Space Station Freedom Transportation Node Concepts and Analysis

William M. Cirillo
Langley Research Center
February 7,1990

Overview

- o Study Objectives
- o Lunar Evolution Case Study Assessment
- o Mars Evolution Case Study Assessment
- o Lunar/Mars Exploration Initiative Assessment
- o Technology Needs Assessment
- o Summary

Transportation Node Concepts and Analysis Study Objectives

The objective of the Transportation Node Concepts and Analysis study task element of the Space Station Freedom Transition Definition program is to pursue those activities necessary to define and prepare for Space Station evolution in keeping with the needs of users and long-term national goals. The overall objectives are:

a. To define Station Station Transportation Node evolution configurations consistent with user requirements and program constraints

b. To define and incorporate baseline design accommodations (hardware "scars" and software "hooks") to satisfy evolution requirements

c. To identify advanced technology that ensures technology readiness to enhance station capabilities and to enable station evolution

The strategy chosen to implement the objectives relies on understanding future space options and the implications of these on today's decisions. The challenge to plan for Space Station Freedom evolution is to understand the probable evolution paths and the corresponding infrastructure options to the extent that current resources can be wisely allocated to the enabling design provisions (hooks and scars) and to the appropriate advanced development efforts. Thorough understanding of the forces and constraints requires close coupling of evolution mission requirements, space and ground infrastructure planning, technology development, and external policy imperatives.

The challenge to provide for Space Station Freedom evolution takes the form of keeping the options open to support future missions. Therefore, planning for evolution is necessarily conducted in parallel with the design and development of the baseline station. The aim is to preserve all dimensions of Space Station Freedom evolution: technology improvements / obsolescence avoidance; expansion of baseline capabilities; addition of new functional capabilities. To that end, this task leads the development of the transportation node reference evolution configurations in response to each OEXP case study, and the associated engineering data required to support the baseline preliminary design process. To ensure the design is capable of evolution, evolution design requirements are developed and advocated in program documentation and assessments are made of the evolutionary capability of baseline system designs. Further, the advanced technology needs required to support each case study will be identified.

Specifically, for the FY89 study period, two Office of Exploration (OEXP) case studies were analyzed to define Space Station Transportation Node growth configurations. A third OEXP case study had no Space Station Freedom user requirements an was not investigated to any depth.

Transportation Node Concepts and Analysis Study Objectives (concluded)

The first OEXP case study dealt with the establishment of a permanent lunar base on the near side of the moon beginning in 2004. This Lunar Evolution case study placed a large number of requirements on Freedom including accommodating and servicing two lunar transfer vehicles, storing large quantities of cryogenic propellants, and providing an orbital test facility for the development and demonstration of adavnced vehicle and base systems.

The other FY89 OEXP case study assessed the feasibility of by-passing the development of a lunar base and placing a permanent outpost on the surface of Mars in 2004. The SRD requirements levied on Space Station were not as great in this case study. No direct Mars transfer vehicle basing was mandated on Space Station. Instead a separate, co-orbiting assembly and processing facility was required. Space Station Freedom was stll required to provide an orbital facility for the testing and development of vehicle and base systems. In addition, Freedom was required to provide the capability to conduct research into the area of long-term crew exposure to a micro-gravity environment.

In addition to the two OEXP FY89 Case Studies, this task helped assess the role of Space Station Freedom in the Lunar/Mars Exploration Initiative. This 90 day study was conducted from August through October 1989 and presented five options for establishing a manned prsesence on both the lunar and Mars surface. Initial results indicate that the present Space Station Freedom assembly complete configuration is capable of evolving to meet the requirements of the Lunar/Mars Exploration Initiative if augmentations to the SSF program are made and the proper hooks and scars are implemented in the rephased program.

Objectives

- Develop Space Station growth concepts and perform human exploration misssion accommodation analyses to determine resource requirements for use of Freedom as a Transportation Node.
- Establish SSF Evolution Reference Configuration(s) for the Transportation Node emphasis.
- Develop design requirements for the SSF PDR which enable evolution of the Phase I configuration.
- Define Hooks & Scars for SSF Evolution Reference Configuration.
- Identify technology needs required to accomplish mission requirements

Lunar Evolution Case Study Assessment

Lunar Evoultion Case Study Outpost Capabilities*

The principle feature of this case study is the emplacement of a human-tended facility on the Moon that evolves into a permanently inhabited outpost capable of supporting crews of up to 12 people with significant self sufficiency. The lunar outpost is established through three phases of development: emplacement, consolidation, and utilization.

