NASA Technical Memorandum 101497

GROWTH REQUIREMENTS FOR MULTIDISCIPLINE RESEARCH AND DEVELOPMENT ON THE EVOLUTIONARY SPACE STATION

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INTRODUCTION

NASA's Space Station Freedom will be an Earth-orbiting, research and development (R&D) facility for utilization by the United States and its international partners beginning in the mid-1990's. Space Station will provide pressurized volume, payload attach points, crew time, electrical power and other essential resources to a diverse user community in support of their scientific research, technology development and commercial endeavors in space. Since this "facility" will operate on-orbit for an indefinite lifetime, its design must be evolutionary to accommodate a dynamic user environment over many years. While the specifics of these out-year missions are not, in most cases, well understood, it is certain that user demand for Station resources and services will increase soon after the assembly phase is complete. In fact, the Phase I Space Station is already oversubscribed, particularly in the areas of electrical power and crew time. To enable on-orbit resource growth and also system technology upgrades, key evolution accommodation requirements must be identified for the Phase I Space Station design. Failure to incorporate the hardware "scars" and software "hooks" in Phase I that enable/facilitate evolution will make station growth on-orbit prohibitively complex and costly.

The Space Station Office (SSO) at NASA, Langley Research Center (LaRC), is responsible for identifying evolution requirements for Space Station Freedom which adequately meet future user needs. In that role, the Evolutionary Definition Office (EDO) of SSO teamed with McDonnell Douglas Astronautics Company (MDAC) to develop and analyze a set of scenarios that determine the manner in which Station evolves as a R&D facility in space. A scenario, for this analysis, is defined by a set of missions consistent with a particular activity emphasis on Station and a level of transportation support from Earth to Space Station orbit. Growth resource requirements (e.g., power, crew, volume) were determined for each scenario constrained by lift capability. This report will identify the assumptions, describe the approach and present the results of the LaRC/MDAC analysis.

Results of this study were combined with analytical results of other system studies in the process of identifying a set of adequate and realistic requirements for Space Station evolution. The selected requirements and supporting rationale were presented and advocated by EDO at the Space Station Freedom Program, Preliminary Requirements Review (PRR).

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SPACE STATION
GROWTH REQUIREMENTS

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SPACE STATION GROWTH REQUIREMENTS - OVERVIEW

The first section of this document presents growth requirements for major Space Station resources. These requirements were derived from a number of analyses of possible Space Station growth paths. Detailed results for the specific growth scenarios are presented in the last section of this document.

Resource requirements for a multidisciplinary Space Station are driven primarily by the level of transportation support which is available. If the resource requirements of existing experiments are met, and there is surplus lift, additional experiments may be brought to the Space Station. This in turn increases the resource requirements and possibly results in the need to grow. Assuming that transportation support is near constant for a period of time, a balance will be achieved when the station grows to the point where support for existing experiments and support for the Space Station systems makes use of the available level of lift.

The steady state resource requirements for a given steady state level of lift support is dependent to some degree on the type of experiments being performed on the Space Station. For example, if the Space Station is supporting extensive automated materials processing, the crew requirement will be lower than if it is supporting life sciences experimentation with the same amount of lift. Likewise, a Space Station which is used primarily as a base for servicing co-orbiting platforms will have a low power requirement as compared to a Space Station which uses the same lift for experimentation on the station.

The ultimate utilization of the Space Station has not been, nor should be, defined at this time. The goal is to design the station as flexibly as possible to allow growth in a variety of directions. In order to project growth resource requirements for a wide envelope of possible utilizations of the Space Station, several growth scenarios were analyzed for their final steady state resource requirements. Each scenario consists of a predetermined level of transportation support and Space Station utilization emphasis.

Three transportation models were used to encompass a range of feasible support levels to the Space Station. Although some of these models show transportation support growing with time, the final resource requirements are driven by the final steady state level of lift.

Four Space Station utilization emphases were also examined in order to cover a range of possible evolution while remaining basically multidisciplinary in nature. These emphases were chosen both as realistic growth possibilities and as minimum and maximum resource requirement drivers.

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SPACE STATION GROWTH REQUIREMENTS
OVERVIEW

- The growth requirements described in the following charts combine the results of 10 growth scenarios

Scenario	Utilization Emphasis	Transportation Support*
1	Microgravity Research	Aggressive
2	Microgravity Research & Materials Production	5 NSTS/yr only
3	" " " "	Moderate
4	" " " "	Aggressive
5	Life Sciences Research	5 NSTS/yr only
6	" " "	Moderate
7	" " "	Aggressive
8	Observational Science	5 NSTS/yr only
9	" "	Moderate
10	" "	Aggressive

* Details of the moderate and aggressive transportation models are presented in the study approach section of this report

- Growth requirements were determined for the following resources
  - •• Power
  - •• Crew
  - •• Pressurized Volume (Laboratory and habitation modules)
  - •• Attach points and truss structure
  - •• Logistics

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SPACE STATION GROWTH REQUIREMENTS - TRANSPORTATION

At this time, the level of Earth-to-orbit transportation support to the Space Station is projected at a level of at least 5 NSTS flights per year. However, with the current emphasis on a mixed fleet (NSTS and ELVs) approach to space transportation in the aftermath of the Challenger accident, it is likely that ELVs will augment NSTS support for Space Station. The ELVs used in the transportation models for this study are shown on this chart and include both United States and International vehicles. This is not intended to be a complete set of ELVs which may serve in a Space Station support role. Most of the vehicles listed are not currently operational, but should be available in the Space Station operational time frame.

It is important to note several issues raised by the use of ELVs for Space Station support. Unique payload carriers will have to be designed for these vehicles, or the NSTS Space Station carriers will have to be designed as ELV compatible. Delivery of the ELV payload from its insertion orbit to the Space Station will require the use of the OMV or some other unique upper stage. Finally, the use of ELVs increases the Earth-to-orbit transportation capability, but does not provide additional capability for returning material or rotating crew from the Space Station to Earth.

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SPACE STATION GROWTH REQUIREMENTS
TRANSPORTATION

Launch Vehicles capable of supporting the Space Station include the National Space Transportation System (NSTS), United States supplied ELVs, and ELVs provided and launched by the International Space Station partners. Earth to orbit transportation support ultimately drives the speed and extent of Space Station growth

Launch Vehicle	Major Operational Uses	Status
NSTS	Crew rotation Logistics delivery Logistics return	Minimum of 5 flights per year projected
Titan IV	Growth element delivery Logistics delivery*	First launch 9/88; current projected availability for NASA approx 2/yr
Ariane V (ESA)	Growth element delivery Hermes vehicle launch (crew rotation)	Operational in 1996; 10/yr max
H-II (Japan)	Japanese Experiment Logistics Module (ELM) delivery	Operational in 1993; 2/yr max
Shuttle-C/Advanced Launch System	Growth element delivery Large experiment delivery Logistics delivery**	Phase A/B stage; Operational as early as 1994 if development is approved

* Modifications to the current Space Station logistics carriers may be required
** Extensive modifications to existing designs or new logistics carriers required

SPACE STATION GROWTH REQUIREMENTS - TRANSPORTATION CONTINUED

The ongoing logistics demands of the Phase 1 configuration and its complement of experimentation require a support level of at least 5 NSTS per year. The feasibility of adding the power and crew required for full utilization of the Phase 1 missions is also questionable at this flight rate, even assuming an enhanced shuttle lift capability. The ability to add power and crew is very sensitive to the exact Phase 1 mission set and the percentage of equipment utilization. We found that the difference of 6 double racks allocated to μ-g experiments as opposed to life science research make the difference of having sufficient lift to launch and maintain a second habitation module and associated crew. The shortage of crew and power at Phase 1 will result in lower equipment utilization for the Phase 1 missions which in turn will lead to lower user lift requirements. The 'additional' lift due to underutilization of equipment may be used for growth; detailed analysis of resource allocation during the Phase 1 time frame when resources are insufficient is a subject for an additional study.

A rough breakdown of the ongoing logistics requirements at Phase 1 (enhanced-NSTS equivalent) are as follows:

Crew & Station Support Logistics	1.7
Experiment Support Logistics	1.4 - 1.6
Logistics Carriers and AFE for the above	1.3 - 1.4
Total	4.4 - 4.7 (Enhanced NSTS)

The addition of a habitation module requires an entire NSTS flight. Although a flight rate of 5 NSTS per year is sufficient for the lift requirements of the Phase 1 missions (ignoring power and crew deficits for a moment), dedication of a full shuttle flight will necessarily reduce available experiment lift by approximately 30-40%.

If the addition of power and a habitation module with crew needed to support the Phase 1 missions is achieved, a rough breakdown of the ongoing logistics requirements (enhanced-NSTS equivalent) would be:

Crew & Station Support Logistics	2.3
Experiment Support Logistics	1.4 - 1.6
Logistics Carriers and AFE for the above	1.5 - 1.6
Total	5.2 - 5.4 (Enhanced NSTS)

In summary, at a flight rate of 5 NSTS/yr, the use of lift to add needed crew and power will severely reduce user support during the growth time frame. Even if this growth is achieved, the ability of 5 enhanced NSTS per year to meet the resulting Space Station and experiment logistics requirements is borderline. Finally, it is clear that experiment growth is not feasible at this flight rate.

SPACE STATION GROWTH REQUIREMENTS
TRANSPORTATION
CONTINUED

A flight rate of 5 NSTS flights per year is insufficient for Space Station experiment growth beyond the Phase 1 level

- Growth of crew and power required to meet the needs of a likely set of missions at Phase 1
  - Crew growth requires additional habitation module and resource nodes with associated significant ongoing logistics support
  - Power growth has a large one time lift requirement with a smaller ongoing logistics support
- Some resource growth may be possible with 5 enhanced NSTS per year, but will impact user support during the growth time frame
- Experiment growth would require additional pressurized volume and/or additional truss structure. Resulting user and station support logistics requirements would exceed the level which 5 NSTS per year could support; even under the assumption of enhanced NSTS lift capability

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SPACE STATION GROWTH REQUIREMENTS
POWER

In order to allow aggressive research in life sciences or microgravity science research and commercial production of materials, the Space Station should be scarred to allow growth to 275 KW

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- Growth power requirements are determined by the type of experimentation being carried out on the Space Station and the level of launch support being provided to the station
- The lowest power requirement occurs when observational science experiments represent a majority of the Space Station utilization
  - 150 KW satisfactory for extensive observational science effort
  - Unlikely scenario considering current Station utilization trends
- The highest power requirement is driven by commercial materials production
  - Requires extensive launch and return transportation support
  - Power requirements could reach 300 KW if NSTS support is complemented by considerable ELV support or Heavy Lift Launch Vehicle support
  - All scenarios requiring power levels greater than 225 KW assume ELV support and alternate methods for returning processed material to earth

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SPACE STATION GROWTH REQUIREMENTS - POWER CONTINUED

This chart shows the full envelope of possible final multidisciplinary Space Station power requirements based on the level of transportation support and Space Station utilization emphasis.

The Y axis is the total power requirement including housekeeping power and user requirements for all activities on the Space Station. The X axis is the total annual amount of lift provided to the Station which must be allocated to users and Space Station subsystem support.

The shaded area above the X axis shows the corresponding level of lift for various combinations of NSTS and ELVs. The purpose of this section is twofold. First, it provides some perspective to the values on the X-axis since few people have the lift capability for the shuttle or other vehicles memorized. Second, it can be used to get a rough feel for the potential power requirements that would result from supporting the Space Station with a particular vehicle mix. For instance, if it is decided that only NSTS flights will be used, and the highest realistic number of flights per year is 10, following the right tic of the NSTS ONLY RANGE will show that the highest power requirements likely to occur is slightly over 250 KW. These ranges are meant to lend perspective to the X-axis values and do not necessarily correspond to the transportation models used in the analyses.

The data points correspond to the final power requirement levels in the 10 growth scenarios analyzed. The shaded region represents the full envelope of likely lift and power levels required for the growth Space Station. The number of specific growth paths analyzed is sufficient to allow interpolation to cases not specifically covered. For example, varying the Space Station utilization emphasis between life sciences and materials production will result in power requirements between the lines for Microgravity Research and Materials Production and Life Sciences. Also, power requirements for any level of likely transportation support may be approximated.

SPACE STATION GROWTH REQUIREMENTS
POWER
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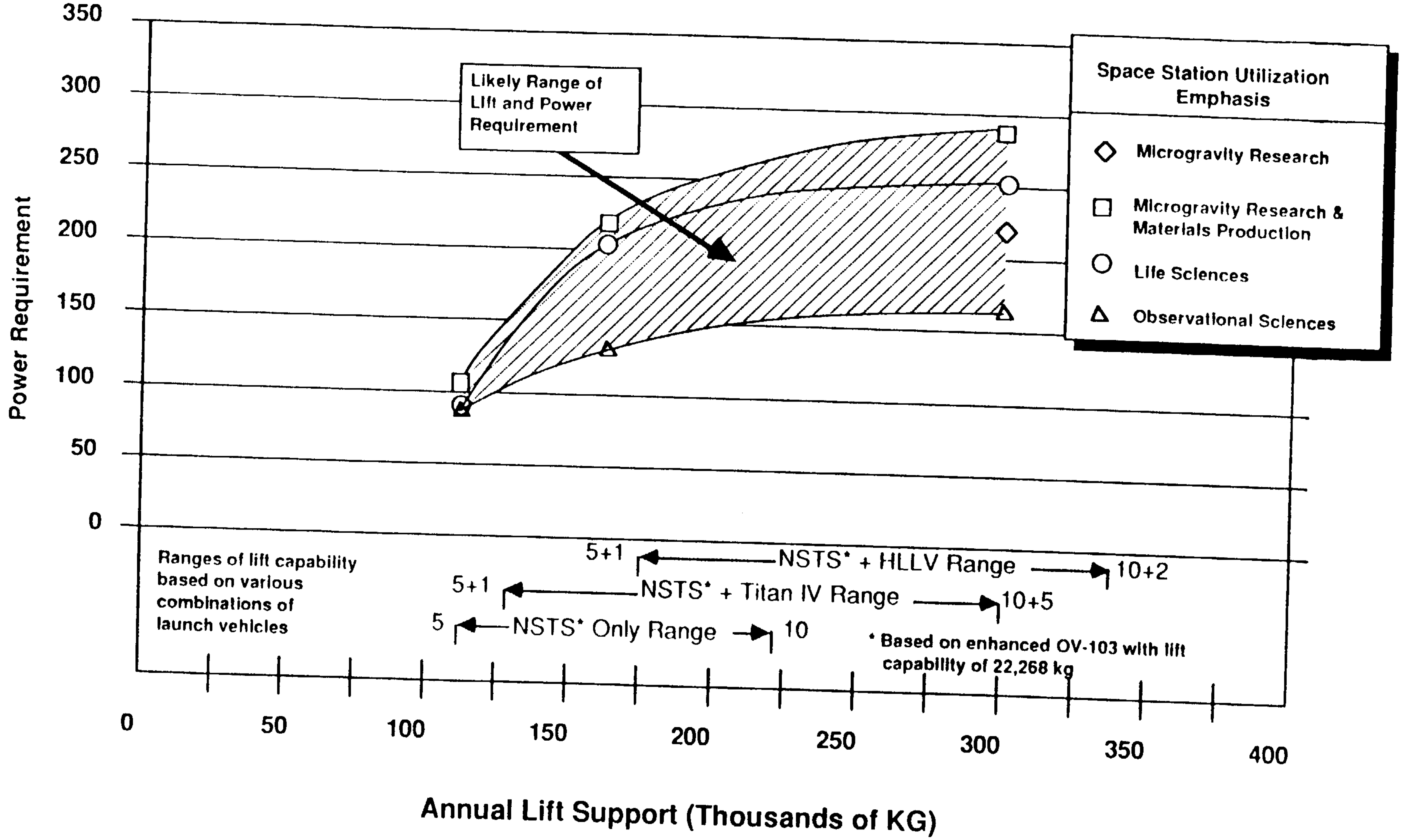

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SPACE STATION GROWTH REQUIREMENTS
POWER
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Limiting the maximum growth power level to 150 KW will prohibit major initiative utilization of the Space Station in the areas of both life sciences and materials production

- 150 KW will support a wide variety of Space Station missions including a full module devoted to microgravity research, a general life sciences facility and a plant & animal vivarium, and observational science such as servicing of free flyers and numerous attached payloads

- The level of transportation necessary to support a 150 KW multidisciplinary Space Station is equivalent to approximately 8 NSTS flights per year. A combination of ELV support and NSTS support may reduce the number of shuttle flights required

- 150 KW is insufficient to perform significant commercial materials production and the research needed to reach the production stage (such as a second laboratory module dedicated to μ-g research)

- 150 KW is insufficient to support the life science research necessary to allow major new exploration initiatives such as a manned mission to Mars

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SPACE STATION GROWTH REQUIREMENTS
CREW SIZE

The planned crew size at Phase 1 is severely insufficient to fully utilize the Phase 1 configuration. Space Station growth will require first correcting this resource imbalance

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- Projected crew supporting users at Phase 1 is 6 (additional 2 crew support Space Station systems tasks)
  - With three laboratory modules to support, an average of less than 1 crew person will be working in each module at any one time
  - Each lab module will be empty (no user crew support) 25% of the time on average
- Between 4 and 4.5 crew (total including user and station support) are needed to fully utilize each laboratory module
  - Phase 1 configuration requires 12 to 14 crew for full utilization
  - One additional habitation module required to support Phase 1 configuration
- Both power and crew are insufficient at Phase 1, but crew support is the most limiting resource

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SPACE STATION GROWTH REQUIREMENTS
CREW SIZE
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Crew rotation is the primary limiting factor to increasing Space Station crew size

- The Space Station crew size could conceivably grow to 24
  - In order to rotate 22 crew using only the NSTS; crew stay time, number of crew rotated per shuttle flight, and the number of NSTS visits per year would all have to be increased (e.g., for 22 crew, 9 NSTS flts/yr are required assuming a 180 day stay and 5 crew rotated per flight; 10 NSTS flts/yr will support up to 25 crew with these assumptions). Such drastic changes are unlikely
  - Using the most optimistic assumptions, the largest crew size that the NSTS could ever realistically rotate is 20 (180 day stay time, 5 crew rotated per shuttle flight, and 8 NSTS flights/yr)

- Four options exist for increasing the capability to rotate the Space Station crew

  1) Increase the frequency of Space Shuttle missions to the Space Station

  2) Increase the size of the Space Shuttle crew, thus the number of crew rotated with each Shuttle flight

  3) Increase the on-orbit stay time (rotation period) for each crew person

  3) Provide an alternate vehicle for crew rotation, such as the Crew Emergency Rescue Vehicle (CERV), Shuttle II, National Aerospace Plane (NASP), Hermes, etc.

SPACE STATION GROWTH REQUIREMENTS - CREW SIZE CONTINUED

This chart shows the full envelope of possible final multidisciplinary Space Station crew requirements based on the level of transportation support and Space Station utilization emphasis.

The Y axis is the total crew requirement including housekeeping and user crew requirements for all activities on the Space Station. The X axis is the total annual amount of lift provided to the Station which must be allocated to users and Space Station subsystem support.

The shaded area above the X axis shows the corresponding range of lift for various combinations of NSTS and ELVs. The purpose of this section is twofold. First, it provides some perspective to the values on the X-axis since few people have the lift capability for the shuttle or other vehicles memorized. Second, it can be used to get a rough feel for the potential power requirements that would result from supporting the Space Station with a particular vehicle mix. These ranges are meant to lend perspective to the X-axis values and do not necessarily correspond to the transportation models used in the analyses.

The data points correspond to the final crew requirement levels in the 10 growth scenarios analyzed. The shaded region represents the full envelope of likely lift and power levels required for the growth Space Station. The number of specific growth paths analyzed is sufficient to allow interpolation to cases not specifically covered. For example, varying the Space Station utilization emphasis between life sciences and materials production will result in crew requirements between the lines for Microgravity Research and Materials Production and Life Sciences. Also, crew requirements for any level of likely transportation support may be approximated.

Because the analyses were constrained by available lift based on the transportation models, crew requirements and actual crew size is identical in most cases. However, because the Phase 1 mission set was predefined and not constrained by available crew and power at Phase 1, a significant difference between actual and required crew size resulted at Phase 1. For very low transportation support levels, a situation occurred in which the growth needed to bring actual crew size up to required crew size was not possible. This region, as indicated on the graph, represents the case where lift may not be sufficient to fully utilize the Phase 1 configuration.

SPACE STATION GROWTH REQUIREMENTS
CREW SIZE
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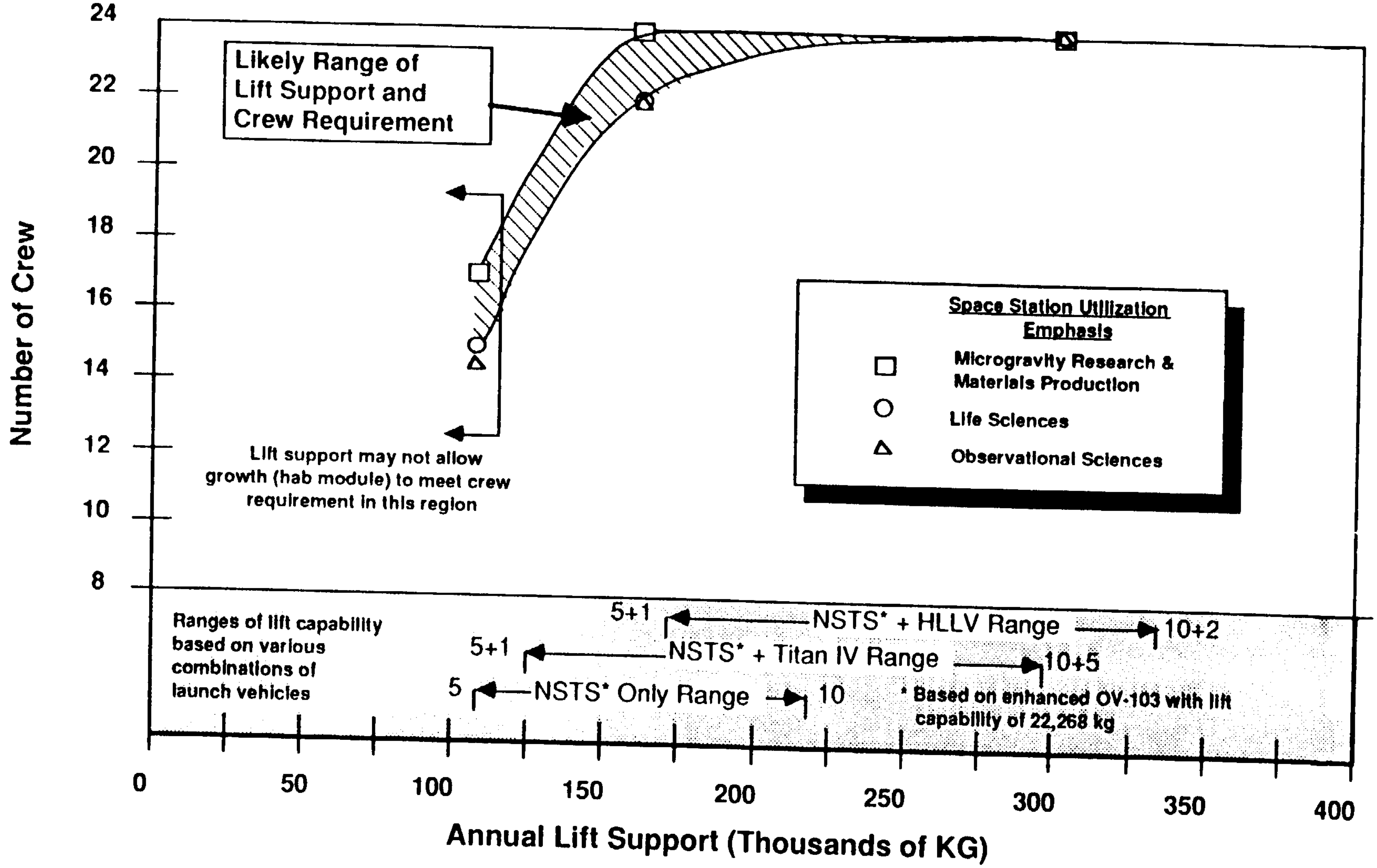

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SPACE STATION GROWTH REQUIREMENTS
PRESSURIZED MODULES

The use of pressurized modules (called pocket or mini labs) that are smaller than the common module yet attach to the common nodes holds many benefits for the growth Space Station

- Features of the pocket lab concept:
  - Provides physical separation from the common modules in order to promote safety (e.g., quarantine facility)
  - Allows housing of equipment not adaptable to the common module due to size or configuration incompatibilities (e.g., 4 meter centrifuge)
  - Allows ease of detachability for possible return to Earth (e.g., materials production units)
  - Provides incentive to the private sector for participation by providing a standard interface and attach mechanism to the Space Station
- Pocket lab type concepts are already being proposed as commercial provided Space Station elements by several companies
  - Spacehab module
  - Industrial Space Facility

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SPACE STATION GROWTH REQUIREMENTS
PRESSURIZED MODULES
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Two major factors in limiting the flexibility of the module growth pattern are the planned location of the lower starboard keel and the payload servicing bay on the transverse boom

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- In the absence of the Payload Servicing Bay, module growth could extend in the -Y direction
  - Greater Space Station center of gravity control flexibility
  - More modules along transverse boom allowing ease of MSC and utilities access and lower structural loads
- The addition of the lower starboard keel (as defined in the IOC configuration) limits module growth along the transverse boom in the +Y direction

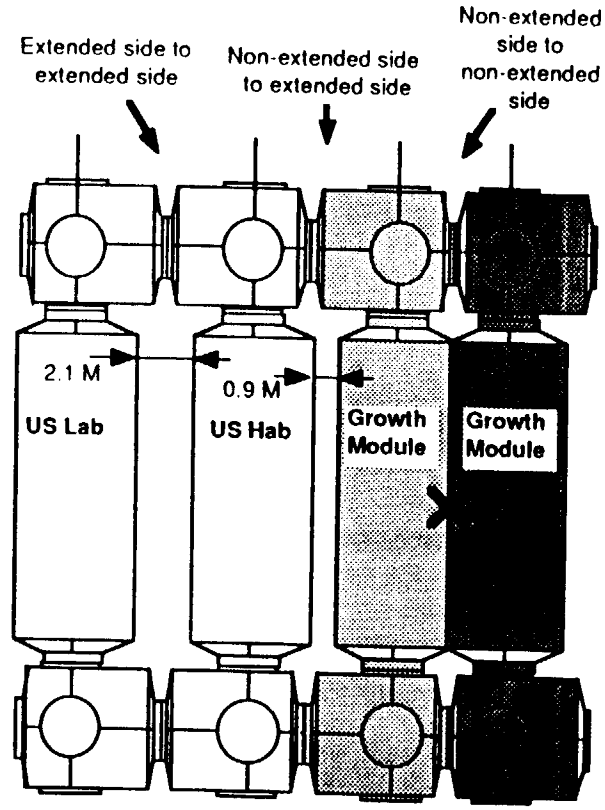
SPACE STATION GROWTH REQUIREMENTS - PRESSURIZED MODULES CONTINUED

The issue of reduced clearance between the modules in the Phase 1 configuration and any growth modules due to the extended node design (shown on this chart) was discussed at the IWS. Apparently, the 2 meter clearance between modules is a requirement driven by the desire to allow access by an EVA crew person between modules for inspection and repair tasks. The 1 meter clearance produced by berthing the extended side of a growth node to the non-extended side of an existing node is likely to be unacceptable.

As a result of this discussion, a preliminary examination of solutions to this problem was made. These alternatives are described on the next chart.

SPACE STATION GROWTH REQUIREMENTS
PRESSURIZED MODULES
CONTINUED

The offset location of the berthing port in the current extended node design will result in decreased clearance between Phase 1 modules and growth modules. Growth modules will be limited to mating the extended side of the node to the non-extended side of the existing node, decreasing the clearance between modules from approximately two meters to one meter



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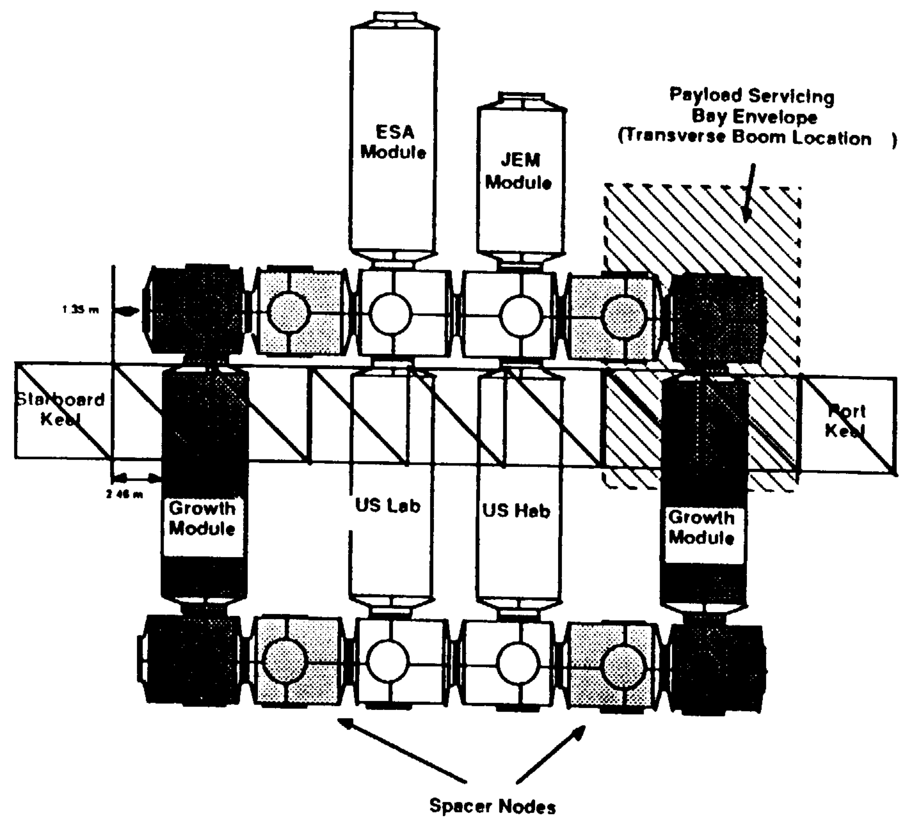
SPACE STATION GROWTH REQUIREMENTS
PRESSURIZED MODULES
CONTINUED

The use of resource nodes between existing and growth modules to provide clearance will result in a limitation of one growth module along the transverse boom in the starboard direction. Relocation of the payload servicing bay will allow an additional growth module along the transverse boom in the port direction

- Alternatives for providing additional clearance between Phase 1 and growth modules:
  - Resource nodes as spacers (shown on diagram)
    - Existing Station element
    - Provides additional berthing ports
    - "Overkill" solution; more clearance than needed and costly
  - Modified "symmetric" resource node design
    - Fixed clearance between all modules
    - Additional node volume for experiments
    - Common node orientation
    - Possibly unacceptable impact to assembly sequence (packaging volume and mass)
    - Increased Phase 1 cost
  - Tunnels or other simple spacing hardware
    - Low cost; no Phase 1 cost impact
    - New station element
    - Reduced commonality
    - 'Wasted' space
  - Use of pocket lab or spacehab as spacers
    - Possible commercial initiative
    - Provides useful volume and well as functioning as a spacer
    - Possibly higher cost solution, but not Phase 1



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SPACE STATION GROWTH REQUIREMENTS
LOGISTICS

At a minimum, the propellant, fluids, and unpressurized equipment carrier elements of the Space Station Logistics System should be designed as ELV-compatible. Extensive use of ELVs will require an ELV-compatible pressurized logistics module and an alternate Station-to-Earth return mechanism

- Aggressive growth of the Space Station using the NSTS only is unlikely due to flight rate limitations

- Although the most direct application of ELVs is for the delivery of growth items, these growth items require ongoing logistic support which may be provided by ELVs as well

- Committing to the concept of ELV compatible logistics carriers provides several benefits
  - Gains flexibility in the Space Station logistics system by not placing total dependancy on the Space Shuttle
  - Takes advantage in the rising interest in a mixed fleet approach to space transportation
  - Allows the capability to provide the high flight rate required for certain carriers in some growth scenarios (e.g., 10 to 20 propellant carrier flights per year for supporting a Space Station utilization emphasis on observational sciences research)

- The issue of return mass buildup on the Space Station due to the use of ELVs in a logistics capacity must also be resolved

SPACE STATION GROWTH REQUIREMENTS - LOGISTICS CONTINUED

The next two graphs show the number of logistics carriers which must be transported to the Space Station each year in support of the various utilization emphases as a function of total annual lift. The first graph shows these values for the pressurized and unpressurized logistics carriers.

Logistics requirements were categorized according to the four carrier classes (pressurized, unpressurized, fluids, and propellant) and approximate carrier mass 'overhead' was calculated by multiplying the logistics mass in each category by a corresponding carrier mass fraction (empty carrier weight/carrier payload capability). The resulting total carrier masses were then divided by the mass of each type of carrier to give the total number of carriers. For instance, 100,000 kg pressurized logistics would require approximately 52,000 kg of pressurized carrier mass (based on 52% mass fraction of this type of carrier) and at a mass of 5,199 kg per pressurized carrier, 10 pressurized carriers would be needed. Neither packaging of logistics nor allocation of carriers to launch vehicles in the transportation models were considered in calculating the required number of logistics carriers.

It is important to note that the number of carriers required each year shown in the graph is the number needed to support of all Space Station activities, not just the requirements of the emphasized discipline.

The shaded area above the X axis shows the corresponding range of lift for various combinations of NSTS and ELVs. The purpose of this section is twofold. First, it provides some perspective to the values on the X-axis since few people have the lift capability for the shuttle or other vehicles memorized. Second, it can be used to get a rough feel for the potential number of logistics carriers needed each year as a result of supporting the Space Station with a particular vehicle mix. These ranges are meant to lend perspective to the X-axis values and do not necessarily correspond to the transportation models used in the analyses.

The data points correspond to the average number of carriers per year following completion of growth for the various growth scenarios. The shaded region represents the full envelope of likely lift and yearly carriers required for the growth Space Station. The number of specific growth paths analyzed is sufficient to allow interpolation to cases not specifically covered. For example, varying the Space Station utilization emphasis between life sciences and materials production will result in carrier requirements between the lines for Microgravity Research and Materials Production and Life Sciences. Also, carrier requirements for any level of likely transportation support may be approximated. This data is highly dependant upon the specific carrier design characteristics; mass fraction and carrier mass in particular.

