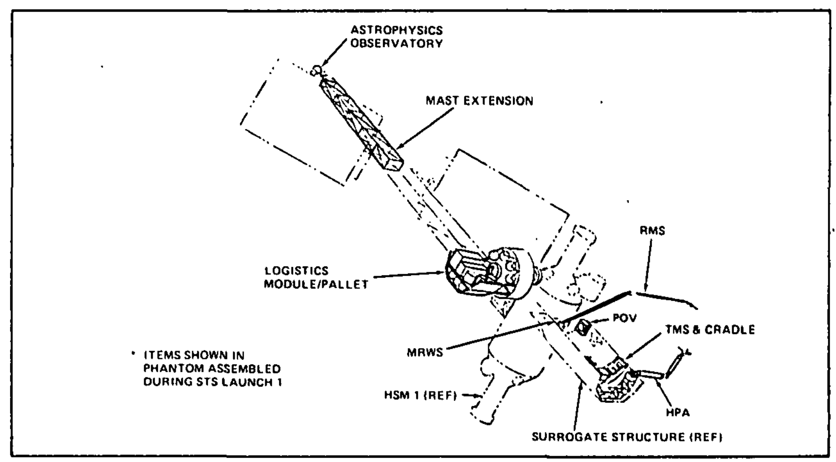


Fig. 3-6 Initial Space Station Assembly of Launch 2 Components

then reberths to the extended mast via its HPA, unloads the celestial instrument and its IPS, then mounts them to the mast tip using its RMS.

Dry mass data used as the program input to the space cost model is summarized in Fig. 3-7. The mass of the ISS is shown for each building block module to a subsystem level. Mass estimates are based on preliminary design details and subsystem analyses; verification came from many other studies and references.

SUBSYSTEM	3-MAN CORE	AIRLOCK	SURROGATE	EXT SUBSYS	OBSERV	LOGIS MOD
STRUCT/MECH	3650	900	964	2491	2110	1771
BERTHING/TUNNELS	900	–	–	–	–	68
SAT. SVC EQPT	–	–	1879	–	–	–
EPS	50	–	50	1800	–	50
ECLS/THERMAL	1984	–	100	–	–	125
DATA MGMT	650	–	25	–	–	–
COMM	550	–	–	–	–	15
GN&C	120	–	–	720	–	–
CREW ACCOM	1050	–	–	–	–	–
MODULE TOTAL	8954	900	3018	5011	2110	2029
STATION TOTAL	22,022					

Fig. 3-7 Initial Space Station Dry Mass Summary (kg)

Subsystems required for the ISS have been reviewed to determine the potential use of previously developed technology or technology currently under development; the results are tabulated in Fig. 3-8. A majority of subsystems appear to be able to use equipment derived from the STS, Skylab, or other ongoing spacecraft programs, and provide growth capability. The DMS, however, would use new components or technology under development to meet the requirements of cost effective autonomy and automation. The overall assessment results in projecting a low cost subsystem development program.

Enabling technology can encompass the complete spectrum from available off-the-shelf hardware to state-of-the-art breakthroughs. Basically, the 1986 technology base and associated design techniques will satisfy ISS requirements and, with appropriate design considerations, will provide an orderly evolution of the Space Station. Figure 3-9 summarizes the ISS enabling technology requirements.

A functional requirements analysis was performed to define the degree of autonomy (ground or onboard) and automation (automatic or manned) of the Space Station. The functional analysis identified onboard and ground top level functions as well as the first level subfunctions to support a manned Space Station and the various missions to be conducted on a Space Station. The analysis was based on experience in Skylab, Apollo, and the Space Shuttle; it was supplemented by current studies of mission requirements and Space Station architecture. After compiling all functions, they were integrated into 18 major functions and 84 first level functions. First level functions were defined in sufficient detail to evaluate the degree of autonomy and automation.

	POWER			DATA MGMT			EC/LS			GN&C			COMM & TRACK.		
	GEN CONT & DIST	ENERGY STORAGE	EMERGENCY	I/O & PROCESSORS	MASS MEMORY	SOFTWARE	ATMOSPHERE	WASTE MGMT	THERMAL CONT & WATER MGMT	SENSORS & PROPULSION	CONTROL	CMGs	ANTENNA PTG & TRACK	RECEIVE & XMIT	REND. RADAR
UNDER DEVELOPMENT	✓	✓		✓	✓	✓	✓		✓			✓		✓	
STS (DERIVED)			✓				✓	✓	✓	✓	✓		✓	✓	✓
OTHER SPACE PROGRAMS		✓		✓						✓	✓				
SKYLAB											✓	✓			

Fig. 3-8 Low Cost Subsystems Genealogy

	BASELINE	ENABLING TECHNOLOGY
EPS	• SOLAR ARRAY • NiH_2 BATTERIES • 180V DIST	• THIN CELL & HIGHER EFFICIENCY 2 • CELL MFG PROCESSES 2 • BATTERY DEVELOPMENT 2 • HI VOLT COMPONENT DEVELOPMENT 1
DMS	• Ada • FIBRE OPTICS • CMOS MAIN MEMORY WITH B/U BATTERY • BUBBLE AUX MEMORY	• MEETING EXISTING Ada SCHEDULE 1 • LOW LOSS COUPLERS 1 • DEV HIGHER DENSITIES 2 • SPACE QUALIFICATION & HIGHER DENSITIES 2
COMM & TRKNG	• S, K_u BAND SUBSYSTEMS • DISH, OMNI ANTENNAS • TDRS • SIMOP	• MODULATION/CODING/BANDWIDTH 1 • DES/DEV FOR APPLICATION 1 • ACQUISITION/TRACKING/DATA RATE 1 • RFI PROTECTION 1
EC/LSS	CLOSED LOOP	EXISTING HARDWARE WITH MODIFICATIONS 1
GN&C	ATTITUDE CONTROL VELOCITY CONTROL STABILIZATION SENSORS	EXISTING HARDWARE WITH MODIFICATIONS 1
	1 (1983-1986) TECHNOLOGY BASE & DESIGN TECHNIQUES ADEQUATE 2 TECHNOLOGY ADVANCE REQUIRED	

Fig. 3-9 Subsystem Enabling Technology Requirements

Initial allocation of the functions was based on an extensive list of criteria including safety, crew capability and load, technical risk, applicability, and onboard data processing load. Each of the 84 functions were subjected to their applicable criteria, and their location and criticality were identified. Twenty-one of these functions were soft (judgemental) allocations. These functions were subjected to a weighted trade-off by considering and quantifying cost, crew load, user access, reliability/maintainability, technical risk, and processing load, as applicable. Costs included both the development cost and the cost of operations, either onboard or on the ground; these were heavily weighted. Most of the initial allocation was confirmed by this trade.