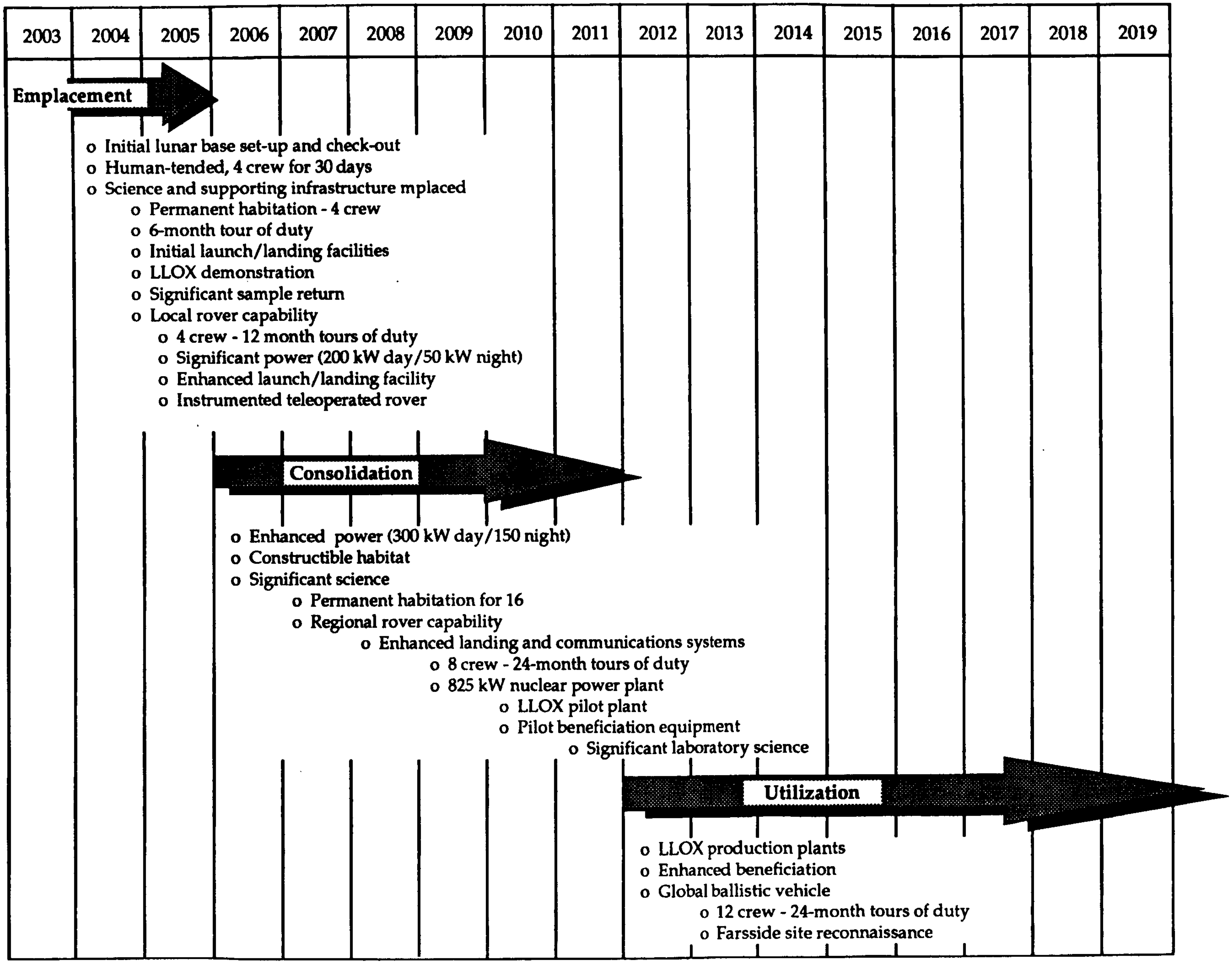
Emplacement Phase. The objective of the emplacement phase is to establish a permanent presence on the Moon and begin developing the knowledge base on how to work and live on a non-terrestrial body. Emphasis is placed on emplacing simple equipment and instrumnts on the lunar surface and laying the foundation for later, more complex surface operations by testing prototypes of more sophisticated systems. Operations on the lu nar surface are restricted to a range of tens of kilometers. Concurrently, the Earth-Moon transportation infrastructure is emplaced, and preparations are made to reuse the transportation elements and service these elements on the lunar surface and at Space Station Freedom.

Consolidation Phase. The objective of this phase is to consolidate permanent presence on the Moon and expand the knowledge base on how to live and work on a non-terrestrial body. Emphasis is placed on constructing surface systems, providing large pressurized volumes, and setting up more complex scientific instruments and laboratories on the lunar surface. Surface operations are expanded to a distance of hundreds of kilometers. Of paramount importance is reducing the supply line from Earth in both a fiscal sense, "exploration wedge", and in developing confidence in operational strategies and element subsystems for future exploration objectives. This is accomplished by relying on more efficient and reliable systems for life support and outpost operations and by testing prototypes of in-situ resource production plants to be operated during the utilization phase.

Utilization Phase. The objectives of this phase are to utilize in-situ resources and to continue to expand the knowledge base of how to live and work on a non-terrestrial body. Production of lunar oxygen reaches a sufficient level to begin fueling lunar based transportation vehicles. At the completion of this phase, further expansion of the outpost is curtailed to allow other planetary exploration missions to begin within a steady level of funding.

* This overview of the Lunar Outpost was taken from an Office of Exploration FY89 Annual Report draft.

Lunar Evolution Case Study Outpost Capabilities



Lunar Evolution Case Study Requirements

In order to better understand the relationship and interaction between Space Station Freedom and the other Office of Exploration (OEXP) program elements (e.g. ETO vehicles, STV's, propellant storage/transfer methods) the utilization of Freedom has been intentionally varied from case study to case study. For the Lunar Evolution case study the OEXP Study Requirements Document (SRD) specifies a major utilization of the Space Station's functional capabilities and resources. The detailed list of requirements is given in the following table.

SRD Specified Lunar Evolution Case Study Space Station Freedom Requirements

- o Provide capability to support advanced development systems for lunar base and space transportation.
- o Provide capability for housing transient mission crew, support crew, and mission equipment.
    - Transient mission crew (Outbound): Pre-experimental phase support mission crew of 4; Experimental phase and beyond support mission crew of 8
    - Transient mission crew (Inbound): Accommodate a crew of 8
    - Mission support crew: Accommodate a support crew of 6, for 6 month tours of duty, twice per year
    - Mission equipment: Accommodate 5 metric tons of cargo
- o Provide Space basing accommodations to satisfy LEO traffic requirements for STV's.
- o Provide the capability to store lunar mission equipment awaiting transport to the lunar system. In addition SSF shall provide the capability for mission equipment:
    - State of health monitoring
    - Assembly
    - Integration
    - Check-out
    - Preparation for transport by STV
    - Other on-orbit processing, as required
- o Provide capability to process space transfer vehicles on-orbit by supporting the following:
    - Vehicle mating/assembly and demating/disassembly
    - Space Construction of elements of STV's
    - Element and integrated vehicle on-orbit check-out
    - Maintenance and servicing of departed and returning lunar STV's
    - Deployment and retrieval of lunar STV's
    - Ground communications with STV's (while berthed?)
    - Provide housekeeping resources and services to STV's and nodes
    - Loading and unloading of mission equipment from STV's and/or ETO vehicles

  * Maximum vehicle processing time is currently TBD.
- o Provide the capability to support on-orbit supply and resupply of:
    - Life support system fluids
    - Cryogenic and storable propellants
    - Mission equipment

  This includes providing for:
    - Fluid storage
    - Determination of fluid quantities
    - Fluid transfer interface capability
    - Operational control
- o Provide debris protection for STV's and mission equipment while resident at SSF.