SPACE STATION GROWTH REQUIREMENTS
LOGISTICS
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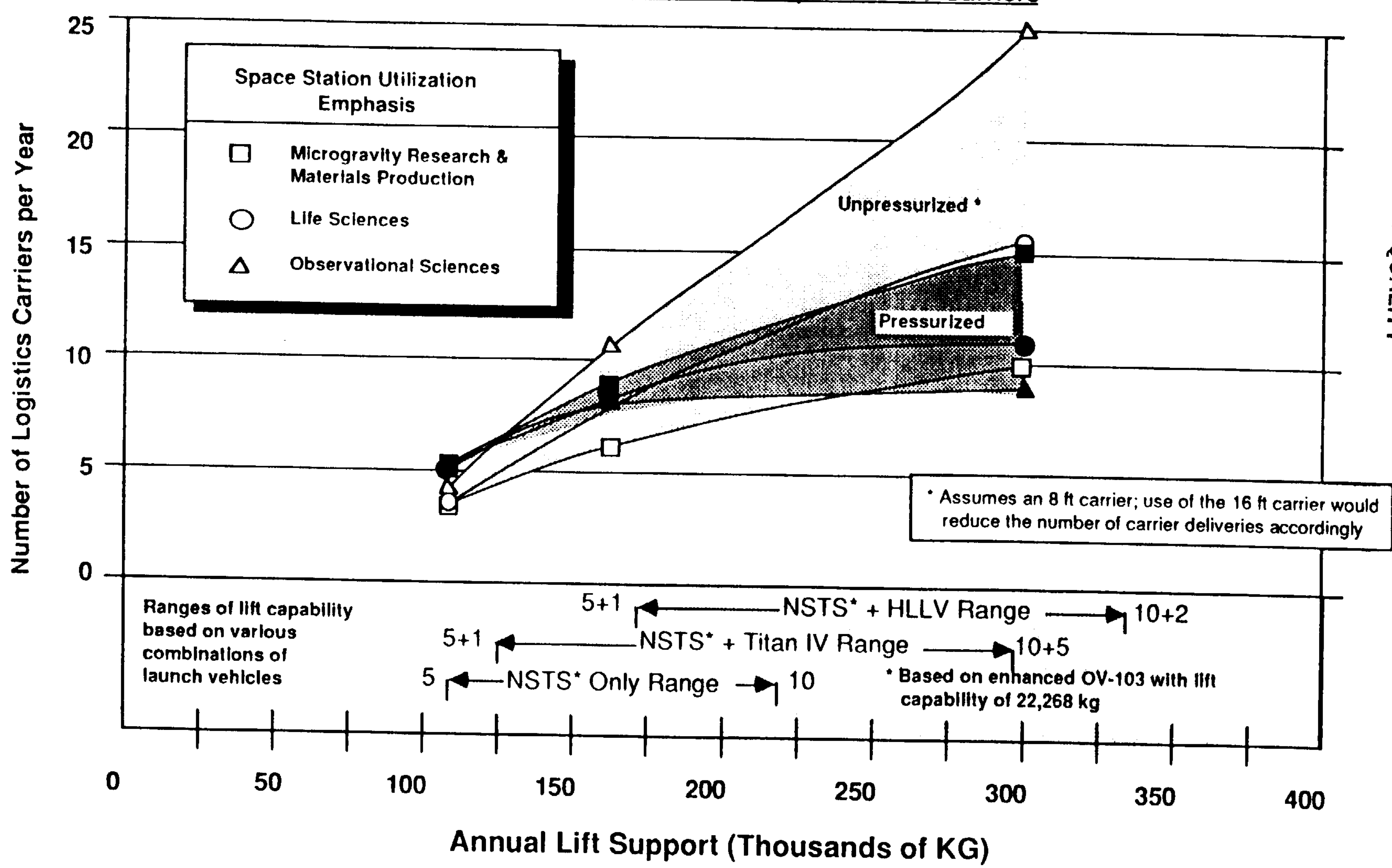
Logistics Flight Rate - Pressurized & Unpressurized Carriers



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SPACE STATION GROWTH REQUIREMENTS - LOGISTICS CONTINUED

This graph shows the number of fluids and propellant carriers required each year as a function of Space Station utilization emphasis and level of transportation support.

Propellant requirements are for OMV operations. The OMV is assumed to be based at the Space Station. The characteristics of a propellant carrier for OMV refueling are assumed to be similar to the earlier Space Station propellant carrier concepts for a combination hydrazine, nitrogen tetraoxide, and monomethal hydrazine carrier.

Logistics requirements were categorized according to the four carrier classes (pressurized, unpressurized, fluids, and propellant) and approximate carrier mass 'overhead' was calculated by multiplying the logistics mass in each category by a corresponding carrier mass fraction (empty carrier weight/carrier payload capability). The resulting total carrier masses were then divided by the mass of each type of carrier to give the total number of carriers. For instance, 100,000 kg pressurized logistics would require approximately 52,000 kg of pressurized carrier mass (based on 52% mass fraction of this type of carrier) and at a mass of 5,199 kg per pressurized carrier, 10 pressurized carriers would be needed.

It is important to note that the number of carriers required each year is in support of all Space Station activities, not just the requirements of the emphasized discipline.

The shaded area above the X axis shows the corresponding range of lift for various combinations of NSTS and ELVs. The purpose of this section is twofold. First, it provides some perspective to the values on the X-axis since few people have the lift capability for the shuttle or other vehicles memorized. Second, it can be used to get a rough feel for the potential number of logistics carriers needed each year as a result of supporting the Space Station with a particular vehicle mix. These ranges are meant to add lend perspective to the X-axis values and do not necessarily correspond to the transportation models used in the analyses.

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SPACE STATION GROWTH REQUIREMENTS
LOGISTICS
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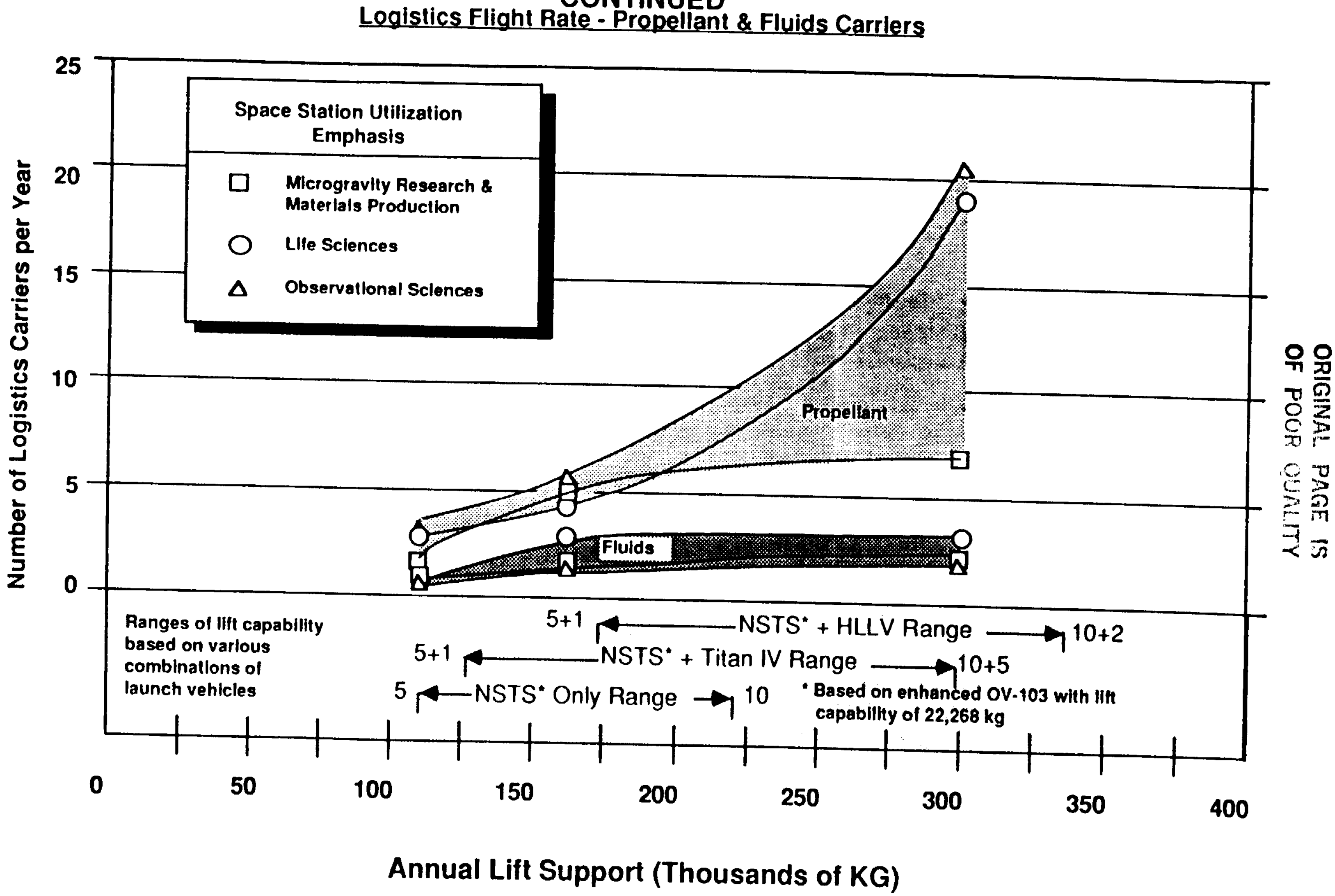

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SPACE STATION GROWTH REQUIREMENTS
ATTACH POINTS & TRUSS STRUCTURE

The Phase 1 configuration provides limited capability for accommodating external attached payloads

- The current plan for a total of 5 external payload attach points on the Phase 1 configuration (on the transverse boom) is insufficient for meeting the needs of even the missions in the Level 2 Trial Payload Manifest (those missions brought to the Space Station during the assembly timeframe)

Trial Payload Manifest Payload	Number Attach Points Required
Cosmic Dust Collection (SAAX112)	1
Spacecraft Materials & Coatings (TDMX2011)	1
Solar Terrestrial Solar Instrument Group (SAAX207)	1 (cps)
Cosmic Ray Nuclei Experiment (SAAX001)	1
Large Format Camera (COMM1015)	< 1

- Limited "real estate" on the Earth pointing side of the transverse boom and viewing restrictions caused by the pressurized modules severely constrains the ability to accommodate Earth pointing payloads. Module growth will further decrease possible attach locations for these payloads

The addition of resource nodes to the aft end of aft growth modules using the mobile Servicing Center (MSC) will require additional truss structure projecting aft of the transverse boom (a "back porch"), and plane change capability for the MSC

SPACE STATION GROWTH REQUIREMENTS - ATTACH POINTS & TRUSS STRUCTURE CONTINUED

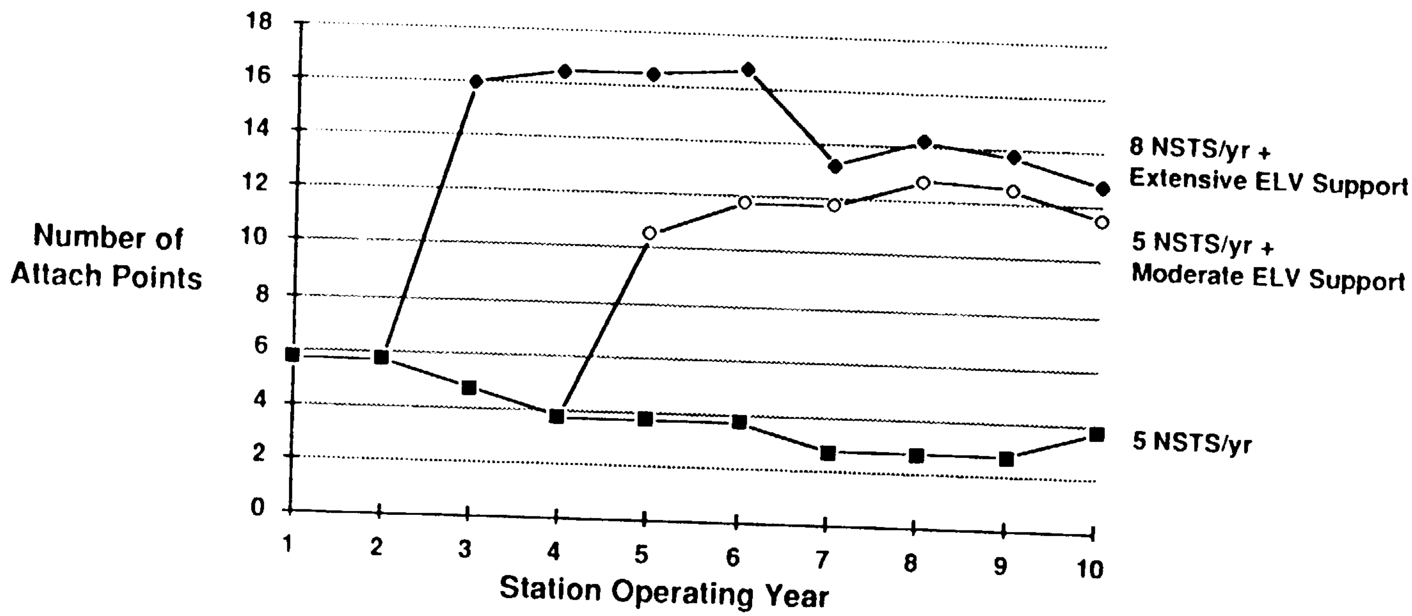
This chart shows the attach point requirements for three growth scenarios in which the level of lift support to the Space Station differs but the utilization emphasis on observational science type payloads is common. Because of the strong emphasis on attached payloads, this graph represents a "worst case" attach point requirement profile.

The three lines correspond to the three transportation models used in the growth scenario analyses. Moderate ELV support includes 1 Shuttle-C type vehicle per year plus a small international contribution. Extensive ELV support includes 2 Shuttle-C type flights per year and higher international contributions. Details of ELV support and assumptions regarding NSTS enhancements are given in the approach section of this document.

Attach point requirements include all mission types but are predominately observational science and technology development in nature.

SPACE STATION GROWTH REQUIREMENTS
ATTACH POINTS & TRUSS STRUCTURE
CONTINUED

<u>Attach Point Requirements for Space Station Utilization Emphasizing Observational Science Payloads</u>



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STUDY APPROACH

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STUDY APPROACH - GROWTH ANALYSIS APPROACH

The approach to these analyses involved two major steps

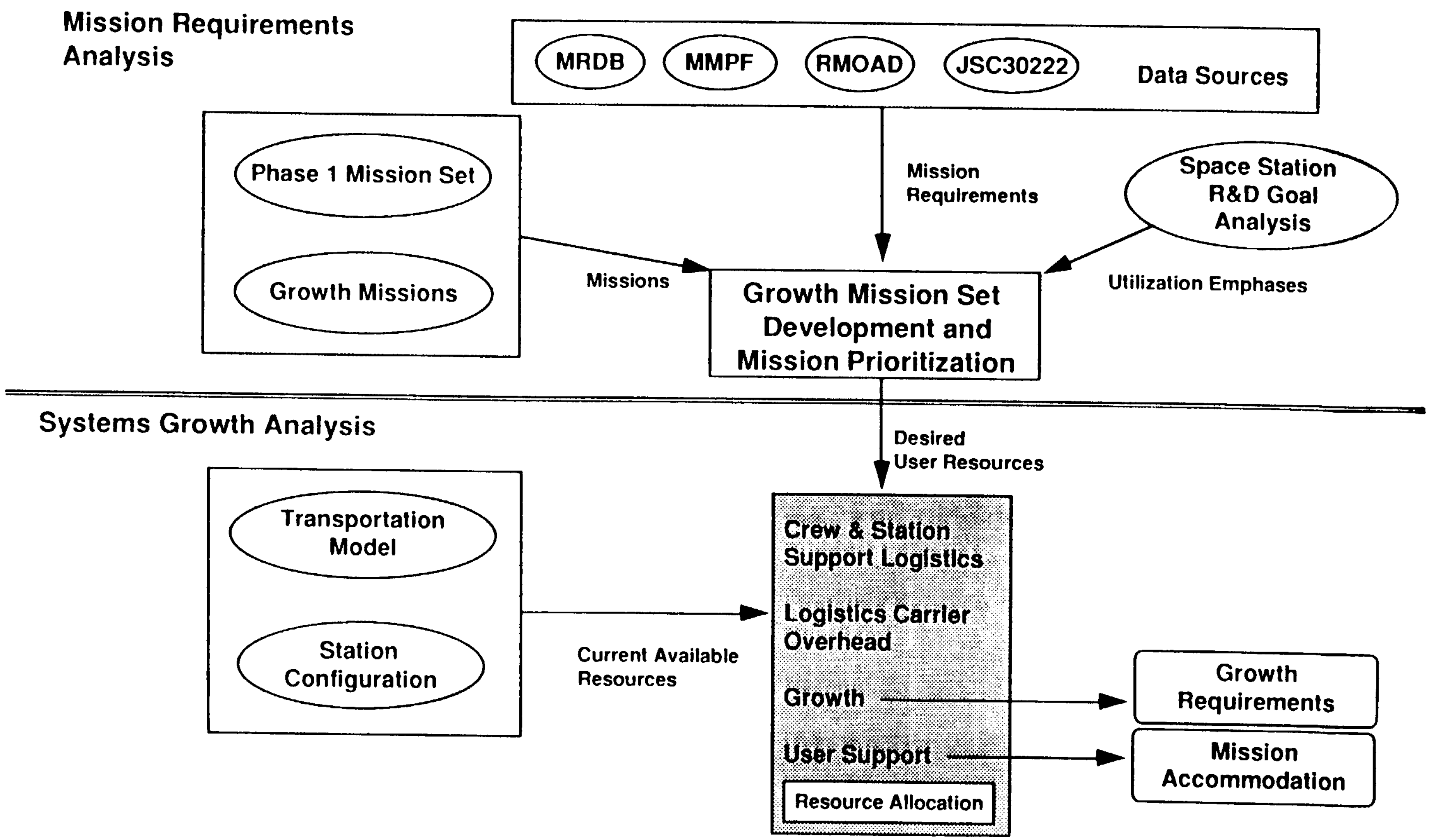
The first step was to develop a realistic mission model. This process included gathering data from a number of documents as well as discussion with principal investigators and attendance of various Space Station users meetings and conferences. A Phase 1 mission set was developed with inputs from the NASA Level II Trial Payload Manifest (November 1987 version) and considering physical limitations within the Phase 1 pressurized modules. Knowledge of the program status for potential missions was also used to refine a likely set of missions that may be present at Phase 1.

The number of potential growth missions was so large that it was obvious that an attempt to accommodate all of them was unrealistic. Instead, three possible discipline emphases were projected for the Space Station, and the growth missions were grouped into unique growth mission sets. A multidisciplinary flavor was maintained in all of the growth mission sets however, as was described earlier in the discussion of the Experiment Mission Set.

The second step involved the actual projection of Space Station growth from a systems analysis level. A primary feature of the approach was the constraining of growth by a projected level of annual lift support to the Space Station. For this reason several transportation models were developed to encompass a range of possibile support levels, from minimal support (5 NSTS/yr only for the entire station lifetime) to aggressive support including the use of large ELVs. Significant effort was put into defining and/or verifying such data as housekeeping power requirements for Phase 1 and growth, capabilities of the Phase 1 configuration, crew & station support logistics requirements for Phase 1 and growth, and logistics carrier characteristics. All of this effort was made in an attempt to achieve the most realistic growth scenarios for the Space Station.

The final step was the actual growth analysis for ten different scenarios. This involved a year by year balancing of Space Station resources and resource requirements in an effort to accommodate existing missions, new missions, and growth where necessary and possible within transportation constraints.

STUDY APPROACH
GROWTH ANALYSIS APPROACH



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STUDY APPROACH
KEY ASSUMPTIONS

- Point of Departure:
  The Phase 1 Configuration as defined in the Level II Engineering Data Book
- Constrained Station Resources:
  - Launch Mass
  - Power
  - Crew Time
  - Internal Pressurized Volume
  - External Attach Points
- Station return mass requirements are tracked but not constrained
- Lift requirements (pressurized, unpressurized, fluids, and propellant) are tracked for
  - Crew and station logistics
  - Mission requirements
  - OMV propellant for retrieving ELV delivered station payload
  - OMV propellant for retrieving co-orbiting spacecraft for on-station servicing
  - OMV propellant for insitu servicing of geostationary spacecraft
  - Carrier requirements for all the above
  - Growth elements with attach fittings
- Distinction between carrier requirements for ELV and NSTS is not made. Allocation of lift requirements between ELVs and NSTS is examined but not constrained

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STUDY APPROACH
EXPERIMENT MISSION SET

- Data sources for mission resource requirements
  - Primary source of data is the Mission Requirements Data Base (MRBD)
  - Detailed resource requirements for microgravity research missions (COMM1201) was derived from information in the Microgravity Materials Processing Facility (MMPF) Data Base
  - Detailed resource requirements for life sciences missions (SAAX307 and SAAX307A) was derived from information in the Reference Mission Operational Analysis Document (RMOAD) for the Life Science Research Facilities.
  - Additional inputs received directly from the principal investigators were used when available

- Phase 1 mission set
  - Assumed to be on station at completion of Phase 1
  - Incorporates data from the NASA/Level 2 Trial Payload Manifest
  - Includes MRDB missions showing equipment up in 1992 and favors missions with operational or funded STATUS entries, while limited by resource availability (primarily internal volume)

- Evolution Mission Model (EMM)
  - Joint definition between MDAC and LaRC
  - Composed of all MRDB missions meeting the following criteria:
    - Core station missions only
    - Reasonably complete MRDB data entries
    - Unique missions (obvious duplication of mission goals was eliminated except in the case of some international missions which duplicate the goals of U.S. missions)

- Missions are divided into six categories:
  - Industrial Services
  - International
  - Life Sciences
  - Microgravity Research & Materials Production
  - Observational Science
  - Technology Development

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STUDY APPROACH
EXPERIMENT MISSION SET
CONTINUED

- Missions in the EMM are further classified as either global in nature (basic research which does not imply dedication to a specific Space Station utilization goal) or specific to a particular emphasis

Mission Type	Missions in Global Growth Mission Set	Emphasis Specific Growth Missions
Industrial Services	All industrial services missions	No emphasis unique missions
International	All international missions	No emphasis unique missions
Life Sciences	Missions directed to understanding the the effects of microgravity on living organisms (e.g., Life Sciences Lab #1)	Advanced life sciences research oriented toward major human exploration initiatives including missions such as CELSS, the vivarium, and a 4m variable-g centrifuge
Microgravity Research & Materials Production	Basic μ-g research such as COMM1201 (US Materials Laboratory)	Commercial production missions such as EOS, ECG, and biological production units and advanced research (US Mat Lab #2)
Observational Science	Servicing of the Great Observatories, and the portion of the Solar Terrestrial Observatory not accommodated at Phase 1	Assembly, deploy and servicing of observational platforms, tethered observational missions on the core station, and operation and servicing of many smaller instruments such as the planetary infrared telescope
Technology Development	General technology missions dedicated to improving our ability to work effectively in space	Additional technology missions related directly to one of the three emphases above will be included in the corresponding emphasis specific growth mission set

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STUDY APPROACH
EXPERIMENT MISSION SET
CONTINUED

Missions on Space Station at Completion of Phase 1

Mission Type	Mission	Name
Life Science	SAAX307*	Life Sciences Lab (subset)
	SAAX307A	1.8M Diameter Var-g Centrifuge
	SAAX308	Gas/Grain Simulation Facilitiy
Microg Res & Mat Prod	COMM1201	US Laboratory (subset)
	COMM1230	Automatic Vapor Crystal Growth
	COMM1231	Acoustic Levitator
	COMM1232	Alloy Solidification
	COMM1237	Bridgeman, Large (BCGL)
	COMM1238	Bridgeman, Small
	COMM1244	Electrostatic Levitator (ELF)
	COMM1245	Protein Crystal Growth
	COMM1246	EM Levitator (EMF)
	COMM1247**	Float Zone Crystal Growth (FZCG)
	COMM1248**	Fluid Physics Facility (FPF)
	COMM1250	P.C.G.U for Company 1245F
	COMM1251	Isoelectric Focusing (IFF)
	COMM1254**	Optical Fiber Pulling
	COMM1255	Organic + Polymer Crystal Growth
	COMM1257	Protein Crytal Growth Faciltiy
	COMM1260	Advanced Levitation Units
	COMM1261	Solution Crystal Faciltiy (SCF)
	COMM1262**	Vapor Crytal Faciltiy (VCF)
	COMM1265-70	Advanced Directional Solidification
	COMM 1275-77**	High Temp Gen Purpose Furnace
Observational Sciences	COMM1015	Large Format Camera
	SAAX001	Cosmic Ray Nuclei Experiment
	SAAX112	Cosmic Dust Collection Expt
	SAAX207	Solar Terrestrial Observatory
	SAAX207A	ACRIM
	SAAX207B	Soft X-Ray Telescope (SXRT)
	SAAX207C	HRTS
	SAAX207D	White Light Coronagraph (WLC)
	SAAX207E	SUSIM
	SAAX207K	UV Coronagraph-Spectrometer UV

Mission Type	Mission	Name
Technology Development	TDMX2011	SC Mat & Coatings
	TDMX2071	Flight Dynamics Identification
	TDMX2072	S/C Strain Sensor
	TDMX2262	Manned Observations Techniques
	TDMX2421	Active Optic Technology
	TDMX2442	Transient Upset Phenomena in VLSI
	TDMX2443	VHXIC Fault Tolerant Processor
	TDMX2461	Teleoperated Assembly
	TDMX2462	Dextrous Teleoperator Technology
	TDMX2521	Acoustics Control Technology
	TDMX2532	Medical Experiments Technology
	TDMX2564	Coatings Maintenance Technology
International	C-001	RFI
	C-003A	Adv Comm & Data Handling Sys - A
	L-001	Biology & Medicine
	L-002	Space Medicine
	L-003	CELSS
	L-004	Biotechnology
	LIF111	Gen Purp "LIF" Research Facility
	M-001	Material Science Experiment
	M-002	Space Processing for Advanced Mat
	MAT110	Materials Science Research Lab
	S-003	High Energy Cosmic Rays
	S-004	Cosmic Gamma Ray Bursts
	SAAX4002	POLCATS
	SAAX4003	Life Sciences Laboratory
	T-001	Space Environment Test
	T-005A	Space Robotics - Step 1
	TDMX4001	Materials Laboratory
	TDMX4004	Solar Cells

*** Partial outfitting in μ-g utilization emphasis to allow additional μ-g facilities; complete outfitting at Phase 1 for other emphases**

**** Phase 1 mission for μ-g utilization emphasis only, growth mission otherwise**

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STUDY APPROACH

EXPERIMENT MISSION SET

CONTINUED

Global Growth Mission Set

Mission Type	Mission	Name
Industrial Services	COMM1014	Remote Sensing Test Dev & Verif
	COMM1020	Commercial SAR
	COMM1119	Com Sat Fuel Deploy Check out
	COMM1115	Class III Comm Sat Delivery
	COMM1116	Class II Comm Sat Delivery
	COMM1117	Class I Comm Sat Delivery
	Comm1124	Geo Satellite Servicing Demo
	COMM1125	Class III Comm Sat Servicing
	COMM1126	Class II Comm Sat Servicing
	COMM1307	Industrial Space Facility (ISF)
	COMM1308	Industrial Space Facility(ISF)
	COMM1310	Spacehab Hardware Prototype Lab
	COMM1311	Spacehab Logistics Module
	SAAX503	M SAT B
	SAAX504	M-SAT-C
International	LIF 311	Exo and Radiation Biology Dev
	LIF 312	Production Bio processing, auto
	COMM4000	Materials Processing Laboratory
	M 003	Commercial Space Processing Test
	Mat120	Materials Processing Development
	MAT130	Automated Materials Processing
	E-003	Observations of Upper Atmosphere
	E 005	DPS for Earth Observation
	E-006	Earth Observation Facility
	S 001	Astronomical Platform
	S 002	Infrared Telescope in Space
	S 005	Line Gamma Detection
	S 006	X-Ray Astronomy Observatory
	S 007	Gravitational Wave Detector
	S 008	Space VLBI
	S-009	Solar Activity Monitor
	S-010	Submillimeter Telescope
	SAAX4000	High Frequency Sounder System
	SAAX4004	Long Base Line Array
	SAAX4005	WISP
	SPA801	Far Infrared/Submm Space Tel

Mission Type	Mission	Name
International (cont)	TDMX4002	Sensor (station)
	C 002	Large Communication
	C 003B&C	Adv Comm & Data Handling Sys
	C 004	Grav Stabild Deployable Ant Text
	C-005	TD of Large Geo Satellite
	E-002A&B	Test of Sensor Technologies
	T 002A&B	Large Antenna Sys Technology
	T-004	Space Energy Experiment
	T-005B&C	Space Robotics
	T-006	Platform System Technology
	TOS235	Robotic Servicing Experiment
	TOS236	Fluid Transfer Management
Life Sciences	SAAX307	Life Sciences Lab (subset)
	SAAX110	Mars Sample Return Mission
	SAAX111	Comet Nucleus Sample Return
	SAAX117	Sample Quarantine Facility
Microg Res & Mat Prod	COMM1201	US Laboratory (subset)
	COMM1233	Atmospheric Microphysics Facility
	COMM1234	Autoignition Furnace Facil
	COMM1235	Automatic Sol'n Crystal Growth
	COMM1236	Bioreactor/Incubator (BIF)
	COMM1240	Con Flow Electorphoresis (CFEP)
	COMM1241	Critical Point Phenomena (CPPF)
	COMM1242	Droplet/Spray Burning Facility
	COMM1243	Electroepitaxy Facility
	COMM1249	Free Float Facility
	COMM1252	Latex Reactor (LR)
	COMM1253	Membrane Production (MP)
	COMM1256	Premixed Gas Combustion Facility
	COMM1258	Rotating Spherical Conv (RSCF)
	COMM1259	Solid Surface Burning Facility
	COMM1263	Var Flow Shell Generator (VFSG)
	COMM1275-77	High Temp General Purpose Furnac
	COMM1280-81	Catalytic Research Units
	COMM1285	Metal Alloy Separation Units
	COMM1290-92	Thin Film Deposition Units

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STUDY APPROACH
EXPERIMENT MISSION SET
CONTINUED

Global Growth Mission Set

Mission Type	Mission	Name
Observational Science	SAAX004A	SIRTF Servicing
	SAAX012	Hubble Space Telescope Servicing
	SAAX017A	AXAF Servicing
	SAAX020	Large Deployable Reflector
	SAAX021	Superconducting Magnet Facility
	SAAX027	Explorer 1 Servicing
	SAAX030	Hitchhiker 1
	SAAX207	Solar Terrestrial Observatory (subset)
	SAAX207F	SEPAC
	SAAX207G	WISP
	SAAX207H	TEBPP
	SAAX207I	Tethered Satellite System
	SAAX207J	Recoverable PDP (RPDP)
	SAAX250	Hitchhiker 4 - Earth Radiation
	SAAX251	Tropical Rainfall Mapping Mssn
Technology Development	COMM1304	OMV/TMS
	SAAX501	Experimental Geo Platform
	SAAX502	Space Based Antenna Test Range
	TDMX2021	Man Machine Mix Investigations
	TDMX2022	Growth of Comp Semicond Crystals
	TDMX2023	Growth of Thin Single Crys Wafer
	TDMX2024	Electrophoresis Separation Tech
	TDMX2061	Large Space Structures
	TDMX2062	Space Station Modifications
	TDMX2063	On Orbit Spacecraft Assy/test
	TDMX2064	Advanced Antenna Assy/Perform
	TDMX2071	Flight Dynamics Identification
	TDMX2072	S/C Strain Sensor
	TDMX2073	Adv Struct Dyn/Control
	TDMX2111	Deploy Large Solar Concentrator
	TDMX2121	Test Solar Pumped Lasers
	TDMX2122	Laser-to-electric Conversion
	TDMX2132	Advanced Radiator Concepts
	TDMX2152	Large Space Power Systems Tech
	TDMX2153	Solar Dynamic Power Tests
	TDMX2211	Multi-fin Space Antenna Rng Test

Mission Type	Mission	Name
Technology Development (cont)	TDMX2212	Mult Antenna Beam Patterns
	TDMX2221	Laser Comm & Tracking Develop
	TDMX2223	Maser Precision Time Generation
	TDMX2224	Space-based Optical DSN Terminal
	TDMX2266	S/C Optical Range Determination
	TDMX2267	Optical Spatial Tracking S/C
	TDMX2311	Long-term Cryogenic Fluid Storage
	TDMX2321	Low Acceleration Propulsion Tech
	TDMX2322	Laser Propulsion
	TDMX2411	Advanced Adaptive Control
	TDMX2412	Distributed Control Experiment
	TDMX 2413	Dynamic Disturbance Experiment
	TDMX2421	Active Optic Technology
	TDMX2422	Thermal Shape Control
	TDMX2431	Advanced Control Device Tech
	TDMX2433	Dynamic Stabilization FF Robot
	TDMX2441	Microelectronic Data Syst Expt
	TDMX2461	Teleoperated Assem
	TDMX2462	Dextrous Teleoperator Technology
	TDMX2463	Autonomous Robotic Maint Demo
	TDMX2464	Autonomous Servicing Robot
	TDMX2471	Human/Machine Interface Workload
	TDMX2472	Advanced Automation Technology
	TDMX2473	Adv Robotic Wrksta Tech Demo
	TDMX2511	Space Power System Environ Int
	TDMX2512	High Voltage in Space Plasma
	TDMX2531	Surgery Technolgoy Development
	TDMX2541	Tethered Electrodynamic Power Gn
	TDMX2542	Tethered Constellation
	TDMX2543	Tethered Transportation
	TDMX2544	Tethered Fluid Storage/Transfer
	TDMX2561	Satellite Servicing and Refurb
	TDMX2562	Satellite Maintenance and Repair
	TDMX2565	Thermal Interface Technology
	TDMX2572	Cryo Prop Transfer/Stor/Reliq

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STUDY APPROACH
EXPERIMENT MISSION SET
CONTINUED

Emphasis Unique Growth Mission Sets

Microgravity Research Emphasis

Mission	Name
COMM1204	Micrograv & Material Process Fac (Mat Lab 2)
COMM1206	Biological Production Units
SAAX402	μ g Variable G Free Flyer
TDMX2432	Pointing and Isolation Devices
TDMX2563	Materials Resupply

Microgravity Research & Materials Production Emphasis

Mission	Name
COMM1202	EOS Production Units
COMM1203	ECG Production Units
COMM1204	Micrograv & Material Process Fac (Mat Lab 2)
COMM1205	ECG Production Units #2
COMM1206	Biological Production Units
COMM1208	Crystal Production Units
COMM1213	Containerless Process Prod Units
SAAX402	μ g Variable G Free Flyer
TDMX2432	Pointing and Isolation Devices
TDMX2563	Materials Resupply

Life Sciences Emphasis

Mission	Name
SAAX302	Plant & Animal Vivarium & Lab
SAAX303	Human Research Facility
SAAX304	CELSS Experimental Systems
SAAX305	Dedicated CELSS Module
SAAX306	DELSS Pallet
SAAX311	4M Diameter Var-G Centrifuge
COMM1309	Orbital Transfer Vehicle
TDMX2571	OTV/Payload Interfacing/Transfer
TDMX2573	OTV Docking and Berthing
TDMX2574	OTV Maintenance Technology

Observational Science Emphasis

Mission	Name
SAAX010	ASO/HRSO Mission
SAAX010A	ASO/HRSO Servicing
SAAX011	ASO/POF Mission
SAAX011A	ASO/POF Servicing
SAAX020	Large Deployable Reflector
SAAX021	Superconducting Magnet Facility
SAAX028	Explorer 2 Servicing
SAAX029	Explorer 3 Servicing
SAAX031	Space Station Hitchhiker 2
SAAX032	Space Station Hitchhiker 3
SAAX113	Planetary Multispectral Telescope
SAAX114	Planetary Infrared Telescope
SAAX115	Astrometric Telescope Facility
SAAX116	Planetary Science Expt Module
SAAX201	Lidar Facility
SAAX221	Large Microwave Antenna
SAAX222	Infrared Sounding
SAAX223	Large Imager
SAAX226	Solar-Terres Geo Platform Expt
SAAX227	Plasma Processes Lab
SAAX309	SETI Geo Antenna Mission
SAAX501	Experimental Geo Platform (XGP)
COMM1309	Orbital Transfer Vehicle
TDMX2261	Sensor Systems Technology Expt
TDMX2263	CO2 Doppler Lidar Wind Sensor
TDMX2264	Microwave Remote Sensing
TDMX2265	Satellite Doppler Meteorol Radar
TDMX2431	Pointing and Isolation Devices
TDMX2571	OTV/Payload Interfacing/Transfer
TDMX2573	OTV Docking and Berthing
TDMX2574	OTV Maintenance Technology

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STUDY APPROACH
MISSION REQUIREMENTS

Microgravity Research Missions

- Requirements for a microgravity research facility were derived from the Microgravity and Materials Processing Facility (MMPF) Study Data Release†
  - Fully outfitted laboratory consists of 30 facilities which represent 47 missions in the MRDB
  - Resource requirements for these facilities is highly dependent upon equipment utilization assumptions. 100% equipment utilization (all facilities operating all the time) is not a practical assumption
  - MMPF provides data on reasonable equipment utilization (run duration and frequency) and corresponding resource requirements

- The Phase 1 configuration does not provide sufficient pressurized volume to fully outfit the microgravity and materials processing lab while allowing research in other areas
  - Resource requirements for the fully outfitted laboratory are based on the global mission set analysis in the MMPF
  - Resource levels for partial configurations of the laboratory are determined by scaling down the global mission set requirements based on maximum power/ minimum run duration utilization of existing facilities

- Facilities present at Phase 1 are based on the Level II Trial Payload Manifest, and the NASA Code EM developed subset of 20 missions out of the 30 MMPF facilities

- The second materials laboratory is assumed to be a duplicate of the first in terms of resource requirements

† Contract No. NAS8-36122, Teledyne Brown Engineering and Boeing Aerospace Co., February 2, 1987

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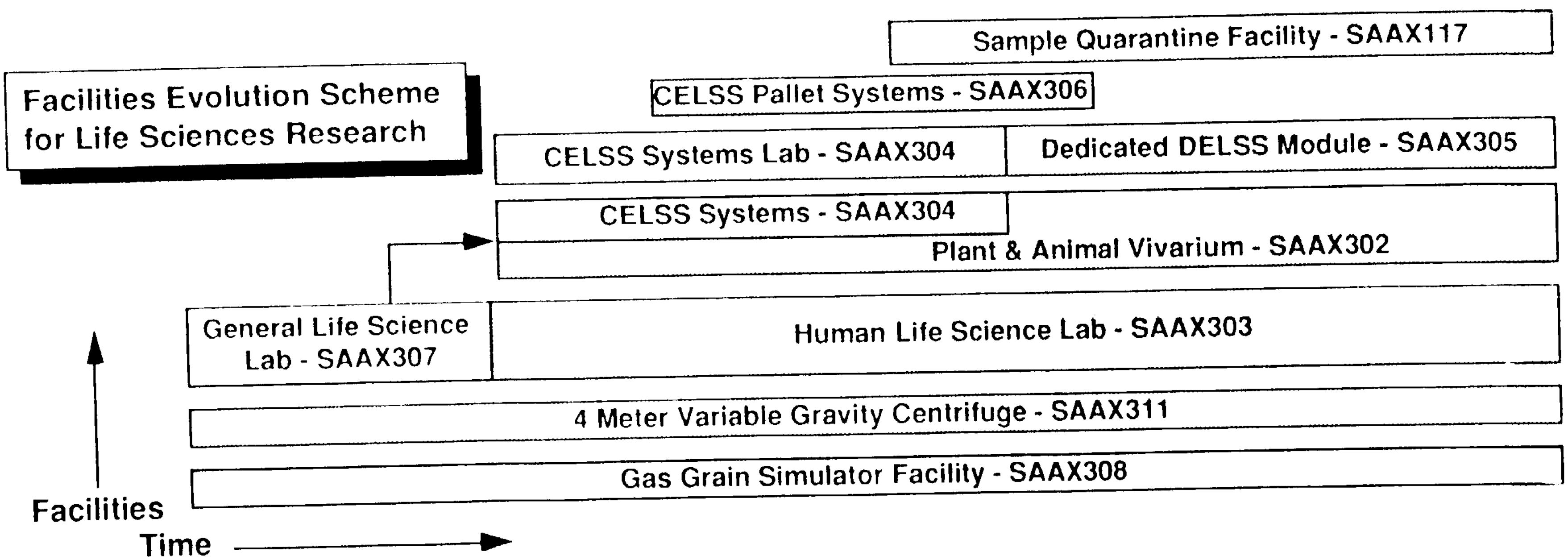
STUDY APPROACH
MISSION REQUIREMENTS
CONTINUED

Life Sciences Missions

- Resource requirements for the General Life Sciences Lab (SAAX307) and 1.8 M centrifuge (SAAX307A) were based on data from the Reference Mission Operational Analysis Document (RMOAD) for the Life Science Research Facilities.
  - The RMOAD breaks the outfitting of the lab into 5 phases
  - Where necessary, partially outfitted configurations were developed by accommodated a subset of the full 5 outfitting phases

- The diagram below shows the desired evolution of the life sciences research facilities. Shaded regions represent missions in the life sciences emphasis mission set only. For other emphases, SAAX307 is assumed to continue indefinately



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STUDY APPROACH
MISSION REQUIREMENTS
CONTINUED

Observational Science & Technology Development Missions

- Mission specifications for the Great Observatories (HST, AXAF, and SIRTF) were derived from the Customer Servicing Requirements Data Book (JSC 30222, March 15, 1986)
  - Mass
  - Operational orbit
  - Servicing interval
  - Expected lifetime

- Launch date for the Great Observatories is based on the October 1987 Payload Flight Assignments, NASA Mixed Fleet
  - GRO not included because end-of-life reached prior to Phase 1 completion based on launch date and expected life
  - HST and SIRTF assumed to be operational at Phase 1

- Requirements for numerous MRDB missions involving observational geostationary platform experiments were synthesized into one mission
  - Designed to represent generic geostationary platform with experiments being serviced and changed out periodically
  - Initial platform construction and deployment based on the experimental geostationary platform mission (SAAX502)
  - Encompasses the following MRDB missions: Large Microwave Antenna, Infrared Sounding, Large Imager, STO Geo Platform Experiment, and the SETI Geo-Antenna Mission
  - All servicing and experiment changeout assumed in-situ

- Tether technology development mission requirements were synthesized into one tether technology and application mission

- Technology development mission requirements were synthesized when shared equipment or a fixed sequence of accommodation was specified

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STUDY APPROACH
TRANSPORTATION MODEL

- Growth scenarios were developed by using a predefined level of earth-to-orbit transportation (frequency and type of launch vehicle) and then determining the growth and mission accommodations that this level of lift would support

- Three levels of transportation support were considered

  - NSTS Only - at a frequency of 5 per year representing the minimum level of support

  - Moderate - 5 NSTS per year until station operating year 3 when 1 Shuttle-C and international ELVs are added

  - Aggressive - 5 NSTS and a mix of ELVs each year increasing to 8 NSTS and including Shuttle-C in year 3 and increasing again in year 5 with more international support

- These transportation models are designed to encompass the full range of possible levels of transportation support to the Space Station in order to determine the maximum and minimum resource requirement levels

STUDY APPROACH - TRANSPORTATION MODEL CONTINUED

This chart shows the lift capability for all the launch vehicles used in this analysis. Launch capabilities for the ELVs are based on data in the document "Transportation Options and Space Station Evolution Study", Teledyne Brown Engineering, Dec. 1, 1987.