Only five pre-allocations were revised. Long term mission trend analysis and mission performance evaluation became onboard functions, and mission data collection and preprocessing, as well as experimental data recording became ground functions. Thus, 48 functions are onboard, 16 are on the ground, and 20 are shared.

Each of the 48 onboard functions were examined to determine whether they were manual, automatic, or shared. Five manual functions require crew intervention (e.g., voice communication). Nineteen shared functions are those that the crew interacts with automatic functions (e.g., scheduling). Twenty-four automatic functions require no crew participation. The results of these trades are shown in Fig. 3-10.

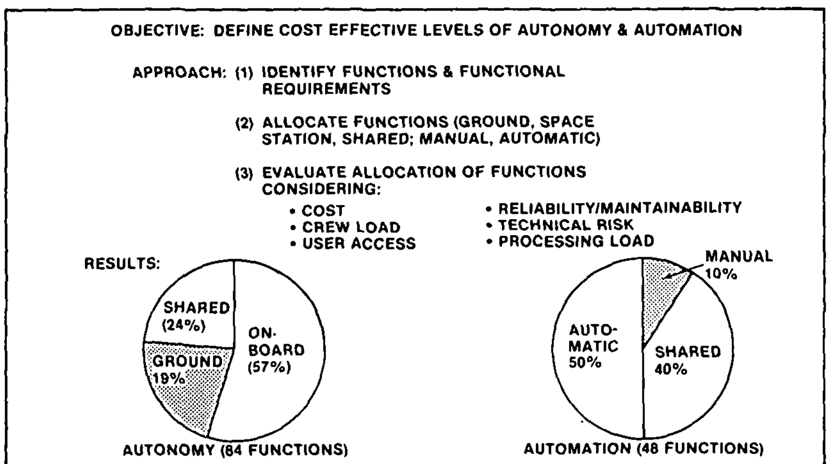


Fig. 3-10 Autonomy & Automation

To select the degree of distributed processing, seven architectural alternatives of the onboard processing system were defined by analyzing the functional interfaces and processing loads of the 48 Space Station functions. The alternatives range from a centralized system to a fully distributed system. Each of the alternatives were evaluated using cost (hardware, software, and integration), expansion potential, technology transparency, isolation of critical functions, and feasibility/risk. These were combined into a figure of merit, wherein the alternative with the highest figure of merit represents the optimum distribution. Alternative 4 (see Fig. 3-11) had the highest score. It consists of two primary processors: Station Operations and Mission Support. These processors interface via a communication and data routing processor. Military and entertainment processors also interface through the data routing processor. The Station Operations Processor interfaces to four processors and they, in turn, interface to the Space Station subsystems. The Mission Support processor supports common functions of the missions and provides an interface to unique mission processors, as required.

Figure 3-12 identifies the effects of designing the initial station with a growth capability. The major impact on the mass of the station is due to oversizing to accommodate an eventual tripling of the solar arrays. The major cost impact is avionics where 20% of the system is due to growth capability.

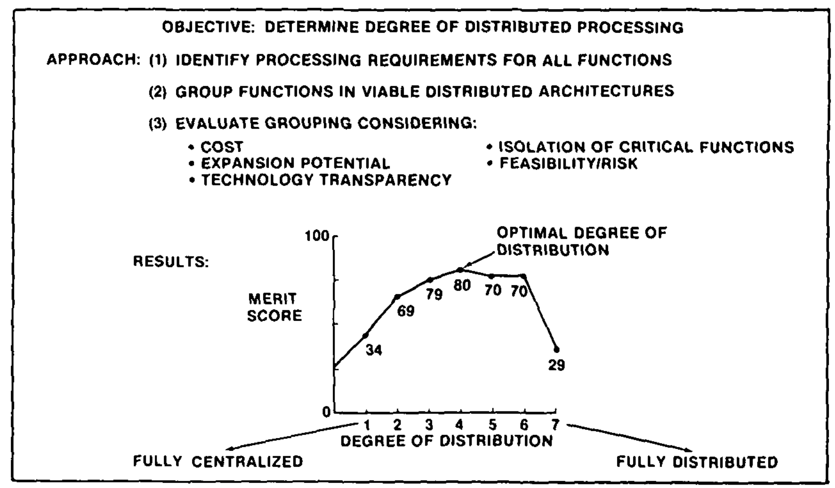


Fig. 3-11 Centralized vs Distributed Processing

PLANNED GROWTH	SCAR	MASS, kg	COST, $M
OBSERV	ADDED POSITION	100	5
ELEC PWR	LONGER TOWER LARGER GIMBAL/INDEX DISTRIB OVERSIZED	250 650 330	10 25 16
AVIONICS	DATA MGMT COMM	130 90	67 42
SERV OPER	ADDIT BERTH POSIT SURROGATE ADD-ON	70 50	5 1
TRANSP		-	6
CREW SIZE	ADD. CREW CAPAC	-	-
	TOTALS	1670	177

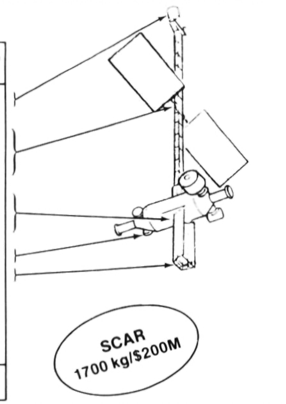


Fig. 3-12 Initial Space Station Evolution Scar Weight/Costs

3.3 EVOLVED SPACE STATION

The ISS can grow incrementally to become the Evolved Space Station (ESS) configuration shown in Fig. 3-13. This is accomplished by adding pressurized modules, surrogate structures for increased EVA activity, and more solar array area to meet increased electrical power demands and increased observation requirements.