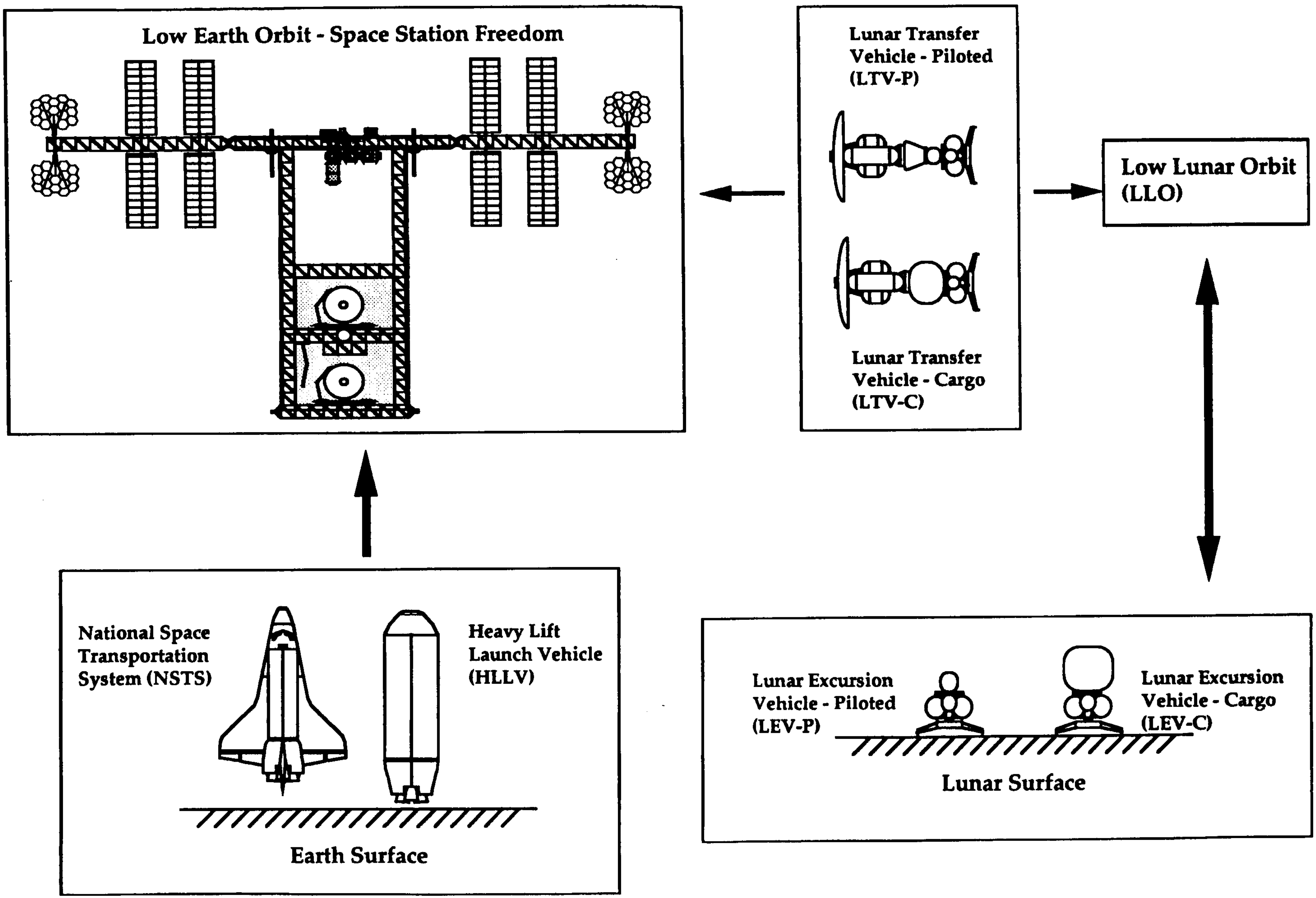
Lunar Evolution Case Study Mission Architecture

The overall Lunar Evolution case study mission architecture is illustrated. Earth-to-Orbit (ETO) transportation is accomplished with Space Shuttle (STS) flights delivering personnel and a small amount of payload, while a Shuttle-C system delivers the Lunar Transfer Vehicle (LTVs) systems, heavy payloads, and the mission propellants to Space Station Freedom.

Upon delivery to the Space Station, the lunar base payloads (habitat's, laboratories, rovers, etc.) are mated to a space-based LTV. Once mating, and checkout of all vehicle systems has occurred, the LTV is loaded with Shuttle-C delivered cryogenic propellants. The LTV the departs Low Earth Orbit (LEO) for a Low Lunar Orbit (LLO) rendezvous with the lunar surface based Lunar Excursion Vehicle (LEV). After LLO orbital operations have been completed (payload, crew, and propellant transfer) the LEV returns to the lunar surface and the LTV returns to the Space Station for any required servicing and/or refurbishment.

Based on currently designed mission manifests, 6 Shuttle-C flights and 2 Space Shuttle flights are required each year to support the 2 LTV delivery missions to LLO.

Lunar Evolution Mission Architecture



Lunar Evolution Case Study Resource Requirements

The magnitude of effort needed to support the Lunar and Mars Evolution case studies requires that the Space Station provide increased resources and capabilities. This expansion of the performance envelope includes such basic resources as crew, power, interior volume, and exterior work space. The plan for accommodating the case studies called for using the requirements specified in the Office of Exploration (OEXP) Study Requirements Document (SRD) to establish evolutionary Freedom resource and facility requirements. These requirements were initially submitted as part of the baseline Preliminary Requirements Review (PRR) that was held in May and June of 1988. The transportation node growth requirements are presently being refined and combined with the Multidisciplinary Research and Development reference configuration growth requirements into a set of composite evolution growth requirements. This composite set of growth requirements will be submitted to the Space Station Freedom Preliminary Design Review (PDR) in 1990. The specific resource requirements for the Lunar Evolution case study are shown in the accompanying figure.

Additional habitable volume will be required on Freedom to accommodate both the lunar transfer vehicle (LTV) mission crew and vehicle processing crew. Vehicle processing analysis results indicate that a processing crew of 4, working 8 hour shifts is capable of meeting the yearly lunar mission flight rate of 1 cargo and 1 crew flight per year. Adding this processing crew to the 4 transient mission crew indicates the need for an additional Space Station habitation module. In order to mate the additional habitat module to the existing module cluster two resource nodes, greater in length than the presently designed node, are required. The extended resource node is required to satisfy the current Freedom requirement of maintaining enough clearance (2.1 meters) between Freedom modules to allow an EVA astronaut to pass inbetween and make repairs if necessary.