The lift capability for the NSTS used in this study assumes the implementation of a certain number of ascent performance enhancements by the Phase 1 time frame. A full set of possible enhancements, based on data in a presentation from the engineering directorate of NASA/JSC, is shown below. In order to be progressive in our projections and at the same time somewhat conservative, 50% of the enhancements below which are marked in bold where incorporated into the NSTS launch capability for this study.

Enhancement	Payload Increase	Required Action
Advanced SRM	**+12,000 Lbs***	**Study and authorization**
Insulator/Liner	400	
Nozzle/Bearing	1000	
HTPB Propellant	2800	
Case Material	2300	
Case Diameter	2000	
Thrust Profile/Heads Up	4000	
Other Vehicle Mods	**+6,600 Lbs**	**Cost/benefit assessment**
109% SSME	5000	SSME A certification
No SRB Recovery	1600	
Loads/Flutter Constraints	+1,500 Lbs	Complete flutter/aero detailed test objectives (additional instrumentation) and 6.0 loads cycle
q from 790 to 819 PSF	1000	
q-alpha from 3500 to 3000 PSF-Deg	500	
Transatlantic Abort Landing (TAL) Priority over Abort to Orbit (ATO)	+1,500 Lbs.	Risk Assessment
Reduced System Dispersions	+1000 Lbs	Flight data reduction
Integrated STS/SS Reserves	**+500 Lbs**	**Coordination**

* itemized values shown add up to 12,500. This inconsistency was present in the referenced presentation.

STUDY APPROACH
TRANSPORTATION MODEL
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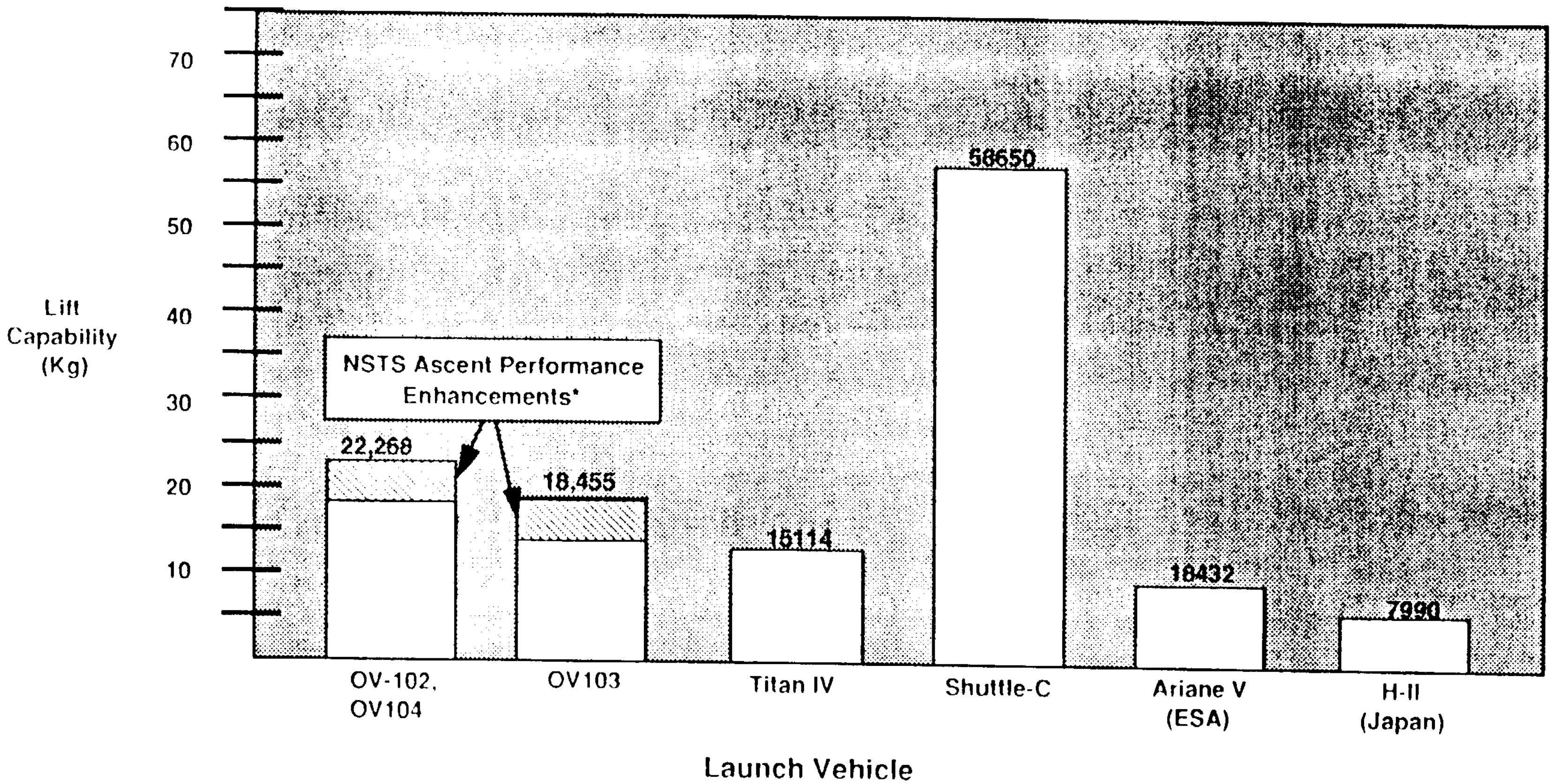

*NSTS upweight capability for the purposes of this study is projected to be equal to the current NSTS commitment to station (14,119 Kg for OV-102, 17,933 Kg for all others) plus 50% of the following potential enhancements identified by JSC (Ref. NSTS Upweight Capability Enhancements, Mark Craig, Engineering Directorate, NASA/JSC, July 21, 1987) : Advanced Solid Rocket Motor (+5448 Kg), other vehicle mods (2996 Kg), Integrated STS/Space Station Reserves (+227 Kg)

STUDY APPROACH - TRANSPORTATION MODEL CONTINUED

The 5 NSTS/yr only transportation model represents the current NSTS commitment to the Space Station. This model was used as the least aggressive, "worst case" scenario where the decision is made to not use ELVs for Space Station support, and the currently projected NSTS flight rate to the station is not increased during the operating lifetime of the station.

STUDY APPROACH
TRANSPORTATION MODEL
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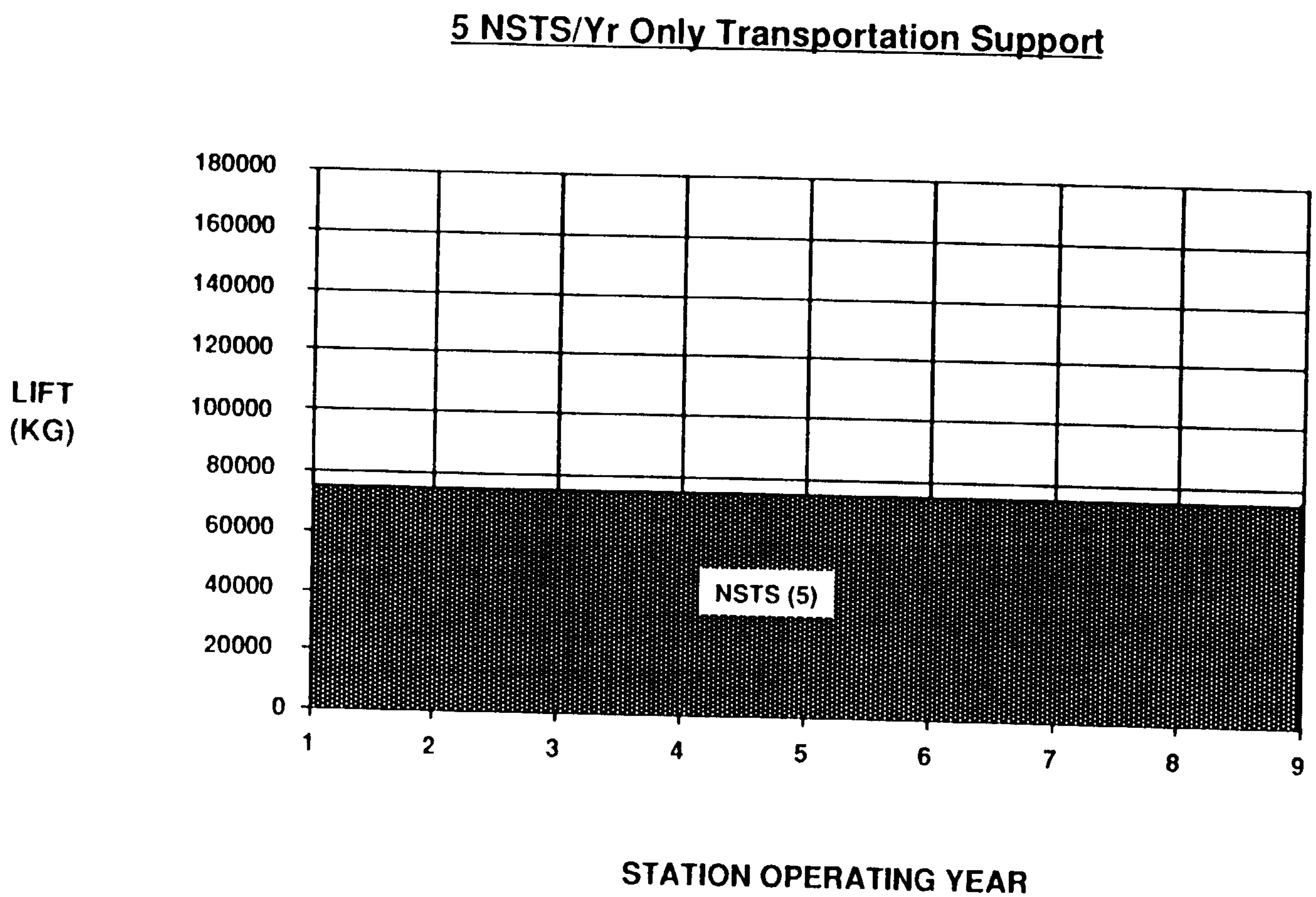

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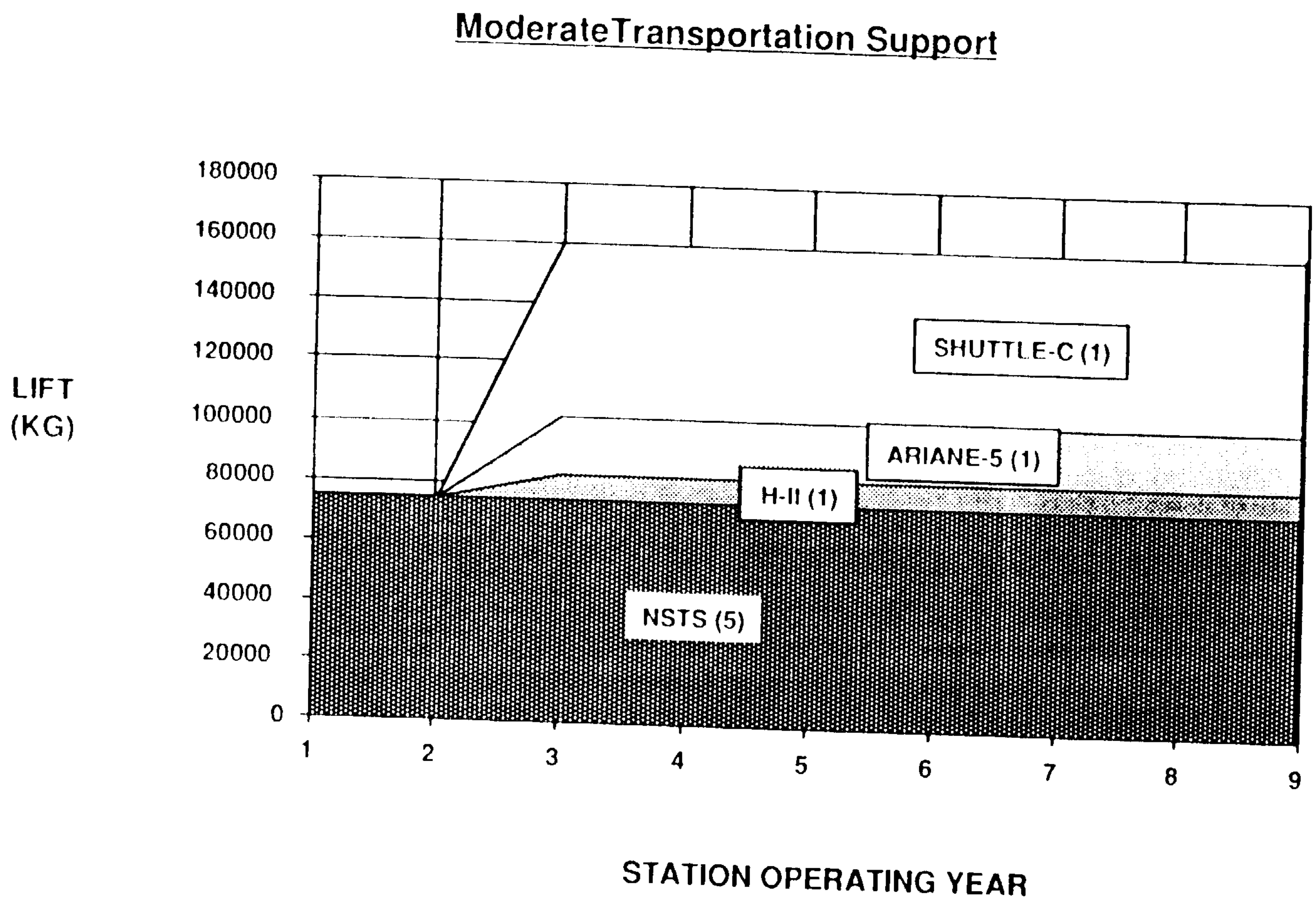
STUDY APPROACH - TRANSPORTATION MODEL CONTINUED

The moderate transportation model maintains the 5 NSTS/yr support level while allowing for the use of some ELV support. ELV support does not begin until the third year following Phase 1 based on the assumption that time will be required to "iron all the bugs out" and fully integrate ELVs into Space Station operations. In the third year, international participation is included by one launch vehicle per year from both ESA and Japan. At the same time, one Shuttle-C or Advanced Launch System (ALS) vehicle per year also comes on line. The time frame for the inclusion of all of these vehicles is consistent with their projected development cycle.

Based on the projected demand for TitanIV vehicles by the DOD and other NASA interests, no TitanIV support was included in the moderate transportation model.

STUDY APPROACH
TRANSPORTATION MODEL
CONTINUED



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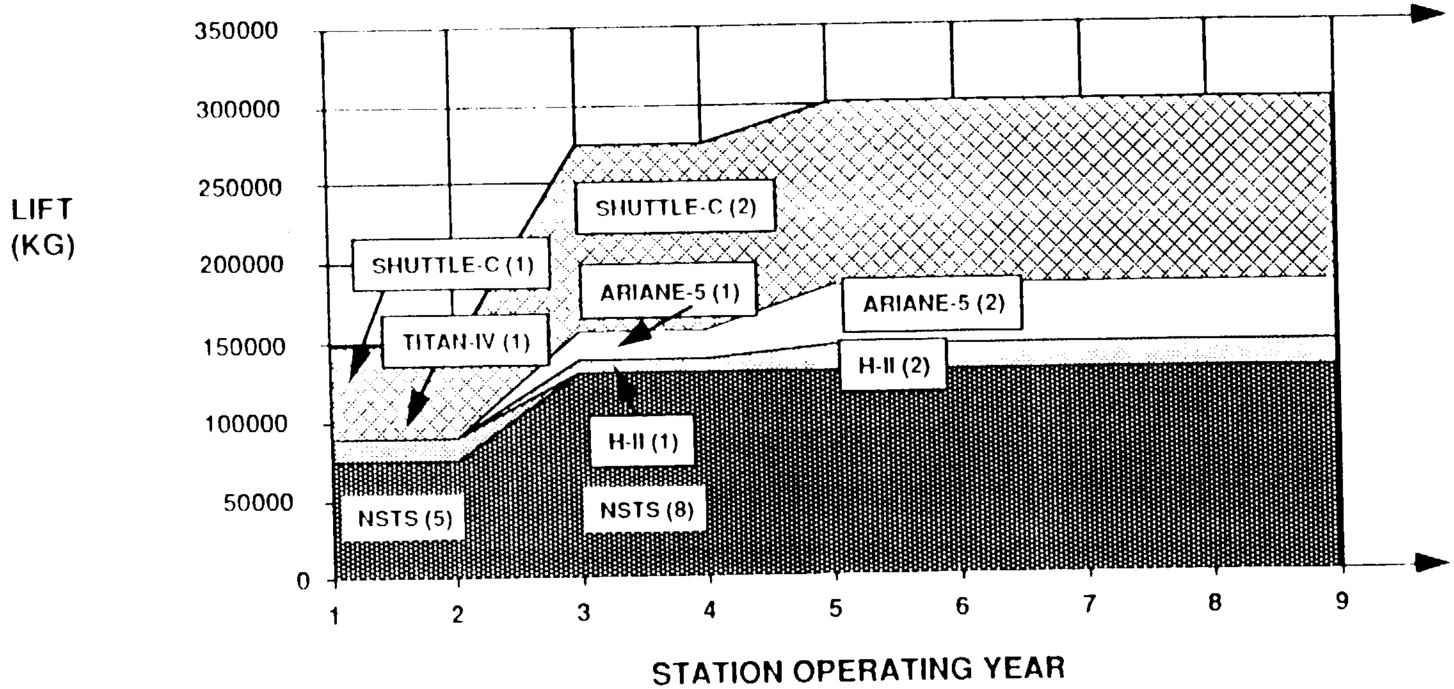
STUDY APPROACH - TRANSPORTATION MODEL CONTINUED

The aggressive transportation model begins with an NSTS flight rate of five per year and increases to eight per year in year 3. The heavy NSTS support requirements during the several years of assembly leading to Phase 1 will result in a backlog of payloads on the launch manifest, making it difficult to justify higher levels of NSTS support in the early years of station operation. One TitanIV and one Shuttle-C type vehicle are also included for the first two years. The Shuttle-C assumption is consistent with the possibility of developing such a vehicle for use during Space Station assembly. The Air Force has stated that it can provide one TitanIV launch per year for NASA by 1993 (Space Business News, 12/14/87), justifying the inclusion of this vehicle in the aggressive model.

As in the conservative model, internationally provided ELVs begin in year 3. At the same time, the TitanIV is phased out as a second Shuttle-C flight per year comes on line. The final increment in this model occurs in year 5 with a second ELV from both ESA and Japan.

STUDY APPROACH
TRANSPORTATION MODEL
CONTINUED

Aggressive Transportation Support



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STUDY APPROACH
LOGISTICS REQUIREMENTS

- Four types of carriers are used to transport logistics material (spares, food, experiments & equipment, etc) to the Space Station†

Carrier	Carrier Mass	Carrier Mass Capacity	Mass Fraction*
Pressurized module	5199 kg	10,011 kg	0.52
Unpressurized module	1498 kg**	2869 kg	0.52
Fluids carrier	1701 kg	1453 kg	1.17
Propellant carrier	1335 kg	3366 kg	0.40

* Empty Carrier Mass/Carrier Mass Capacity

** Only the 8 ft length unpressurized carrier was considered in this study

- The total carrier mass requirement for any station operating year is calculated by determining the logistics mass for each category and multiplying by the respective carrier mass fraction

- The number of carriers required in a particular year is calculated by dividing the total carrier mass requirement by the corresponding carrier mass

† Mass properties and capabilities for the logistics carriers are based on data presented by Boeing Corp. at the Critical Evaluation Task Force (CETF) meeting at LaRC on 8/30/86. The pressurized module data represents the baseline carrier.

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STUDY APPROACH
LOGISTICS REQUIREMENTS
CONTINUED

Annual Crew & Station Support Logistics at Phase 1 *

	LIFT	RETURN
Crew Support	7,581 Kg	5,370 Kg
• Food	5,885 Kg	
• Personnel Support (hygiene, clothing, etc)	1,045 Kg	521 kg
• Station Support (housekeeping, waste management, trash)	651 Kg	4,849 Kg
Station Support	13,606 Kg	11,242 Kg
• Spares, Documentation, etc	6,884 Kg	6,884 Kg
• ECLSS Fluids	1,445 Kg	1,354 Kg
• Station N2H4	2,273 Kg	
• EVA Support	3,004 Kg	3,004 Kg
Totals	21,187 Kg	16,612 Kg

* Based on Level B SSCN #BM010026A

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STUDY APPROACH
LOGISTICS REQUIREMENTS
CONTINUED

Additional Annual Crew & Station Support Logistics During Growth *

	LIFT	RETURN
Additional Crew	948 Kg/Crewman	671Kg/Crewman
Additional Power (Solar Dynamic)	1,000 Kg/50 KW	1,000 Kg/50 KW
Additional Pressurized Volume		
• Hab/Lab Module	2,868 Kg	2,473 Kg
• Node	547 Kg	472 Kg
• Large Pocket Lab	1,238 Kg	1,068 Kg
• Small Pocket Lab	613 Kg	528 Kg

* Based on proportionate increases of Phase 1 requirements with crew size, power and mass for crew, power and volume increases respectively

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STUDY APPROACH
LOGISTICS REQUIREMENTS
CONTINUED

Housekeeping Power Budget

Station Element	Housekeeping Power Requirement*
Phase 1 Configuration	35 KW
Per Additional Habitation Module	7.0 KW
Per Additional Laboratory Module	6.7 KW
Per Additional Large Pocket Lab	2.2 KW
Per Additional Small Pocket Lab	1.1 KW
Per Additional Resource Node	0.63 KW
Per Additional Truss Bay	0.153 KW

* Power requirements for baselined station elements are based on the PDRD, Section 6, Rev B, January 1988, Table 5-2.
Resource node requirement is based on Resource Node 1
Pocket lab power requirements are proportionate to laboratory module requirements based on relative size.
Truss bay requirements include overhead for line loss and attached payload support equipment

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STUDY APPROACH
OMV SUPPORT

- The OMV is assumed to be NSTS based until the payload servicing facility is accommodated
  - OMV up and down mass is charged to the transportation model
  - The OMV is temporarily berthed at the station until propellant is spent, then returned to Earth

- OMV propellant is budgeted for free flyer mission support and ELV payload retrieval
  - Propellant requirements are estimated on a per mission basis as a function of OMV payload mass and delta height requirements plus a 10% dispersion allowance
  - Insitu servicing capability is not assumed. All servicing is at the station and requires a free flyer retrieval flight and, after servicing, a free flyer deployment flight
  - ELV payload retrieval assumes payload delivered to an orbit in plane 10 n.m. below the station
  - OMV mass for propellant budgeting assumes 3/4 propellant load.
  - OMV mass (vehicle fully fueled) = 8,115 kg*; OMV full prop load = 3,990 kg*
  - OMV specific impulse = 290 seconds*

* "Space Station/OMV Design Reference Mission Analysis", MDAC ES TM No. 1.2-TM-FM88034-02, 15 October 1987

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GROWTH SCENARIO RESULTS

GROWTH SCENARIO RESULTS - FINAL STATION RESOURCE LEVELS

Station resource levels at completion of growth are a function of transportation model and resource requirements of the mission emphasis. Resource levels are initially increased as the transportation model allows to relieve the resource deficits created by accommodation of the Phase 1 mission set. After initial deficits are relieved, resource levels grow as required to support new mission accommodations.

Lift allocation for resource growth is limited since available lift is required for support of ongoing missions, crew and station logistics, and logistics carriers. Resource levels are increased if available resources are lower than user requirements and the transportation model can support delivery of growth components in addition to the ongoing lift requirements. The 5 enhanced NSTS flights per year transportation model allows an increase of crew in only one growth scenario. This was possible since the Phase 1 mission requirements are lower for this particular emphasis and allow the support of an additional module, crew, and associated logistics.

Required resource levels vary with the mission emphasis. Microgravity Research & Materials Production missions have the highest power and crew requirements of the major emphases. Pocket lab requirements are high for this emphasis since these are required to house several of the production facilities. Microgravity Research missions (with minimal materials production)has a substantially lower power requirement. The Life Sciences emphasis tends to require more lab volume than the other emphases. This is due to requirements of dedicated lab modules for several life science facilities. The Observational Science emphasis has the most moderate requirements of the emphases. Due to moderate lift, crew, and power requirements of missions in this category, a greater percent of missions in other categories can be accommodated within existing station resource limits.

GROWTH SCENARIO RESULTS
FINAL STATION RESOURCE LEVELS

Emphasis	Transportation Model	Power	Crew	Hab Modules	Lab Modules	Pocket Labs
Microgravity Research	Aggressive	225	24	3	5	2
Microgravity Research & Materials Production	5 NSTS/yr only	125	14	2	3	1
	Moderate	225	24	3	5	2
	Aggressive	325	24	3	5	3
Life Sciences	5 NSTS/yr only	125	8	1	3	2
	Moderate	225	22	3	6	2
	Aggressive	275	24	3	6	2
Observational Science	5 NSTS/yr only	125	8	1	3	1
	Moderate	175	22	3	4	2
	Aggressive	175	24	3	4	2

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GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH EMPHASIS

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- Objective

  Accommodate facilities devoted to microgravity research in their desired time frame, while maintaining support to other station activities close to the Phase 1 level. While one goal of microgravity research is to lead to commercial production of materials in space, this scenario emphasizes only limited production unit accommodation under the assumption that most production units requiring very low gravity levels will be branched to co-orbiting facilities or platforms

- Emphasized Growth Missions

US Materials Laboratory (COMM1201)	A subset of this lab is present at Phase 1; complete outfitting is a primary priority
Microgravity & Materials Processing Laboratory (COMM1204)	A second major laboratory which will extend the capabilities of the first materials lab
Biological Production Units (COMM1206)	A full scale biological processing facility for commercial production of pharmaceuticals

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GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT

Summary of Mission Accommodation

- General
  - Mission accommodation included 2 dedicated materials research labs, 1 materials production facility and primary missions in other mission categories. Mission accommodation in non-emphasized categories was poor due to high resource requirements of the microgravity research missions
  - Growth activities for the first 2 years were devoted to correcting resource deficiencies at Phase 1, providing lab volume to support complete outfitting of materials lab #1 and accommodating the OMV and payload service facility
  - Growth to the dual keel configuration was accomplished in station operating year 2. This resulted in growth to 10 attach points available for Technology Development and Observational Science missions

- Microgravity Research
  - All missions in this category were accommodated. This does not include the materials production facilities which are part of the Microgravity Research and Materials Production emphasis scenarios (Electroepitaxial Crystal Growth Production Units 1 and 2, EOS Production Units, Crystal Production Units, and Containerless Process Production Units)
  - Complete outfitting of materials lab #1 was accomplished in year 2; materials lab #2 was accommodated and completely outfitted in year 3
  - The Micro-g Variable-g Free Flyer was accommodated on time (i.e., accommodated during the desired start year) in year 7

- Industrial Services
  - The growth missions accommodated within this category include the Industrial Space Facility free flyer and attached missions. These were accommodated in years 4 and 5, respectively

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GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED

Summary of Mission Accommodation (cont)

- Life Sciences
  - Full outfitting of the life sciences lab was completed in year 8
  - The sample quarantine mission added in year 7 allowed the accommodation of the sample return missions on time

- Observational Sciences
  - Addition of the payload servicing facility in year 2 allowed the on time servicing of the Hubble Space Telescope
  - Both observational co-orbiting platforms were accommodated in early station operations. SIRTF was serviced 1 year late in year 3 and AXAF was serviced on time in year 5
  - Numerous attached and free flyer missions were not accommodated since resource allocation was directed to the Microgravity Research missions

- Technology Development
  - Few growth missions in this category were accommodated due to high lift and crew requirements of the Microgravity Research emphasis. Missions which were accommodated are primarily low resource, short duration missions

GROWTH SCENARIO RESULTS - MICROGRAVITY RESEARCH EMPHASIS AGGRESSIVE TRANSPORTATION SUPPORT CONTINUED

The final station configuration including module, pocket lab, solar dynamic collector, and truss additions is shown for the Microgravity Research emphasis, aggressive transportation support scenario. The module pattern given is conceptual only and is meant to illustrate volumetric size of the station in terms of number of modules and pocket labs and their associated facilities. Configuration analysis to determine an optimal module pattern would involve numerous operational issues which were not addressed in this study.

This configuration shows the addition of 2 hab modules, 2 lab modules, and 2 pocket labs to the Phase 1 station. Also added are truss bays for the evolution of the dual keel and for support of additional solar dynamic collectors. Not shown but also included is the addition of the payload servicing facility and the station-based OMV. Facilities in support of the Microgravity Research emphasis include 2 dedicated microgravity research lab modules and a materials production pocket lab.

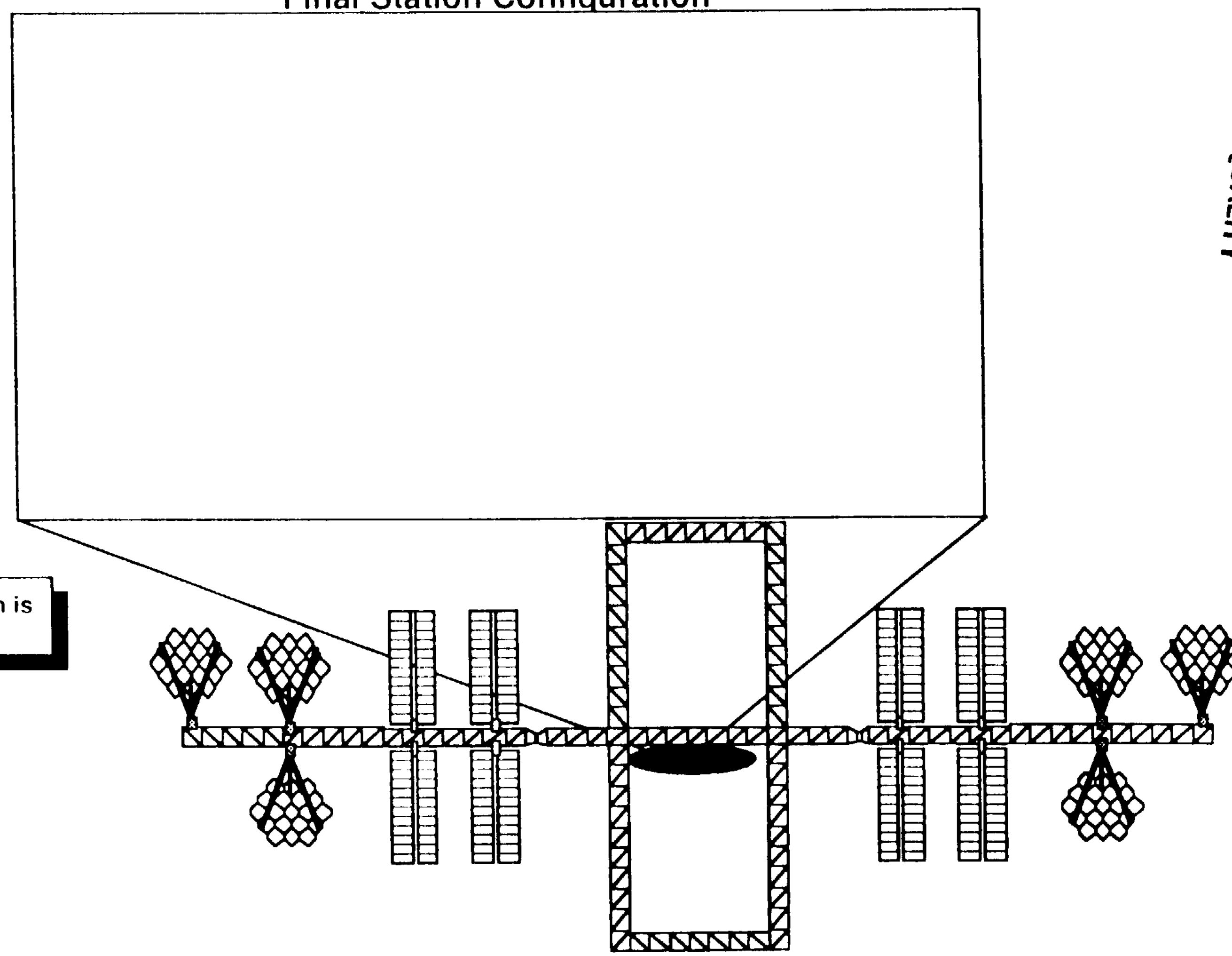
Station growth components added per year and the resulting available resources for this scenario are given in the following table.

