SPACE STATION FREEDOM
INTEGRATED RESEARCH AND DEVELOPMENT GROWTH

P.R. Ahlf and R.J. Saucillo
McDonnell Douglas Space Systems Company - Engineering Services Division
Washington SI&I

B.D. Meredith
NASA Langley Research Center

SPACE STATION EVOLUTION - BEYOND THE BASELINE
February 6 - 8, 1990
League City, Texas

ABSTRACT

Space Station Freedom is designed to be an Earth-orbiting, multidiscipline research and development (R&D) facility capable of evolution to accommodate a variety of potential uses. One evolution scenario is growth to an enhanced R&D facility. In support of the Space Station Freedom Program Preliminary Design Review (PDR), the NASA Langley Research Center Space Station Office is analyzing growth requirements and evaluating configurations for this R&D utilization. This paper presents a summary of FY1989 study results including time-phased growth plans, R&D growth issues and configurations, and recommendations for the program baseline design which will facilitate evolutionary R&D growth.

This study consisted of three major areas of concentration: mission requirements analysis; Space Station Freedom systems growth analysis; and growth accommodations and trades. Mission requirements analysis was performed to develop a realistic mission model of post-Phase 1 R&D missions. A systems-level analysis was performed to project incremental growth requirements of Space Station Freedom needed to support these R&D missions. Identification of growth requirements and specific growth elements led to the need for special accommodations analyses and trades. These studies included identification of hooks and scars on the baseline design, determination of an optimal module growth pattern, analysis of the dual keel length, and determination of an optimal location for the customer servicing facility.

Results of this study show that Space Station Freedom must be capable of evolving to a dual keel, 8 pressurized module configuration (2 growth habs and 2 growth labs); providing 275 kW power (for experimenters and station housekeeping); accommodating a crew of 24; and supporting other growth structures and special facilities to meet projected R&D mission requirements.

OVERVIEW

OVERVIEW
STUDY OBJECTIVES

- Develop Space Station Freedom growth concepts and perform mission accommodations analyses in order to identify major resource requirements for an evolutionary Space Station which has as its primary emphasis, multidisciplinary Research and Development

- Perform trades and analyses related to major configuration issues

- Develop and maintain an Evolution Mission Model for use in the various trades and analyses related to reference configuration development

- Identify hooks and scars and major technology needs to guarantee the Space Station's ability to evolve into a growth configuration which meets mission requirements

- Develop reference configurations for incremental growth phases of the Space Station

Overview - Study Approach

This study consisted of three major areas of concentration; mission requirements analysis, systems growth analysis, and growth accommodations analysis and trades.

Mission requirements analysis was performed 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 using data from the NASA Level II Trial Payload Manifest (November 1987 version).

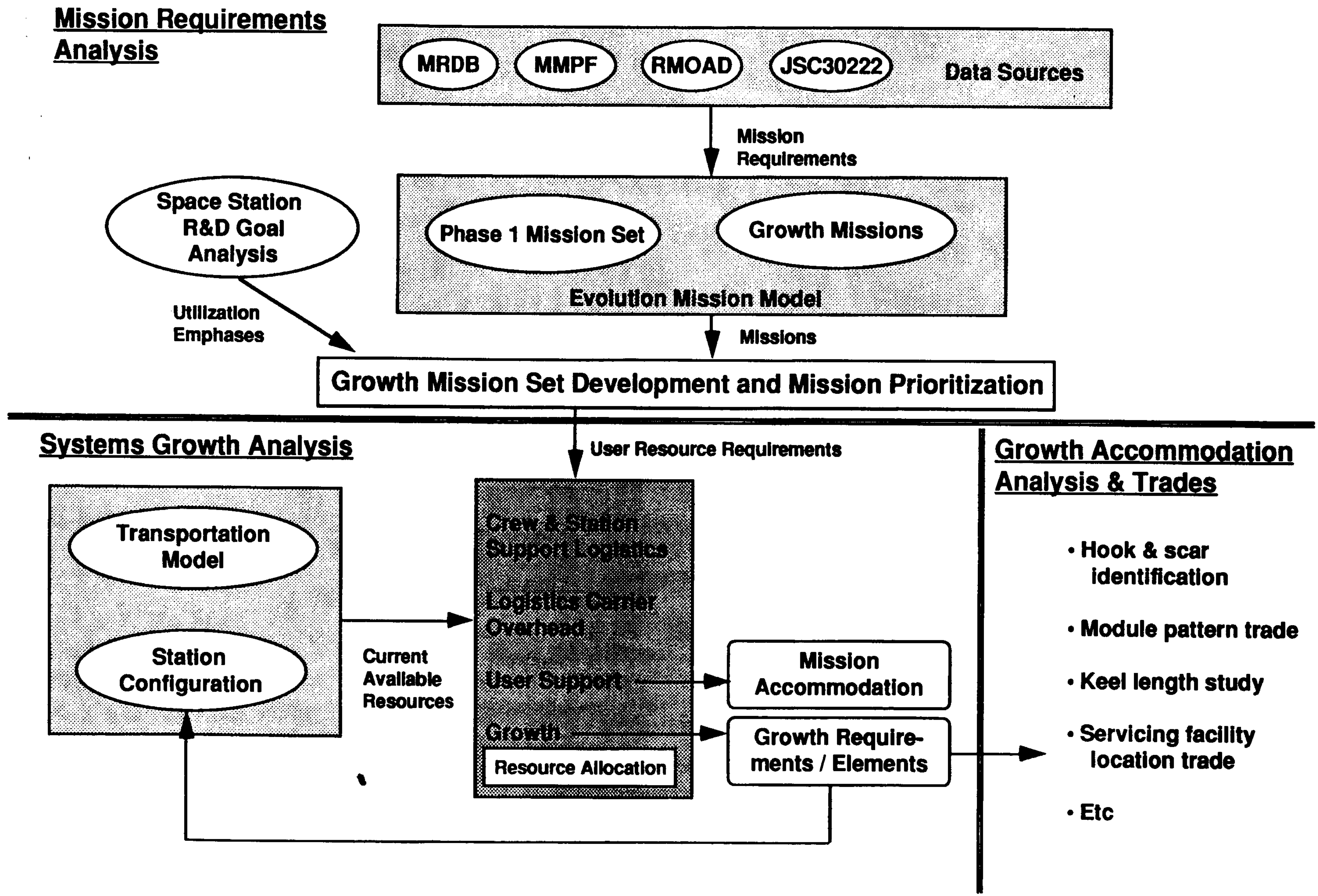
Mission data sets were developed based on the goal of accommodating research and development "missions" on an evolutionary Space Station Freedom. In order to establish resource requirement envelopes, multiple mission accommodation analyses were performed emphasizing several different R&D disciplines. These disciplines included: microgravity research, microgravity research with materials production, life sciences, and observational sciences.