In addition to the habitat module, addional truss and utility runs are required to provide resources (power, fluids, data, etc.) to the LTV processing facilities located on a lower keel and boom structure. This processing facility will eventually evolve to accommodate 2 LTVs on-orbit at the same time. The processing facility will have a docking/berthing attachment, an assesmbly/mating/servicing track along which a teleoperated remote manipulator system can operate, and will be enclsed by a combination aluminum/multi-layer insulation (MLI) blanket to provide micrometeoroid and thermal protection.

100 kW of dynamic power is required to provide the additional power for the habitat, resource nodes, and LTV processing facilities.

The ability to evolve to these levels of capabilities preserves the option to accommodate, at a top level of functionality, the OEXP Lunar Evolution case study which requires Space Station Freedom as a part of the overall infrastructure.

LUNAR EVOLUTION CASE STUDY
TRANSPORTATION NODE RESOURCE REQUIREMENTS

Station Resource	Current Recommendation
Power	
Average	175 kW
Peak	NA
Crew	18
Pressurized Modules	
US Habitation	2
US Laboratory	1
ESA Laboratory	1
JEM Laboratory	1
Pocket Laboratory	0
Resource Nodes	6
Transverse Boom	
Dual Keel	Scar for distributed systems
Servicing Facility	Scar for facility and distributed systems
Power Modules	Scar for addition of power modules at boom ends
Payloads	
APAE	TBD
Location points for APAE	TBD
Tether Payloads	2

Lunar Evolution Time-Phased Space Station Freedom Growth Deltas

The time-phased Space Station Freedom growth augmentations, or growth deltas, are shown. These growth deltas reflect major incremental increases in various resources including power, habitable volume, truss, payload attach points, etc. The growth deltas do not reflect the actual hardware manifesting on a flight-by-flight basis, but instead illustrate major incremental increases in various resources including power, habitable volume, structure, etc. The growth increments are shown in this manner because the time-phasing of the additional Space Station hardware elements are directly related to the amount of transportation support that Space Station receives after assembly complete.

LUNAR EVOLUTION CASE STUDY TIME-PHASED SPACE STATION FREEDOM GROWTH DELTAS

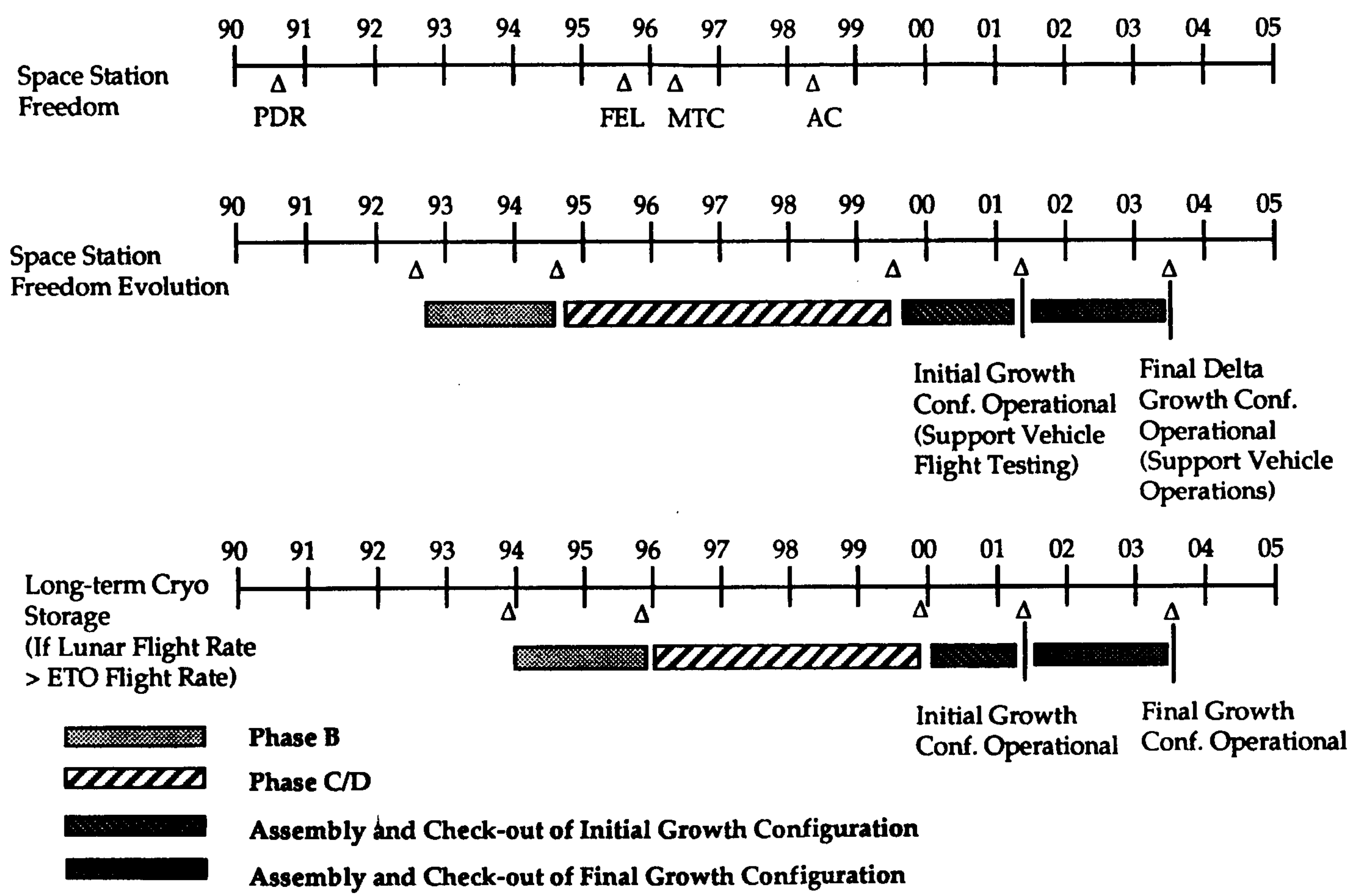
- Δ1 (2 - 25 kW) Solar Dynamic Modules; (2) 25 meter Transverse Boom Extensions; Space Based OMV & Space Based OMV accommodations
- Δ2 Lower Keels & Booms; Utility Trays
- Δ3 (1) Habitat Module; (2) Resource Nodes
- Δ4 (2 - 25 kW) Solar Dynamic Modules; Servicing Facility Phase 1
- Δ5 Servicing Facility Phase 2
- Δ6 Phase 1 STV Processing Facility; Phase 3 Servicing Facility (Completed CSF); (1) MSC; Shuttle-C Docking Adapter
- Δ7 Additional Lower Keel and Boom Truss Structure; Utility Trays
- Δ8 Phase 2 STV Processing Facility (STV Processing Facility complete)

Lunar Evolution Case Study Programmatic Schedule

Based on the currently proposed Lunar Outpost mission scenario a two phase Space Station evolution process has been developed. T he first phase, growth deltas 1 through 6, will provide the Space Station with the capability to process 1 expedable LTV/LEV system with accompanying payload. The second phase when complete, growth delta 8, will have the capability to accommodate 2 reusable LTV/LEV systems and associated mission payload.