Microgravity Research Emphasis
Aggressive Transportation Model

Year	SD Arrays	Total Powe	User Power	Total Crew	User Crew	Habs	Labs	Sm Pocket	Lg Pockets	Attach Pnt	Truss bay	OMV	OTV	Growth Mass
Phase 1	0	75	45.2	8	6	1	3	0	0	4	0	0	0	
1	1	125	75.2	16	12	2	4	0	0	4	17	0	0	75175 Kg
2	1	125	66.9	16	12	2	4	0	0	10	71	1	0	49105 Kg
3	2	175	98.8	22	16.5	3	5	0	0	10	71	1	0	73945 Kg
4	2	175	93.9	24	18	3	5	1	1	10	81	1	0	22553 Kg
5	3	225	142.1	24	18	3	5	1	1	10	81	1	0	11114 Kg

GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED

Final Station Configuration



Note: Module pattern shown is representative only

GROWTH SCENARIO RESULTS - MICROGRAVITY RESEARCH EMPHASIS AGGRESSIVE TRANSPORTATION SUPPORT CONTINUED

Allocation of lift, crew, and power is shown for station operations after completion of growth. The pie charts are representative of mature station operations for this scenario and are based on an average of annual requirements during this period.

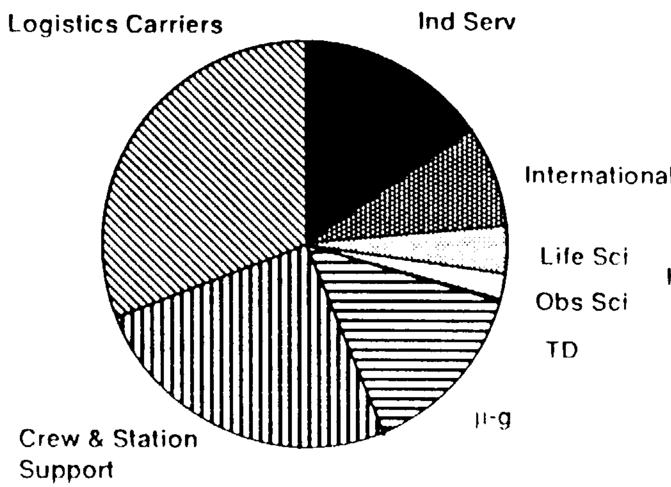
The lift allocation pie shows a large percent of total lift required for Microgravity Research and Industrial Services missions. Facilities which are reflected under Microgravity Research include 2 dedicated materials research laboratories (COMM1201 and COMM1204), biological production units facility (COMM1206), and a microgravity/variable gravity free flyer (SAAX402). The majority of the Industrial Services lift is required for support of the attached and free flyer Industrial Space Facilities. These facilities provide laboratory volume for a variety of uses including microgravity research. Logistics carrier lift requirements reflect equivalent lift to support 15 pressurized log module, 18 unpressurized carrier, 3 fluids carrier, and 7 propellant carrier flights per year. Lift allocation for crew & station support represents logistics resupply for 8 station modules and 24 crew persons.

User crew requirements are highest for International and Microgravity Research missions. International crew requirements are primarily in support of microgravity research and life science research facilities. Housekeeping crew requirements are assumed to be 25% of the total station crew.

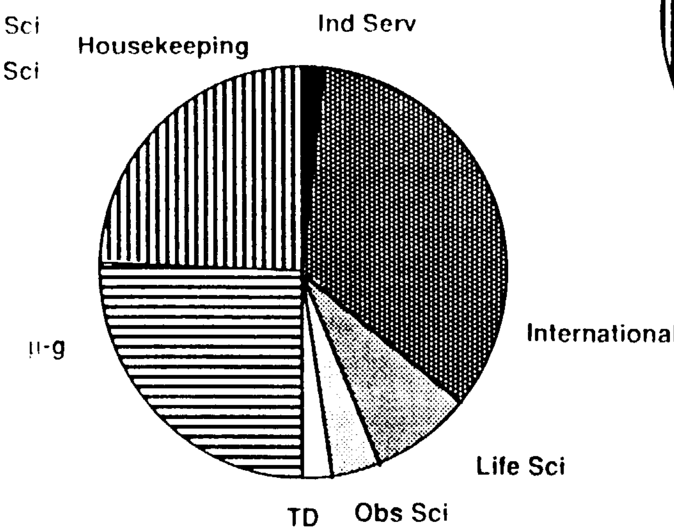
Power requirements among users are greatest for the Microgravity Research and International missions. International missions which have the highest power requirements are the European materials research lab and materials processing development facility (MAT110 and MAT120). The percent of total power required for housekeeping is high due to a moderate total power capability (225 kW) providing housekeeping support for a relatively high number of hab and lab modules (3 habs, 5 lab modules).

GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED

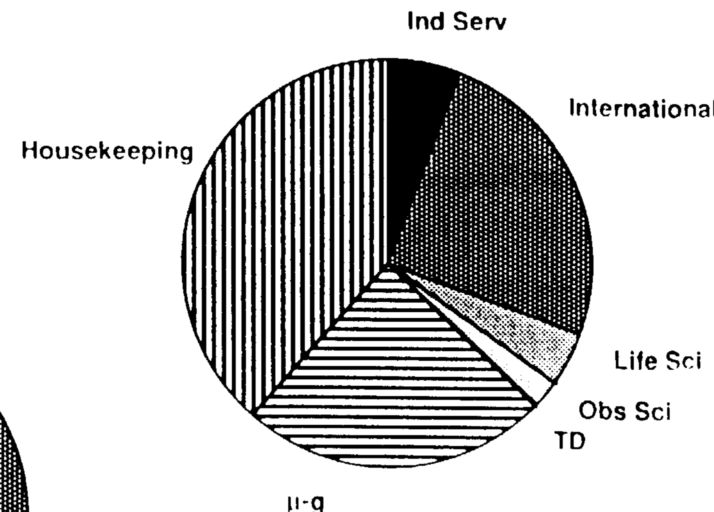
Resource Allocation



Lift



Crew



Power

GROWTH SCENARIO RESULTS - MICROGRAVITY RESEARCH EMPHASIS AGGRESSIVE TRANSPORTATION SUPPORT CONTINUED

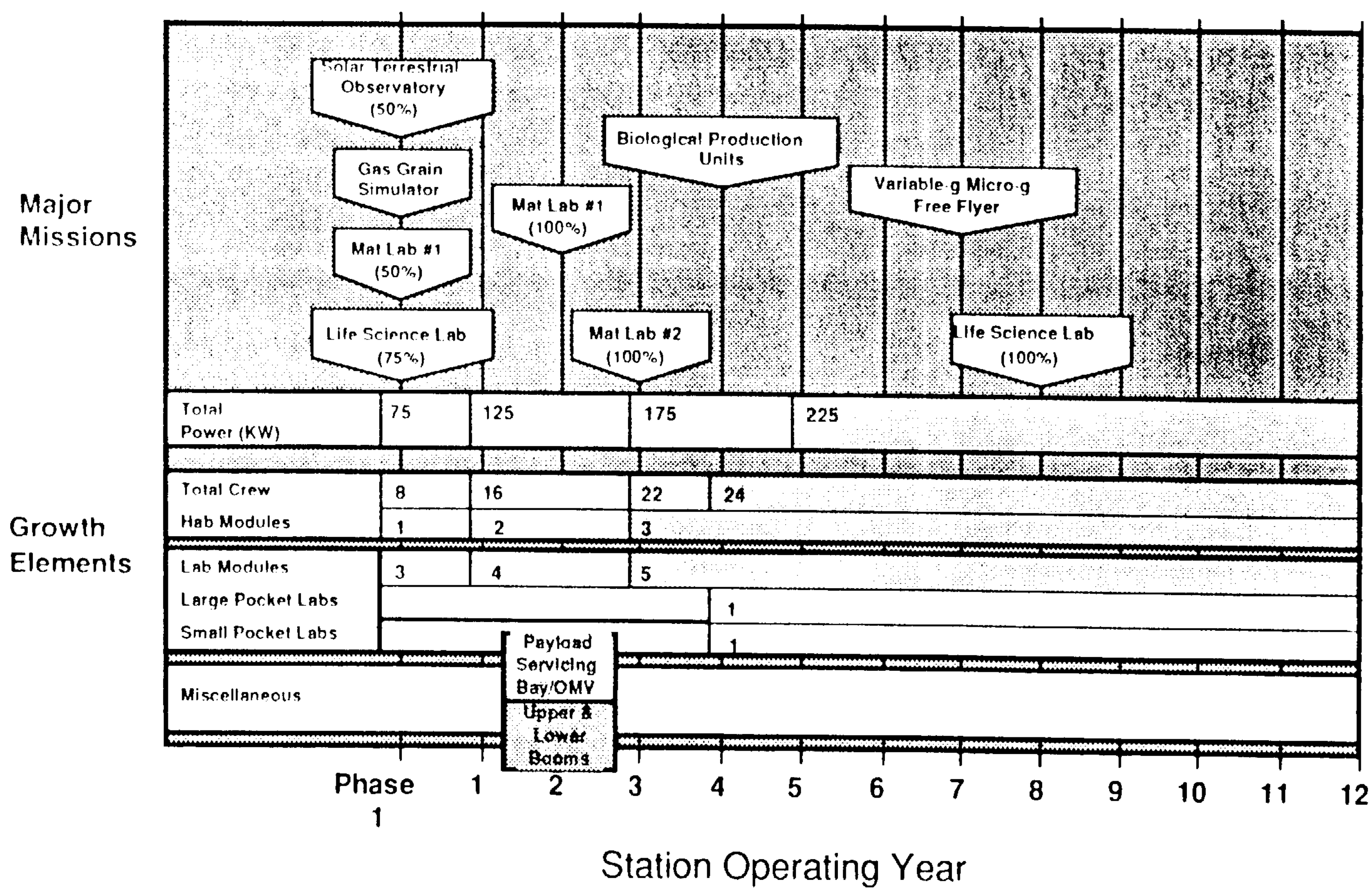
The timeline of major mission accommodation and growth element addition for the Microgravity Research emphasis, aggressive transportaton support scenario is given below. This timeline shows the correlation of resource growth (i.e., additions of power, crew, lab volume) with the accommodation of growth missions and the evolution of station facilities.

Facilities in support of the Microgravity Research emphasis include materials lab #1, materials lab #2, the biological production units facility, and the variable-g micro-g free flyer. Evolution of core station facilities in support of this emphasis is complete in station operating year 3. The 100% outfitting of materials lab #1 requires the additional lab volume shown by the accommodation of the 4th lab module in year 2. Also required for complete outfitting and utilization of materials lab #1 is additional power (50 kW power with the addition of 2 solar dynamic collectors) and crew (accommodation of hab module #2 and 8 crew persons). Materials lab #2 is fully outfitted in station operating year 3. This requires an additional dedicated lab module, crew, and power for support. Crew growth above 16 crew persons requires the accommodation of hab module #3. The biological production units facility requires a large pocket lab for housing. This facilitiy and the accommodation of a European materials research facility create the requirement for power growth to 225 kW.

Additional growth components are the dual keel and booms required for support of Observational Science and Technology Development missions, and the OMV and payload servicing facility required for servicing of the variable-g micro-g free flyer and Observational Science free flyers. The small pocket lab houses the sample quarantine facility.

GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED

Summary of Major Mission and Station Element Growth



GROWTH SCENARIO RESULTS - MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS

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GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS

- Objective

  Accommodate major microgravity research laboratories and materials processing production units in their desired time frame, while maintaining support to other station activities close to the Phase 1 level

- Emphasized Growth Missions

US Materials Laboratory (COMM1201)	A subset of this lab is present at Phase 1; complete outfitting is a primary priority
Microgravity & Materials Processing Laboratory (COMM1204)	A second major laboratory which will extend the capabilities of the first materials lab
Electroepitaxial Crystal Growth Production Units (#1 and #2)	Two production units used to grow large gallium arsenide crystals in bulk quantities for the commercial market
Biological Production Units (COMM1206)	A full scale biological processing facility for commercial production of pharmaceuticals
Crystal Production Units	Commercial production of high purity, low defect density semiconductor materials
Containerless Process Production Units (COMM1213)	Commercial production of high quality optical fibers
Electrophoresis Operations in Space (EOS) Production Units (COMM1202)	Production facility mission used to represent a generic lift and power intensive process requiring a separate large pocket lab

GROWTH SCENARIO RESULTS - MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT

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GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT

Summary of Mission Accommodation

- General
  - Accommodation of growth missions in all mission categories was very poor due to the heavy lift requirements needed by the Phase 1 missions and crew & station logistics
  - Growth activities for the first 3 years were devoted to correcting resource deficiencies at Phase 1 and accommodating the OMV and payload service facility
  - Lift capability was insufficient to accommodate an additional lab module and associated logistics. This resulted in inadequate rack volume for complete accommodation of materials lab #1 and the life sciences lab

- Microgravity Research & Materials Production
  - The only growth mission accommodated in this category is an external attached production facility. This was accommodated in year 11
  - Complete outfitting of materials lab #1, accommodation of several production facilities and accommodation of materials lab #2 was not possible due to inadequate lift

- Industrial Services
  - The missions in this category have significant lift requirements in general. For this reason none were accommodated in this scenario

- International
  - The only growth mission accommodated in this category was a materials production free flyer which was accommodated in year 12

GROWTH SCENARIO RESULTS - MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT
CONTINUED

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GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT
CONTINUED

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Summary of Mission Accommodation (cont)

- Life Sciences
  - Inadequate lift did not allow full outfitting of the life sciences lab
  - The sample quarantine mission added in year 7 allows the accommodation of the sample return missions on time

- Observational Sciences
  - Addition of the payload servicing facility in year 3 allows the on time servicing of the Hubble Space Telescope
  - Lift requirements of the microgravity and materials processing emphasis did not allow the evolution of the dual keel; no additional external attached missions were accommodated

- Technology Development
  - No growth missions in this category were accommodated due to high lift requirements of the Microgravity Research and Materials Production emphasis and lack of available attach points

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GROWTH SCENARIO RESULTS - MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT
CONTINUED

The final station configuration including module, pocket lab, solar dynamic collector, and truss additions is shown for the Microgravity Research and Materials Production emphasis, 5 NSTS/year transportation support scenario. The module pattern given is conceptual only and is meant to illustrate volumetric size of the station in terms of number of modules and pocket labs and their associated facilities. Configuration analysis to determine an optimal module pattern would involve numerous operational issues which were not addressed in this study.

Major growth components for this scenario include an additional hab module, 1 pocket lab, a pair of solar dynamic collectors, and truss to support the solar dynamic collectors. Also included but not shown is the addition of the payload servicing facility and the OMV. Lift for this 5 NSTS flights/year transportation scenario was inadequate for evolution of the dual keel or the accommodation of additional lab modules. The Microgravity Research and Materials Production emphasis is the only emphasis for the 5 NSTS flights/year transportation support scenarios in which an additional module was able to be accommodated. This is due to lower Phase 1 mission lift requirements than the other emphases. The resulting additional available lift is adequate to support delivery and logistics resupply of a single hab module.

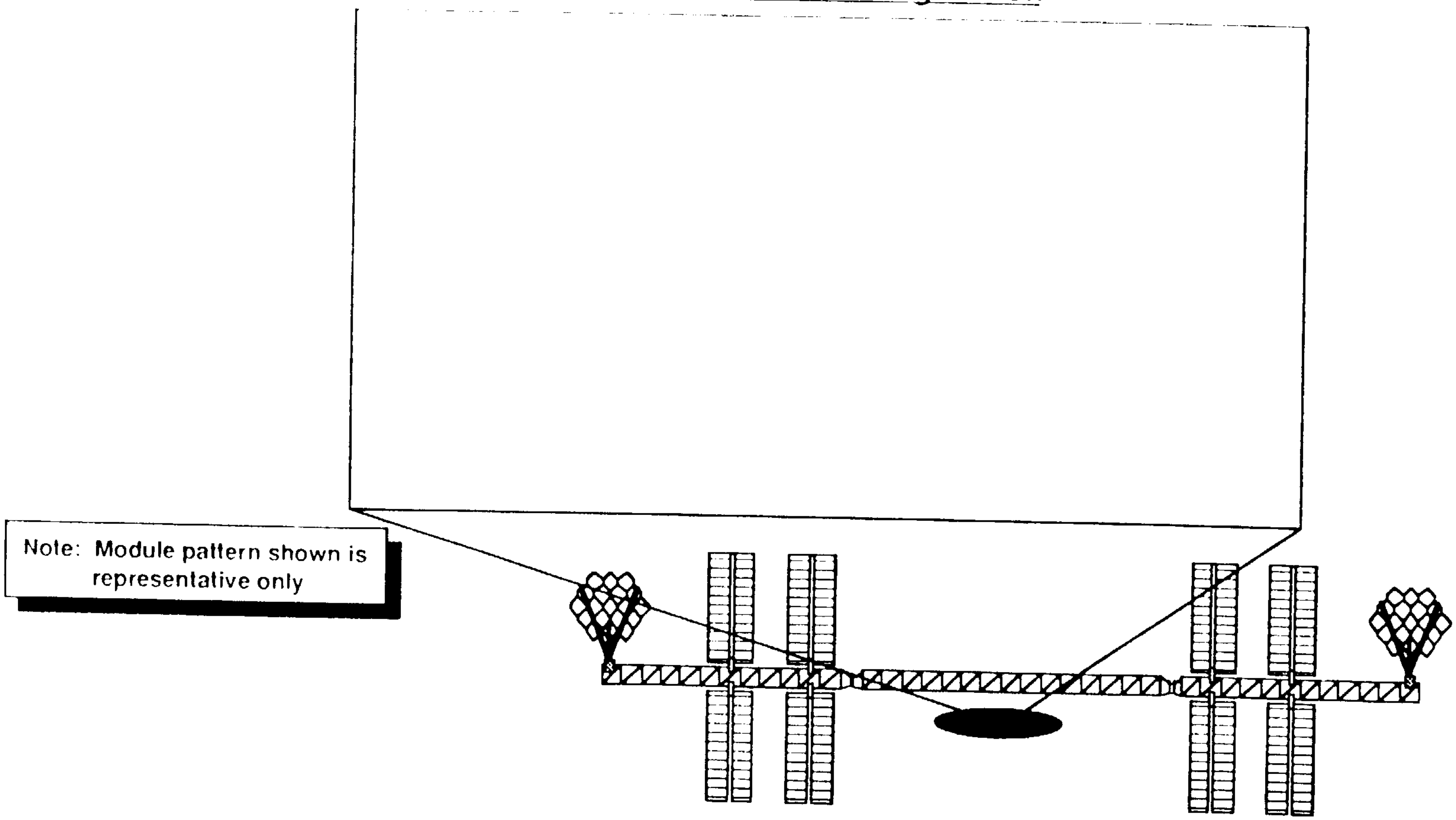
Growth components added per year and resulting available resources are given in the following table.

Microgravity Research & Materials Production Fntpasis
5 NSTS/Year Transportation Model

Year	SD Arrays	Total Power	User Power	Total Crew	User Crew	Habs	Labs	Sm Pocket	Lg Pockets	Attach Pnts	Truss bays	OMV	OTV	Growth Mass
Phase 1	0	75	45 2	8	6	1	3	0	0	4	0	0	0	
1	1	125	90 7	8	6	1	3	0	0	4	17	0	0	14989 Kg
2	1	125	90 7	8	6	1	3	0	0	4	17	0	0	Kg
3	1	125	82 5	12	9	2	3	0	0	4	17	1	0	36411 Kg
4	1	125	82 5	12	9	2	3	0	0	4	17	1	0	Kg
5	1	125	82 5	12	9	2	3	0	0	4	17	1	0	Kg
6	1	125	82 5	12	9	2	3	0	0	4	17	1	0	Kg
7	1	125	81 4	12	9	2	3	1	0	4	17	1	0	6500 Kg
8	1	125	81 4	12	9	2	3	1	0	4	17	1	0	Kg
9	1	125	81 4	12	9	2	3	1	0	4	17	1	0	Kg
10	1	125	81 4	14	10 5	2	3	1	0	4	17	1	0	Kg

GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT
CONTINUED

Final Station Configuration



GROWTH SCENARIO RESULTS - MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS 5 NSTS/YRTRANSPORTATION SUPPORT CONTINUED

Allocation of lift, crew, and power is shown for station operations after completion of growth. The pie charts are representative of mature station operations for this scenario and are based on an average of annual requirements during this period.

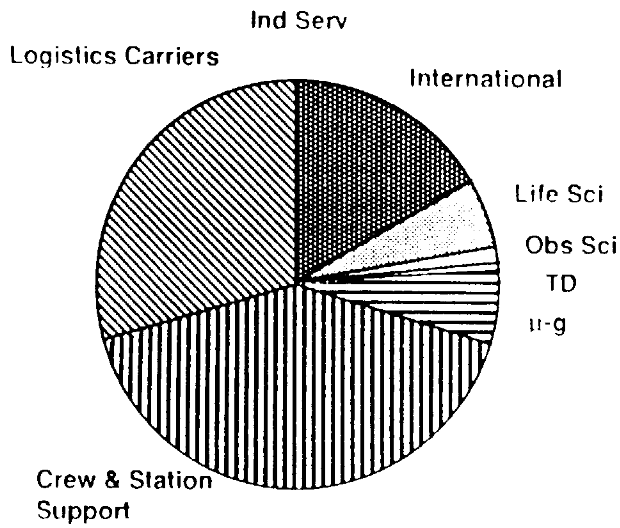
The lift allocation pie chart shows a majority of total lift is required for crew & station support logistics and logistics carriers. This distribution results from the minimal lift available with the 5 NSTS flights per year transportation model. The logistics carrier allocation reflects lift required for 6 pressurized log module, 4 unpressurized carrier, 2 fluids carrier, and 2 propellant carrier flights per year. The crew & station support logistics allocation represents lift to support 5 modules and 14 crew persons. Lift allocated in support of Microgravity Research and Materials Production is required for 50% accommodation of materials lab #1 (COMM1201) and accommodation of the containerless production units facility (COMM1213).

User crew requirements are highest for the International, Microgravity Research & Materials Production, and Life Sciences missions. The International missions include the International missions of the Phase 1 mission set and a Canadian materials production free flyer (COMM4000). Crew for the microgravity research and materials production missions and life science missions represent requirements for the two major labs of the Phase 1 station.

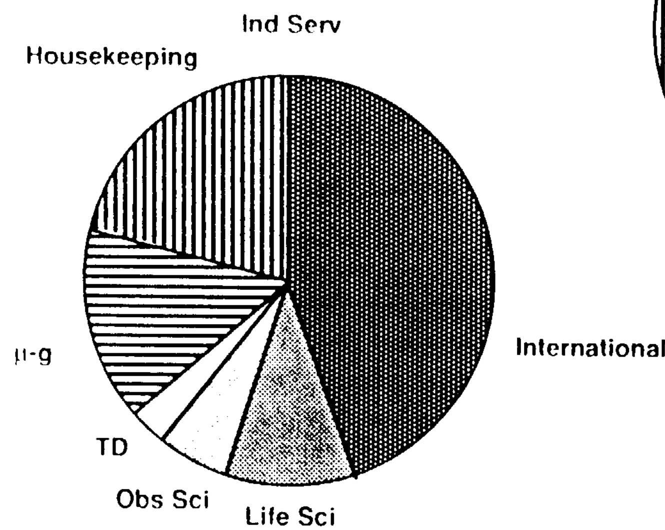
Primary power requirements are from station housekeeping, International missions, and Microgravity Research & Materials Production missions. Station housekeeping power is approximately 44 kW in support of 2 hab modules, 3 lab modules, and a small pocket lab. The International mission set includes several major power users including materials research and life science laboratories.

GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
5 NSTS/YR TRANSPORTATION SUPPORT
CONTINUED

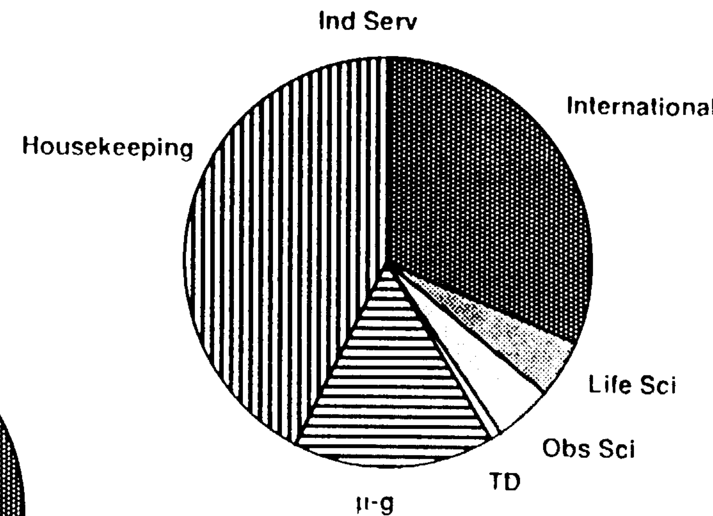
Resource Allocation



Lift



Crew



Power

GROWTH SCENARIO RESULTS - MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS 5 NSTS/YR ONLY TRANSPORTATION SUPPORT CONTINUED

The timeline of major mission accommodation and growth element addition for the Microgravity Research & Materials Production emphasis, 5 NSTS flights/year transportaton support scenario is given below. This timeline shows the correlation of resource growth (i.e., additions of power, crew, lab volume) with the accommodation of growth missions and the evolution of station facilities.

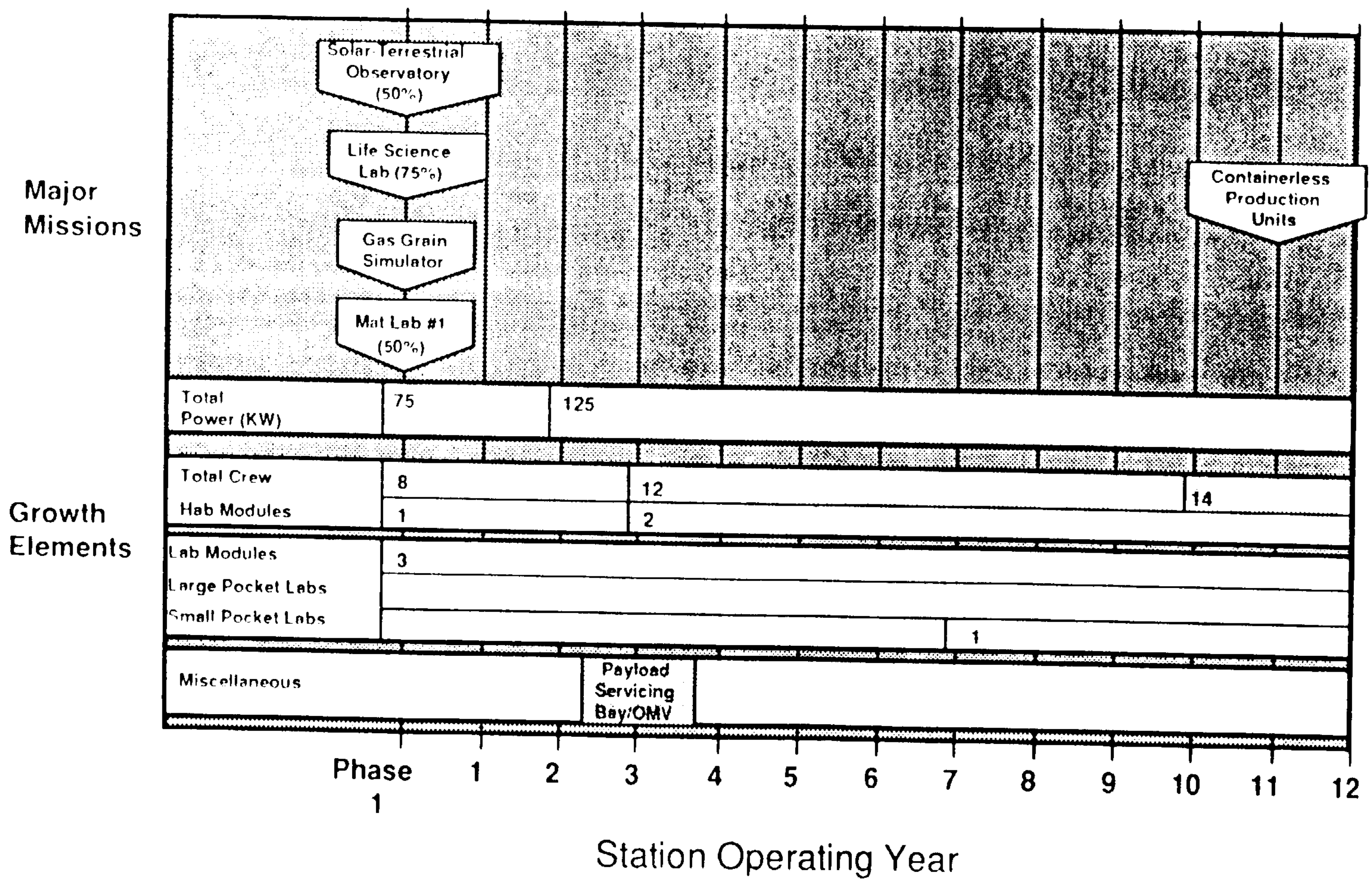
Station evolution and facilities accommodation is minimal for the 5 NSTS flights/year transportation support scenario. The only growth mission accommodated in support of this emphasis is the containerless production units facility in station operating year 11. This facility is an external, attached faciltiy which does not require the addition of a pocket lab. Complete outfitting of materials lab #1 was not possible since additional rack volume is required and a new lab module could not be accommodated.

Growth items in this scenario include 2 solar dynamic collectors (50 kW power increment) , hab module #2 and 6 crew persons, a small pocket lab, and the OMV and payload servicing facility. The additional power and first increase in crew is required to relieve resource deficits of the Phase 1 mission set. The OMV and payload servicing facility are accommodated to service the Great Observatories. The small pocket lab is required to house the sample quarantine facility. Although the sample quarantine facility is not required for support of the Microgravity Research & Materials Production missions, this facility is accommodated under the assumption that it is a requirement for support of the Mars Sample Return and Comet Nucleus Sample Return missions. These missions are high priority and resources to support them are assumed to be budgeted from ongoing station activities.

The Microgravity Research & Materials Production emphasis is the only emphasis of the 5 NSTS flights per year scenarios in which an additional hab module is able to be accommodated. This is due to lower lift requirements of this Phase 1 mission set than in other scenarios. The resulting "additional" lift in this scenario is adequate for delivery and logistics resupply of hab module #2.

GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT
CONTINUED

Summary of Major Mission and Station Element Growth



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GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
MODERATE TRANSPORTATION SUPPORT

Summary of Mission Accommodation

- General
  - Growth for the first 2 years was devoted to correcting crew and power deficiencies at Phase 1
  - Lift for the first 3 years was insufficient to allow accommodation of any growth missions
  - The accommodation of only a few of the materials production units prevented significant accommodation of non-micro-g missions

- Microgravity Research & Materials Production
  - Complete outfitting of the first Microgravity and Materials Processing Facility was not possible before the fourth station operating year
  - The second general Materials Laboratory was accommodated over the course of four years and was delayed by three years due to slow growth during the first three years
  - Only two of six materials production units were accommodated due to insufficient lift. These two facilities, Crystal Production Units and Containerless Process Production Units have the lowest resource requirements of the production units in the EMM and were begun 4 and 6 years late, respectively

- Industrial Services
  - The missions in this category have significant lift requirements in general. For this reason none were accommodated in this scenario

- International
  - Several of the lower resource using international growth missions were accommodated on time
  - Although most of the on-time missions were the Phase 1 missions, only 15% of the international missions in the EMM were not started at all, and delays for slipped missions average only 5 years

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GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
MODERATE TRANSPORTATION SUPPORT
CONTINUED

Summary of Mission Accommodation (cont)

- Life Sciences
  - The sample return missions were accommodated on time because these missions were given high priority
  - The only other Life Sciences growth mission was the complete outfitting of the general life sciences lab. This occurred in the fourth operating year of the Space Station

- Observational Sciences
  - Servicing of the Great Observatories (Space Telescope and AXAF) was not possible prior to Station Operating year 5
  - Several other smaller observational science missions were accommodated very late including the Tropical Rainfall Mapper and Earth Radiation Hitchhiker (both in year 14)

- Technology Development
  - Less than half of the Technology Development missions were accommodated due to lift and user crew limitations. These missions were considered lower priority missions within this emphasis and typically were accommodated after completion of station growth

GROWTH SCENARIO RESULTS - MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS MODERATE TRANSPORTATION SUPPORT CONTINUED

The final station configuration including module, pocket lab, solar dynamic collector, and truss additions is shown for the Microgravity Research & Materials Production emphasis, moderate transportation support scenario. The module pattern given is conceptual only and is meant to illustrate volumetric size of the station in terms of number of modules and pocket labs and their associated facilities. Configuration analysis to determine an optimal module pattern would involve numerous operational issues which were not addressed in this study.

This final configuration includes the addition of 2 hab modules, 2 lab modules, 2 pocket labs, 3 pair of solar dynamic collectors, and the dual keel to the initial Phase 1 station. Not shown but also included are the payload servicing facility and the OMV. Facilities in support of the Microgravity Research & Materials Production emphasis include 2 dedicated materials research lab modules and a crystal production unit pocket lab.