A systems level analysis was performed to project the growth of Space Station Freedom. Major assumptions of this analysis were:

- point of departure was the Phase 1 configuration defined in the Level II Engineering Data Book
- constrained resources included: launch mass, power, crew time, internal pressurized volume, and external attach points
- station return mass requirements were tracked but not constrained
- destinction between carrier requirements for ELVs and the Shuttle is not made. Alloction of life requirements between ELVs and the Shuttle is examined but not constrained.

Identification of growth requirements and specific growth elements led to the need for special accommodations analyses and trades. These studies included identification of hooks and scars on the baseline design, determination of optimal growth module pattern and pattern buildup, analysis of the length of the dual keel, and determination of an optimal location for the customer servicing facility.

OVERVIEW
STUDY APPROACH



Overview - R&D Utilization of Space Station Freedom

Research and development activities on Space Station Freedom are broadly classified as: microgravity research, commercial materials production, life sciences research, and attached & observational payloads.

Requirements for the microgravity research experiments were derived primarily from the Microgravity and Materials Processing Facility (MMPF) Study Data Release (Contract No. NAS8-36122, Teledyne Brown Engineering and Boeing Aerospace Co., Feb. 2, 1987). This report describes a fully outfitted laboratory consisting of 30 facilities which represent 47 missions in the Mission Requirements Data Base (MRDB). Resource requirements for these facilities are highly dependent upon equipment utilization assumptions. 100% equipment utilization (i.e., all facilities operating all of the time) is not a practical assumption due to high resource requirements of individual facilities. The MMPF Study provides data on realistic equipment utilization (run duration and frequency) and corresponding resource requirements.

Resource requirements for the General Life Sciences Lab and the 1.8-meter centrifuge were based on data from the Reference Mission Operational Analysis Document (RMOAD) for the Life Science Research Facilities. This document divides the outfitting of a dedicated Life Sciences Module into 5 phases.

Mission specifications for the Great Observatories (Hubble Space Telescope, Advanced X-ray Astrophysics Facility [AXAF], and the Space Infrared Telescope Facility [SIRTF]) were derived from the Customer Servicing Requirements Data Book (JSC 30222, March 15, 1986). The launch dates for these missions were based on the October 1987 Payload flight Assignments, NASA Mixed Fleet. The Gamma Ray Observatory (GRO) was not included because its end-of-life is expected to be reached prior to Space Station Freedom Assembly Complete.

The technology development missions represent a wide range of disciplies and programs within disciplines. Missions include both pressurized and external attached facilities. Examples of attached technology development missions include in-space assembly, tether operations, and robotics.

OVERVIEW
R&D UTILIZATION OF SPACE STATION FREEDOM

- **Microgravity Research**
  - Basic research in such areas as **Electronic Materials, Glasses and Ceramics, Combustion, Fluid Dynamics & Transport Phenomena, and Metals & Alloys**
  - Will use facilities within the pressurized modules such as **Modular Containerless Processing** Facility, **Modular Multizone Furnace** Facility, **Biotechnology** Facility, **Advanced Protein Crystal Growth** Facility, **Modular Combustion** Facility, and a **Fluid Physics/Dynamics** Facility

- **Commercial Materials Processing**
  - **Pilot production facilities** for testing processing involved in large scale manufacturing in space
  - Housed either on **unpressurized attached pallets,** or within pressurized **"pocket labs"**
  - Potential applications include **Electro-epitaxial Crystal Growth** Production Units, **Biological** Production Units, **Electrophoresis** Production Units, and **Containerless Processing** Production Units

- **Life Sciences**
  - Basic research in such areas as **Gravitational Biology, Biomedical Research, Environmental Factors, Operational Medicine, Biospherics Research, Physiochemical and Bioregenerative Life Support Systems, and Exobiology**
  - Will use facilities within the pressurized modules such as a **Human Physiology Lab**, **Plant & Animal Vivarium**, **Centrifuge** Facilities, and **Closed Life Support Systems Test Bed** Facilities; will also use attached payloads such as a **Cosmic Dust Collection** Facility

- **Attached and Observational Payloads**
  - Servicing of the **Great Observatories** & construction of large facilities like the **Large Deployable Reflector** and **Geostationary Earth Observing System Platforms**
  - Unpressurized attached payloads such as **Astromag, Solar Terrestrial Observatory,** and the **Tropical Rainfall Mapping Mission**
  - Technology development in areas like **in-space assembly, tether ops,** and **robotics**