It is important to note that initial growth hardware delivery must begin in 1999 in order to support the defined Lunar Outpost mission. Any additional delays in the current baseline Freedom program could impact the Space Station's ability to meet the designated mission requirements.

Lunar Evolution Case Study Programmatic Schedule



Growth Configuration Analysis

Several candidate evolution configuration options were analyzed using the ten discriminators listed below The discriminators with the greatest weighting factor were the controllability, operability, and the static micro-gravity environment for each option. It is desirable to have an evolution Space Station that would serve primarily as a transportation node, and yet provide a quiescent research and development environment when no major vehicle processing activities are occurring. To this end, configurations were sought which would provide all of the functional capabilities of a transportation node (LTV processing, propellant storage and transfer, payload accommodation, etc.), minimize operational impacts on Freedom (controllability, reboost propellant, crew time, etc.) and still provide a suitable microgravity environment.

In order to determine which configuration(s) would be most suitable for each phase of evolution the following analyses were conducted on each configuration:

a. Generation of solid computer models using $IDEAS^2$ software system
b. Mass properties determination including, center of mass and moments of inertia
c. Open-loop control system sizing including secular and cyclic momentum determination and torque equilibrium angle (TEA) determination
d. Closed-loop control system sizing including secular and cyclic momentum determination and TEA determination
e. Microgravity envelope calculation
f. Orbital decay and propellant reboost assessment
g. Space Station growth element and STV/payload clearance analysis
h. Module cluster field of view determination
i. Electrical Power and thermal rejection determination
j. Structural dynamic characterization including, system modes, forced response (only on selected configurations)

The Interactive Design and Evaluation of Advanced Spacecraft (IDEAS**2) Computer Aided Engineering (CAE) system was used to assess spacecraft design capabilities to meet mission goals and requirements by performing analytical simulations of spacecraft performance in the dynamic environment of space. The IDEAS**2 computer software modules include structural synthesizers; orbital mechanics simulators; aerodynamics, gravity gradient and solar-pressure orbital environmental synthesizers; solid geometry and finite element modelers; on orbit static, dynamic and structural analyzers; thermal analyzers; structural element design modules; subsystem design database; performance parameters; and cost and reliability analysis algorithms. These multidisciplinary analytical tools are interfaced such that data from one module can be accessed by other modules in an interactive process which provides the capability to evaluate spacecraft systems design concepts whose performance predictions include disciplinary interaction.

SPACE STATION GROWTH DISCRIMINATORS

Discriminator	Measures of Effectiveness
Space Station Control	TEA, CMG momentum storage requirements Roll magnitude to dump secular momentum
Structural Capability	Truss member structural integrity under reboost loads Controls-Structures Interaction acceptability
Operational Capability	Ability to perform all vehicle processing requirements
Microgravity Environment	Highest microgravity level in the US Lab module TEA (affects micrgravity gradient along the Space Station x-axis)
Viewing	Stellar viewing from the JEM exposed facilties: % viewing blockage Greatest field of view Average swath angle
Main Radiator Interference	Clearance between radiator wing and growth elements
Module Closure / Dual Egress	Number and length of time with modules having less than half closure (racetrack) or lack of dual egress (two ways out)
Structure / Ease of Assembly	Number of modules along the transverse boom Number of modules within MSC reach
Ability to Accommodate Further Growth	Number of free and useable berthing ports on the final configuration
Growth Mass	Total weight of growth elements (approximate measure of cost)

Recommended LTV Configurations

As was described earlier, Space Station evolution occurs in two phases. The first phase will accommodate both an initial Lunar Transfer Vehicle (LTV) verification flight and then several expendable LTV flights. To support the initial LTV verification flight a preliminary servicing track assembly is attached to a lower keel and boom truss structure. This configuration, figure 1, provides (1) gravity gradient flight stabilization, and (2) Space Shuttle docking/berthing clearance. Also, an additional habitat module and two solar array modules are required to support LTV processing operations. In order to accommodate the next several expendable LTV flights a hanger is attached to the servicing track assembly to provide orbital debris protection as illustrated in figure 2.

The second phase of Space Station evolution requires the addition of a second LTV processing facility, figure 3, to accommodate the two reusable LTVs that are stored permanently in low Earth orbit.