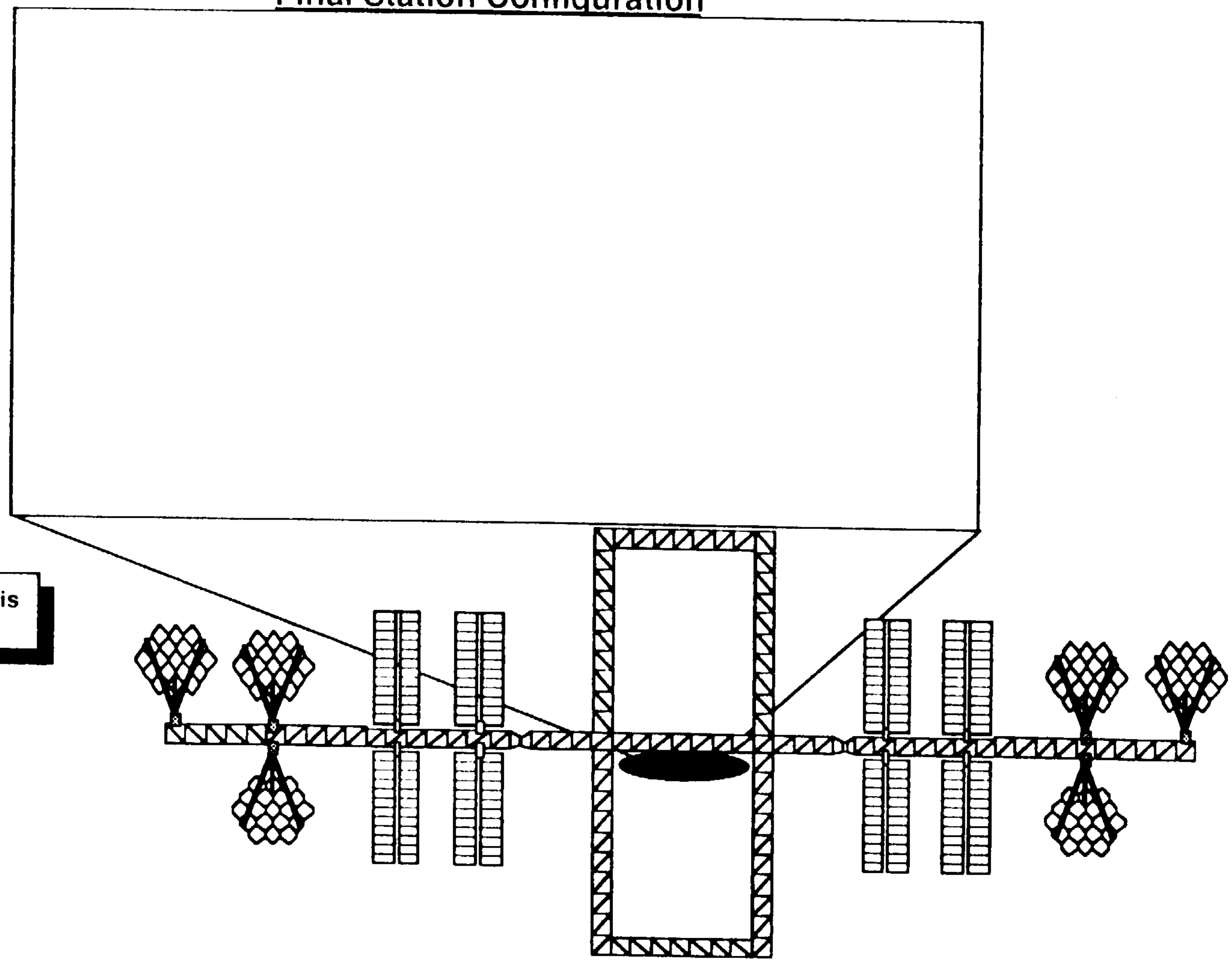
Station growth components added per year and the resulting resource additions are shown in the following table.

Microgravity Research & Materials Production Emphasis
Moderate Transportation Model

Year	SD Arrays	Total Powe	User Power	Total Crew	User Crew	labs	Labs	Sm Pocket	Lg Pockets	Attach Pnt	New Truss Bay	OMV	OTV	Growth Mass
Phase 1	0	75	45.2	8	6	1	3	0	0	4	0	0	0	
1	0	75	38.8	8	6	2	3	0	0	4	10	0	0	33684 Kg
2	0	75	38.8	12	9	2	3	0	0	4	10	0	0	Kg
3	1	125	81.2	20	15	3	3	0	0	4	17	1	0	58213 Kg
4	1	125	75.9	20	15	3	4	0	0	4	17	1	0	32700 Kg
5	1	125	67.6	21	15.75	3	4	0	0	6	71	1	0	20698 Kg
6	2	175	110.5	22	16.5	3	5	0	0	6	71	1	0	41648 Kg
7	2	175	109.9	22	16.5	3	5	1	0	6	71	1	0	6500 Kg
8	2	175	109.3	22	16.5	3	5	2	0	6	71	1	0	6500 Kg
9	2	175	109.3	23	17.25	3	5	2	0	6	71	1	0	Kg
10	3	225	155.9	24	18	3	5	2	0	6	81	1	0	12501 Kg

GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
MODERATE TRANSPORTATION SUPPORT
CONTINUED

Final Station Configuration



Note: Module pattern shown is representative only

GROWTH SCENARIO RESULTS - MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS MODERATE TRANSPORTATION SUPPORT CONTINUED

Allocation of lift, crew, and power is shown for station operations after completion of growth. The pie charts are representative of mature station operations for this scenario and are based on an average of annual requirements during this period.

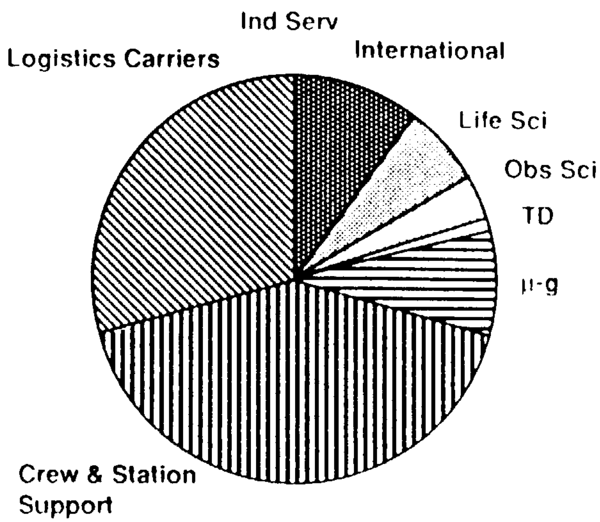
The lift allocation pie shows the majority of lift is required for crew and station support logistics and logistics carriers. Allocation for crew and station logistics represents support of 7 modules, 2 pocket labs, and 24 crew persons. The logistics carrier allocation includes lift required for 9 pressurized log module, 7 unpressurized carrier, 3 fluids carrier, and 5 propellant carrier flights per year. Primary user lift requirements are from International missions, Microgravity Research & Materials Production missions, and Life Sciences missions. The International missions include the International missions of the Phase 1 mission set and a second European materials research laboratory. Major facilities under Microgravity Research & Materials Production include materials lab #1 (COMM1201), materials lab #2 (COMM1204), crystal production units facility (COMM1208), and the containerless process production units facility (COMM1213). Major Life Sciences facilities include the fully outfitted life science lab (SAAX307).

Station crew is allocated primarily to station housekeeping, Internation missions, and Microgravity Research & Materials Production missions. Station housekeeping is assumed to require 25% of total station crew. Crew allocation for International missions is relatively high with respect to rack volume and lift allocation. This is probably due to poor requirements definition of many of these missions.

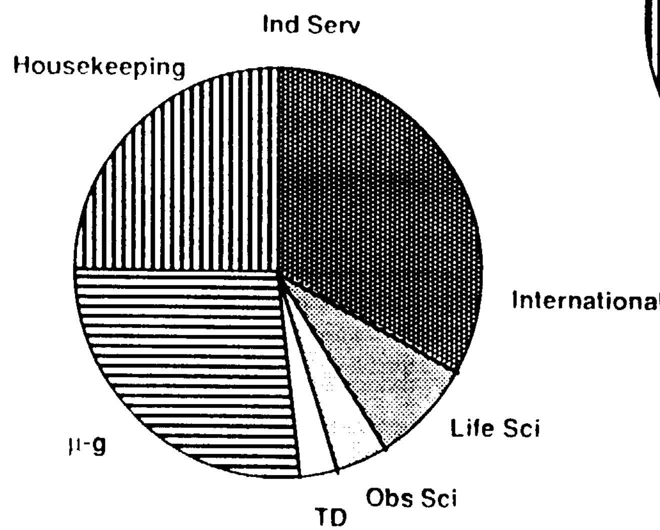
Major power requirements are from station housekeeping, International missions, and Microgravity Research & Materials Production missions. The large percent of power allocated for Microgravity Research & Materials Production is expected since these production facilities are typically large power users.

GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
MODERATE TRANSPORTATION SUPPORT
CONTINUED

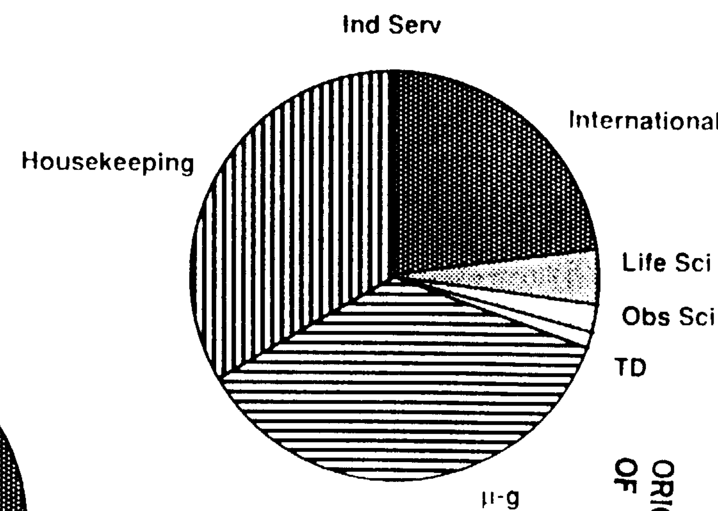
Resource Allocation



Lift



Crew



Power

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GROWTH SCENARIO RESULTS - MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS MODERATE TRANSPORTATION SUPPORT CONTINUED

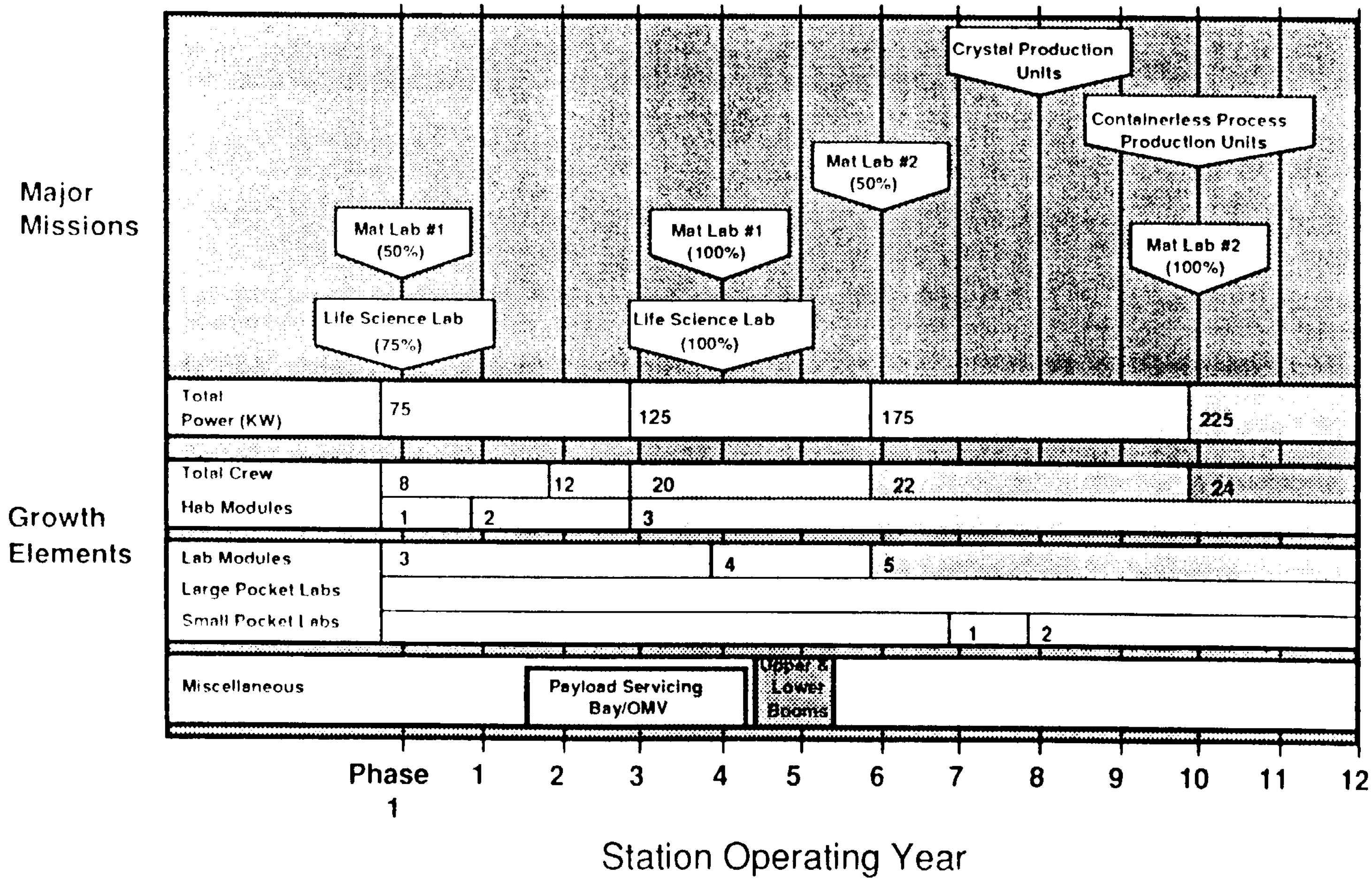
The timeline of major mission accommodation and growth element addition for the Microgravity Research & Materials Production emphasis, moderate transportaton support scenario is given below. This timeline shows the correlation of resource growth (i.e., additions of power, crew, lab volume) with the accommodation of growth missions and the evolution of station facilities.

Facilities in support of the Microgravity Research & Materials Production emphasis include materials lab #1, materials lab #2, the crystal production units facility, and the containerless process production units facility. Evolution of these facilities is complete in station operating year 10. Materials lab #1 is completely outfitted in station operating year 4. This requires additional rack volume (i.e., accommodation of lab module #4), power, and crew. Also in year 4 the 100% outfitting and utilization of the life sciences lab as well as the accommodation of several smaller missions require the addition of hab modules 2 and 3. Materials lab #2 is partially accommodated in station operating year 6. This requires addition of a dedicated lab module (lab module #5) and an increase in available power. Accommodation of the crystal production units facility and the containerless process production units facility create the requirement for power growth to 225 kW. The crystal production units facility is housed in a small pocket lab. The containerless process production units facility is an external, attached facility which does not require a pocket lab.

Additional growth items in this scenario include a small pocket lab accommodated in station operating year 7 to house the sample quarantine facility, the OMV and payload servicing facility accommodated in year 3, and the dual keel and booms added in year 5.

GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
MODERATE TRANSPORTATION SUPPORT
CONTINUED

Summary of Major Mission and Station Element Growth



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GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT

<u>Summary of Mission Accommodation</u>

- General
  - Mission accommodation included 2 dedicated materials research labs, 4 additional materials production facilities, and primary missions in other mission categories. Mission accommodation in non-emphasized categories was poor due to high lift requirements of the microgravity research and materials production missions
  - Growth activities for the first 2 years were devoted to correcting resource deficiencies at Phase 1, providing lab volume to support complete outfitting of materials lab #1 and accommodating the OMV and payload service facility
  - Growth to the dual keel configuration was accomplished in station operating year 4. This resulted in growth to 10 attach points available for Technology Development and Observational Science missions

- Microgravity Research & Materials Production
  - All missions in this category were accommodated except EOS Production Units and ECG Production Units #2. Two pocket labs are accommodated to support the Biological Production Units (year 3) and Crystal Production Units (year 4) missions
  - Complete outfitting of materials lab #1 is accomplished in year 2; materials lab #2 is accommodated in year 3 with outfitting completed in year 5
  - Additional missions accommodated include Electroepitaxial Crystal Production Units in year 2 and the Micro-g Variable-g Free Flyer in year 7 (both accommodated on time)

- Industrial Services
  - The only growth mission accommodated within this category is the Industrial Space Facility accommodated 5 years late in year 6; additional accommodation was not possible due to lift and crew limitations

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GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED

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Summary of Mission Accommodation (cont)

- Life Sciences
  - Complete outfitting of the life sciences lab is accomplished in year 8
  - The sample return missions and sample quarantine facility are accommodated on time; this provides complete accommodation of the Life Sciences missions in this scenario
- Observational Sciences
  - Primary missions accommodated include Hubble Space Telescope servicing on time in year 3, SIRTF 1 year late in year 3, and AXAF on time in year 5
  - Only other growth missions accommodated are Tropical Rainfall Mapping facility 4 years late in year 5 and Hitchhiker 4 - Earth Radiation facility 3 years late in year 4; high lift requirements of the emphasized missions prevented additional accommodation of Observational Science missions
- Technology Development
  - Accommodation of growth missions in this category is poor due to lack of available resources which were allocated to the major emphasis. Accommodated missions include power generation technology development missions, space structures technology missions, and propulsion technology missions

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GROWTH SCENARIO RESULTS - MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS AGGRESSIVE TRANSPORTATION SUPPORT CONTINUED

The final station configuration including module, pocket lab, solar dynamic collector, and truss additions is shown for the Microgravity Research and Materials Production emphasis, aggressive transportation support scenario. The module pattern given is conceptual only and is meant to illustrate volumetric size of the station in terms of number of modules and pocket labs and their associated facilities. Configuration analysis to determine an optimal module pattern would involve numerous operational issues which were not addressed in this study.

Major components added to the Phase 1 configuration include 2 hab modules, 3 lab modules, 3 pocket labs, 5 pairs of solar dynamic collectors and required truss additions, and the dual keel. Not shown but also included are the payload servicing facility and the OMV. Facilities in support of the Microgravity Research & Materials Production emphasis include 2 dedicated materials research lab modules and 3 materials production pocket labs.

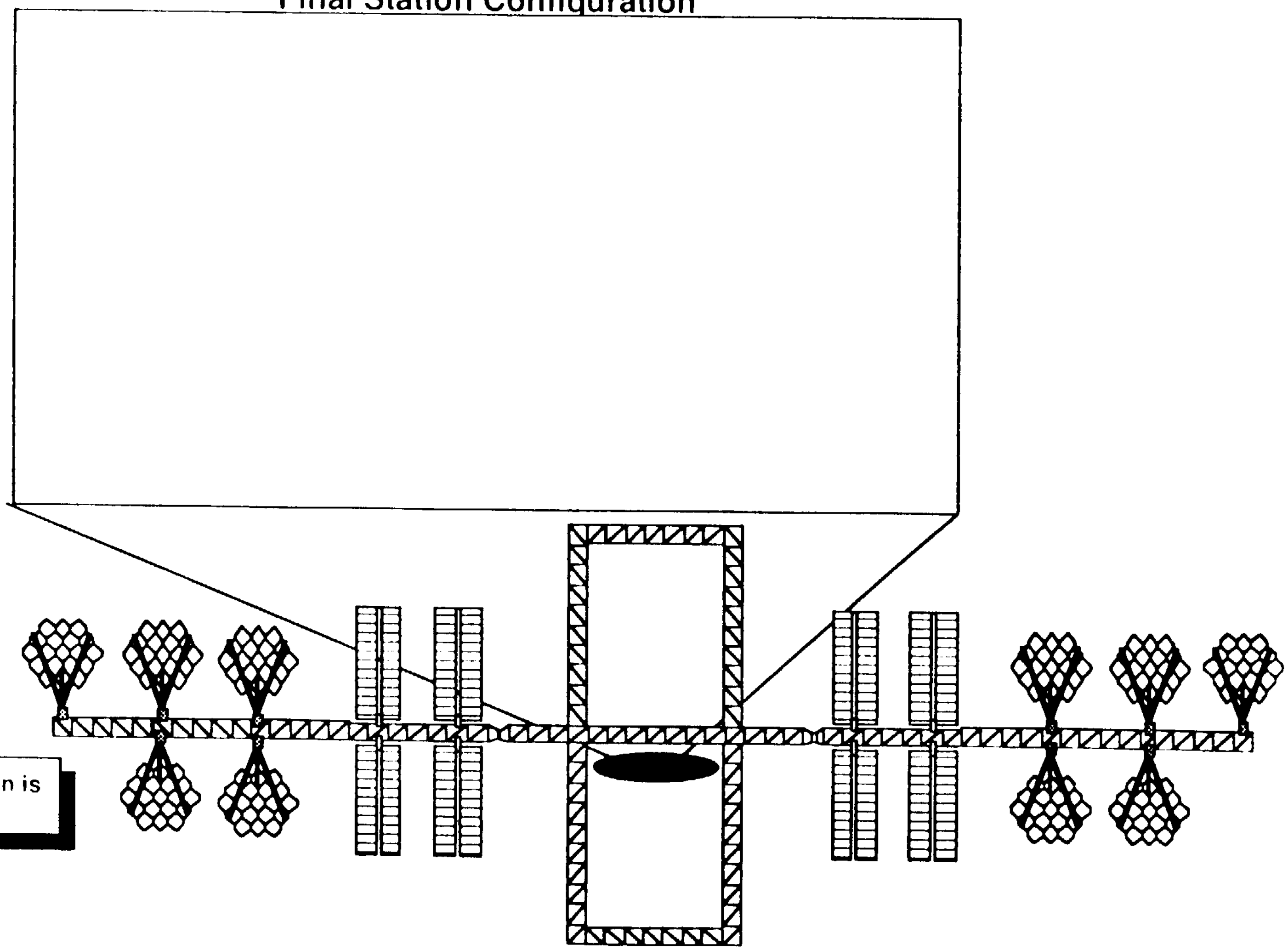
Component additions per year and resulting increases in station resources are given in the following table.

Microgravity Research & Materials Production Emphasis
Aggressive Transportation Model

Year	SD Arrays	Total Power	User Power	Total Crew	User Crew	Habs	Labs	Sm Pockets	Lg Pockets	Attach Pnts	Truss bays	OMV	OTV	Growth Mass
Phase 1	0	75	45.2	8	6	1	3	0	0	4	0	0	0	
1	1	125	75.2	16	12	2	4	0	0	4	17	0	0	75175 Kg
2	2	175	123.3	16	12	2	4	0	0	4	17	1	0	36501 Kg
3	3	225	159.4	22	16.5	3	4	0	1	4	27	1	0	57299 Kg
4	4	275	190.2	24	18	3	5	1	1	10	81	1	0	74032 Kg
5	4	275	190.2	24	18	3	5	1	1	10	81	1	0	Kg
6	5	325	236.8	24	18	3	5	1	1	10	91	1	0	14668 Kg
7	5	325	235.7	24	18	3	5	2	1	10	91	1	0	6500 Kg

GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED

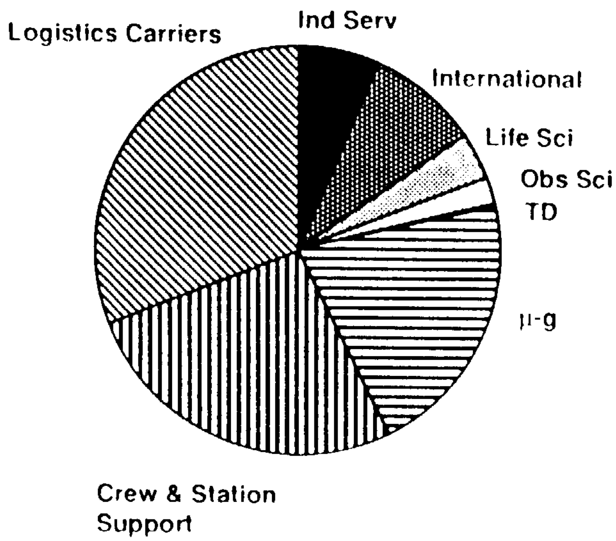
Final Station Configuration



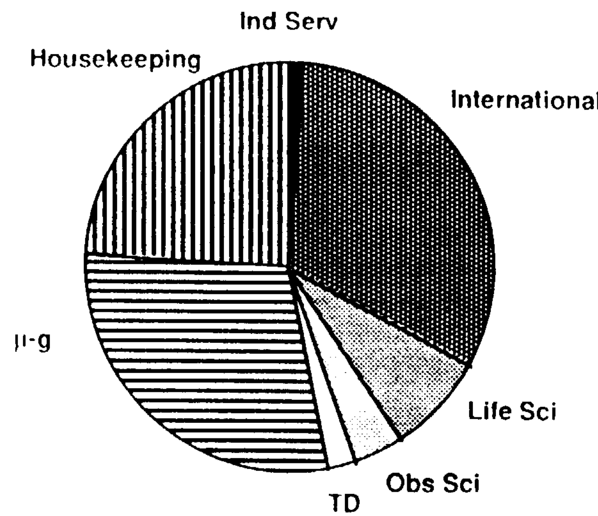
Note: Module pattern shown is representative only

GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED

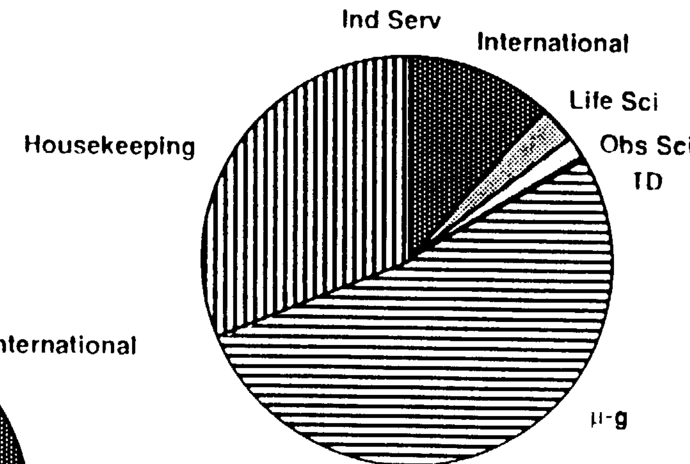
<u>Resource Allocation</u>



Lift



Crew



Power

GROWTH SCENARIO RESULTS - MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS AGGRESSIVE TRANSPORTATION SUPPORT CONTINUED

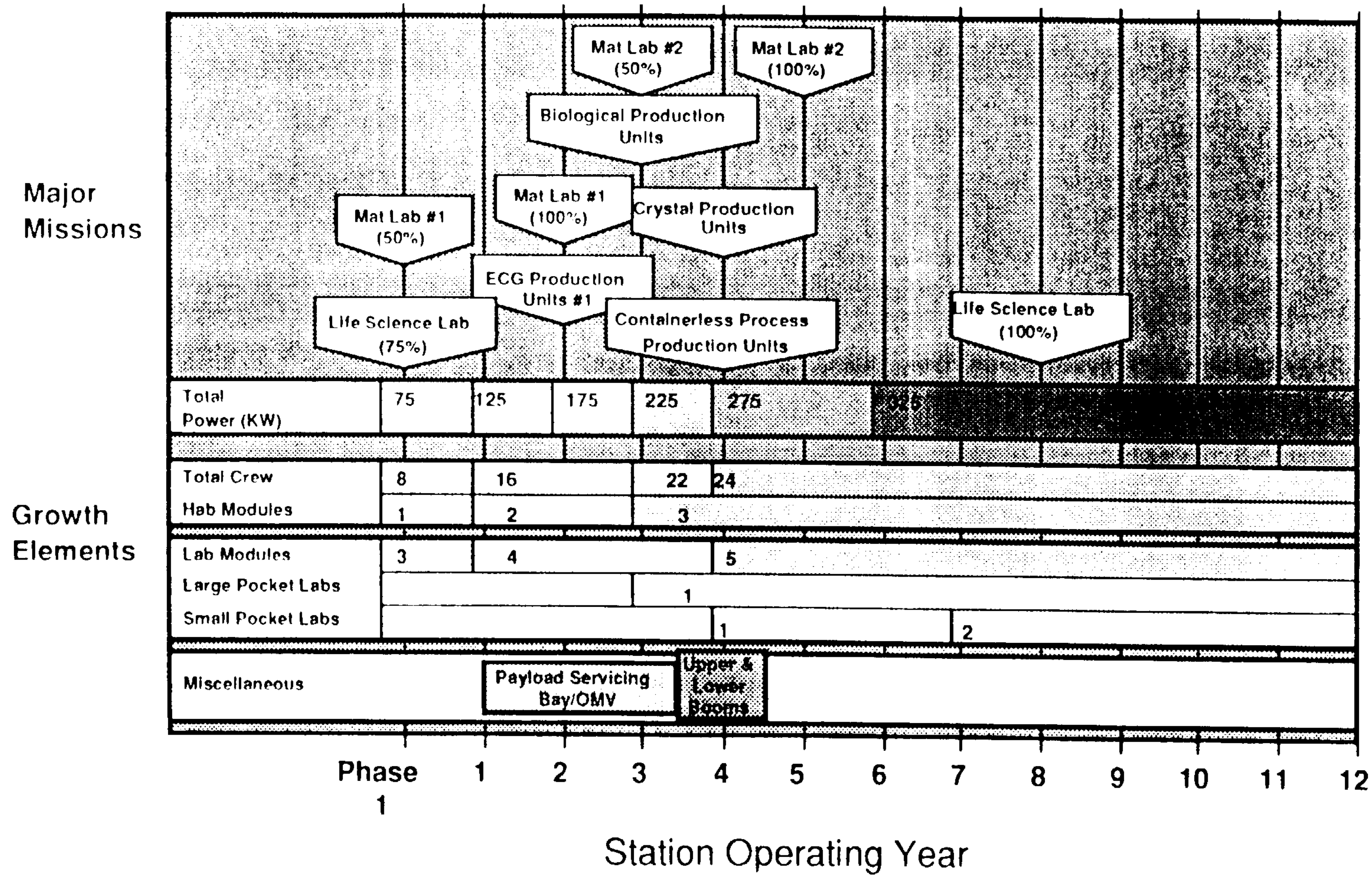
The timeline of major mission accommodation and growth element addition for the Microgravity Research & Materials Production emphasis, aggressive transportaton support scenario is given below. This timeline shows the correlation of resource growth (i.e., additions of power, crew, lab volume) with the accommodation of growth missions and the evolution of station facilities.

Facilities in support of the Microgravity Research & Materials Production emphasis include materials lab #1, materials lab #2, the ECG crystal production units #1 facility, the biological production units facility, the crystal production units facility, and the containerless process production units facility. Complete outfitting and utilization of materials lab #1 requires the addition of rack volume (i.e., the addition of lab module #4), crew (i.e., the addition of hab module #2), and power. Complete accommodation of materials lab #2 requires the addition of a dedicated lab module (lab module #5). The biological production units facility and the crystal production units facility require a large pocket lab and a small pocket lab for housing, respectively. The containerless process production units facility is an external, attached facility and the ECG production units #1 faciltiy is housed in materials lab #1. Accommodation of these research and production facilities and full accommodation of the life sciences lab create a total station power requirement of 325 kW.

Additional growth items in this scenario include a small pocket lab required to house the sample quarantine facility, the OMV and payload servicing facility accommodated in year 2 for servicing of automated materials production and Observational Science free flyers, and the dual keel and booms for support of Observational Science and Technology Development missions.

GROWTH SCENARIO RESULTS
MICROGRAVITY RESEARCH AND MATERIALS PRODUCTION EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED

Summary of Major Mission and Station Element Growth



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GROWTH SCENARIO RESULTS
LIFE SCIENCES EMPHASIS

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- Objective

  Accommodate life science laboratories devoted both to the understanding of the effects of microgravity on the human body in order to improve safety and productivity in space; experiments oriented toward preparation for further human exploration of the solar system such as the establishment of a lunar base, or a manned expedition to Mars.

- Emphasized Growth Missions

Life Sciences Lab (SAAX307 and 307A)	A subset of this lab is present at Phase 1; complete outfitting is a primary priority
Plant & Animal Vivarium and Lab (SAAX302)	Animal research performed in the life sciences lab will be expanded and extended to include plant research through the accommodation of this mission
Human Life Science Lab (SAAX303)	At the time the vivarium comes on line, the general life sciences lab will become dedicated to human life science
Closed Ecology Life Support Systems (SAAX304, 305, & 306)	CELSS research will initially share a module with other research disciplines, but will eventually evolve into a dedicated module and a pallet for algae and yeast growth
4 Meter Variable-G Centrifuge (SAAX311)	This centrifuge will enhance the capability of the 1.8M centrifuge in the general life sciences lab

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GROWTH SCENARIO RESULTS - LIFE SCIENCES EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT

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GROWTH SCENARIO RESULTS
LIFE SCIENCES EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT

Summary of Mission Accommodation

- General
  - Accommodation of growth missions in all mission categories was very poor due to the heavy lift requirements needed by the Phase 1 missions and crew & station logistics
  - Growth activities for the first 2 years were devoted to correcting resource deficiencies at Phase 1 and accommodating a large pocket lab to support the 4 meter centrifuge
  - Lift capability was insufficient to accommodate an additional lab module and associated logistics. This resulted in inadequate rack volume for complete accommodation of materials lab #1
  - The OMV remained NSTS based and the payload service facility was not accommodated in order to allocate maximum lift to life science mission support; free flyer servicing requirements are minimal for the life science emphasis

- Microgravity Research & Materials Production
  - Complete outfitting of materials lab #1 was not possible due to insufficient rack volume and inadequate lift for delivery and logistics support of an additional lab module
  - No growth missions in this category were accommodated

- Industrial Services
  - The missions in this category have significant lift requirements in general. For this reason none were accommodated in this scenario

- International
  - The only growth mission accommodated in this category was a radiation biology free flyer which was accommodated in year 14

GROWTH SCENARIO RESULTS - LIFE SCIENCES EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT
CONTINUED

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GROWTH SCENARIO RESULTS
LIFE SCIENCES EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT
CONTINUED

Summary of Mission Accommodation (cont)

- Life Sciences
  - The 4 meter centrifuge was accommodated in a large pocket lab in year 5
  - The sample quarantine mission was accommodated in year 7 for the on time accommodation of the sample return missions
  - Inadequate lift was available to allow the evolution of the life sciences facilities including the accommodation of the plant and animal lab & vivarium and the development of the CELSS facilities

- Observational Sciences
  - Hubble Space Telescope is serviced on time but without the availability of the payload servicing facility. Minimal lift did not allow evolution of a station based OMV and the payload servicing facility
  - Mission accommodation for this category was poor; only additional missions accommodated were growth components of the Solar Terrestrial Observatory accommodated in year 17

- Technology Development
  - Mission accommodation for this category was poor due to inadequate lift resources. Only growth mission accommodated was the antenna test range in year 17

GROWTH SCENARIO RESULTS - LIFE SCIENCES EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT
CONTINUED

The final station configuration including pocket lab, solar dynamic collector, and truss additions is shown for the Life Sciences emphasis, 5 NSTS flights per year transportation scenario. The locations of the pocket labs as shown is conceptual only and is meant to illustrate volumetric size of the station in terms of number of modules and pocket labs and their associated facilities. Configuration analysis to determine an optimal pocket lab arrangement would involve operational issues which were not addressed in this study.

The final configuration of this scenario shows growth in power and pocket lab volume. Phase 1 power was increased by 50 kW with the addition of 2 solar dynamic collectors to relieve the power deficit of the Phase 1 mission set. Two pocket labs were added which expand the Life Sciences research facilities by accommodating the quarantine facility and the 4 meter centrifuge. Additional growth to support evolution of the Life Sciences facilities was not possible due to inadequate lift of the 5 NSTS flights per year transportation model. In this scenario the payload servicing facility is not accommodated, the dual keel is not evolved, and the OMV remains NSTS -based.

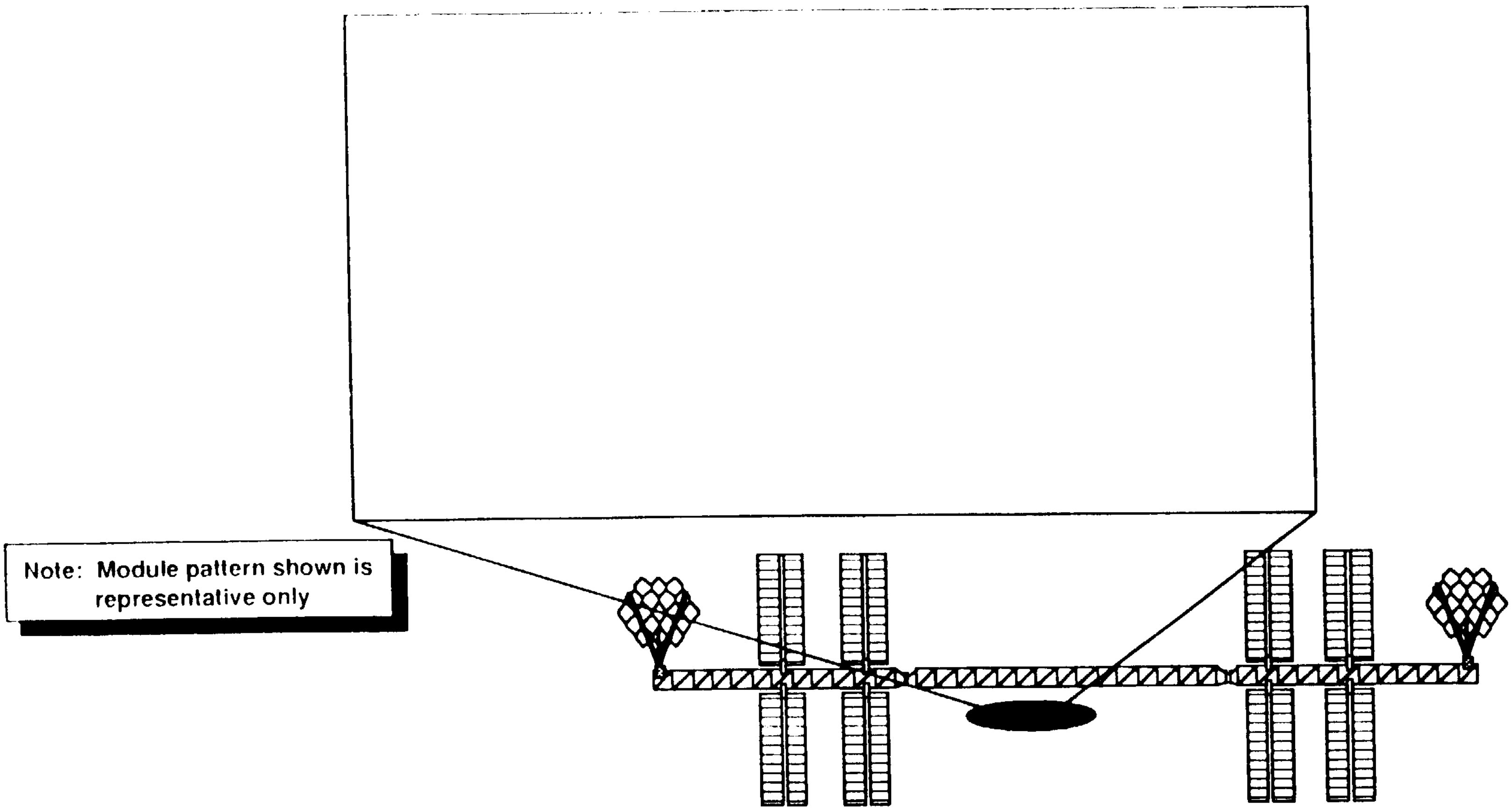
Component growth per year and resulting increases in station resources are shown in the following table.