Overview - Transportation Model

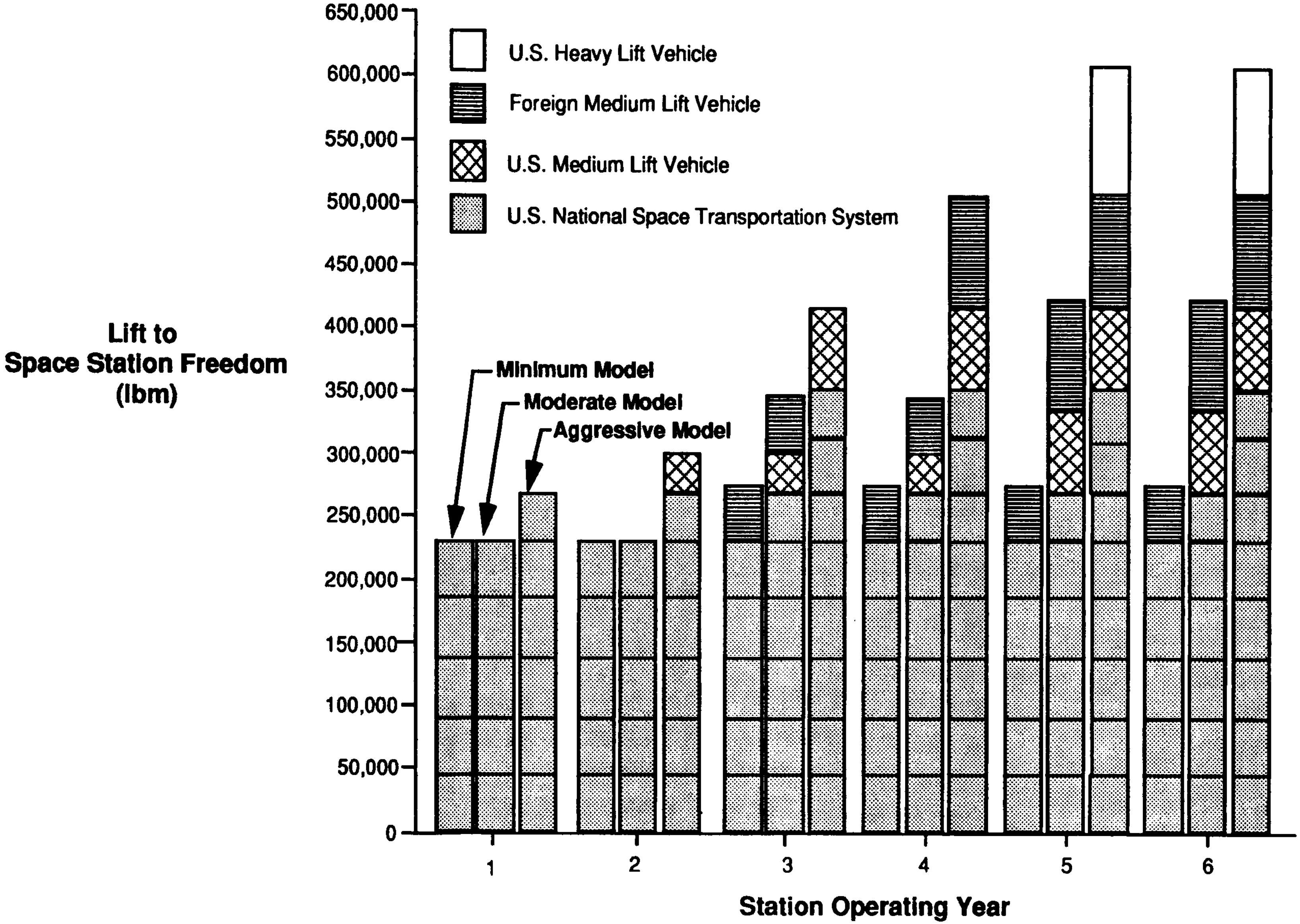
The most constraining resource on the level of activity on and potential growth of Space Station Freedom is the amount of Earth-to-station launch support. Rather than predict this level of support, a range of scenarios (i.e., transportation models) was developed for this analysis. These models cover the range of likely launch support to Space Station Freedom, from minimal support using primarily Shuttle-only, to aggressive support using Shuttle, Expendable Launch Vehicles, and a Heavy Lift Launch Vehicle.

The minimal transportation model used in this study assumes no increase of Shuttle support over the baseline of 5 flights to Space Station Freedom per year for logistics resupply and crew rotation. A contribution from internationals in the form of expendable launch vehicles is assumed, beginning several years after Assembly Complete.

The moderate transportation model assumes a small increase of Shuttle support over the baseline as well as a substantial augmentation by U.S. and international ELVs. The Shuttle flight rate is assumed to build to 6 flights per year several years after Assembly Complete. ELV support includes U.S. Titan IVs and ESA & Japanese contributions.

The aggressive transportation model assumes that a Heavy Lift Launch Vehicle is available for Space Station Freedom support. A 2-SSME Shuttle-C was used for Earth-to-orbit performance assumptions. The Shuttle flight rate for the model was also aggressive increased to a level of 8 flights per year five years after Assembly Complete. Additionally, a complement of U.S. and international medium-class ELVs was included.

OVERVIEW
TRANSPORTATION MODEL



SYSTEM GROWTH REQUIREMENTS

System Growth Requirements - Power / Thermal

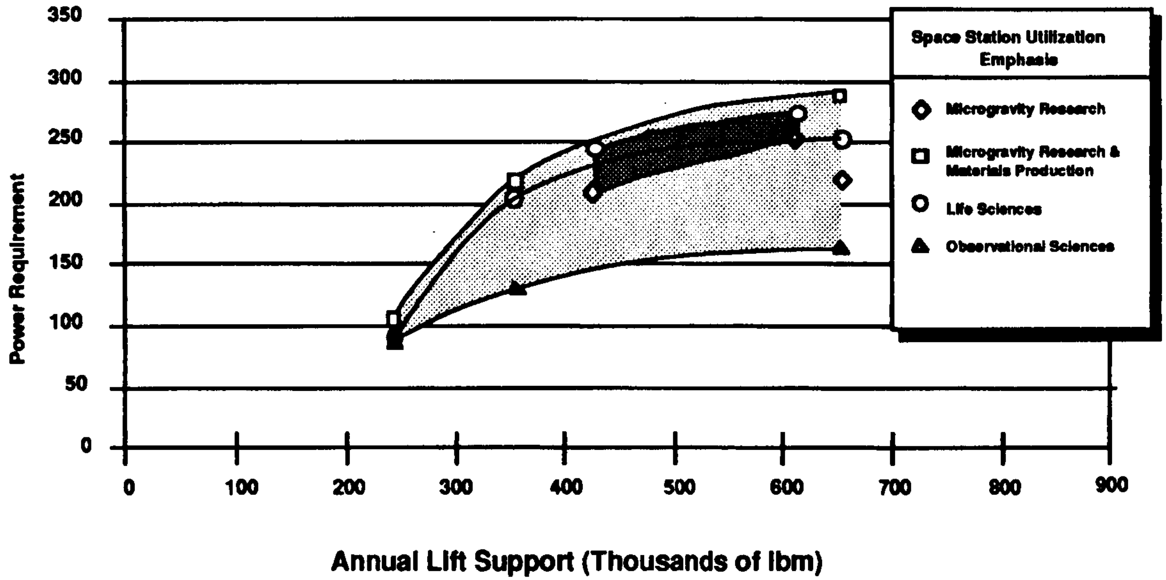
Analysis of fourteen scenarios which consisted of combinations of transportation support and utilization emphasis resulted in an envelope of power requirements. In order to protect for the maximum projected power requirement (aggressively supported microgravity research and materials production), eventual power growth to 275 kW must be possible. Design features in structures & mechanical systems, thermal control, and electrical power system must be included to permit this growth.

The anticipated method of increasing power generation capability is through the addition of solar dynamic modules. Each module pair will provide an additional 50 kW of electrical power. Primary scars to allow this growth involve the alpha gimbal roll rings and the utility distribution system (trays, cables, and breakouts).