Recommended LTV Verification Configuration

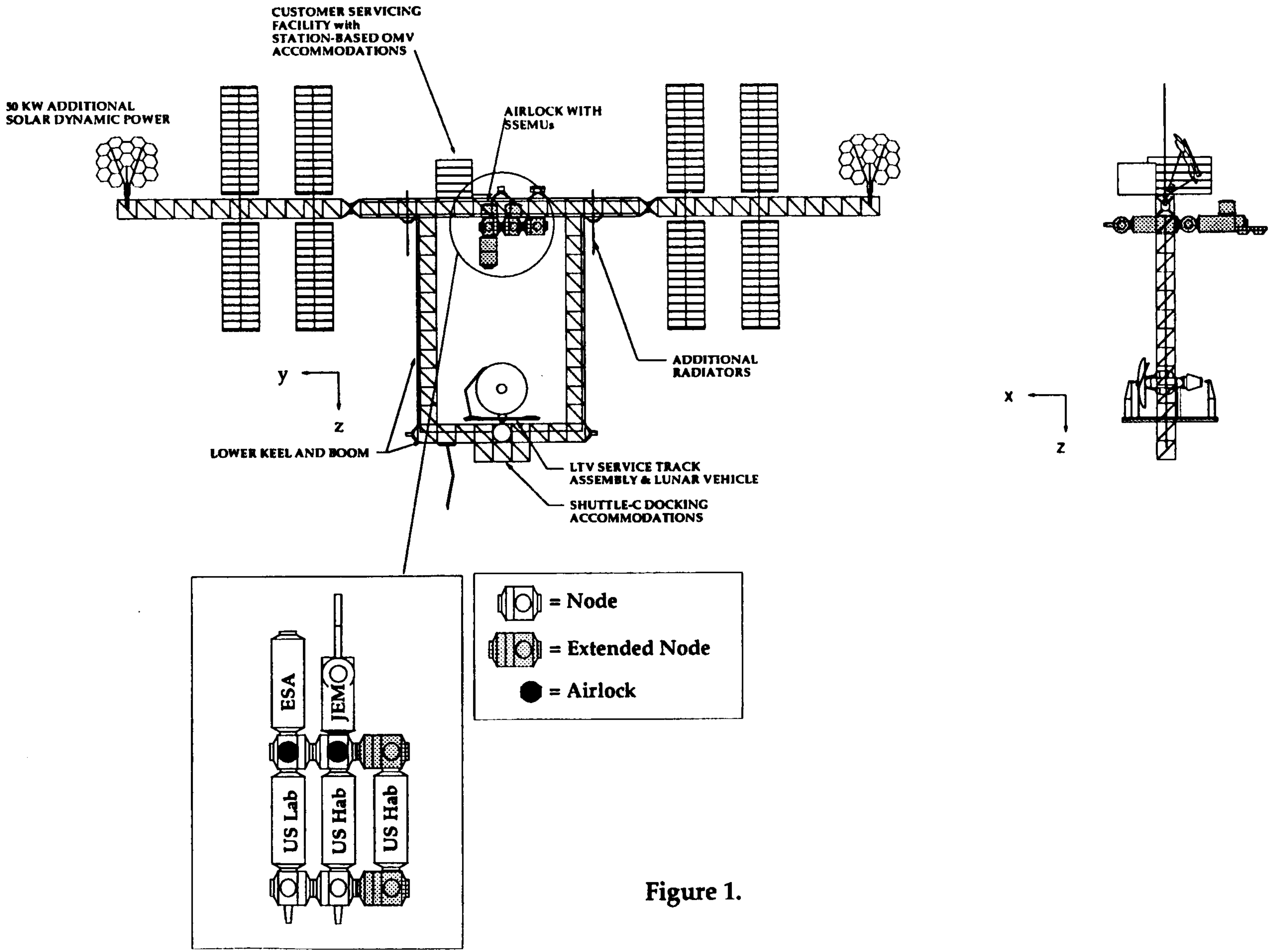


Figure 1.

Recommended LTV Processing Configuration (1 LTV)

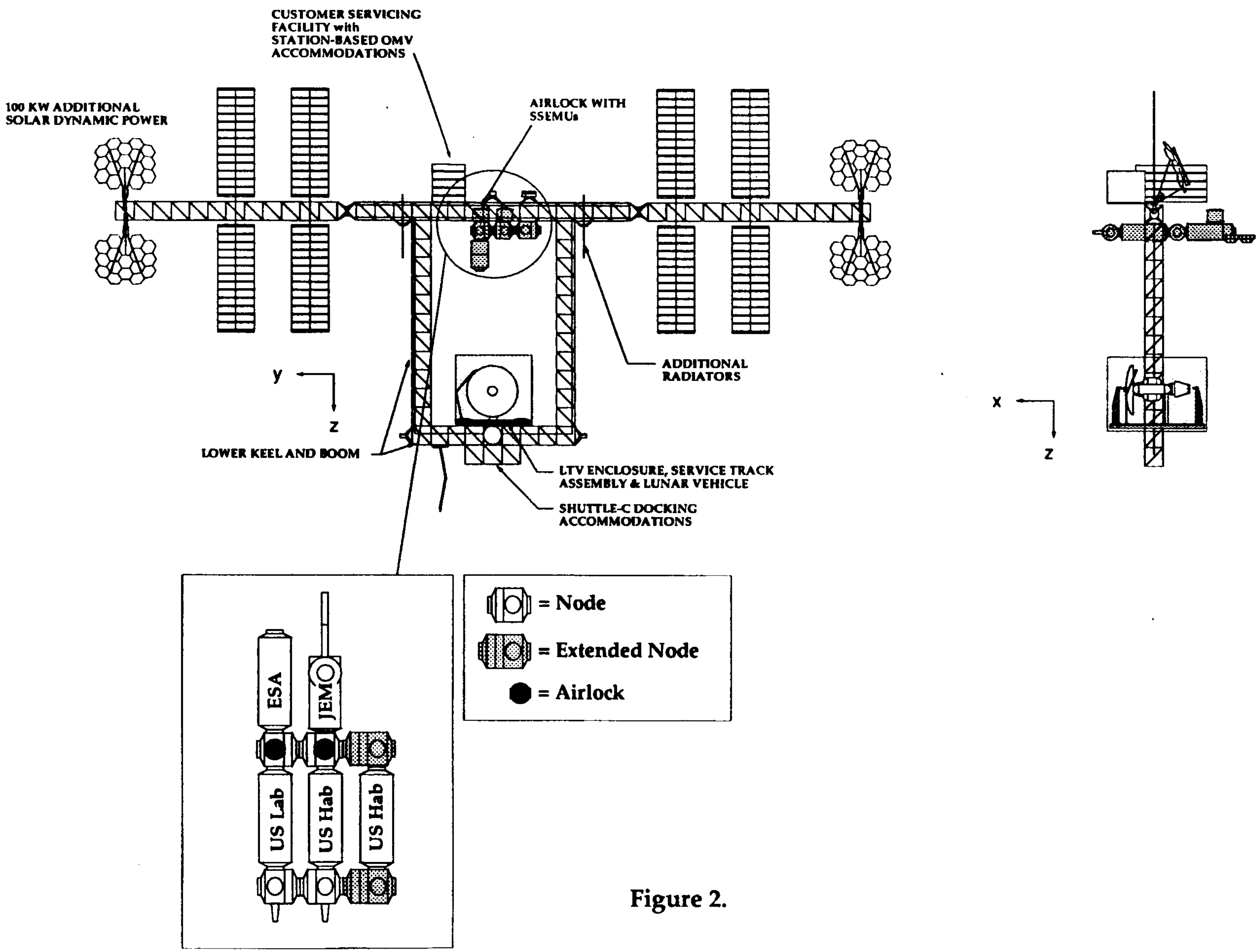


Figure 2.