Two standard, three man habitation core modules are added to the complex to house six more crewmen. Two core modules are modified to be laboratories and added for science and industrial processing R&D. Modules are attached by tunnels that extend from each cone end to provide redundant escape paths from each module and intermodule traffic flow that is clear of the main activities areas. Outboard tunnels can mount logistic modules, air locks, and growth modules.

Additional surrogate structures (installed back-to-back) provide increased facilities for satellite service, space test, and the transport harbor that must now accommodate OTV turnaround activities. These additions can be accomplished from an Orbiter berthed to the core module tunnel extension.

The solar array triples in size and power output from ISS to ESS. These increments are installed by a tethered EVA astronaut on an MMU/WRU to transfer each folded solar array panel to its mount on the cross arm and then to actuate a SEPS-type deployment.

Functional capabilities required to perform missions on the ESS are illustrated in Fig. 3-14. Celestial observations are performed outboard of the solar arrays since they need clear viewing for 2π steradians, anti-earth. In general, the satellite service and space test range share facilities; if more convenient for a particular test, however, the transport harbor can accommodate a test activity. The industrial park is berthed to the core module for exchange of processed materials, but its subsystems are serviced at the transport harbor.

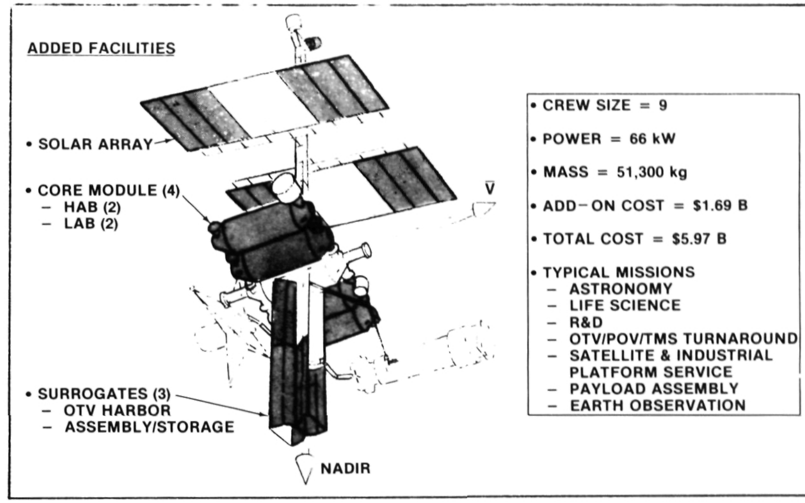


Fig. 3-13 Evolved Space Station At 28.5° Inclination

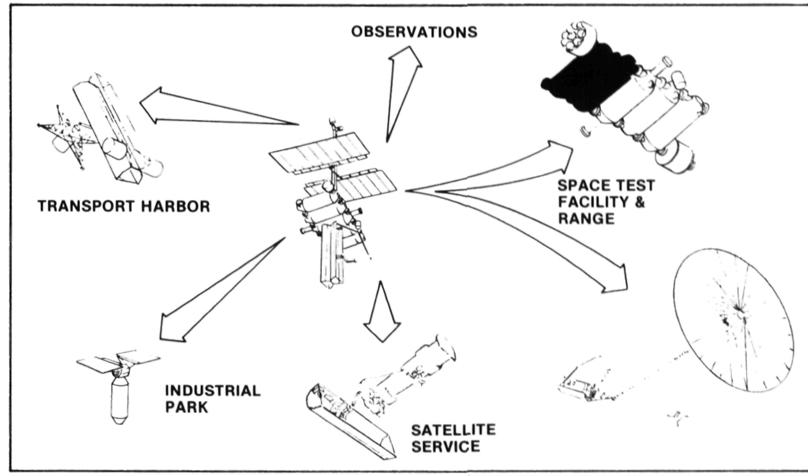


Fig. 3-14 Mission Functional Capabilities

The transport harbor is used to turn around an OTV that uses storable propellant, and is refuelled by removing the empty propellant tank and replacing it with a ground-filled tank. R&D laboratories are shaded in the group of core modules shown in Fig. 3-14.

3.4 TENDED INDUSTRIAL PLATFORM

Micro-g requirements and very high power demands (for materials production) are difficult to satisfy as part of the main Space Station. Providing a commercial materials processing facility as a free flying industrial park avoids added design scars on the initial space station and decouples subsequent growth from the scheduled start of MPS production.

Four free flyers will be required for the program; Fig. 3-15 shows a typical one. The pressurized core module used for Space Station habitations and laboratories provides the pressurized shell and appropriate subsystems. Additional subsystems will be installed in the module as required. As with the main station, a pallet mounts external subsystems such as batteries, power processing, and CMGs. The solar array power source has no gimballing requirements since the satellite will be flown inertially fixed relative to the sun, which simplifies the array and minimizes potential undesirable accelerations.

Allocation of the potential 40 processing units to the four free flyers will be on a duty cycle basis. The power requirement for each will vary with a total requirement of approximately 110 kW, continuous. The average is 28 kW per free flyer, the size of the array shown in Fig. 3-15. Salient features of the vehicle are also given.

The operational sequence of a free flyer enables it to boost itself to a higher orbit using onboard propulsion. The new orbit is dictated by the duty cycle time of the furnaces. The flyer is allowed to orbit decay in that time period; at the end of the duty cycle, its location is suitable for rendezvous, capture, and berthing to the Space Station for materials exchange and servicing of subsystems.

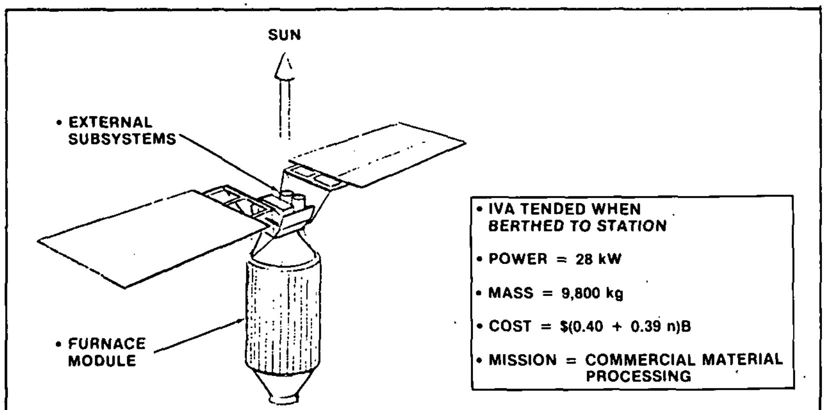


Fig. 3-15 Tended Industrial Platform

The industrial park complex is shown interfacing with the Space Station in Fig. 3-16. A sector of space trailing behind the Space Station is used for their formation flight. Free flyers are deployed into relative trajectory paths so that they traverse to within close proximity of the Space Station at the prescribed time intervals. Free flyers would be cycled so that only one would arrive or depart at the Space Station on any given day. To average this flight formation corridor, a boundary region is required around the Space Station that is a few kilometers above and below and extends behind to approximately 2000 km.