The active thermal control system must keep pace with the growth of the power generation capability. Additional radiator panels will be required (i.e., a volume scar needed for space station element clearance), and eventually, forward radiator "wings" will be added.

SYSTEM GROWTH REQUIREMENTS
POWER / THERMAL

Growth power requirements are a function of utilization emphasis and annual lift support; scarring for power growth to 275 kW will allow aggressive microgravity research on SSF



Resource	Recommended Growth Rqmt	Growth Implementation	Scars
Power	275 kW	Addition of Solar Dynamic Power Modules	• Alpha Joint roll rings • EPS (lines, trays, breakouts)
Thermal	Consistent with 275 kW power generation	Additional aft radiators Addition of forward beta gimbals and radiators	• Forward gimbal • Transport lines • Radiator growth volume

System Growth Requirements - Pressurized Modules

Growth of the pressurized module pattern is required for additional laboratory space and crew habitation. The common module, used for the initial U.S. lab and U.S. hab of Space Station Freedom, provides standard growth elements for lab volume and crew quarters.

Analysis of mission requirements has led to the identification of a new pressurized module element which is not included in the baseline program: the pocket lab. A pocket lab is a pressurized mini-module which attaches to berthing ports on the resource nodes. Features of the pocket lab include:

- physical separation from the common modules which promotes safety for applications such as a quarantine facility
- ability to accommodate equipment which is not adaptable to the common module due to size or configuration incompatibilities (e.g., the 2.5-meter and 4-meter centrifuge), and
- ease of detachability for return to Earth, desirable for temporary facilities and materials production resource modules

Pressurized laboratory volume growth is anticipated to occur in three increments. The first increment will allow the evolution of the original multipurpose U.S. lab into two dedicated or near-dedicated modules. One for life sciences and one for microgravity research. Utilization of the second increment of lab volume will be highly dependent upon R&D requirements of Space Station Freedom. Pursuing a life sciences emphasis, this increment would allow the life sciences module to evolve into two facilities; one for human physiology research, and one for plan and animal research. The final increment along this path would add a facility for closed life support systems (CLSS) development including physiochemical processing and bioregenerative processes. If the utilization emphasis for Space Station Freedom is on microgravity research, the second laboratory increment would add another microgravity research module. The final step would involve the addition of one or more pilot processing plants for the testing of commercial production processes.

SYSTEM GROWTH REQUIREMENTS
PRESSURIZED MODULES

Pressurized volume includes common modules, resource nodes, and pocket labs; Space Station Freedom design must allow growth to a maximum of eight common modules

- Crew growth beyond eight requires addition of a habitation module
- Advantages of pocket labs for lab volume growth include:
  - Physical separation from common modules
  - Size and outfitting flexibility
  - Detachability
- Additional resource nodes provide interconnect to growth modules and additional berthing

SSF Lab Volume Growth

Phase 1	**Increment 1**	**Increment 2**	**Increment 3**
Multipurpose US Lab	Life Science Lab	Human Physiology Lab Plant & Animal Lab Microgravity Research Lab ***Life Sciences Emphasis***	Human Physiology Lab Plant & Animal Lab CLSS / CELSS Lab Microgravity Research Lab
	Microgravity Research Lab	Life Science Lab Microgravity Lab #1 Microgravity Lab #2 ***Microgravity Research Emphasis***	Life Science Lab Microgravity Lab #1 Microgravity Lab #2 Materials Processing Pilot Plant
Internationals	Internationals	Internationals	Internationals

System Growth Requirements - Crew Support

Analysis of mission requirements has revealed trends in the ratio of crew to pressurized laboratory volume for an R&D utilization of Space Station Freedom. For each lab module, a number of crew between four and four and a half is required to fully utilize the laboratory capabilities. This implies that for the Assembly Complete configuration of three lab modules, the total Space Station crew size should optimally be between 12 and 14. Growth to five lab modules and 2 or more pocket labs will require crew growth to as many as 24.

A significant issue associated with increasing the size of the permanent Space Station Freedom crew is the requirement to rotate the crew (i.e., return and replace station crew once their tour of duty is complete). The burden crew rotation places on the Space Shuttle in terms of visits to Space Station Freedom each year is driven by the tour of duty length for each station crew member (i.e., the stay time on station) and the size of the Space Station crew. The ability of the Space Shuttle to rotate crew is measured by the number of station crew it can rotate with each visit to the Space Station. Crew tour of duty must be extended to at least 180 days through the validation of effective microgravity countermeasures and the number of crew rotated per Shuttle flight must be increased to at least 5 to support station crew growth to 16 and beyond.

SYSTEM GROWTH REQUIREMENTS
CREW SUPPORT

The Space Station Freedom crew size may grow as large as 24 in support of multidisciplinary R & D activities and core station maintenance

- Between 4 and 4.5 crew (total) are needed to fully utilize each laboratory module
  - Phase 1 configuration requires 12 to 14 crew for full utilization (with Phase 1 crew size of 8, an average of less than 1 crew person will be working in each module at any one time)
  - A growth configuration including 5 laboratory modules will require between 20 and 24 crew for maximum utilization
- Ability to rotate crew depends upon frequency of Shuttle visits, number of crew rotated per Shuttle flight, and crew stay time at Space Station Freedom

SSF Crew Size	Crew rotated per STS	Stay time (days) 90	120	180
4 (PMC)	4	4	NA	NA
	5	4	NA	NA
8 (AC)	4	8	6	NA
	5	7	5	NA
16	4	16	12	8
	5	13	10	7
24	4	24	18	12
	5	20	15	10

INTEGRATED GROWTH CONCEPT

Integrated Growth Concept - Growth Deltas

Incremental growth analysis of Space Station Freedom led to the development of a generic set of "growth deltas" (i.e., additions of station hardware which provide an increment in capability). These growth deltas were derived from a synthesis of growth requirements from the 14 scenarios examined.

The level of transportation support to Space Station Freedom affects the growth deltas in two ways. First, the speed at which the station grows (how quickly the deltas are achieved) is driven by the transportation model. Secondly, the number of achievable deltas is limited by the transportation model which supports station logistics resupply and new user accommodation in addition to station growth elements.

Assuming a moderate transportation model, one to two deltas are met with each year of station operation, with all deltas being accommodated within 10 years of Assembly Complete. An aggressive transportation model will allow growth through delta 12 in just 6 years.