Recommended LTV Processing Configuration (2 LTV's)

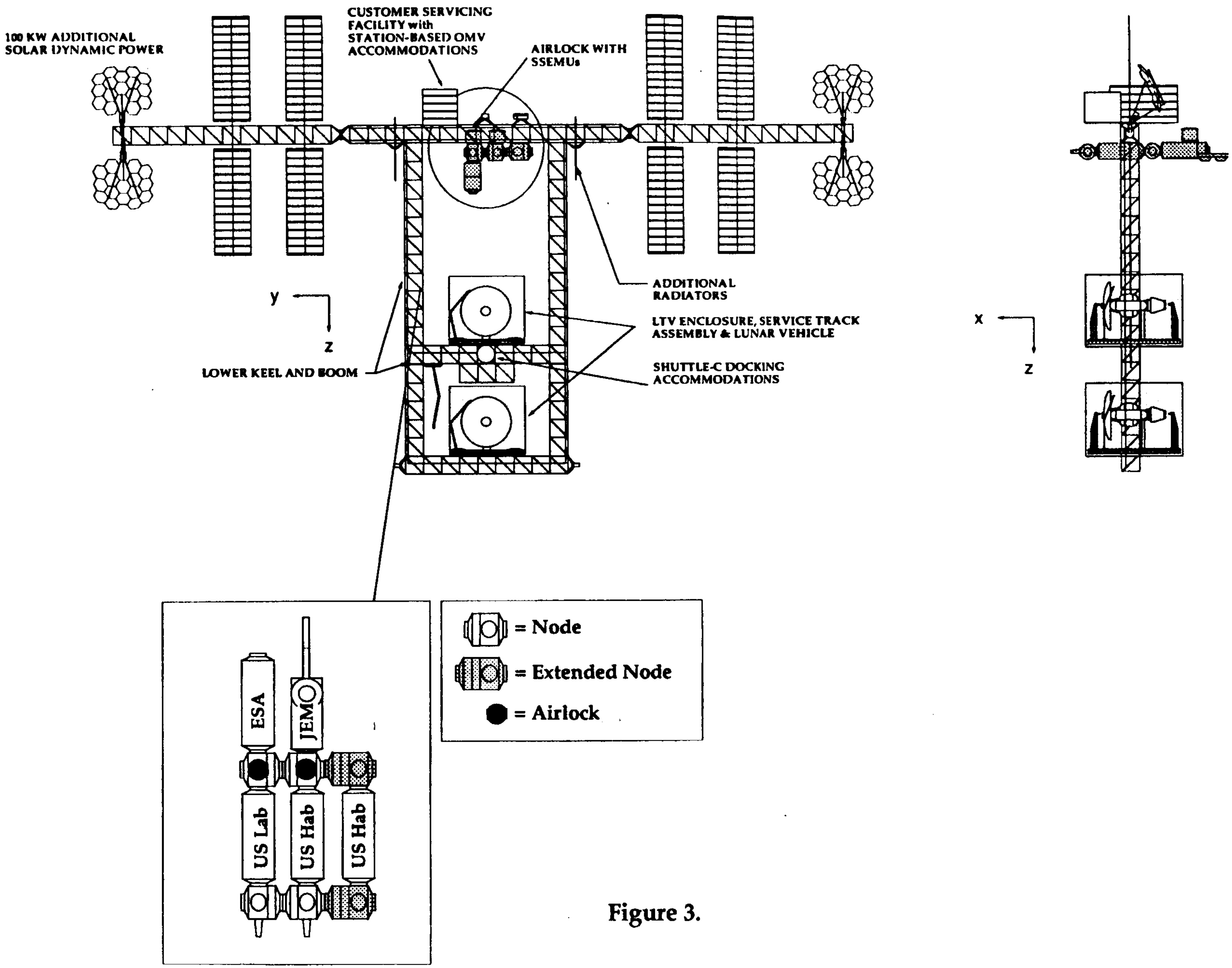


Figure 3.

Earth to Orbit Manifest Options for Space Station Freedom Growth Harware

A top-level assessment of the manifesting of ETO launches required to achieve the final growth delta is shown below, for both an Advanced Solid Rocket Motor (ASRM) enhanced Space Shuttle launch system, and an expendable Shuttle-C launch vehicle. As anticipated, a greater number of Space Shuttle flight is required to launch the Freedom growth hardware than would be required if a Shuttle-C launch vehicle was used. However in this preliminary study, the Shuttle-C configuration chosen was under utilized in its available launch mass capability for a majority of launches. This result indicates that a detailed assessment of the design and manifesting of an alternative ETO launch system to the Space Shuttle is required to optimize ETO payload launches.

Earth to Orbit Manifest Options for Space Station Freedom Lunar Evolution Case Study Growth Hardware

SEQUENCE \ FLIGHT		1	2	3	4	5	6	7	8	9
Lunar Evolution Configuration 3 Manifest Using Space Shuttle	Mass	●	●	●	●	●	●	●	●	●
	Volume	●	●	●	○	●	●	●	●	●
Lunar Evolution Configuration 3 Manifest Using Shuttle-C	Mass	●	○	○	○	○	○			
	Volume	●	●	●	●	●	●			

● - Greater than 90% of available launch vehicle mass/volume utilized for cargo deleivery

○ - Less than 90% of available launch vehicle mass/volume utilized for cargo deleivery

Lunar Transfer Vehicle Processing Operations

The overall timeline for lunar vehicle refurbishment (lunar vehicle berthing at SSF through deployment from the propellant depot for launch) is shown below. This timeline is a summation of the timelines discussed above for the refurbishment of each major engineering systems.

Post Flight Operations: Upon return to SSF from the lunar mission, a self-diagnostic health check will be performed on all vehicle systems to verify a safe condition (no fluid/gas leaks, etc.) and a visual inspection (similar to an arriving STS) will be performed prior to entering the SSF servicing hangar. Appendages will be retracted (high gain antenna, etc.). An advanced OMV will bring the vehicle within grappling range of one of the servicing hangar manipulator arms, which will then berth the vehicle. This phase also includes the vehicle deservicing flows. After berthing in the SSF hangar, the vehicle will be connected and switched to SSF facility power, fluids, gases, and data system. Vehicle systems will be powered down, and residual propellants will be drained. Vehicle inspection will be performed.

Refurbishment Operations: For the purpose of determining on-orbit timelines, manpower, and resource requirements, the refurbishment of the lunar vehicle was broken down into six engineering systems:

Aerobrake Refurbishment. Deployable aerobrake configuration is used which requires replacement every five flights. TPS repair is performed "as needed" between aerobrake replacement. Tile cavities are repaired using the spray-on/fill-in ablative repair kit developed for Shuttle. Fabric tears and punctures are repaired with patches.