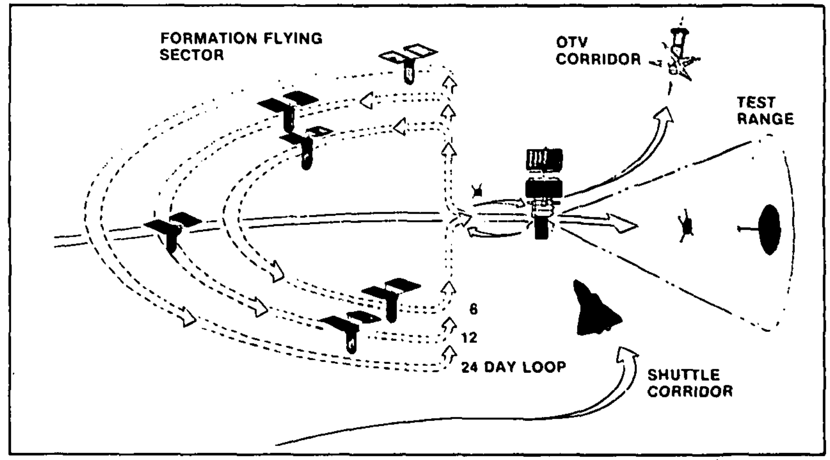


Fig. 3-16 Formation Flight & Operations Corridors

3.5 TENDED POLAR PLATFORM

Requirements call for a total of three astrophysics missions, three solar missions, and twelve terrestrial observation missions to be aboard a LEO facility in high inclination orbit by the year 2000. Some of the earth observation missions dictate a noon sun synchronous orbit to provide light/dark contrasts.

System analysis shows that an unmanned platform can satisfy the missions if visited by the Shuttle at approximately six-month intervals to service the platform, change out observation instruments, and to service satellites.

Initially, the platform caters to earth viewing; it is configured as shown in Fig. 3-17. A standard three man habitation module, replicated from the 28.5° inclination Space Station, houses subsystems and provides extended living volume for a visiting Orbiter crew. When tended, the Orbiter berths to the module to enable shirt sleeve servicing of the subsystems.

Surrogate bay structures mount IPSs that, in turn, mount the packages of earth observation instruments. Solar array panels are mounted outboard of the surrogates on structures designed to support solar observation instruments at a later date. The array is sized to give 14.5 kW of continuous power.

An external subsystems pallet mounts batteries for dark side power, conversion equipment, and control moment gyros for attitude control.

The evolved platform is shown in Fig. 3-18. To accommodate the full complement of earth observation missions, a surrogate bay structure is added orthogonally to the two existing structures. Another surrogate is added to mount satellite service equipment. These are added directly from the Orbiter berthed to the pressure module extension tunnel.

From this same berthed Orbiter location, a tethered EVA man with an MMU transfers folded mast segments, one at a time, to construct a mast outboard of the external subsystems pallet. The mast tip mounts a celestial observation instrument that requires a viewing field of 2π steradians, anti-earth.

Solar array wings are extended by adding panels to provide a total continuous power of 29 kW. IPS-mounted solar viewing mission equipment is located on the solar array wing support structures. Their gross pointing is provided by the solar array gimbal.

Two celestial observation packages are mounted to the back, anti-earth face of the surrogate structures. Their viewing requirement is local zenith and they are, therefore, located outboard of the volume swept out by the movements of the mast-mounted celestial instrument.

Berthing points for the Orbiter will be provided on the mast and surrogate structures. The Orbiter can berth its HPA end effector to a suitably located point that enables the RMS to reach for additional celestial and solar observation equipment, and extend the solar arrays.

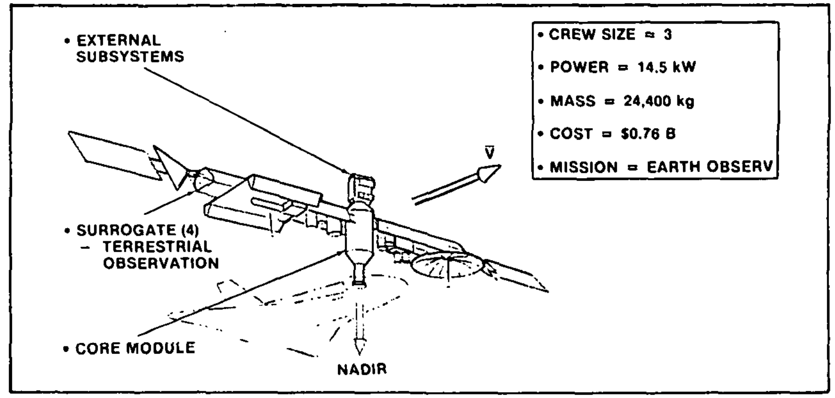


Fig. 3-17 Tended Polar Platform — Initial

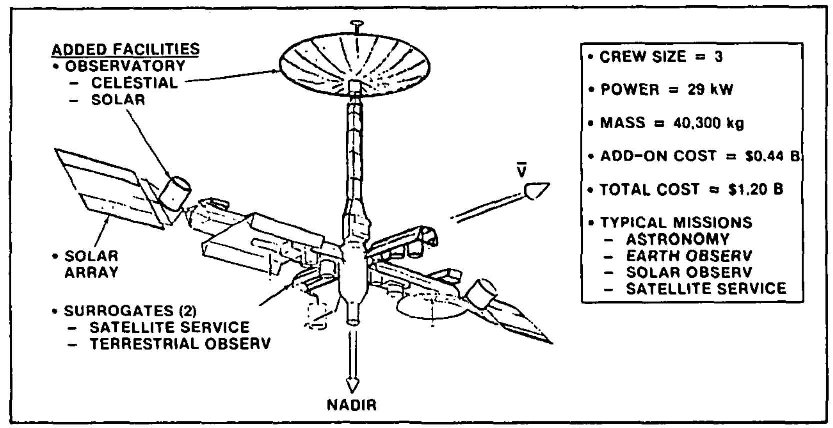


Fig. 3-18 Tended Polar Platform — Evolved

4.1 METHODOLOGY & GROUNDRULES

Since detailed engineering designs were not required (or desired) for this study, the costing approach used was parametric.