Life Sciences Emphasis
5 NSTS/Year Transportation Model

Year	SD Arrays	Total Powe	User Power	Total Crew	User Crew	labs	Labs	Sm Pocket	Lg Pockets	Attach Pnt	Truss bays	OMV	OTV	Growth Mass
Phase 1	0	75	45 2	8	6	1	3	0	0	4	0	0	0	
1	0	75	40 4	8	6	1	3	0	1	4	17	0	0	18541 Kg
2	1	125	88 5	8	6	1	3	0	1	4	17	0	0	8948 Kg
3	1	125	88 5	8	6	1	3	0	1	4	17	0	0	Kg
4	1	125	88 5	8	6	1	3	0	1	4	17	0	0	Kg
5	1	125	88 5	8	6	1	3	0	1	4	17	0	0	Kg
6	1	125	88 5	8	6	1	3	0	1	4	17	0	0	Kg
7	1	125	87 4	8	6	1	3	1	1	4	17	0	0	6500 Kg

GROWTH SCENARIO RESULTS
LIFE SCIENCES EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT
CONTINUED

Final Station Configuration



GROWTH SCENARIO RESULTS - LIFE SCIENCE EMPHASIS
5 NSTS/YR TRANSPORTATION SUPPORT
CONTINUED

Allocation of lift, crew, and power is shown for station operations after completion of growth. The pie charts are representative of mature station operations for this scenario and are based on an average of annual requirements during this period.

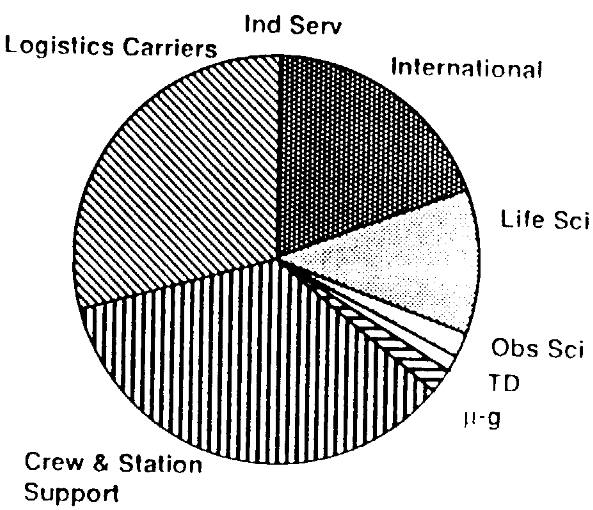
The lift allocation pie chart shows a majority of total lift is required for crew & station support logistics and logistics carriers. This distribution results from the minimal lift available with the 5 NSTS flights per year transportation model. The logistics carrier allocation reflects lift required for 5 pressurized log module, 4 unpressurized carrier, 2 fluids carrier, and 2 propellant carrier flights per year. The crew & station support logistics allocation represents lift to support 4 modules, 1 pocket lab, and 8 crew persons. Lift allocated in support of Life Sciences is required for 100% accommodation of the life sciences lab (SAAX307) and accommodation of the 4 meter variable-g centrifuge.

User crew requirements are highest for the International, Life Sciences, and Microgravity Research & Materials Production missions. The International missions include the International missions of the Phase 1 mission set and a European biological science co-orbiting platform. The total crew allocation for the International missions appears high relative to the lift and rack volume allocation. This is probably due to poor definition of actual crew requirements to support international facilities.

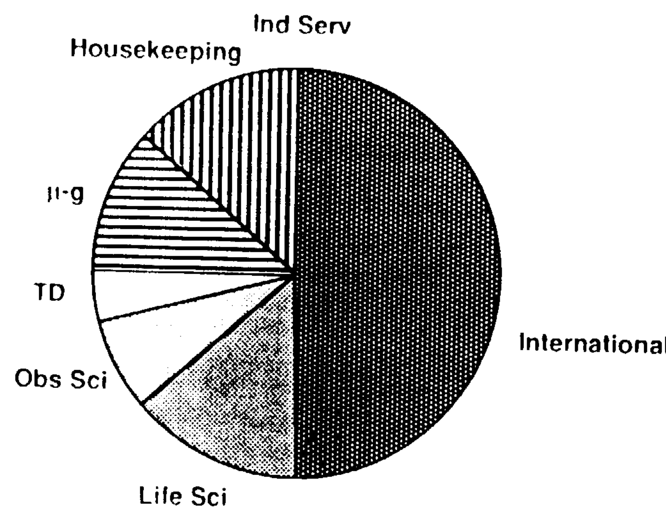
Primary power requirements are from station housekeeping, International missions, and Life Sciences missions. Station housekeeping power is approximately 38 kW in support of 1 hab module, 3 lab modules, and a small pocket lab. The International mission set includes several major power users including life sciences and materials research laboratories.

GROWTH SCENARIO RESULTS
LIFE SCIENCE EMPHASIS
5 NSTS/YR TRANSPORTATION SUPPORT
CONTINUED

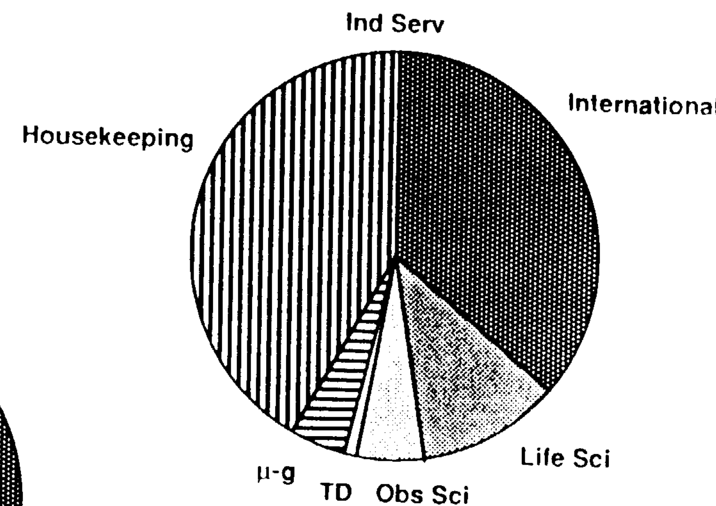
<u>Resource Allocation</u>



Lift



Crew



Power

GROWTH SCENARIO RESULTS - LIFE SCIENCES EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT
CONTINUED

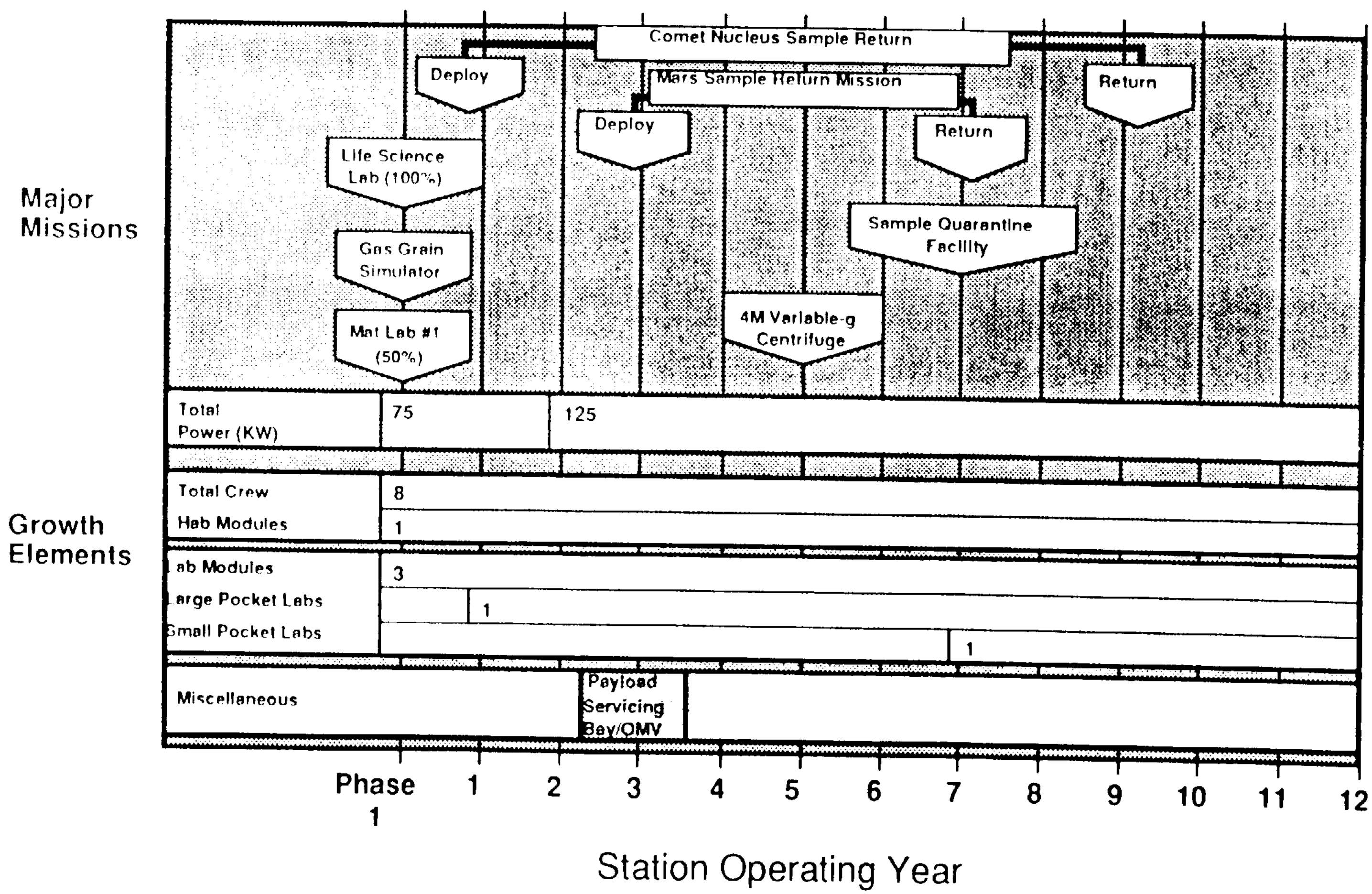
The timeline of major mission accommodation and growth element addition for the Life Sciences emphasis, 5 NSTS flights per year transportation support scenario is given below. This timeline shows the correlation of resource growth (i.e., additions of power, crew, lab volume) with the accommodation of growth missions and the evolution of station facilities.

Major facilities in support of the Life Sciences emphasis include the life science lab, gas grain simulator facility, 4 meter variable-g centrifuge, and the sample quarantine facility. The minimal transportation support in this scenario does not allow the evolution of the life sciences facilities into multiple lab modules. Growth of the Life Sciences facilities from the Phase 1 configuration includes the addition in station operating year 1 of a large pocket lab to house the 4 meter centrifuge. Outfitting of this facility is completed in year 5. A small pocket lab is added in year 7 to house the sample quarantine facility. This facility is required for support of the Mars sample return and comet nucleus sample return missions. These missions are assumed to be high priority and resources required for their support is budgeted from ongoing station activities since available lift and crew resources are minimal with this transportation scenario.

Power is added in station operating year 2 to relieve the power deficit of the Phase 1 mission set. User crew is also a deficit with the Phase 1 mission set but could not be relieved since an additional hab module and associated logistics can not be accommodated with the 5 NSTS flights per year transportation model. Although user crew is a deficit for the entire scenario, several growth missions were accommodated. These missions include the 4 meter variable-g centrifuge and the sample quarantine facility. The rationale for accommodating additional missions/facilities when the crew resource is a deficit is that these additions are considered enhancements to the life science lab and do not require continuous support from user crew to be useful. The life science lab is a better equipped laboratory with these additions which allow the available crew to perform a wider variety of experiments.

GROWTH SCENARIO RESULTS
LIFE SCIENCES EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT
CONTINUED

Summary of Major Mission and Station Element Growth



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GROWTH SCENARIO RESULTS
LIFE SCIENCES EMPHASIS
MODERATE TRANSPORTATION SUPPORT

Summary of Mission Accommodation

- General
  - Growth for the first 3 years was devoted to correct crew and power deficiencies at Phase 1
  - Lift for the first 3 years was insufficient to allow accommodation of any growth missions
  - The accommodation of several laboratory modules required by Life Sciences resulted in resource shortages and therefore poor accommodation of non-life science missions

- Life Sciences
  - All of the Life Sciences missions were accommodated, although allocation of lift to growth and the low ELV support level in the first few years resulted in slipping all of the growth missions
  - The average slip for beginning major Life Sciences missions was 2 years

- Industrial Services
  - The missions in this category have significant lift requirements in general. For this reason none were accommodated in this scenario

- International
  - Very few of the growth missions were accommodated
  - None of the International growth missions were accommodated on time; missions which were accommodated were primarily smaller Japanese technology development missions

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GROWTH SCENARIO RESULTS
LIFE SCIENCES EMPHASIS
MODERATE TRANSPORTATION SUPPORT

Summary of Mission Accommodation (cont)

- Microgravity Research & Materials Production Missions
  - The only growth mission accommodated in this category was the complete outfitting of the Microgravity and Materials Processing Facility #1. This was accomplished in station operating year 10

- Observational Sciences
  - Although none of the growth missions in this category were started on time, most were accommodated with an average delay of 5 years
  - Servicing of the Great Observatories (Space Telescope and AXAF) was not possible prior to Station Operating year 5
  - Neither the tethered satellite portion of the Solar Terrestrial Observatory nor the servicing of the Explorer spacecraft were accommodated

- Technology Development
  - Very few of the Technology Development missions were accommodated. None of the growth missions were accommodated on time, and those which were accommodated late were in general very short duration, low resource using experiments

GROWTH SCENARIO RESULTS - LIFE SCIENCES EMPHASIS
MODERATE TRANSPORTATION SUPPORT
CONTINUED

The final station configuration including module, pocket lab, solar dynamic collector, and truss additions is shown for the Life Sciences emphasis, moderate transportation support scenario. The module pattern given is conceptual only and is meant to illustrate volumetric size of the station in terms of number of modules and pocket labs and their associated facilities. Configuration analysis to determine an optimal module pattern would involve numerous operational issues which were not addressed in this study.

Major growth items added to the Phase 1 configuration include 2 hab modules, 4 lab modules, 2 pocket labs, 3 pairs of solar dynamic collectors, and truss additions for the dual keel and transverse boom. Three lab modules and 2 pocket labs are dedicated Life Sciences facilities. Not shown but also included are the payload servicing facility and the OMV.

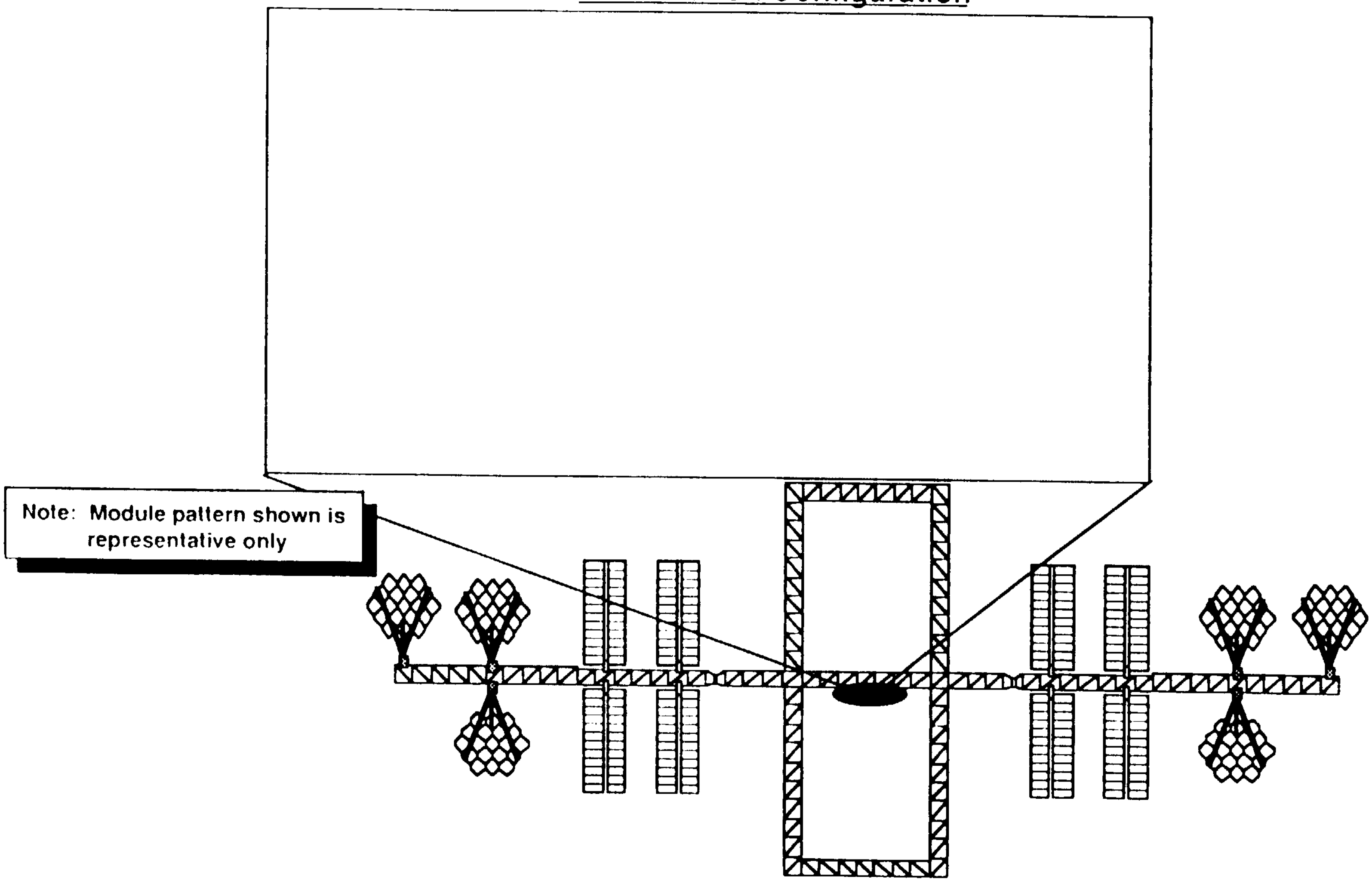
Growth items added per year and the resulting increases in station resources are given in the following table.

Life Sciences Emphasis
Moderate Transportation Model

Year	SD Arrays	Total Power	User Power	Total Crew	User Crew	Habs	Labs	Sm Pockets	Lg Pockets	Attach Pnts	Truss bays	OMV	OTV	Growth Mass
Phase 1	0	75	45 2	8	6	1	3	0	0	4	0	0	0	
1	0	75	44 6	8	6	1	3	0	0	4	0	0	0	4811 Kg
2	0	75	37 0	10	7 5	2	3	0	0	4	0	0	0	25320 Kg
3	1	125	81 9	16	12	2	3	0	0	4	17	1	0	41258 Kg
4	1	125	64 0	20	15	3	4	0	1	4	17	1	0	70520 Kg
5	2	175	104 8	21	15 75	3	5	0	1	4	17	1	0	36837 Kg
6	2	175	104 8	21	15 75	3	5	0	1	4	17	1	0	Kg
7	2	175	94 8	21	15 75	3	5	1	1	9	71	1	0	34274 Kg
8	2	175	88 1	21	15 75	3	6	1	1	9	71	1	0	23078 Kg
9	3	225	134 7	21	15 75	3	6	1	1	9	81	1	0	12501 Kg
10	3	225	134 7	22	16 5	3	6	1	1	9	81	1	0	Kg

GROWTH SCENARIO RESULTS
LIFE SCIENCES EMPHASIS
MODERATE TRANSPORTATION SUPPORT
CONTINUED

<u>Final Station Configuration</u>



GROWTH SCENARIO RESULTS - LIFE SCIENCES EMPHASIS
MODERATE TRANSPORTATION SUPPORT
CONTINUED

Allocation of lift, crew, and power is shown for station operations after completion of growth. The pie charts are representative of mature station operations for this scenario and are based on an average of annual requirements during this period.

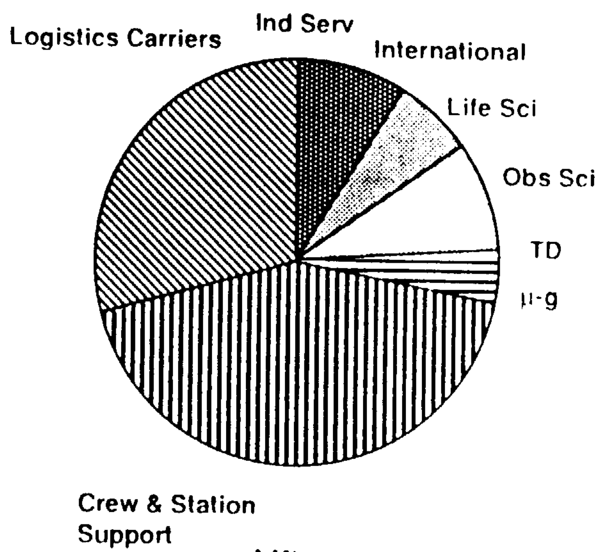
The lift allocation pie shows a large percent of total lift required for crew & station support logistics and logistics carriers. Lift represented under crew & station support is required for support of 9 modules, 2 pocket labs, and 22 crew persons. Logistics carrier lift reflects 9 pressurized module, 9 unpressurized carrier, 3 fluids carrier, and 5 propellant carrier flights per year. Life Sciences lift allocation represents requirements for 100% accommodation of the life science facilities. These facilities include the human life science lab, plant and animal vivarium & lab, 4 meter variable-g centrifuge, dedicated CELSS module, gas grain simulator facility, and sample quarantine facility. A major portion of user lift is allocated to Observational Science missions. Missions in this category include servicing of the Great Observatories (Hubble Space Telescope, SIRTF, and AXAF), Space Station Spartan, Hitchhiker 1, Hitchhiker 4 - Earth Radiation, growth components of the Solar Terrestrial Observatory, and the Tropical Rainfall Mapping Mission.

User crew requirements are highest for International, Microgravity Research & Material Production, and Life Sciences missions. Crew level for life sciences represents 100% desired crew support for these facilities. Crew represented under Microgravity Research & Materials Production is for full accommodation of materials lab #1 (COMM1201). Housekeeping crew requirements are assumed to be 25% of the total station crew.

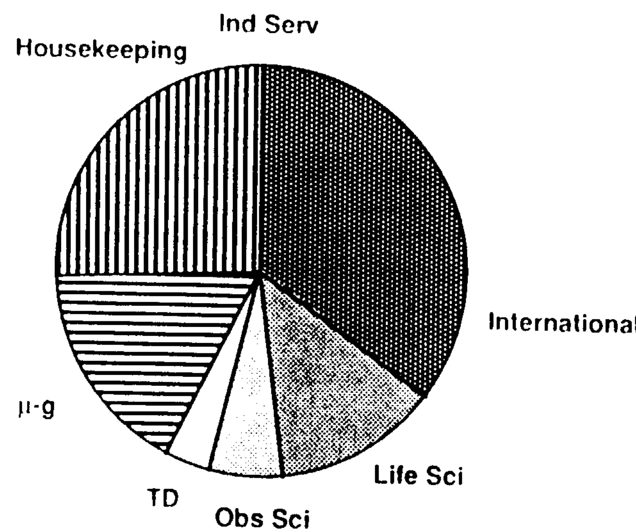
Power requirements among users are greatest for the Life Sciences and International missions. International missions which have the highest power requirements are the European and Japanese materials research labs (MAT110 and M-001, M-002).

GROWTH SCENARIO RESULTS
LIFE SCIENCES EMPHASIS
MODERATE TRANSPORTATION SUPPORT
CONTINUED

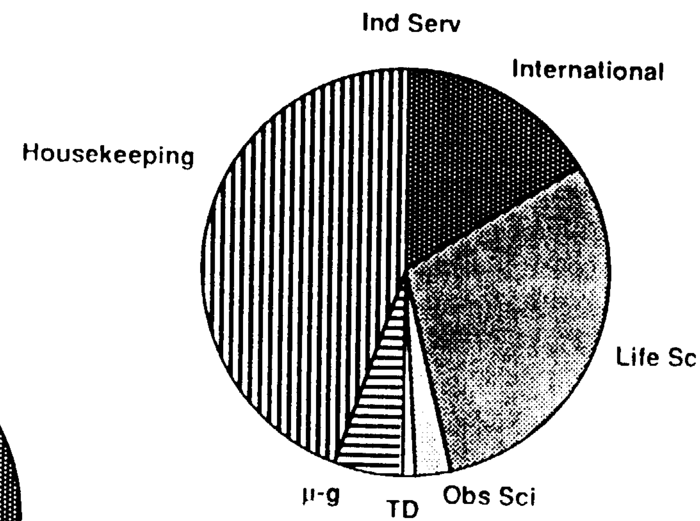
<u>Resource Allocation</u>



Lift



Crew



Power

GROWTH SCENARIO RESULTS - LIFE SCIENCES EMPHASIS MODERATE TRANSPORTATION SUPPORT CONTINUED

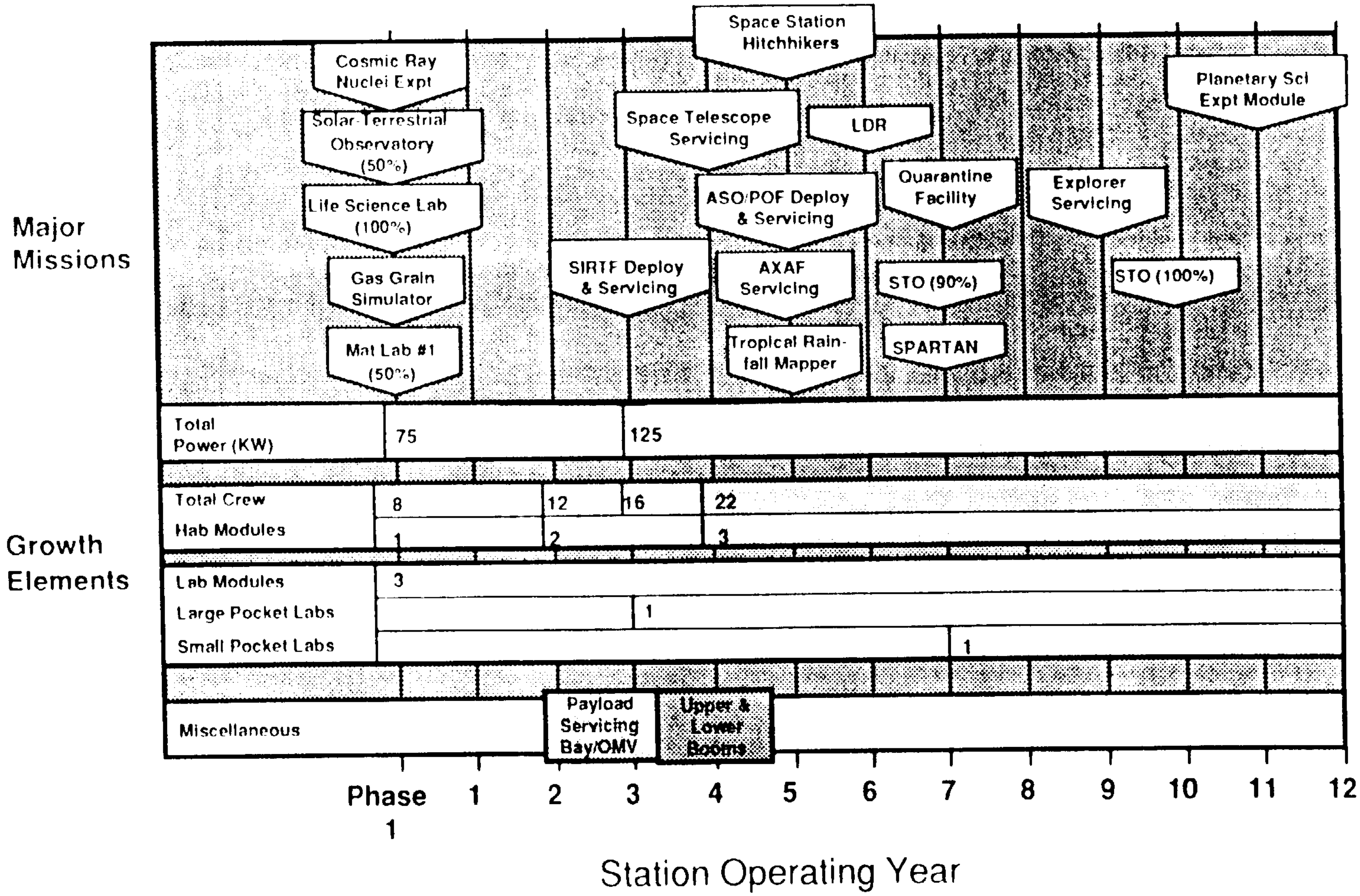
The timeline of major mission accommodation and growth element addition for the Life Sciences emphasis, moderate transportation support scenario is given below. This timeline shows the correlation of resource growth (i.e., additions of power, crew, lab volume) with the accommodation of growth missions and the evolution of station facilities.

Facilities in support of the Life Science emphasis include the lab science laboratory, gas grain simulator facility, 4 meter variable-g centrifuge, plant and animal vivarium & lab, human life science lab, CELSS (Closed Ecology Life Support Subsystem) system lab, CELSS pallet system, dedicated CELSS module, and the sample quarantine facility. The early increments in power and crew are required to relieve resource deficits of the Phase 1 mission set. A large pocket lab is added in year 4 to house the 4 meter centrifuge. Lab modules 4 and 5 are dedicated Life Sciences facilities which house the plant and animal vivarium & lab and the CELSS system lab. The life science lab is reconfigured as the human life science lab with the accommodation of the vivarium and does not require an additional lab module. The sample quarantine facility is housed in a small pocket lab and the CELSS pallet system is an external, attached payload. Full accommodation of materials lab #1 requires the additional rack volume of lab module #6. The dedicated CELSS module shown in station operating year 11 is an evolution of the CELSS system lab and does not represent accommodation of an additional lab module.

Additional growth items in this scenario include the OMV and payload servicing facility added in year 3 and the dual keel and booms added in year 7. The OMV is required for servicing of a variety of free flyers including Japanese biological free flyers and the Great Observatories. The upper and lower booms provide additional attach points for Observational Science and Technology Development payloads. Requirements of the Life Sciences facilities and other accommodated missions result in station growth to 225 kW and 22 total crew.

GROWTH SCENARIO RESULTS
LIFE SCIENCES EMPHASIS
MODERATE TRANSPORTATION SUPPORT
CONTINUED

Summary of Major Mission and Station Element Growth



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GROWTH SCENARIO RESULTS
LIFE SCIENCES EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT

Summary of Mission Accommodation

- General
  - Accommodation of growth missions included major missions in all categories; evolution of the Life Sciences facilities was completed by year 8
  - Growth through year 2 is devoted to correcting crew and power deficiencies of the Phase 1 missions and evolving the dual keel configuration including additional attach points
  - Later growth included the accommodation of the OMV, payload servicing facility, OTV, and OTV hangar. This allowed the deployment and servicing of a variety of free flyers and co-orbiting platforms

- Microgravity Research & Materials Production
  - Outfitting of materials lab #1 was completed in year 6. This provided full accommodation of the Microgravity Research and Materials Production missions in this scenario

- Industrial Services
  - Primary missions accommodated include the Spacehab module in year 8 and several classes of communications satellite deploy and servicing missions. Spacehab was accommodated 5 years later than desired; the communications satellite deploy missions were accommodated a minimum of three years later than desired

- International
  - Numerous missions within this category are accommodated within first 10 years of station operation. Primary missions include a European life science co-orbiting platform, Japanese and European materials processing missions (internal and free flying), and the Japanese astrophysics platform

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GROWTH SCENARIO RESULTS
LIFE SCIENCES EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED

Summary of Mission Accommodation (cont)

- Life Sciences
  - Evolution of the life science facilities was completed in year 8; major facilities include the Plant and Animal Vivarium & Lab accommodated on time in year 3, CELSS Experimental Systems accommodated 1 year late in year 4, dedicated CELSS module accommodated on time in year 8, and the 4 meter centrifuge accommodated on time in year 3
  - The sample return missions and the sample quarantine mission were also accommodated on time

- Observational Sciences
  - Full accommodation of growth missions in this category was completed in year 7; included are the SIRTF and AXAF co-orbiting platforms, Hubble Space Telescope servicing, Solar Terrestrial Observatory growth components, and several smaller attached missions

- Technology Development
  - Full accommodation of growth missions in this category was completed in year 7; major missions include OTV technology demonstration missions, tether technology missions, and a variety of communications, power, and structures technology missions

GROWTH SCENARIO RESULTS - LIFE SCIENCES EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED

The final station configuration including module, pocket lab, solar dynamic collector, and truss additions is shown for the Life Sciences emphasis, aggressive transportation support scenario. The module pattern given is conceptual only and is meant to illustrate volumetric size of the station in terms of number of modules and pocket labs and their associated facilities. Configuration analysis to determine an optimal module pattern would involve numerous operational issues which were not addressed in this study.

Growth component additions to the Phase 1 station include 2 hab modules, 4 lab modules, 2 pocket labs, 4 pairs of solar dynamic collectors, and truss additions for the dual keel and transverse boom. Also added but not shown are the payload servicing facility and the OMV. The final configuration has 3 lab modules and 2 pocket labs which are dedicated Life Sciences facilities.