INTEGRATED GROWTH CONCEPT
GROWTH DELTAS

Δ 1 - Solar Dynamic Module Pair; 2 - 25m Transverse Boom Extensions, Space-based OMV & OMV Accommodations

Δ 2 - Upper/Lower Keels & Booms

Δ 3 - 1 Hab Module; 2 Resource Nodes

Δ 4 - 1 Solar Dynamic Module Pair; Servicing Facility Phase 1

Δ 5 - 1 Large Pocket Lab; 1 Lab Module; 2 Resource Nodes; Servicing Facility Phase 2

Δ 6 - STV / STV Hangar; Assembly Platform; Servicing Facility Phase 3 (Competed Servicing Facility)

Δ 7 - 1 Lab Module; Back Porch (if needed); 1 Resource Node (if needed)

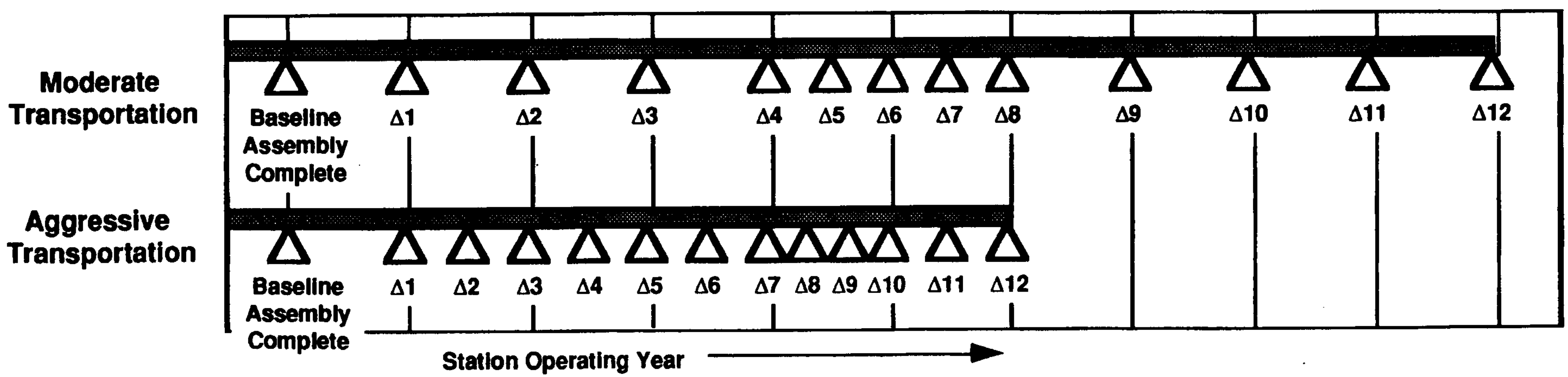
Δ 8 - 1 Solar Dynamic Module Pair; 2 - 25m Transverse Boom Extensions

Δ 9 - 1 Hab Module; 1 Resource Node (if needed)

Δ 10 - 1 Small Pocket Lab

Δ 11 - 1 Solar Dynamic Module Pair

Δ 12 - 1 Large Pocket Lab

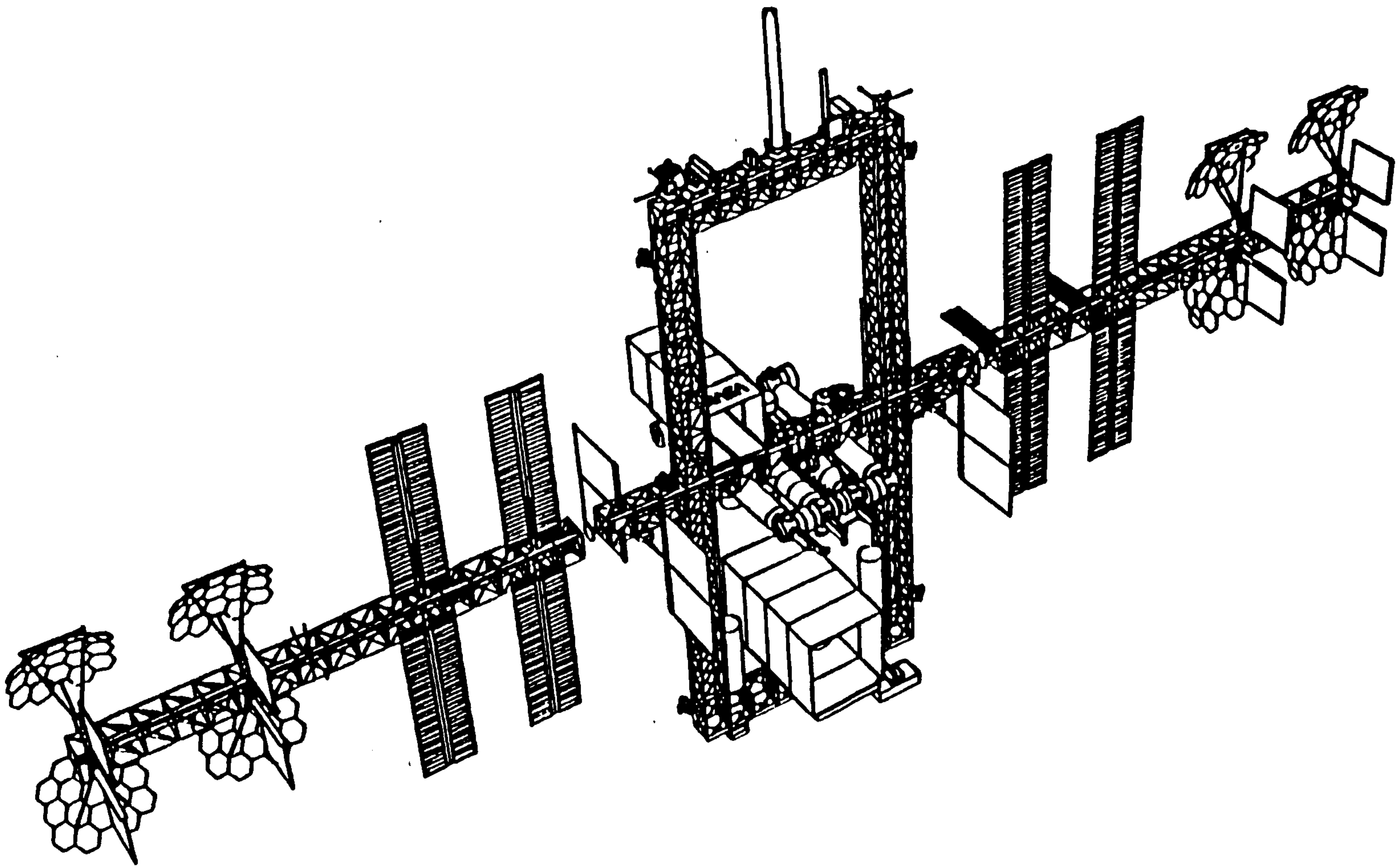


Integrated Growth Concept - Configuration

The "end-of-growth" R&D configuration includes the following features:

- Dual keels with the upper boom providing attach volume for solar and stellar viewing payloads and the lower boom providing attach volume for Earth viewing payloads in addition to an STV accommodations facility
- Additional power provided by 8 solar dynamic power modules which are mounted on extensions of the transverse boom
- Enhancement of the active thermal control system including increased umber of radiators on the aft panels and a second set of radiator wings projecting forward of the transverse boom
- Two additional habitation modules to permit an increase of the crew size to 24
- Two additional laboratory modules and two to three pocket lab modules to allow a greater volume of pressurized experimentation
- A customer servicing facility to allow servicing of free flyers and provide storage for spare ORUs.

INTEGRATED GROWTH CONCEPT
CONFIGURATION



Integrated Growth Concept - Keel Length & Scars

A trade study was performed to examine dual keel length requirements. The following drivers were examined in determining the required keel lengths: Shuttle docking clearances, large space structure assembly, technology development mission accommodations, space transfer vehicle (STV) accommodations, and microgravity environment (i.e., center of gravity location).

"Tail down" Shuttle approach and docking at one of the forward resource nodes is the baseline procedure. For the current configuration, a lower keel length of 6 truss bays provides adequate clearance between the orbiter tail and the lower boom. However, a seventh bay protects against potential configuration changes (e.g., attach point of the modules to the transverse boom or specific dimensions of the docking mast) which could result in violation of clearance requirements. The shuttle may also have the ability to dock tail up at Space Station Freedom. A minimum upper keel length of six truss bays is required to provide adequate clearance between the orbiter tail and the upper boom.

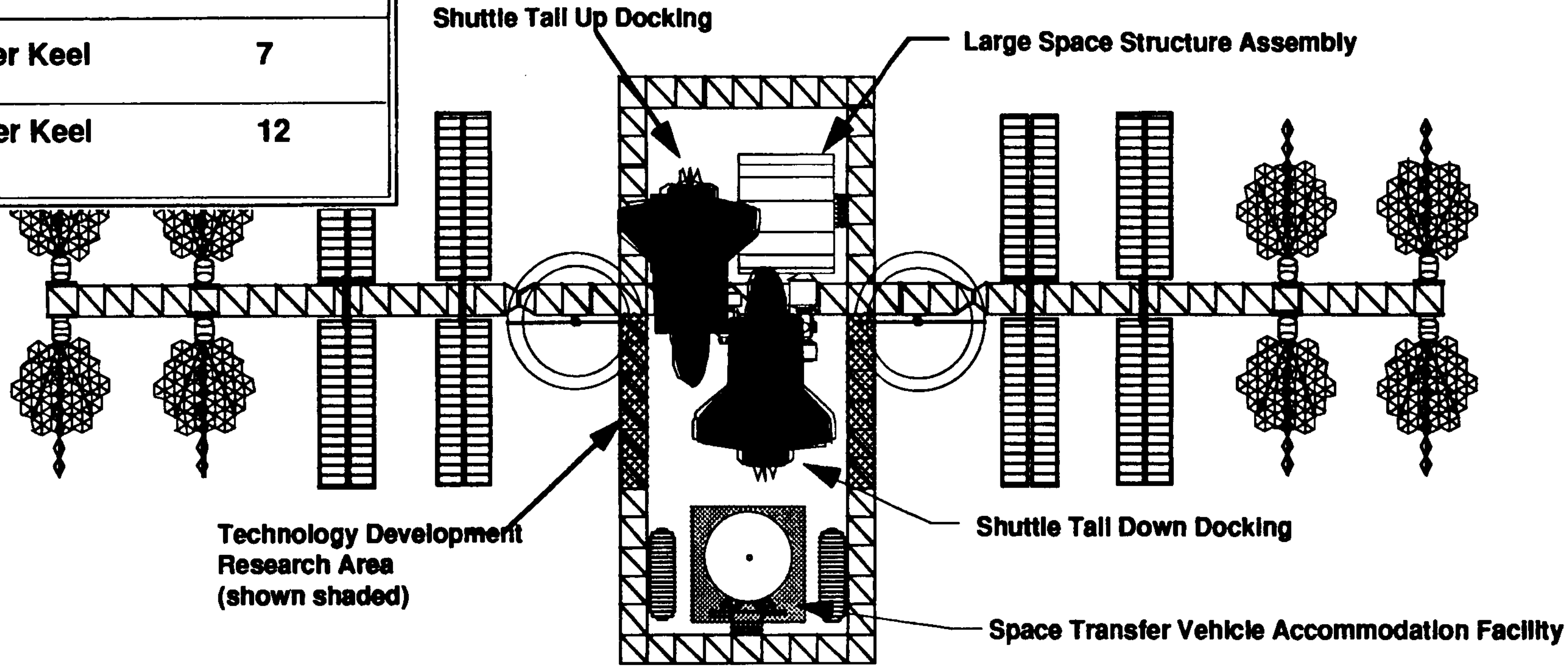
The area between the upper keels provides a location for assembly and construction of large space structures. The Large Deployable Reflector (LDR) is an example of a planned assembly structure and was used as a reference mission to size the upper keel. LDR is a 20 meter diameter by 17 meter long cylindrical payload. Allowing for a working clearance between the LDR and the upper and transverse booms, an upper keel length of 7 truss bays is required.

A technology Develop Mission (TDM) facility is being considered which would provide resources for the accommodation of a number of experiment. This facility may be housed within the truss structure of the keels and requires 6 continuous truss bays in either both upper keels or both lower keels. A lower keel placement was assumed for this analysis. The actual placement will be driven by Space Station Freedom mass properties considerations at the time of accommodation which in turn have an impact on microgravity levels in the pressurized modules and space station flight attitude (i.e., torque equilibrium attitude).