Parametric estimates are derived by statistically correlating the historical cost of several systems to physical or performance characteristics of those same systems, and then using the identified characteristics (or cost drivers) of the system being estimated to calculate the cost of the subject program. The observed mathematical relationships, called Cost Estimating Relationships (CERs), between cost and technical variables are treated as time-constant expressions of reality. CERs are subject to revision only as additional/more current data can be observed and reflected in the mathematical expressions.

Weight is the cost driving parameter used in most subsystem CERs. To input the CERs, an experienced weights engineer reviewed each architectural configuration. The most likely weight (without contingency) was then estimated by analogy or direct calculation.

Grumman's in-house cost model, called Systems Parametric Algorithm for Cost Estimating (SPACE), was used to facilitate cost calculations and graphics for this study. This computer program provides rapid and accurate cost computations, repeatability, and consistency of results.

Key cost groundrules are listed in Fig. 4-1. All costs are normalized to constant FY 1984 dollars using the NASA escalation factors supplied. Module level costs are provided in all cases. Most estimates were performed at the subsystem level, and these are shown as an Appendix to the Cost/Programmatics volume. Costs include contractor G&A, but exclude fee.

The organization followed the Work Breakdown Structure (WBS) developed by the joint Industry Government Space System Cost Analyses Group (SSCAG). It contains all labor and material required for the DDT&E, production and operation phases of all program elements.

A flightworthy spare was estimated to cost 60% of the Theoretical First Unit (TFU) cost; this was added to the estimated production cost. Transportation to LEO was also included in production cost totals. Facility costs were not estimated. NASA wraparound costs (program support, management and integration, launch and landing) were estimated and reported, but not included in the totals.

- FY 84 CONSTANT $ (NASA ESCALATION FACTORS)
- MODULE LEVEL COSTS (ALL CASES)
- SUBSYSTEM LEVEL COSTS WHERE ESTIMATED (MAJORITY)
- COSTS INCLUDE CONTRACTOR G&A, EXCLUDE FEE
- COSTS AT MOST LIKELY WEIGHT, NO CONTINGENCY
- FACILITY COSTS NOT ESTIMATED
- NASA WRAPAROUNDS REPORTED SEPARATELY

Fig. 4-1 Key Costing Groundrules

4.2 SPACE STATION SUMMARY, ACQUISITION COSTS

The initial Space Station in 28.5° orbit will encompass a full range of capabilities; it is expected to consist of a three man Habitat, External Subsystems and Power Supply, Surrogate Modules for Satellite Services and Transportation Harbor, an Observation Module, and a Shuttle-borne logistics module for regular resupply functions. The DDT&E phase for the initial station is estimated to be $3.2B and production will be $1.1B, for a total acquisition cost of $4.3B.

The augmented capability station contains additions to be phased in later and will require an additional $0.4B DDT&E, and $1.3B for production. Four Tended Industrial Platforms complete the 28.5° cluster for an additional $0.4B DDT&E and $1.5B production cost. Total acquisition cost for the mature 28.5° station is anticipated to be $7.9B.

The initial high inclination Tended Polar Platform is expected to have a DDT&E cost of $0.6B and a production cost of $0.7B. A later add-on for augmented capability will cost an additional $0.6B for DDT&E; and $0.4B for production.

Total acquisition cost for the mature 28.5° Station and the mature Polar Platform is expected to be $9.1B. These costs are summarized in Fig. 4-2.

4.3 MASS/COST SUMMARY, ISS

Initial Space Station costs and masses are summarized by modules, as shown in Fig. 4-3.

This parametric data is for a dry station that requires two initial Shuttle launches ($84M each) and, thereafter, the use of three logistic vehicles for resupply and crew rotation ($328M). The result is an inclusive cost of $4280M, with an accompanying mass of 22,000 kg.

	PHASE	DDT&E	PRODUCTION*	TOTAL
28 1/2	INITIAL SPACE STATION **	3165	1114	4278
	SPACE STATION ADD ON**	376	1312	1688
	INDUSTRIAL PLATFORM (4)	404	1546	1950
	TOTAL	3945	3972	7916
POLAR	INITIAL TENDED POLAR PLATFORM	57	702	759
	POLAR PLATFORM ADD ON	57	382	439
	TOTAL	114	1084	1198
	TOTAL	4059	5056	9114

*INCLUDES TRANSPORTATION TO LEO
**EXCLUDES OTV ACQUISITION

Fig. 4-2 Space Station Summary, Acquisition Costs, '84 $M

MODULE	MASS, kg	DDT&E, $M	NO. OF UNITS	PRODUCTION, $M	TOTAL TO IOC, $M
HABITAT	8954	1702	1	386	2088
EXT SUBSYSTEMS	5011	624	1	351	975
AIRLOCK	900	-	1	22	22
SURROGATE	3018	400	1	90	490
OBSERVATORY	2110	179	1	30	208
LOGISTICS	2029	260	3	68	328
TRANSPORTATION	-	-	-	168	168
TOTALS	22,022	3165		1115	4280

Fig. 4-3 Mass-Cost Summary — Initial Space Station

4.4 SPACE STATION FUNDING PROFILE

Assuming a thorough Phase B effort and an Approval To Proceed (ATP) at the end of FY'86, the Baseline Schedule calls for an initial operational capability (IOC) of the Initial Space Station at the end of FY'90. This four year period is about the minimum time reasonably expected without a strenuous 'crash' program. On the average, Phase C/D aircraft programs run about two years from ATP to first flight, with that for LM and Shuttle (viewed as more complex) being about eight years.