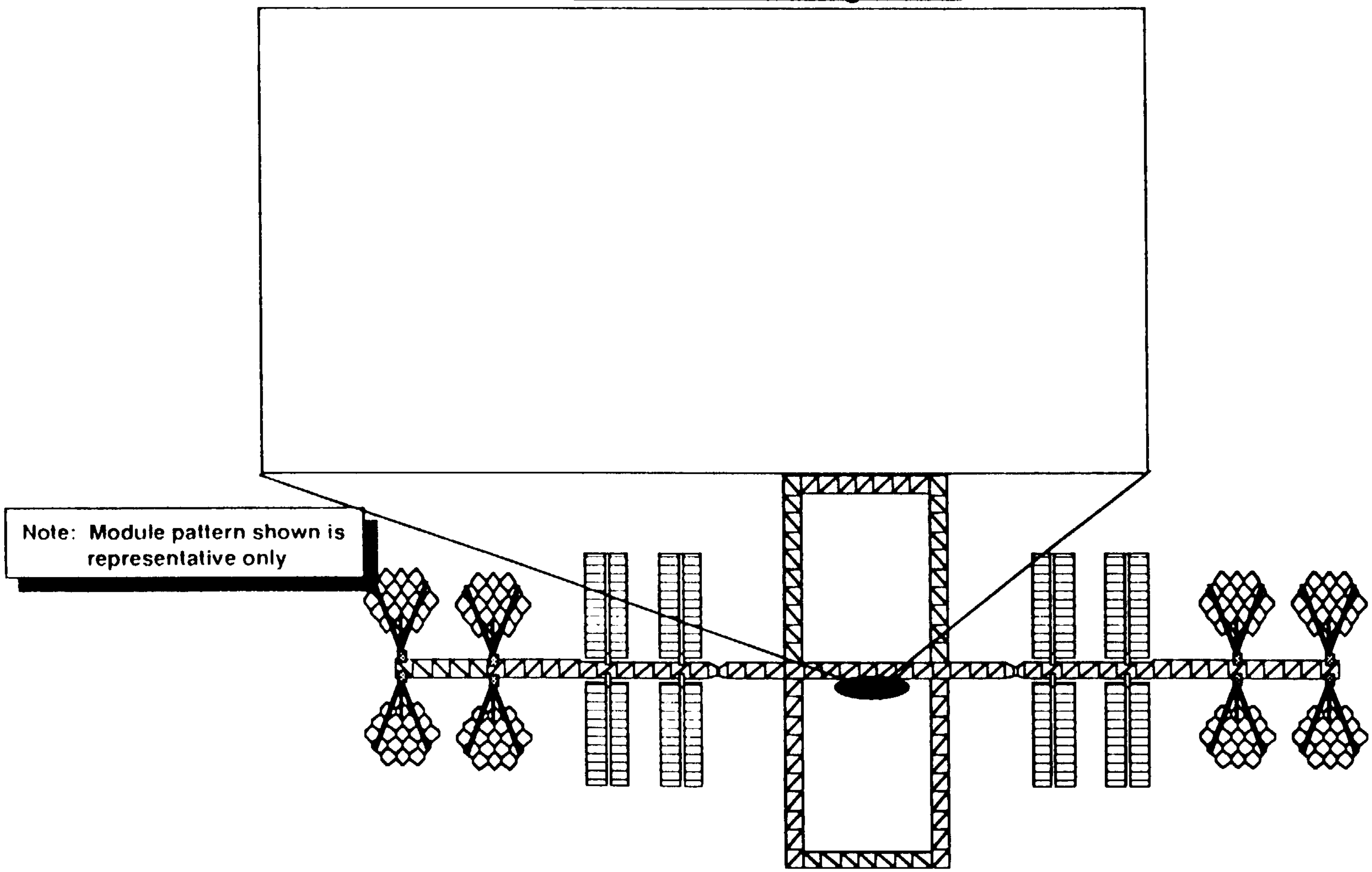
Growth increments per year and increases in station resources are given in the following table.

Life Sciences Emphasis
Aggressive Transportation Model

Year	SD Arrays	Total Power	User Power	Total Crew	User Crew	Habs	Labs	Sm Pocket	Lg Pockets	Attach Pnls	Truss bays	OMV	OTV	Growth Mass
Phase I	0	75	45.2	8	6	1	3	0	0	4	0	0	0	
1	1	125	82.5	16	12	2	3	0	0	4	17	0	0	45120 Kg
2	1	125	74.2	16	12	2	3	0	0	14	71	0	0	26738 Kg
3	2	175	112.8	16	12	2	4	0	1	14	71	1	0	70795 Kg
4	2	175	96.6	20	15	3	5	0	1	14	71	1	0	62831 Kg
5	2	175	89.2	24	18	3	6	0	1	14	71	1	0	66148 Kg
6	3	225	137.4	24	18	3	6	0	1	14	71	1	1	52573 Kg
7	4	275	182.9	24	18	3	6	1	1	14	81	1	1	19001 Kg

GROWTH SCENARIO RESULTS
LIFE SCIENCES EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED

<u>Final Station Configuration</u>



GROWTH SCENARIO RESULTS - LIFE SCIENCE EMPHASIS AGGRESSIVE TRANSPORTATION SUPPORT CONTINUED

Allocation of lift, crew, and power is shown for station operations after completion of growth. The pie charts are representative of mature station operations for this scenario and are based on an average of annual requirements during this period.

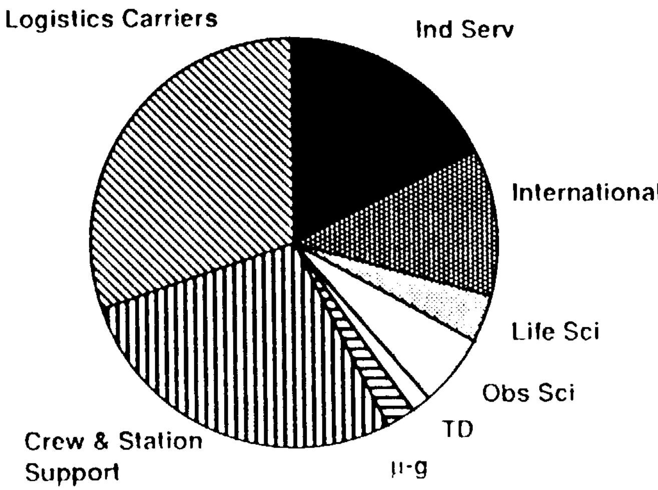
The lift allocation pie shows the majority of lift is required for crew & station support logistics and logistics carriers. Crew & station support logistics is in support of 9 modules, 2 pocket labs, and 24 crew persons. Logistics carrier allocation represents 11 pressurized log module, 18 unpressurized carrier, 3 fluids carrier, and 21 propellant carrier flights per year. User lift is allocated primarily to Industrial Services, International, and Observational Science missions. Although Life Sciences lift is fourth greatest among users, this represents full allocation of desired lift for the Life Sciences facilities. Industrial Services lift is in support of the attached Spacehab module and several classes of communications satellite deploy missions. Observational Sciences missions represented include servicing of the Great Observatories (Hubble Space Telescope, SIRTF, and AXAF), Space Station Spartan, Explorer 1 servicing, growth components of the Solar Terrestrial Observatory, Hitchhiker 1, Hitchhiker 4 - Earth Radiation, and the Tropical Rainfall Mapping Mission.

User crew requirements are highest for International and Microgravity Research & Materials Production missions. International crew requirements are primarily in support of microgravity research and life science research facilities. Crew shown under Microgravity Research & Materials Production are in support of full accommodation of materials lab #1 (COMM1201). Housekeeping crew requirements are assumed to be 25% of the total station crew.

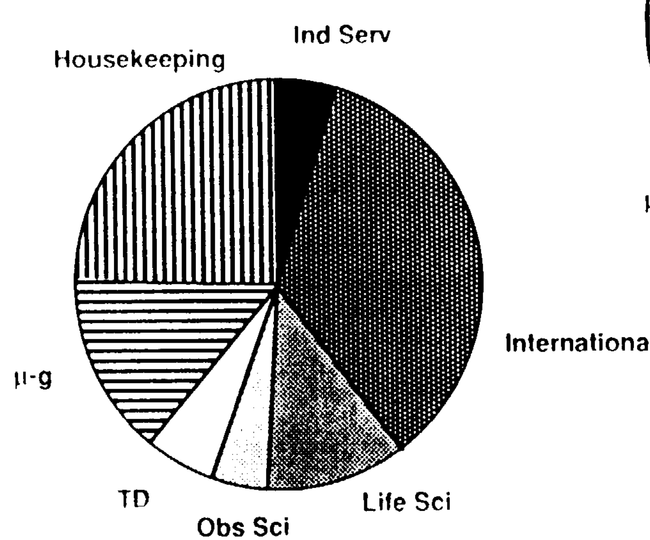
Power requirements among users are greatest for the Life Sciences and International missions. International missions which have the highest power requirements are the European and Japanese materials research labs (MAT110, MAT120, M-001, M-002, and M-003).

GROWTH SCENARIO RESULTS
LIFE SCIENCE EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED

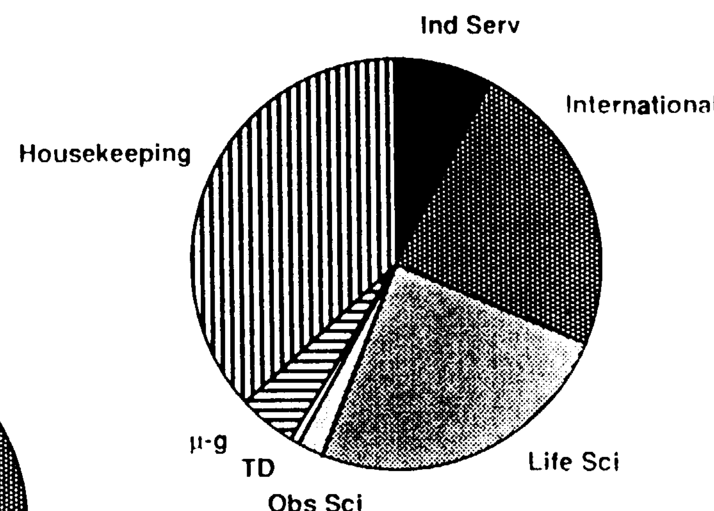
Resource Allocation



Lift



Crew



Power

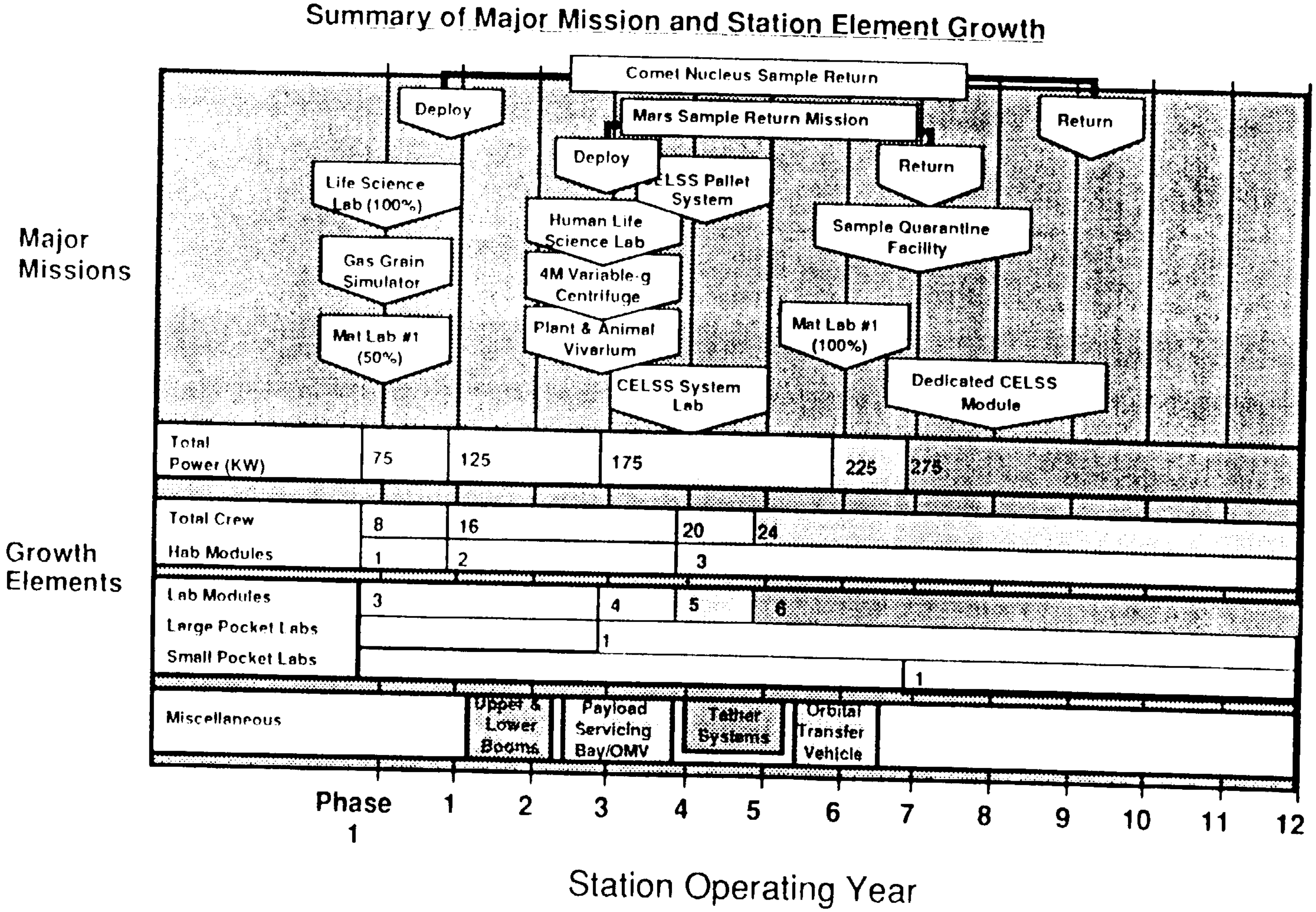
GROWTH SCENARIO RESULTS - LIFE SCIENCES EMPHASIS AGGRESSIVE TRANSPORTATION SUPPORT CONTINUED

The timeline of major mission accommodation and growth element addition for the Life Sciences emphasis, aggressive transportation support scenario is given below. This timeline shows the correlation of resource growth (i.e., additions of power, crew, lab volume) with the accommodation of growth missions and the evolution of station facilities.

Facilities in support of the Life Sciences emphasis include the life science lab, gas grain simulator facility, human life sciences lab, 4 meter variable-g centrifuge, plant and animal vivarium & lab, CELSS (Closed Ecology Life Support Subsystem) system lab, CELSS pallet system, sample quarantine facility, and the dedicated CELSS module. Early additions of crew and power are required to fully accommodate the Phase 1 mission set. A large pocket lab is added in station operating year 3 to house the 4 meter centrifuge. Dedicated lab modules are required for the accommodation of the plant and animal vivarium & lab and the CELSS system lab. The CELSS pallet system is an external, attached payload. The sample quarantine facility accommodated in year 7 is housed in a small pocket lab. Full accommodation of materials lab #1 requires the additional rack volume of lab module #6. The dedicated CELSS module shown in station operating year 8 is an evolution of the CELSS system lab and does not require the addition of a new lab module.

Additional growth items added in this scenario include the dual keel and booms in station operation year 2, OMV and payload servicing facility in year 3, and the OTV and OTV hangar in year 6. The upper and lower booms provide additional attach points required by the Observational Science and Technology Development missions. The OMV is required for servicing of a variety of free flyers including European and Japanese biological free flyers and the Great Observatories. The OTV is used for deployment and servicing of several classes of communications satellites. Requirements of the Life Sciences facilities and other accommodated missions result in station growth to 275 kW total power and 24 total crew.

GROWTH SCENARIO RESULTS
LIFE SCIENCES EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED



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GROWTH SCENARIO RESULTS
OBSERVATIONAL SCIENCE EMPHASIS

- Objective

Accommodate missions devoted to observational sciences such as astrophysics, solar-terrestrial processes, plasma physics, and earth observation. Accommodation of these missions stresses the operation of external attached payloads, servicing of co-orbiting free-flyers, and the construction and deploy of geostationary platforms

- Emphasized Growth Missions

Hubble Space Telescope & Advanced X-Ray Astronomy Facility Servicing	Retrieval and return to the Space Station by the OMV for servicing of these large space based observatories
Plasma Interactions Experiments (part of the Solar-Terrestrial Observatory)	This portion of the STO will enable active perturbation of the environment in order to study cause-and-effect mechanisms in space plasmas
Geostationary Observational Platform Assembly & Servicing	Assembly & OTV deploy of a large geostationary platform which will serve as a base for Earth observing and other astrophysics experiments. Regular servicing and equipment changeout will be performed insitu with the OTV
Space Station Spartan	The Spartan concept will be extended to the Space Station allowing quick and inexpensive spacecraft to perform a variety of astronomy & astrophysics experiments

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GROWTH SCENARIO RESULTS
OBSERVATIONAL SCIENCE EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT

<u>Summary of Mission Accommodation</u>

- General
  - Accommodation of growth missions in all mission categories was very poor due to the heavy lift requirements needed by the Phase 1 missions and crew & station logistics
  - Evolution of the free flyer support facilities including the station based OMV and payload servicing facility was accomplished at the expense of not evolving to a dual keel configuration (including additional attach points). This was done to provide full support facilities for the major observatories including the SIRTF co-orbiting platform and Hubble Space Telescope. The minimal number of attach points available with the Phase 1 configuration (four) are used to support primary attached payloads of this emphasis such as the Solar Terrestrial Observatory
  - Growth activities for the first 3 years were devoted to correcting resource deficiencies at Phase 1 and accommodating the OMV and payload servicing facility
  - Lift capability was insufficient to accommodate an additional lab module and associated logistics. This resulted in inadequate rack volume for complete accommodation of materials lab #1

- Microgravity Research & Materials Production
  - Complete outfitting of materials lab #1 was not possible due to insufficient rack volume and inadequate lift for delivery and logistics support of an additional lab module
  - No growth missions in this category were accommodated

- Industrial Services
  - The missions in this category have significant lift requirements in general. For this reason none were accommodated in this scenario

GROWTH SCENARIO RESULTS - OBSERVATIONAL SCIENCE EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT
CONTINUED

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GROWTH SCENARIO RESULTS
OBSERVATIONAL SCIENCE EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT
CONTINUED

<u>Summary of Mission Accommodation (cont)</u>

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- Life Sciences
  - The sample return missions were accommodated on time because these missions were given high priority
  - The only additional mission in this category which was accommodated was the sample quarantine mission. This is required for support of the two sample return missions
- Observational Science
  - The co-orbiting astrophysics platform, SIRTF, was accommodated in year 6
  - Hubble Space Telescope servicing is performed on time with full availability of the payload servicing facility
  - Solar Terrestrial Observatory growth components were accommodated in year 10
  - Several other smaller observational science missions were accommodated late including the station hitchhikers 1, 2, and 3 in year 11 and Explorer 1, 2, and 3 satellite servicing missions in years 12, 13, and 14
- Technology Development
  - No growth missions in this category were accommodated due to lack of available attach points and minimal lift support of this scenario

GROWTH SCENARIO RESULTS - OBSERVATIONAL SCIENCE EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT
CONTINUED

The final station configuration including pocket lab, solar dynamic collector, and truss additions is shown for the Observational Science emphasis, 5 NSTS flights per year transportation support scenario. Growth beyond the Phase 1 configuration includes the addition of a single pocket lab and a pair of solar dynamic collectors. Also accommodated but not shown is the payload servicing facility and the OMV.

Lift available with the 5 NSTS flights per year transportation model was inadequate for the accommodation of additional hab or lab modules or the evolution of the dual keel. Due to the limited number of available attach points in this configuration, the primary facilities for support of the Observational Science emphasis are the payload servicing facility and OMV.

Growth components added per year and the resulting changes in station resources are shown in the table below.

Observational Science Emphasis
5 NSTS/Year Transportation Model

Year	SD Arrays	Total Power	User Power	Total Crew	User Crew	Habs	Labs	Sm Pocket	Lg Pockets	Attach Pnts	Truss bays	OMV	OTV	Growth Mass
Phase 1	0	75	45 2	8	6	1	3	0	0	4	0	0	0	
1	0	75	42 6	8	6	1	3	0	0	4	17	0	0	6041 Kg
2	1	125	90 7	8	6	1	3	0	0	4	17	0	0	8948 Kg
3	1	125	90 7	8	6	1	3	0	0	4	17	1	0	21458 Kg
4	1	125	90 7	8	6	1	3	0	0	4	17	1	0	Kg
5	1	125	90 7	8	6	1	3	0	0	4	17	1	0	Kg
6	1	125	90 7	8	6	1	3	0	0	4	17	1	0	Kg
7	1	125	89 6	8	6	1	3	1	0	4	17	1	0	6500 Kg

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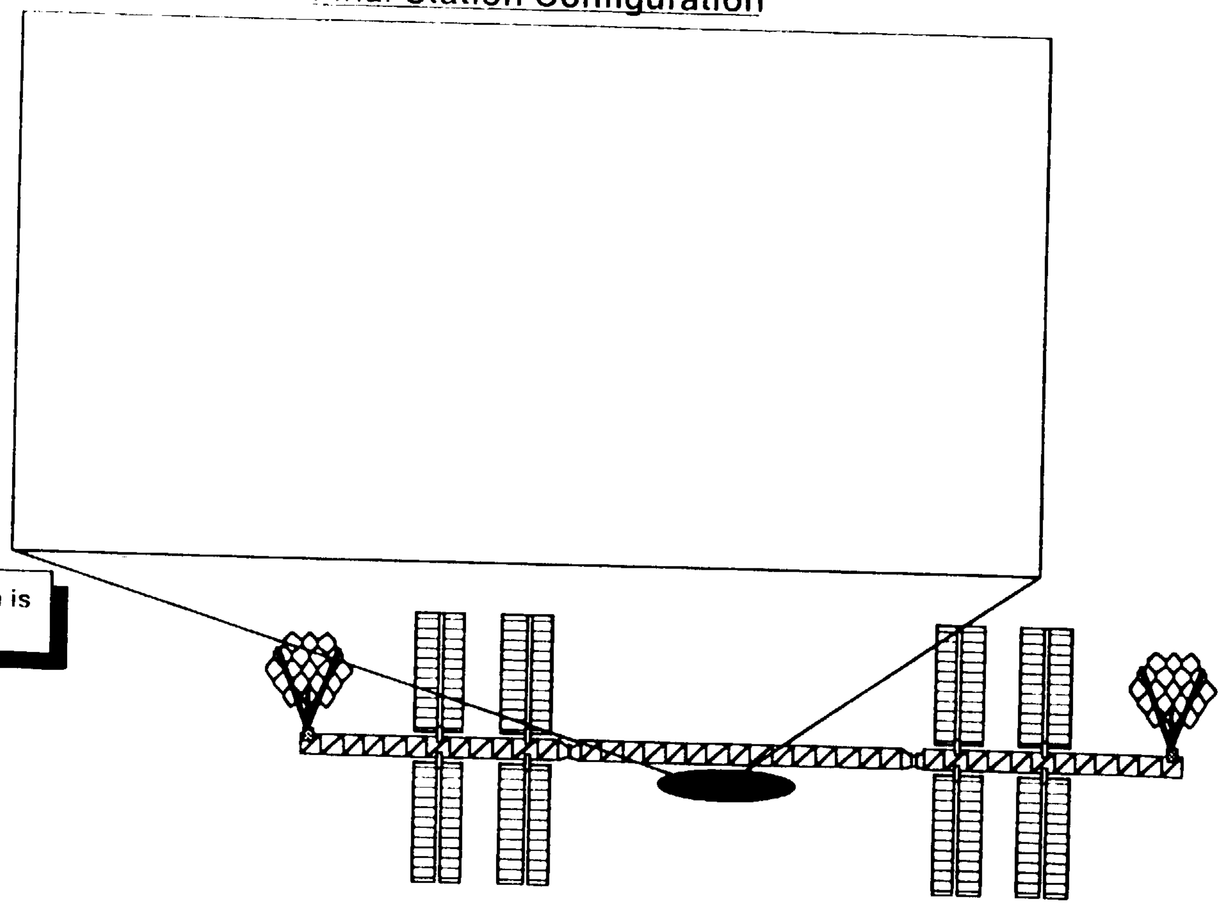
GROWTH SCENARIO RESULTS
OBSERVATIONAL SCIENCE EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT
CONTINUED

Final Station Configuration



Note: Module pattern shown is representative only

GROWTH SCENARIO RESULTS - OBSERVATIONAL SCIENCES EMPHASIS
5 NSTS/YR TRANSPORTATION SUPPORT
CONTINUED

Allocation of lift, crew, and power is shown for station operations after completion of growth. The pie charts are representative of mature station operations for this scenario and are based on an average of annual requirements during this period.

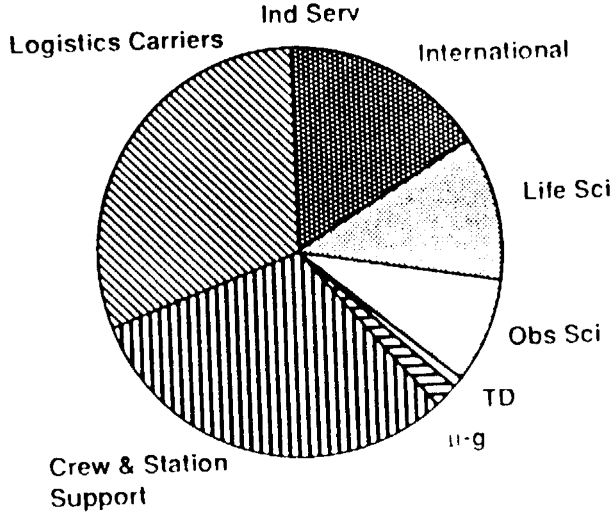
The lift allocation pie chart shows a majority of total lift is required for crew & station support logistics and logistics carriers. The logistics carrier allocation reflects lift required for 5 pressurized log module, 5 unpressurized carrier, 1 fluids carrier, and 3 propellant carrier flights per year. The crew & station support logistics allocation represents lift to support 4 modules, 1 pocket lab, and 8 crew persons. Lift allocated to Observational Science is in support of Hubble Space Telescope servicing, SIRTF servicing, Explorer 1, 2, and 3 servicing, and growth components of the Solar Terrestrial Observatory.

User crew requirements are highest for the International, Life Sciences, and Microgravity Research & Materials Production missions. The International missions include only the International missions of the Phase 1 mission set. The total crew allocation for the International missions appears high relative to the lift and rack volume allocation. This is probably due to poor definition of actual crew requirements to support International facilities.

Primary power requirements are from station housekeeping, International missions, and Life Sciences missions. Station housekeeping power is approximately 35 kW in support of 1 hab modules, 3 lab modules, and a small pocket lab. The International mission set includes several major power users including life sciences and materials research laboratories.

GROWTH SCENARIO RESULTS
OBSERVATIONAL SCIENCES EMPHASIS
5 NSTS/YR TRANSPORTATION SUPPORT
CONTINUED

<u>Resource Allocation</u>



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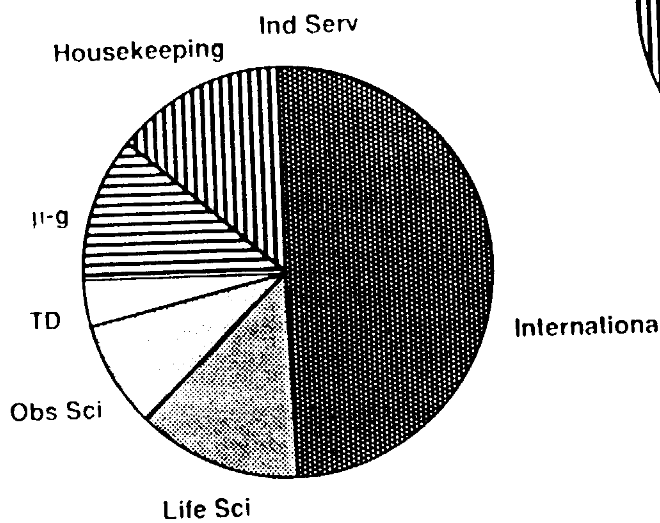

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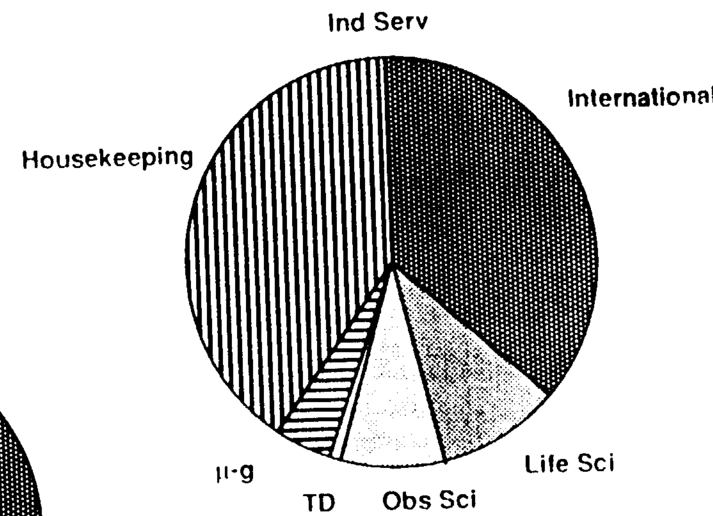

Power

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GROWTH SCENARIO RESULTS - OBSERVATIONAL SCIENCE EMPHASIS 5 NSTS/YR ONLY TRANSPORTATION SUPPORT CONTINUED

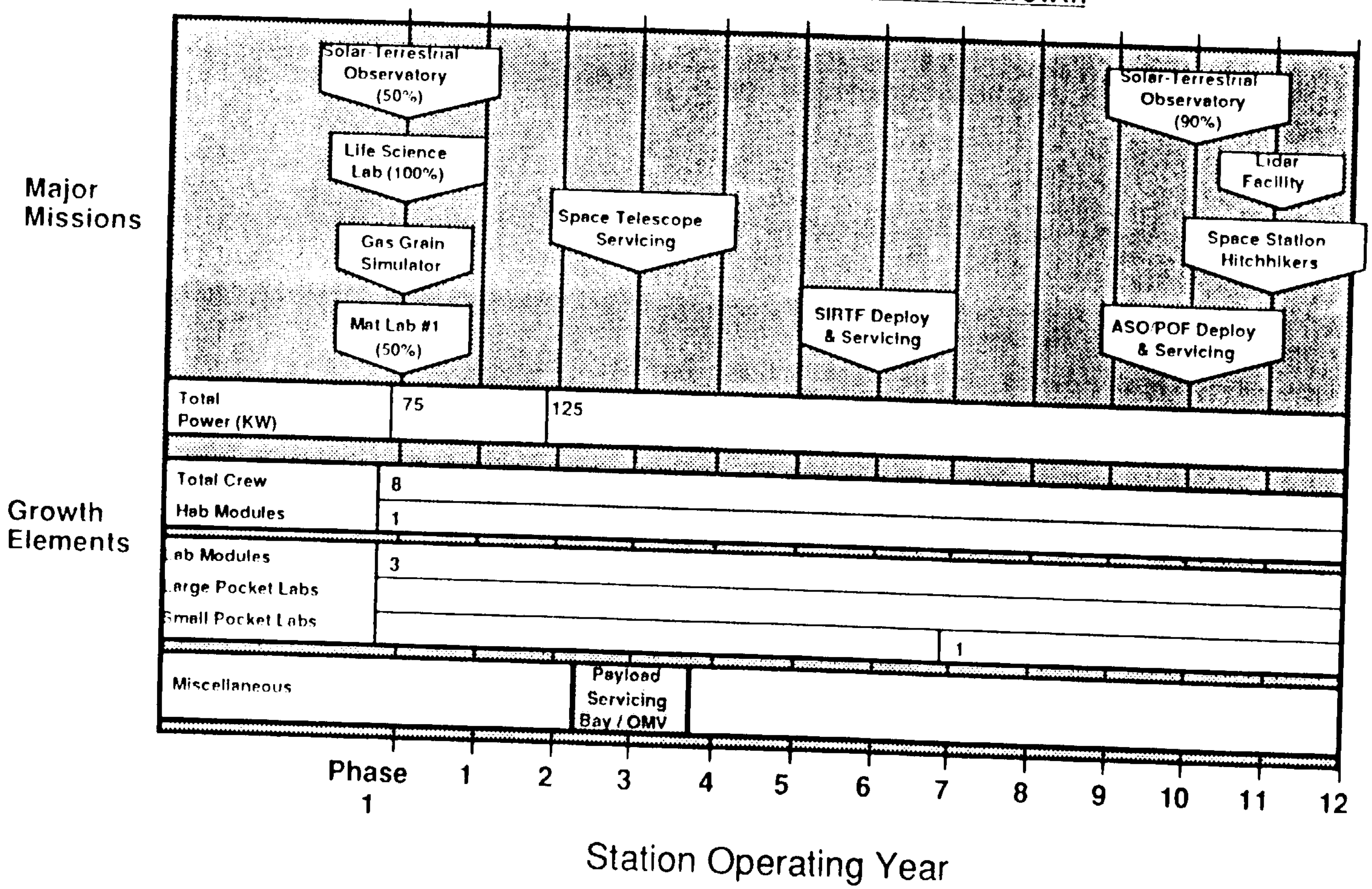
The timeline of major mission accommodation and growth element addition for the Observational Science emphasis, 5 NSTS flights per year transportation support scenario is given below. This timeline shows the correlation of resource growth (i.e., additions of power, crew, lab volume) with the accommodation of growth missions and the evolution of station facilities.

The primary growth facilities in support of the Observational Science emphasis are the payload servicing facility and station-based OMV. These facilities were added in lieu of evolving to a dual keel configuration with the minimal lift available in this scenario since servicing the Great Observatories (Hubble Space Telescope and SIRTF) and other observational science free flyers is a major capability which requires minimal crew support on an annual basis. Power and crew are deficit resources which result from accommodation of the Phase 1 mission set. The power deficit is relieved with the addition of 2 solar dynamic collectors in station operating year 2. The crew deficit can not be relieved with the 5 NSTS flights per year transportation scenario since delivery and logistics support of an additional hab module requires lift greater than can be provided. Results of the crew deficit are that any growth missions in this scenario must have minimal crew requirements to be accommodated. The servicing interval of the Great Observatories is 2 to 3 years with each servicing requiring approximately 2 man-weeks to complete. The impact of this crew requirement is assumed to have a negligible effect on overall station operations. Other Observational Science missions accommodated are primarily external, attached payloads which require minimal crew monitoring.

The sample quarantine facility is accommodated in year 7 since it is a requirement for support of the Mars Sample Return and Comet Nucleus Sample Return missions. These missions are high priority and resources required for their support are budgeted from ongoing station activities since available lift and crew resources are minimal with this transportation scenario.

GROWTH SCENARIO RESULTS
OBSERVATIONAL SCIENCE EMPHASIS
5 NSTS/YR ONLY TRANSPORTATION SUPPORT
CONTINUED

Summary of Major Mission and Station Element Growth



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GROWTH SCENARIO RESULTS
OBSERVATIONAL SCIENCE EMPHASIS
MODERATE TRANSPORTATION SUPPORT

Summary of Mission Accommodation

- General
  - Growth for the first 3 years was devoted to correcting crew and power deficiencies at Phase 1
  - Lift for the first 2 years was insufficient to allow accommodation of any growth missions
  - Upper and lower booms were established early (year 4) as was the addition of the payload servicing facility
  - Growth did not emphasize addition of laboratory modules since pressurized volume requirements are minimal for most of the observational science experiments. Large amounts of lift were instead allocated to transporting external unpressurized equipment
- Observational Sciences
  - Mission accommodations included all growth missions except one attached mission and the Experimental Geosynchronous Platform and associated payloads
  - Hubble Space Telescope and SIRTF servicing were accommodated 1 year late in years 4 and 3, respectively; AXAF was serviced on time in year 5; growth payloads for the Solar Terrestrial Observatory were accommodated by year 10
  - Other missions accommodated within 9 years include Space Station Spartan, Hitchhikers 1 through 4, and Explorer 1, 2, and 3 servicing
- Industrial Services
  - The missions in this category have significant lift requirements in general. For this reason none were accommodated in this scenario
- International
  - Very few of the growth missions were accommodated
  - None of the international growth missions were accommodated on time; primary missions include smaller Japanese and Canadian technology development missions and the European radiation biology free flyer

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GROWTH SCENARIO RESULTS
OBSERVATIONAL SCIENCE EMPHASIS
MODERATE TRANSPORTATION SUPPORT
CONTINUED

<u>Summary of Mission Accommodation (cont)</u>

- Life Sciences
  - The general purpose life science laboratory was fully accommodated as part of the Phase 1 mission set for this scenario
  - The only growth missions were the planetary sample return missions and the associated quarantine facility. All of these missions were accommodated on time due to their high priority
  - The exemplary accommodation of missions in this category was due in most part to the limited number of missions in the growth mission set (only three)

- Microgravity Research & Materials Production
  - The only growth mission in this category, complete outfitting of the Microgravity & Materials Processing Facility (COMM1201), did not occur
  - The on-time accommodations reflect the Phase 1 portion of the MMPF

- Technology Development
  - Very few of the Technology Development missions were accommodated. None of the growth missions were accommodated on time, and those which were accommodated late were in general very short duration, low resource using experiments

GROWTH SCENARIO RESULTS - OBSERVATIONAL SCIENCE EMPHASIS
MODERATE TRANSPORTATION SUPPORT
CONTINUED

The final station configuration including module, pocket lab, solar dynamic collector, and truss additions is shown for the Observational Science emphasis, moderate transportation support scenario. The module pattern given is conceptual only and is meant to illustrate volumetric size of the station in terms of number of modules and pocket labs and their associated facilities. Configuration analysis to detèrmine an optimal module pattern would involve numerous operational issues which were not addressed in this study.