The STV accommodation facility is a structure capable of housing an STV with an aeroshell. This structure is centered on the zenith face of the lower boom. A lower keel length requirement of 12 truss bays is based on providing clearance between the STV accommodation facility and the docked Shuttle. For a space station configuration with the STV accommodation facility attached to the lower boom, a minimum lower keel length of 7 truss bases is required for Shuttle clearance.

INTEGRATED GROWTH CONCEPT
KEEL LENGTH & SCARS

Recommended Keel Lengths (5 meter truss bays)	
Upper Keel	7
Lower Keel	12



	Upper Keels / boom	Lower Keels / boom
Structure (keel length)	7 bays	12 bays
EPS	77 kW peak	78 kW peak
TCS	77 kW peak	78 kW peak
DMS	Yes, rate TBD	Yes, rate TBD
C & T	Yes	Yes
ECLSS	No	No
FMS		
Integrated Nitrogen System	Yes	Yes
Integrated Water System	Yes	Yes
Integrated Waste Gas System	TBD	TBD
EVA - Crew Access	CETA required	CETA required

Integrated Growth Concept - Module Pattern Development

The objective of this study was to examine options for module patterns on a growth Space Station in order to:

- Identify any issues related to module growth
- Specify scars, if any, to the Phase 1 station required to allow ease of module growth
- Develop supporting data for baselining a reference growth module configuration

Module growth requirements used in this study are the product of the Transition Definition Program, sponsored by the Level 1, Strategic Plans and Programs Office. These requirements have been reviewed and endorsed by the Evolution Working Group (EWG) and the User Accommodations Panel (UAP) and have been submitted as a change request to the SSP.

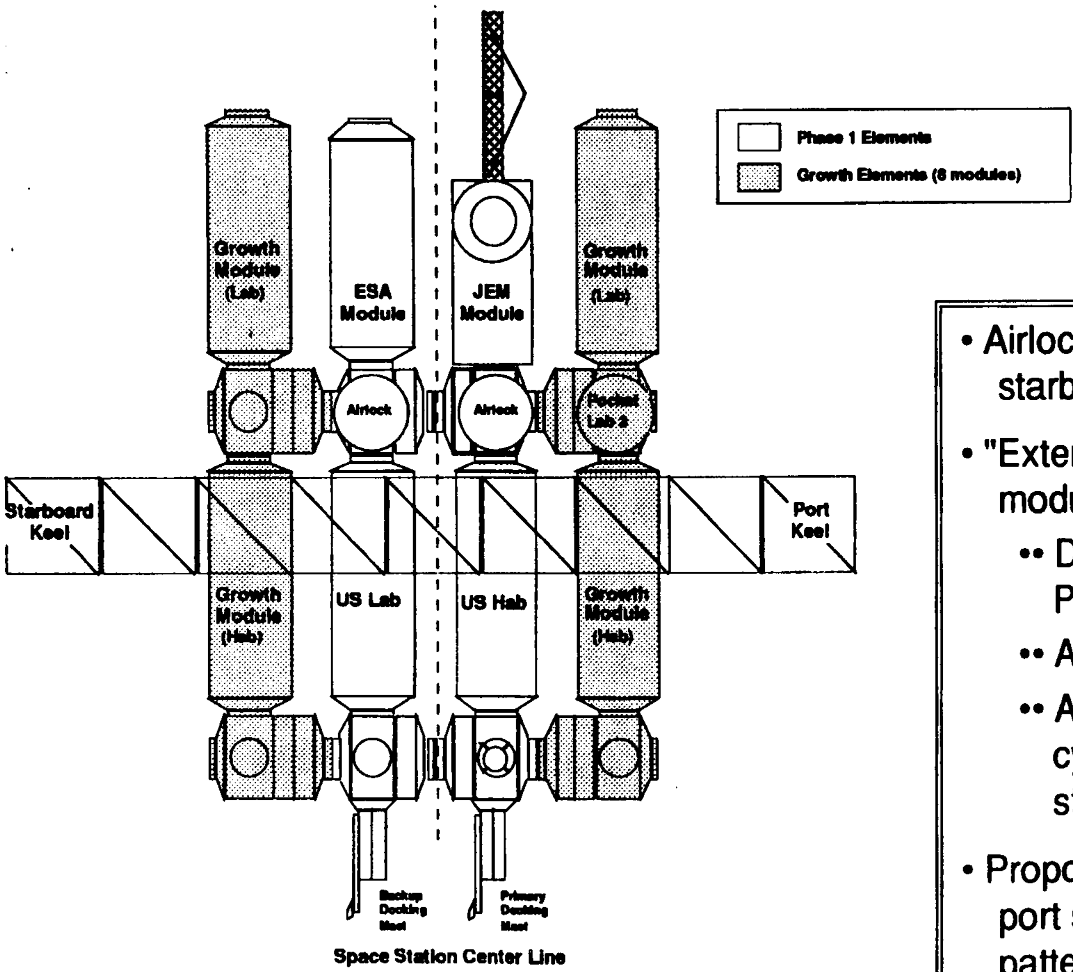
Maximum pressurized facility requirements, derived from analyses of both multidisciplinary science and new initiative support evolution options and including Phase 1 elements, include the following:

4 U.S. Laboratory Modules	1 Human Life Science; 1 Animal & Plant Science; and 2 Materials Processing OR 1 Materials Processing + 1 CELSS
1 ESA Laboratory Module	
1 JEM Module	
3 Habitation Modules	
3 Attached Pressurized Payloads (pocket or mini lab modules)	1 Sample Quarantine Facility; and 1 Commercial Materials Processing Facility + 4-Meter Centrifuge
OR 2 Commercial Materials Processing Facilities	

The total pressurized (common) module requirement of nine is one greater than the baseline growth requirement used in the Space Station Program Phase B definition studies.

INTEGRATED GROWTH CONCEPT
MODULE PATTERN

The module pattern for eventual growth to eight common modules will include four modules abreast forward and four modules abreast aft



- Airlock located on starboard axial port of aft starboard node must be relocated
- "Extended" resource nodes needed for growth module interconnect
  - Due to unsymmetric berthing of modules on Phase 1 pattern
  - Additional 42" length required
  - Additional length can be achieved with two cylindrical sections rather than one (no new structural design)
- Proposed location for customer servicing facility on port side of the US hab does not allow module pattern development

Integrated Growth Concept - Customer Servicing Facility Location

The objective of this study was to perform a systems level evaluation of alternate locations for the customer servicing facility. This was done in order to make recommendations for placement which will provide flexibility for module pattern growth. Specifically, study objectives included:

- Identifying operational impacts of alternate locations for the customer servicing facility
- Identifying Space Station interface and scar requirements for Phase 2 support of the customer servicing facility in order to insure adequate scarring for a growth location during Space Station evolution
- Identifying any Phase 1 Space Station configuration issues which may impact customer servicing facility relocation
- Identifying customer servicing facility design issues, if any, which may limit location alternatives
- Developing supporting data for baselining a growth location for the servicing facility

This study assumes initial placement of the customer servicing facility on the transverse boom during Phase 2 operations. No evaluations were made of alternate Phase 2 locations away from the pressurized modules.