The funding profile (see Fig. 4-4a) for this baseline program reveals two disadvantages. First, the rapid buildup of expenditures may cause difficulties; peak annual funding comes to about $1.3B in FY'89, which exceeds the desired limit of $1.0B.

Delaying the ISS IOC from the end of FY'90 to FY'91 (see Fig. 4-4b), with a corresponding postponement in deployment of the Evolved Station, Tended Industrial Platforms, and Tended Polar Platform, yields a program conforming to a $1.0B peak annual funding requirement.

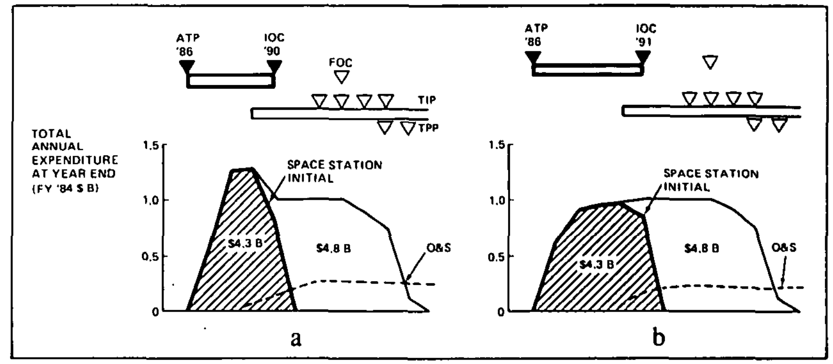


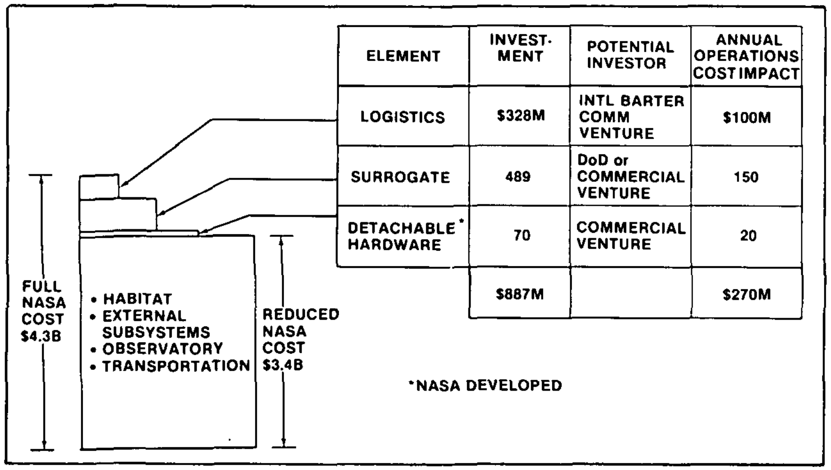
Fig. 4-4 Space Station Funding Profile

4.5 NASA INITIAL SPACE STATION, ACQUISITION OPTIONS

Examination of the projected cost involved to produce the ISS, revealed that consideration should be given to the proposition that some (if not all) parts might be 'farmed out' to large contractors, a consortium, or foreign interests. The contracted parties could finance and develop these parts (or modules) and be repaid by a lease or barter arrangement.

The Logistics Module ($328M) and the Surrogate Module ($489M) appear to be within the financial capability of large aerospace contractors, or a consortium of them. To reduce the NASA 'up-front' cost, it might be quite feasible for such a contractor (or consortium) to design, qualify, and build these modules and lease them to NASA for operation. A foreign government might participate with a barter arrangement.

This scheme (see Fig. 4-5) has the potential of offloading $817M from NASA's investment. It must be observed, however, that lease costs would increase operating costs. Assuming a 20 year life and 30% return before taxes, the annual lease cost would be approximately $30 per $100 invested. Thus, NASA would pay back the investment, after taxes, in about six years; this is about as long as any entrepreneur would find attractive.



ELEMENT	INVEST-MENT	POTENTIAL INVESTOR	ANNUAL OPERATIONS COST IMPACT
LOGISTICS	$328M	INTL BARTER COMM VENTURE	$100M
SURROGATE	489	DoD or COMMERCIAL VENTURE	150
DETACHABLE* HARDWARE	70	COMMERCIAL VENTURE	20
	$887M		$270M

Fig. 4-5 NASA Initial Space Station Acquisition Options

A more modest proposition would be to develop such participation in the supply of 'detachable' hardware such as berthing ports, pallets, airlocks, etc. A total potential offload of $70M is available using this scheme. The net effect would be to reduce NASA 'up front' costs from $4.3B to $3.2B.

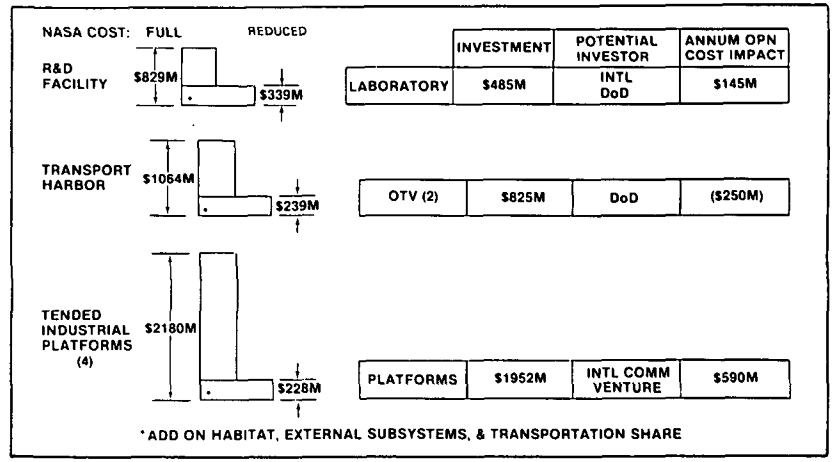
4.6 NASA SPACE STATION, GROWTH ACQUISITION OPTIONS

As the Space Station evolves into its mature growth configuration, additional opportunities present themselves for non-NASA participation. Three of these are of particular interest (see Fig. 4-6).