Major growth components added in this scenario include 2 hab modules, 2 pocket labs, 1 pair of solar dynamic collectors, the dual keel, and 8 attach points. Not shown but also accommodated are the payload servicing facility and OMV. Major facilities in support of the Observatonal Science emphasis are the upper and lower booms with attach points, transvservse boom with the Phase 1 attach points, OMV and payload servicing facility, and the planetary science experiment module.

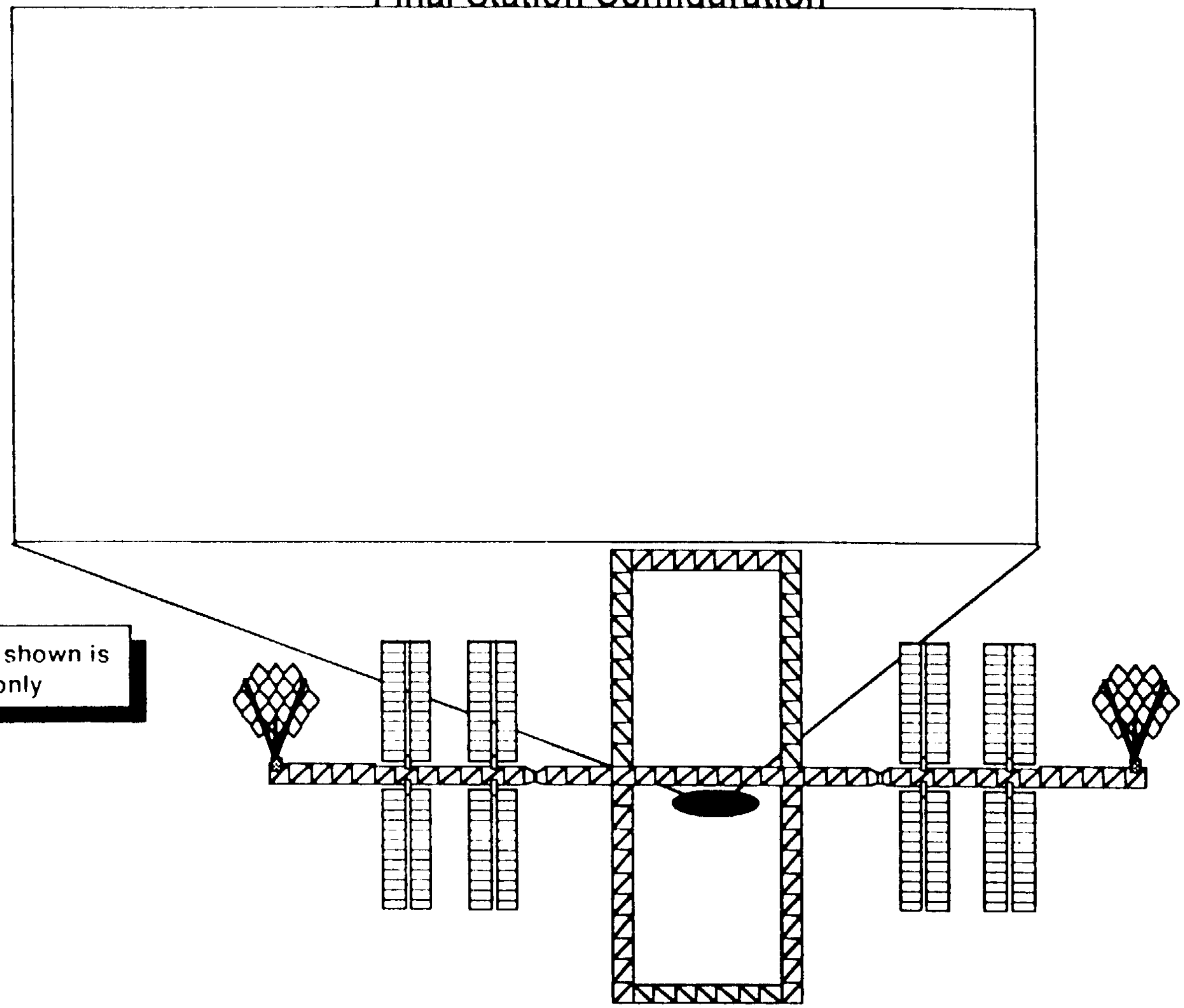
Growth items added per year and the resulting increases in station resources are given in the following table.

Observational Science Emphasis
Moderate Transportation Model

Year	SD Arrays	Total Power	User Power	Total Crew	User Crew	labs	Labs	Sm Pocket	Lg Pockets	Attach Pnt	Truss bays	OMV	OTV	Growth Mass
Phase I	0	75	45.2	8	6	1	3	0	0	4	0	0	0	
1	0	75	44.6	8	6	1	3	0	0	4	0	0	0	4811 Kg
2	0	75	37.6	12	9	2	3	0	0	4	0	0	0	20509 Kg
3	1	125	79.6	16	12	2	3	0	1	4	17	1	0	58569 Kg
4	1	125	64.4	22	16.5	3	3	0	1	10	71	1	0	44227 Kg
5	1	125	64.4	22	16.5	3	3	0	1	10	71	1	0	Kg
6	1	125	64.4	22	16.5	3	3	0	1	12	71	1	0	1510 Kg
7	1	125	63.2	22	16.5	3	3	1	1	12	71	1	0	6500 Kg

GROWTH SCENARIO RESULTS
OBSERVATIONAL SCIENCE EMPHASIS
MODERATE TRANSPORTATION SUPPORT
CONTINUED

Final Station Configuration



Note: Module pattern shown is representative only

GROWTH SCENARIO RESULTS - OBSERVATIONAL SCIENCES EMPHASIS MODERATE TRANSPORTATION SUPPORT CONTINUED

Allocation of lift, crew, and power is shown for station operations after completion of growth. The pie charts are representative of mature station operations for this scenario and are based on an average of annual requirements during this period.

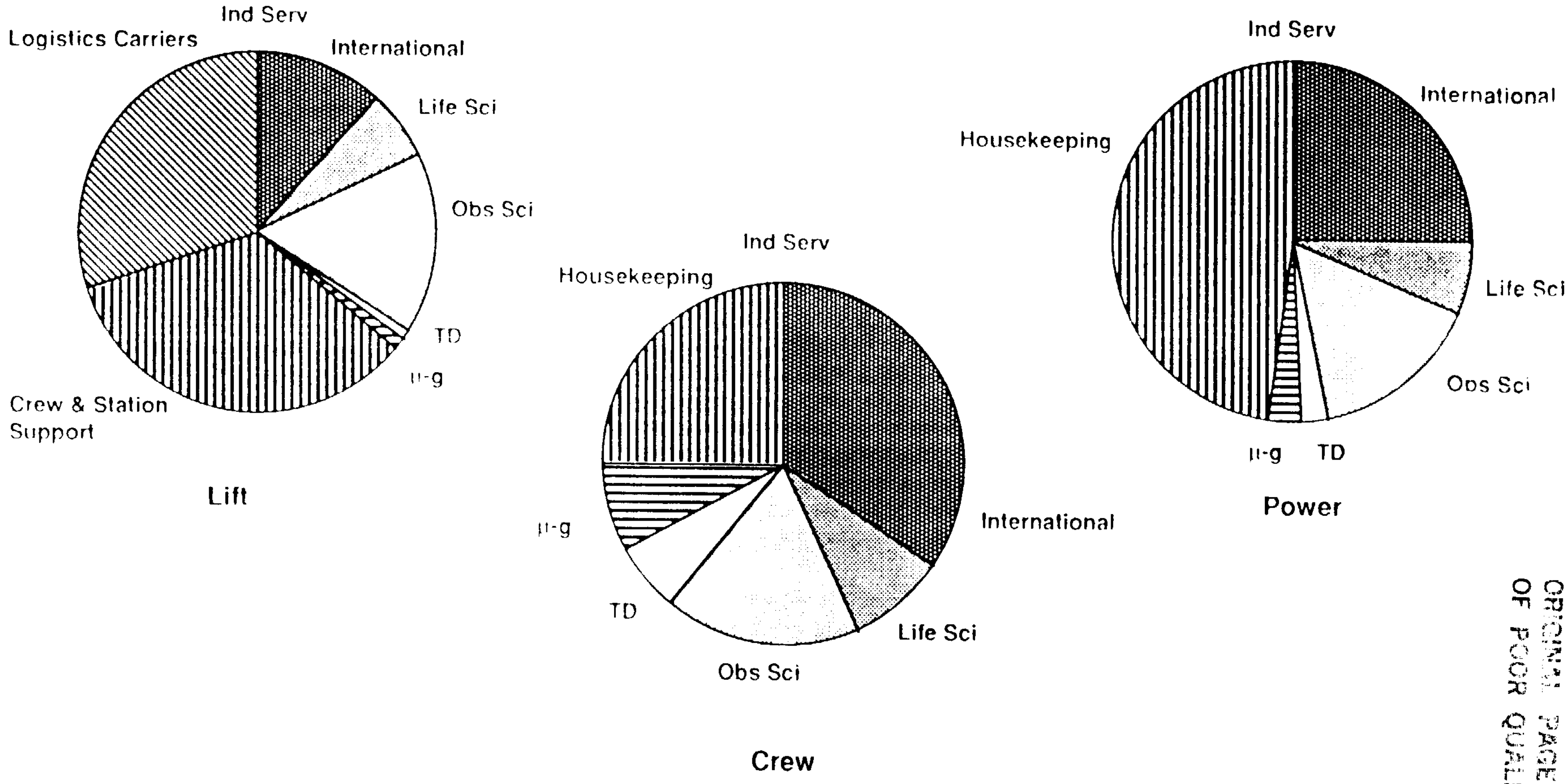
The lift allocation pie chart shows that the majority of lift is required for crew & station support logistics and logistics carriers. The logistics carrier allocation represents 8 pressurized log module, 12 unpressurized carrier, 2 fluids carrier, and 6 propellant carrier flights per year. Crew & station support logistics represents support for 6 modules, 2 pocket labs, and 22 crew persons. User lift is allocated primarily to Observational Science, International, and Life Sciences missions. The Observational Science allocation represents accommodation of 92% of the missions in this category. Examples of these missions include servicing of the Great Observatories (Hubble Space Telescope, AXAF, and SIRTF), deployment and servicing of the Large Deployable Reflector, and growth components of the Solar Terrestrial Observatory. International mission allocation is in support of the International missions of the Phase 1 mission set, a European biological platform, and several smaller Japanese technology development missions. Life Sciences lift allocation is required for support of the life sciences lab (SAAX307).

User crew requirements are highest for international and Observational Science missions. International crew requirements are primarily in support of microgravity research and life science research facilities. Housekeeping crew requirements are assumed to be 25% of the total station crew.

Power allocation among users is highest for International, Observational Science, and Life Sciences missions. Observational Science power is required mainly for daily operations of the external, attached missions. Additionally, free flyers being serviced in the payload servicing facility typically require station power during the service interval.

GROWTH SCENARIO RESULTS
OBSERVATIONAL SCIENCES EMPHASIS
MODERATE TRANSPORTATION SUPPORT
CONTINUED

Resource Allocation



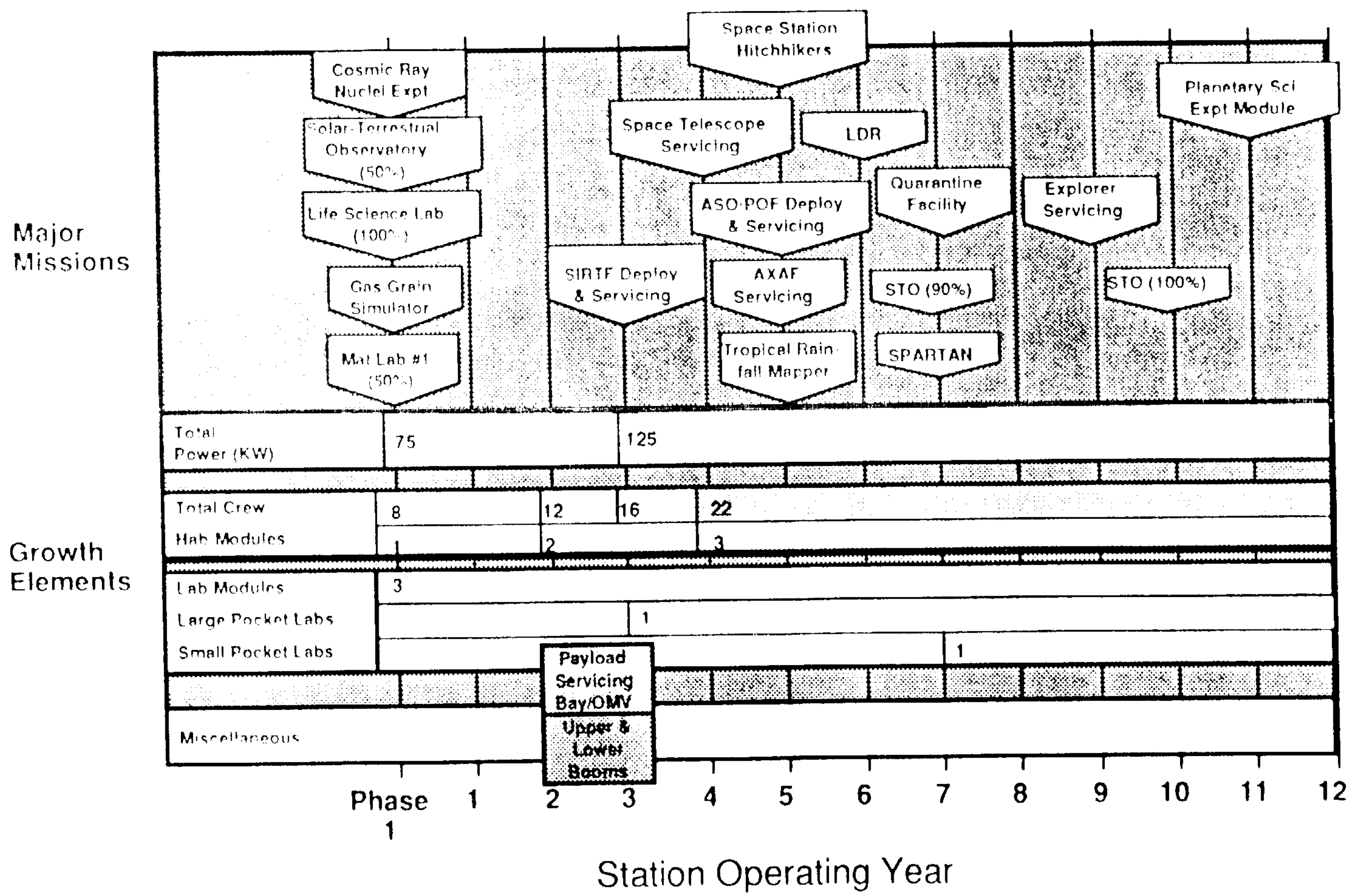
GROWTH SCENARIO RESULTS - OBSERVATIONAL SCIENCE EMPHASIS MODERATE TRANSPORTATION SUPPORT CONTINUED

The timeline of major mission accommodation and growth element addition for the Observational Science emphasis, moderate transportation support scenario is given below. This timeline shows the correlation of resource growth (i.e., additions of power, crew, lab volume) with the accommodation of growth missions and the evolution of station facilities.

Primary facilities in support of the Observational Science emphasis are the payload servicing facility, station-based OMV, the dual keel with upper and lower booms, and the planetary science experiment module. The planetary science experiment module is accommodated in station operating year 11. The sample quarantine facility is accommodated in year 7 with the addition of a small pocket lab. This facility is required for isolation of samples from the Mars sample return mission and the comet nucleus sample return mission. These facilities provide the capability to support a variety of observational science free flyers and attached payloads. Increases in power and crew in station operating years 2 and 3 are required to relieve resource deficits created by the Phase 1 mission set. Additional increases in crew is required for approximately 95% accommodation of all Observational Science missions and accommodation of numerous Technology Development and International missions.

GROWTH SCENARIO RESULTS
OBSERVATIONAL SCIENCE EMPHASIS
MODERATE TRANSPORTATION SUPPORT
CONTINUED

Summary of Major Mission and Station Element Growth



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GROWTH SCENARIO RESULTS
OBSERVATIONAL SCIENCE EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT

Summary of Mission Accommodation

- General
  - Mission accommodation emphasized both free flyer and attached payload missions in the Observational Science category. A dual keel configuration was evolved to satisfy pointing requirements of the Earth observing and astrophysics attached missions. The station based OMV and payload servicing facility were accommodated to support the Great Observatories and other free flying missions
  - Year 1 growth was devoted to correcting power and crew deficits of the Phase 1 missions. The dual keel configuration is completed in year 3, OMV and payload servicing facility accommodated in year 3, and the OTV and hangar accommodated in year 4

- Microgravity Research & Materials Production
  - Complete outfitting of materials lab #1 was not possible due to insufficient rack volume and inadequate lift to support an additional lab which was not required by the emphasized missions

- Industrial Services
  - Mission accommodation included the deployment of 3 classes of communications satellites, deployment of M-Sat-B and support of the Industrial Space Facility. Deployment of the geostationary satellites began in year 5 with a minimum slip of 2 years. The Industrial Space Facility was accommodated 4 years late in year 5

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GROWTH SCENARIO RESULTS
OBSERVATIONAL SCIENCE EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED

Summary of Mission Accommodation (cont)

- Life Sciences
  - Growth missions which were accommodated are the sample return missions and the sample quarantine facility. These are high priority missions and are accommodated on time

- Observational Sciences
  - All missions within this category were accommodated. Mission slips were primarily due to lack of available attach points prior to evolution of the dual keel in year 3
  - The major observatories including Hubble Space Telescope, SIRTF, and AXAF were serviced on time
  - A subset of other missions accommodated include the Solar Terrestrial Observatory growth components, the Experimental Geo Platform and associated payloads, Hitchhikers 1 through 4, Space Station Spartan, and Explorer 1 through 3 servicing

- Technology Development
  - All missions in this category were accommodated within 7 years of station operation. The maximum start delay for these missions is 4 years

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GROWTH SCENARIO RESULTS - OBSERVATIONAL SCIENCE EMPHASIS AGGRESSIVE TRANSPORTATION SUPPORT CONTINUED

The final station configuration including module, pocket lab, solar dynamic collector, and truss additions is shown for the Observational Science emphasis, aggressive transportation support scenario. The module pattern given is conceptual only and is meant to illustrate volumetric size of the station in terms of number of modules and pocket labs and their associated facilities. Configuration analysis to determine an optimal module pattern would involve numerous operational issues which were not addressed in this study.

Major growth components added in this scenario include 2 hab modules, 2 pocket labs, dual keel with 14 attach points, payload servicing facility and OMV, and the OTV and OTV hangar. Facilities in support of the Observational Science emphasis include the upper and lower booms with attach points, the transverse boom with Phase 1 attach points, payload servicing facility and OMV, the planetary science experiment module, and the OTV.

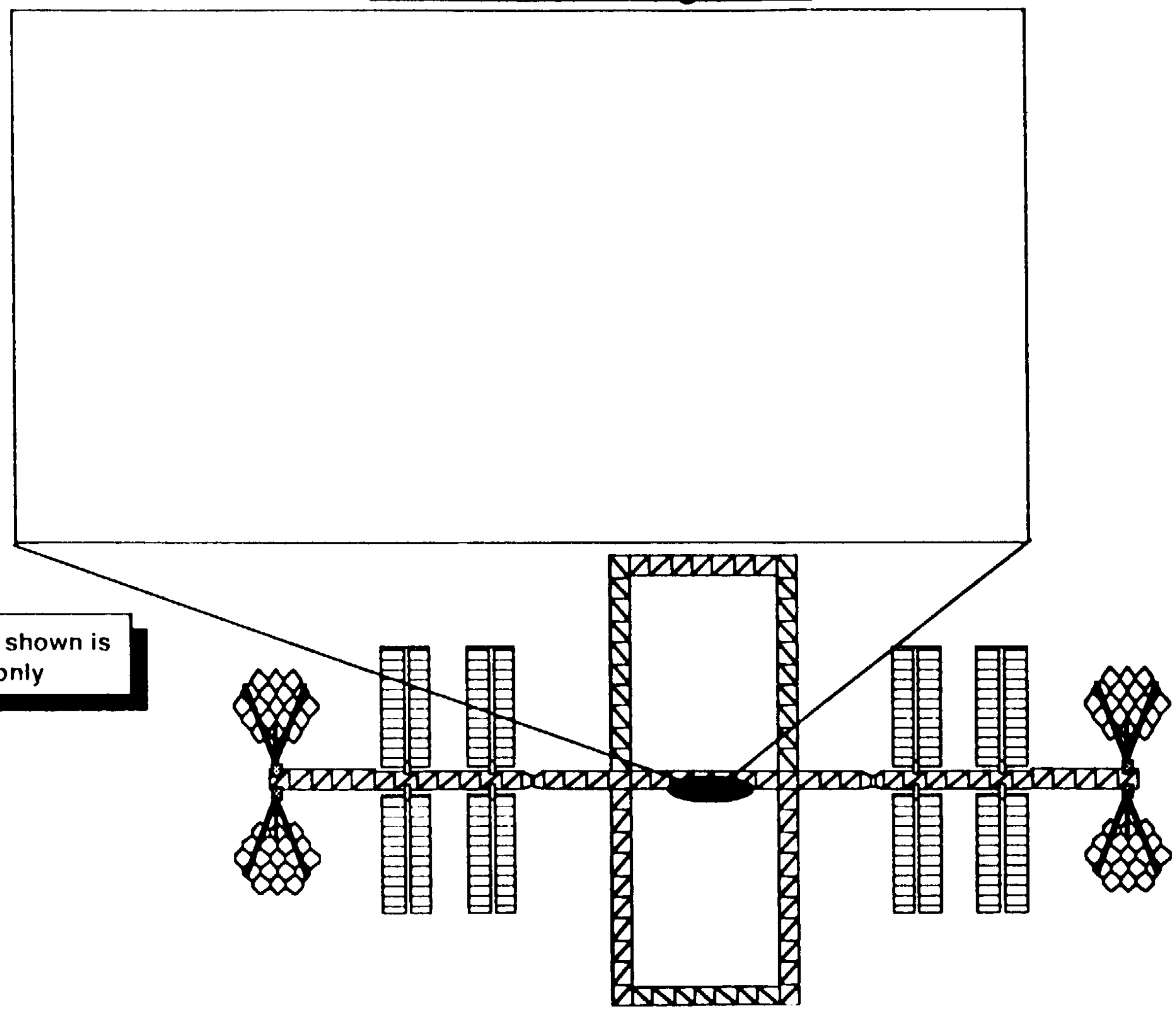
Growth components added per year and changes in station resources are given in the table below.

Observational Science Emphasis
Aggressive Transportation Model

Year	SD Arrays	Total Power	User Power	Total Crew	User Crew	Habs	Labs	Sm Pockets	Lg Pockets	Attach Pnts	Truss bays	OMV	OTV	Growth Mass
Phase 1	0	75	45.2	8	6	1	3	0	0	4	0	0	0	
1	1	125	82.5	16	12	2	3	0	0	4	17	0	0	45120 Kg
2	1	125	82.5	16	12	2	3	0	0	4	17	0	0	Kg
3	2	175	114.7	24	18	3	3	0	0	18	71	1	0	85484 Kg
4	2	175	112.5	24	18	3	3	0	1	18	71	1	1	86481 Kg
5	2	175	111.4	24	18	3	3	1	1	18	71	1	1	6500 Kg

GROWTH SCENARIO RESULTS
OBSERVATIONAL SCIENCE EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED

Final Station Configuration



Note: Module pattern shown is representative only

GROWTH SCENARIO RESULTS - OBSERVATIONAL SCIENCES EMPHASIS AGGRESSIVE TRANSPORTATION SUPPORT CONTINUED

Allocation of lift, crew, and power is shown for station operations after completion of growth. The pie charts are representative of mature station operations for this scenario and are based on an average of annual requirements during this period.

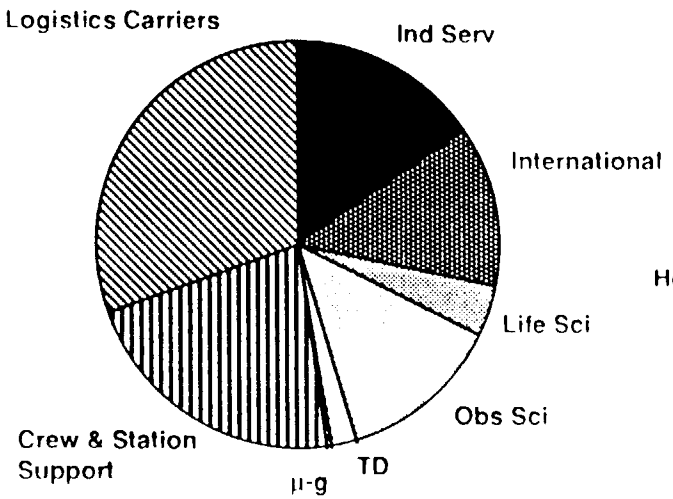
The lift allocation pie chart shows that the majority of lift is required for crew & station support logistics and logistics carriers. The logistics carrier allocation represents 9 pressurized log module, 30 unpressurized carrier, 2 fluids carrier, and 23 propellant carrier flights per year. Crew & station support logistics represents support for 6 modules, 2 pocket labs, and 24 crew persons. User lift is allocated primarily to Observational Science, International, and Industrial Services missions. The Observational Science allocation represents accommodation of 100% of the missions in this category. Examples of these missions include servicing of the Great Observatories (Hubble Space Telescope, AXAF, and SIRTF), deployment and servicing of the Large Deployable Reflector, and growth components of the Solar Terrestrial Observatory. International mission allocation is in support of the international missions of the Phase 1 mission set and all growth missions except 1. These missions include a Japanese astronomical platform and associated payloads, Canadian attached observational missions, and a European free flyer telescope. Life Sciences lift allocation is required for support of the life sciences lab (SAAX307). Lift for Industrial Services missions is in support of the free flying Industrial Space Facility.

User crew requirements are highest for International and Observational Science missions. International crew requirements are primarily in support of microgravity research and life science research facilities. Housekeeping crew requirements are assumed to be 25% of the total station crew.

Power allocation among users is highest for International, Observational Science, and Life Sciences missions. Observational Science power is required mainly for daily operations of the external, attached missions. Additionally, free flyers being serviced in the payload servicing facility typically require station power during the service interval.

GROWTH SCENARIO RESULTS
OBSERVATIONAL SCIENCES EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED

<u>Resource Allocation</u>



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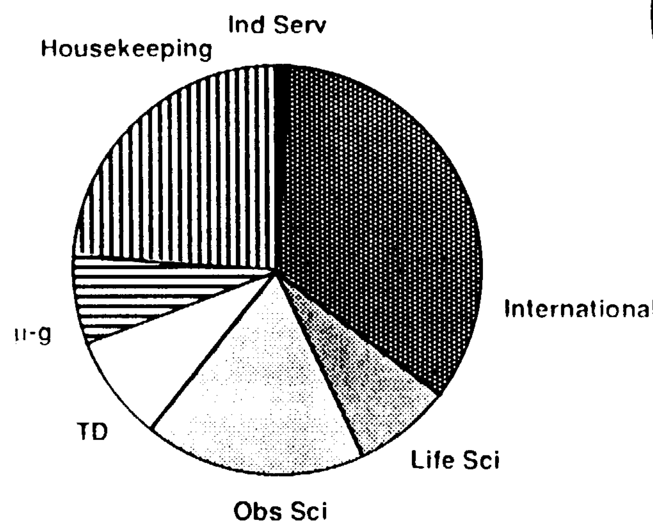

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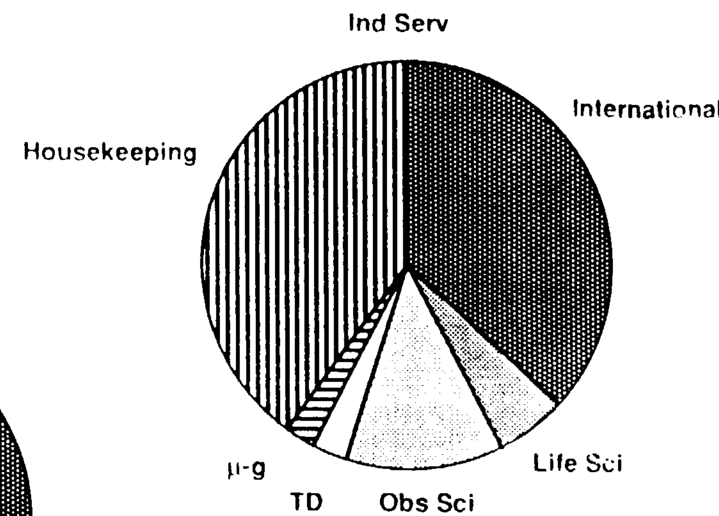


Power

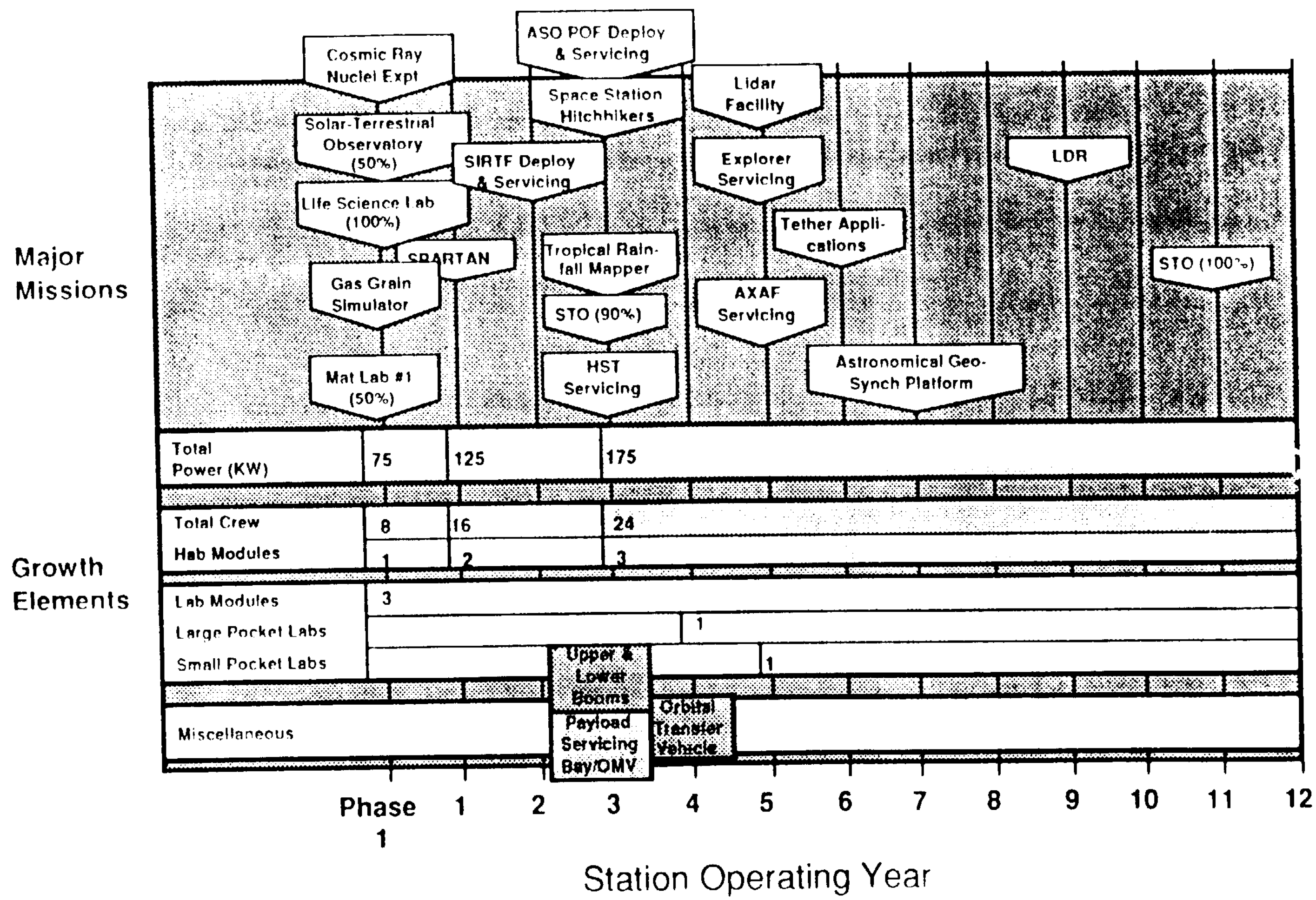
GROWTH SCENARIO RESULTS - OBSERVATIONAL SCIENCE EMPHASIS AGGRESSIVE TRANSPORTATION SUPPORT CONTINUED

The timeline of major mission accommodation and growth element addition for the Observational Science emphasis, aggressive transportation support scenario is given below. This timeline shows the correlation of resource growth (i.e., additions of power, crew, lab volume) with the accommodation of growth missions and the evolution of station facilities.

Facilities in support of the Observational Science emphasis include the dual keel with upper and lower booms added in station operating year 3, the payload servicing facility and station-based OMV added in year 3, the OTV and OTV hangar added in year 4, the planetary science experiment module accommodated in year 4, and the astronomical geosynchronous platform accommodated in 7. The OTV is required for deployment and payload changeout of the astronomical geosynchronous platform. The large pocket lab added in station operation year 4 and the small pocket lab added in year 5 house the planetary science experiment facility and the sample quarantine facility, respectively. Increases in power and crew in station operating year 1 is required to relieve resource deficits created by accommodation of the Phase 1 mission set. Station growth to 24 total crew persons and 175 kW total power is required for the accommodation of 100% of the Observational Science missions and numerous Technology Development, Industrial Services, and International missions.

GROWTH SCENARIO RESULTS
OBSERVATIONAL SCIENCE EMPHASIS
AGGRESSIVE TRANSPORTATION SUPPORT
CONTINUED

Summary of Major Mission and Station Element Growth



CONCLUDING REMARKS

A unique requirement for NASA's Space Station Freedom is that it must evolve over an indefinite operational lifetime to accommodate changing user needs which are, in many cases, difficult to foresee. The LaRC Space Station Office, in support of the Program's Level I- Strategic Plans and Programs Office, is responsible for identifying viable evolution options for Space Station (e.g., multidiscipline, R&D facility or transportation node for lunar base support). System studies and analysis are being conducted to determine requirements for each of the potential options. These requirements are assessed by LaRC and selected for input to the program review process based on their adequacy in enabling future options for Station evolution.

Analysis results have been presented which are relevent to the growth of Space Station as a multidiscipline, R&D facility in Earth orbit. Mission sets were developed that reflect the nature of a specific utilization emphasis on Station (e.g., life science research emphasis) and multiple growth scenarios resulted from the combination of each emphasis with three mixed-fleet, transportation models (conservative to aggressive lift capability). The application of computer-based, analytical tools to the analysis process yielded growth resource requirements for each scenario constrained by lift to Space Station orbit. Growth requirements were computed for the following resources: electrical power, crew, pressurized volume, attach points, truss structure and logistics. As an example, the growth power requirement varied from a minimum of 125 Kw. for scenarios constrained by 5 NSTS flights per year to 325 Kw. for the microgravity research and materials production emphasis with aggressive transportation support. These results were key inputs to the process of selecting evolution requirements for the Space Station Program, Preliminary Requirements Review (PRR).

For the Space Station PRR, the Langley SSO, Evolutionary Definition Office integrated data from this analysis with that of other sources to form a four-phased evolution scenario for multidiscipline R&D support. This "adequate and reasonable" scenario identified a need in the mature operational phase for 275 Kw., 24 crew, 6 U.S. and international labs, 3 mini or "pocket" labs, and 18 external payload attach points. Since this envelope of requirements is also adequate for Space Station support of the currently identified "new initiatives", these were recommended at the PRR as Space Station growth requirements.

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15. Supplementary Notes

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Peter Ahlf, Rudy Saucillo, and David Eakman: McDonnell Douglas Astronautics Company, Washington Operations Division, Rockville, Maryland.

16. Abstract

The NASA Space Station Freedom is being designed to facilitate on-orbit evolution and growth to accommodate changing user needs and future options for U.S. space exploration. In support of the Space Station Freedom Program Preliminary Requirements Review, the Langley Space Station Office has identified a set of resource requirements for Station growth which is deemed adequate for the various evolution options. As part of that effort, analysis was performed to scope requirements for space station as an expanding, multidiscipline facility for scientific research, technology development and commercial production. This report describes the assumptions, approach and results of the study.

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