The approach to the customer servicing facility location analysis included:

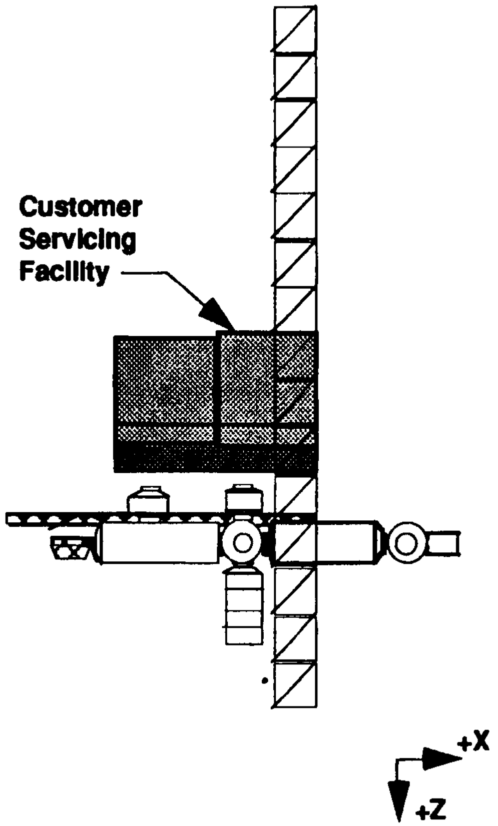
- Identifying customer servicing facility operational constraints which limit location and orientation alternatives
- Proposing feasible customer servicing facility location options
- Identifying location discriminators and performing trades comparing the location options

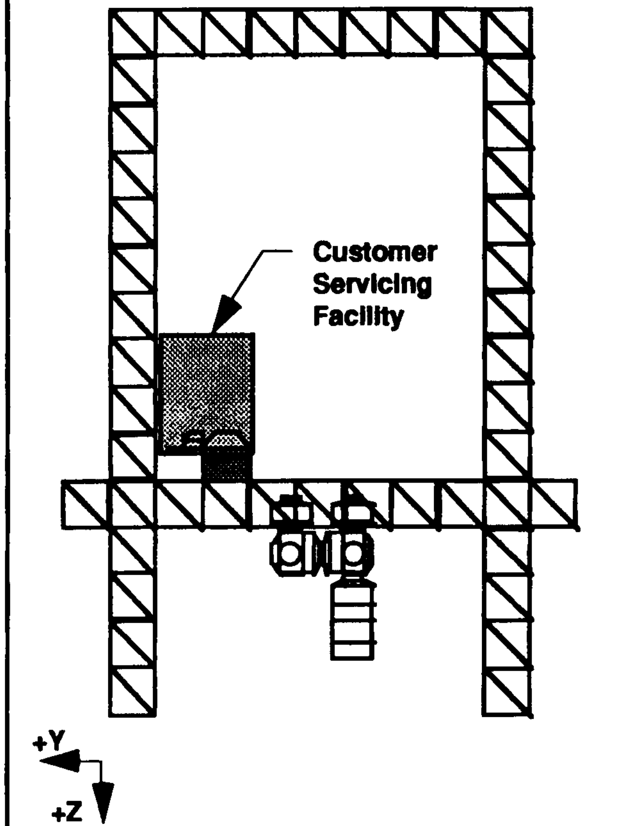
INTEGRATED GROWTH CONCEPT
CUSTOMER SERVICING FACILITY LOCATION

The Customer Servicing Facility (CSF) will be located on the zenith side of the transverse boom against the starboard keel (attached at upper starboard bay #3)

Advantages
- Minimal EVA travel time for access
- Capability to transfer payloads directly from the Shuttle cargo bay to the CSF with the CSF manipulator assuming orbiter tail-up docking capability
- Minimal impact to Space Station operational environment (pointing and control, μ-gravity environment, attached payloads viewing, aerodynamic considerations)

Issues
- Degraded CSF passive heat radiation capability caused by proximity to the main thermal radiators and the growth module pattern; potential thermal radiator sweep envelope clearance issues
- Hardware issues involved with a tail-up Shuttle final approach and docking required for direct Shuttle-to-CSF cargo transfer





Recommendations

The following recommendations are a subset of the recommendations and suggested Space Station Freedom Program requirements resulting from this FY1989 study. These recommendations pertain primarily to current configuration issues associated with the baseline program which impact evolutionary configuration development.

RECOMMENDATIONS

- Monitor changes to the baseline location of the TCS (Thermal Control System) radiator and recommend against any move to relocate inboard of truss bays SB7, PB6 (i.e., 2 bays inboard of the alpha joint)
  - TCS radiator sweep envelope during growth may be obstructed by other growth elements
  - Initial placement of the TCS radiator pallets should consider impact of module pattern growth, dual keel attach location, and location of other growth elements

- Relocate the hyperbaric airlock from the starboard side to the zenith side of resource node 1
  - The baseline location of the hyperbaric airlock is in the module growth path
  - Change to the baseline location will prevent a need to relocate on-orbit prior to module pattern growth

- Provide an area on the truss structure for unpressurized cargo and OMV storage
  - No storage area currently is planned within the baseline for unpressurized ORU storage
  - A storage and maintenance facility is required for a Space Station-based OMV

- Insure that the axial berthing ports of the baseline resource nodes can accommodate berthing of additional resource nodes allowing passage of crew and utilities
  - Outfitting concepts of the baseline nodes show the life sciences 2.5-m centrifuge mounted against an axial berthing port
  - Design of baseline nodes and equipment layout must not preclude module pattern growth

- Insure that attached payloads, antennas, pallets, carriers, and other equipment attached to the transverse boom are relocatable so that the module growth path and the dual keel attach locations are not obstructed

- Provide adequate internal volume within the baseline nodes and modules to accommodate pressurized system elements needed to support truss, power and attached payload growth