The first is the R&D facility, which has a total cost of $824M (including its share of the add-on Habitat, External Subsystems, and transportation costs). The latter costs are estimated to be $339M, with the Laboratory Module share at $485M. The module may be a candidate for international participation, or possibly DoD sharing, with a potential offload of the $405M from the NASA investment. The annual impact on operating costs was calculated as before (30% return, 20 year life, or $145M).

With the same approach, the initial investment of the Transport Harbor ($1064M), including the OTV, might be offloaded by $825M if the OTV development and production effort were undertaken by DoD or a commercial venture.

The third element is the Tended Industrial Platform complex, with a total cost of $2180M and an offload potential of $1952M.



	INVESTMENT	POTENTIAL INVESTOR	ANNUM OPN COST IMPACT
LABORATORY	$485M	INTL DoD	$145M
OTV (2)	$825M	DoD	($250M)
PLATFORMS	$1952M	INTL COMM VENTURE	$590M

Fig. 4-6 NASA Space Station Growth Acquisition Options

It is obvious that many other options and arrangements are possible and feasible; these should also be explored.

4.7 PARTIAL PROGRAM OPTIONS SUMMARY

Program options involving international participation, DoD involvement, and commercial and industrial cooperation are virtually limitless. The more promising options should be explored in depth as the program proceeds, not only to ease NASA investment, but also to ensure that beneficiaries of the Space Station participate in planning and investment.

Figure 4-7 indicates that the ISS total NASA investment of $4.3B may be reduced to $3.4B. With other suitable participation (primarily DoD), a duplicate 28.5^0 station might be possible for a total investment of $4.0B.

"Normal" evolution of an ISS to a mature system (with associated industrial platforms and the Polar Platform) with participation by others may be possible with a NASA investment of $5.8B, as opposed to $9.9B if no participation is obtained.

4.8 ACCRUED ECONOMIC BENEFITS

Most users can expect a substantial economic benefit, and an even larger group (potentially the whole country) could reap performance and social benefits from realization of an Initial Space Station.

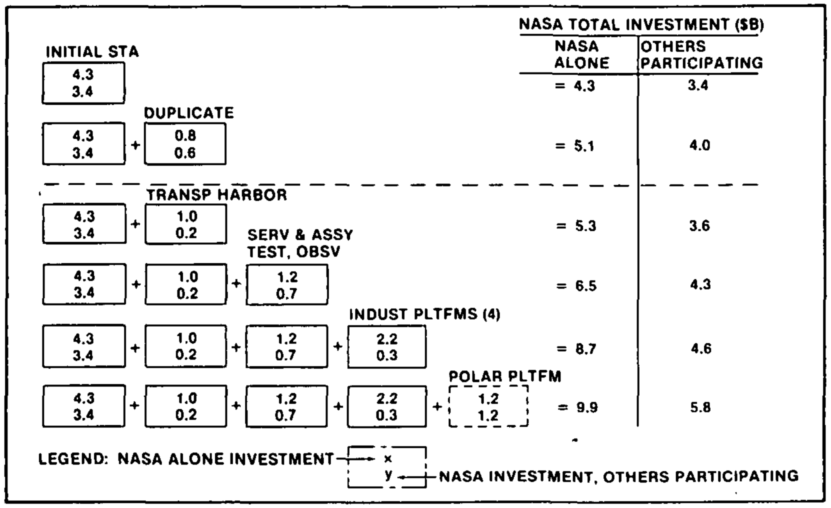


Fig. 4-7 Partial Program Options Summary

Six activities that yield economic benefits are shown in Fig. 4-8 and 4-9. For each area, the cost of the "Space Station way" of performing a task is compared with the lowest cost non-Space Station method; cumulative savings are plotted through the year 2000. Space Station investment to support the activity is also shown and the cross-over point is marked with a small circle. Excess of savings over investment is the net benefit.

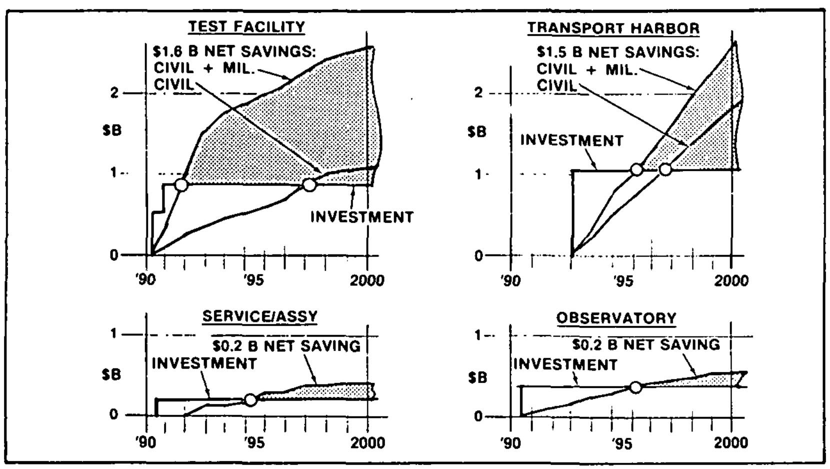


Fig. 4-8 Accrued Economic Benefits At 28.5° Space Station

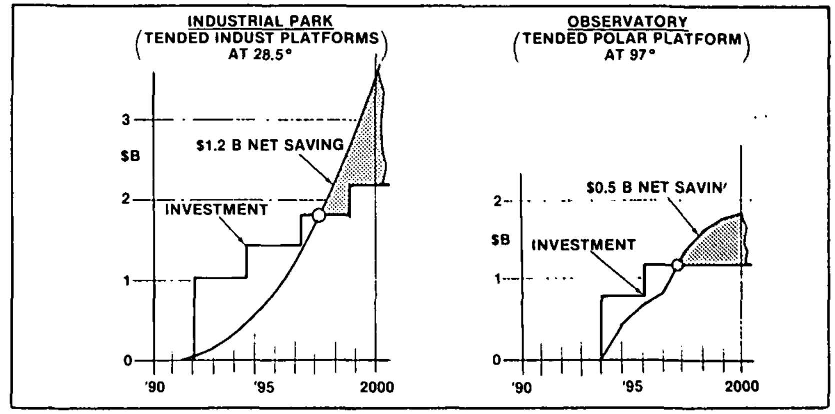


Fig. 4-9 Accrued Benefits: 28.5° & 97° Tended Platforms

In the case of the Transport Station, for example, the recurring cost of transporting the expected manifest of civil and military communication satellites to GEO averages $318M less per year when using a space-based, reusable OTV compared to another available method — expendable SRMS and Centaurs. Gross savings from 1993 (when the Transport Harbor is assumed to start operations) through 2000 amount to $2550M. The added Space Station cost to provide the service is $240M and the new OTV costs $820M, for a total investment of $1060M. The payback period is a little more than three years, and the net benefit by the year 2000 is $1490M. With regard to economic benefits, there are four general comments:

- Three of the six activities (Test Facility, Transport Harbor, and Industrial Park) show net benefits of more than $1B each; the others are less
- There are three types of cumulative savings curves
  - Exponential Upwards (i.e., Industrial Park as platforms are added)
  - Steady Slope (i.e., Transport Harbor, assuming constant traffic)
  - Leveling Off (i.e., Observatories reaching instrument saturation)
  - Cumulative Savings curves for Test Facility and Service & Assembly activities (late 1990s) will probably exhibit steady slope characteristics
- The distribution of benefits (whether by user category or by Space Station capability) is spread fairly evenly. This suggests that the value of the Space Station is not unduly sensitive to a particular mission mix

- We have treated the ISS investment (approximately $4B) as a sunk cost. We have offset the growth costs of the Space Station against the six activities in Fig. 4-8 and 4-9 to arrive at the net savings. Some of these savings will have to be passed on to the user to induce a change from pre-Space Station way to doing business. We have not addressed what this proportion should be.

4.9 MILITARY SPACE STATION FUNCTIONS WITH HIGH PAYBACK

As shown in detail in the accrued benefit analysis, the most attractive Space Station capabilities for the military are the Test Laboratory/Test Range Facility, and the space-based OTV (see Fig. 4-10). The former yields a significant decrease in development time and cost for military developments, and the latter offers significant savings in transport to high inclination orbit or to GEO.

STATION CAPABILITY	MISSION	PAY-BACK
▷ NATIONAL SPACE TEST FACILITY & RANGE	• ENGINEERING DEV • PROOF OF CONCEPT	26% OF SPACE TEST COSTS SAVED
▷ TRANSPORT HARBOR & SPACE-BASED OTV	• SATELLITE DEPLOYMENT TO GEO	PAYBACK IN > 4 YEARS, CIVIL/MILITARY TRAFFIC

DoD INVOLVEMENT AS ON SPACE SHUTTLE

Fig. 4-10 Military Space Station Functions With High Payback

4.10 PERFORMANCE BENEFITS

All mission operations will benefit from the reduced impact on mission operations caused by Shuttle reschedules, payload priorities, or delays. This will be especially significant as the station matures and develops its full capability of crew and equipment. A summary tabulation of these benefits is shown in Fig. 4-11.

We anticipate that the current trend of making larger satellites will be encouraged by the capability of lifting large payloads to GEO, and that such satellites will be designed with that in mind.

The on-orbit assembly capability affords an economical method for very large structures without Shuttle-size limitations, excessive Shuttle loiter time, and extensive EVA activities.

In two of our studies, development programs were reduced 50% by Space Station use.

▷ALL MISSION OPERATIONS	• DECOUPLED FROM SHUTTLE LAUNCH SCHEDULE, PAYLOAD PRIORITIES, & GROUND DELAYS
▷SPACE BASED OTV	• 10,000 kg + USEFUL PAYLOAD INTO GEO • ON-DEMAND CAPABILITY
▷ON-ORBIT ASSEMBLY	• ASTRONAUT CAN INSPECT, WORK AROUND, & COMPLEMENT ROBOTICS & AUTOMATION • SHUTTLE SIZE LIMITS SURMOUNTED
▷ON-ORBIT TECHNOLOGY AND R&D	• ASTRONAUT CAN CALIBRATE, OPERATE, & MODIFY • TRUE SPACE ENVIRONMENT • INTERACTION OF MULTIPLE DISCIPLINES & CAPABILITIES IN A NOVEL ENVIRONMENT WILL PRODUCE SYNERGISTIC ADVANCES • SHORTER DEVELOPMENT PROGRAMS
▷SCIENTIFIC OBSERVATIONS	• SHORT LIVED EXPERIMENTS EXTENDED • ASTRONAUT CAN MONITOR, INTERVENE, REPLENISH, & UPDATE.

Fig. 4-11 Performance Benefits

4.11 SOCIAL BENEFITS

Although difficult to quantify in precise terms, the social/societal benefits to be expected from implementation of a viable Space Station program are none the less real, important, and of considerable magnitude. Figure 4-12 describes some of the more important benefits.

Our nation has been consistently in the forefront of high technology development and this is an implicit and explicit national goal. The Space Station augments national capabilities for high technology in a very significant manner and provides a focus for what some feel is our lagging engineering and science educational aims.

International cooperation has been generated by the Shuttle program, and the Space Station can provide a much greater and broader stimulation for international cooperation.

In terms of a unique development facility, there can be no earthbound parallel. The possibilities for development of communication services, commercial products, and industries in the semiconductor and medical fields are all realizable benefits.

New therapeutic and diagnostic techniques have been demonstrated by limited Shuttle experiments, with a Space Station offering vastly augmented capabilities. Furthermore, the Space Station may well represent the military 'high ground' required for our security.

These near-term benefits lead to the inevitable conclusion that, in the long term, the Space Station is truly a "GATEWAY TO THE FUTURE."

IN THE SHORT TERM:

• HI-TECH – A NATIONAL GOAL	• UNIQUE, AFFORDABLE DEVELOPMENT FACILITY
• FOCUS FOR ENGINEERING/ SCIENCE EDUCATION	• NEW COMMUNICATION SERVICES
• UNIQUE LUNAR & BEYOND EXPLORATION	• NEW COMMERCIAL PRODUCTS & INDUSTRIES – MEDICAL, SEMI-CONDUCTOR
• INTERNATIONAL COOPERATION	• NEW THERAPEUTIC, DIAGNOSTIC TECHNIQUES
	• ENHANCED NATIONAL SECURITY

IN THE LONG TERM:

• GATEWAY TO THE FUTURE

Fig. 4-12 Social Benefits

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