Propulsion System Refurbishment. Aerobrake will be removed to provide access for engine replacement. The only propulsion ORU's identified for EVA/RMS operations are the engines, cryogenic tanks, pneumatic tanks and regulator panels, RCS thrusters and some instrumentation. Other EVA/RMS required servicing consists of engine internal inspections, engine drying, minor nozzle cooling tube repair, and turbo pump gear box oil servicing. System pressure decay tests will be used to verify system integrity. Individual valve and joint leak checks will be done on a contingency basis. Other engine and pneumatic regulator panel components can be serviced if done in a shirt sleeve environment of a pressurized pocket lab, and will be studied at a later date.

Fuel Cell Refurbishment. Fuel cells can be serviced in-place via access panel. Crew Module (CM) battery removal, charging, and open circuit voltage checks will be performed post flight. Batteries will be reinstalled during vehicle closeout activities.

Thermal System Refurbishment. Radiator panels are located on exterior of avionics bays which allows for modular replacement and coolant loop servicing by EVA or robotic operations. MLI replacement or repair is performed on an "as needed" basis.

Lunar Transfer Vehicle Processing Operations (continued)

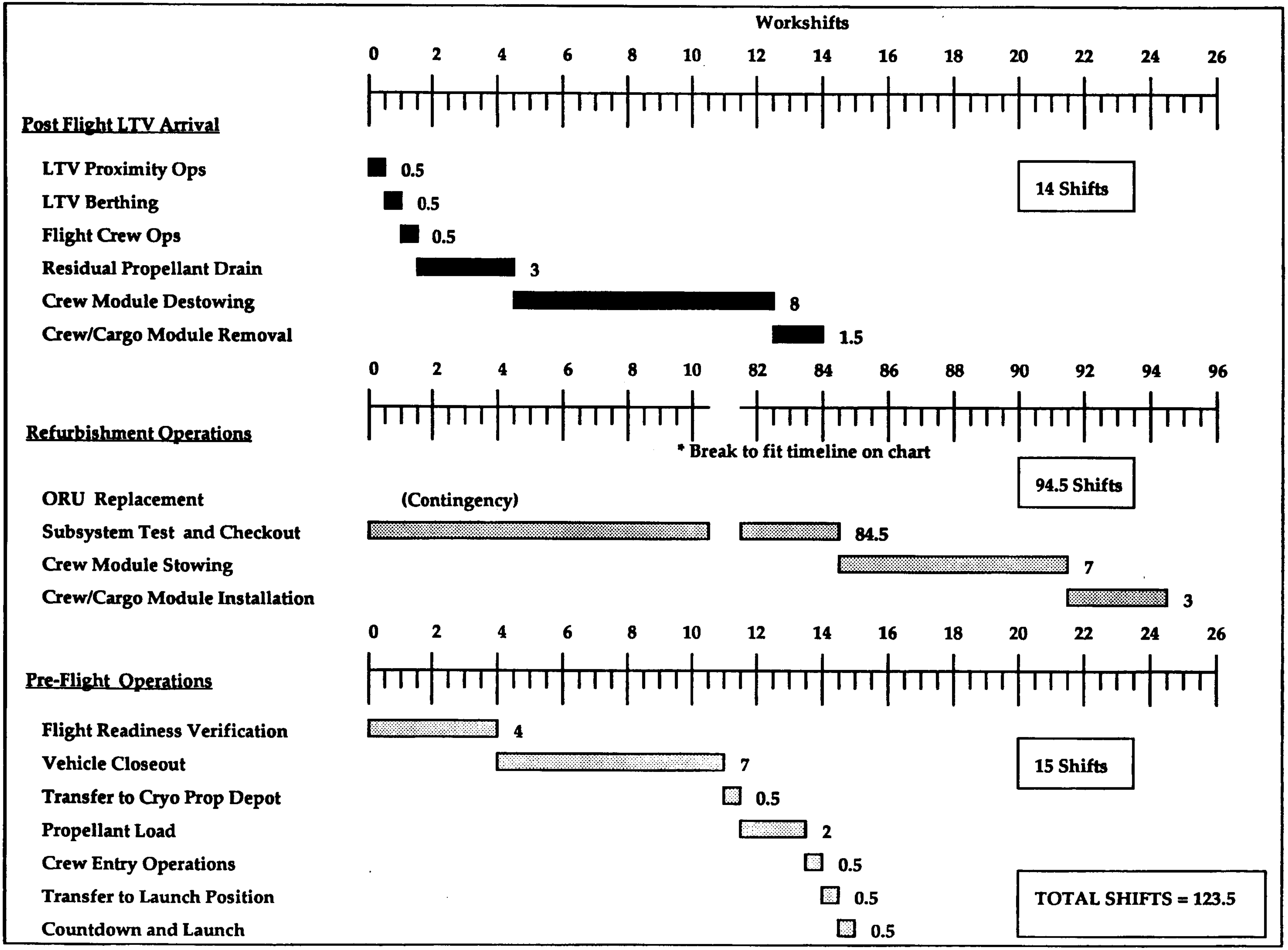
Avionics System Refurbishment. ORU replacement of avionics ring boxes may require cargo or crew module removal unless ORU is accessible through access panel or by radiator panel removal. Crew module avionics boxes will be replaced IVA as required. Antenna repair / replacement will be performed on an "as needed" basis.

Crew Module Refurbishment. Refurbishment of crew module is visualized as being very much the same as Shuttle refurbishment operations. Lunar missions and shuttle missions are approximately the same duration with similar crew size and crew module internal space. Replacement of crew consumables is by lockers and pre-packs. Flight crew, waste management containers, lockers, trash (wet & dry) and required equipment will be removed prior to vehicle refurbishment. Crew module waste management system is serviceable (drain & flush) in place. EVA suits will be exchanged as required.

Pre-Flight Operations: Following ORU replacement and vehicle system servicing, integrated testing will be performed on the transfer vehicle (and crew module if a piloted mission is being prepared). Portions of the flight sequence will be simulated to verify functional integrity of vehicle systems. For an LCV mission, the cargo will be mated to the transfer vehicle prior to leaving the SSF servicing hangar. Fluids and gases will be topped-off. For an LPV mission, final crew equipment, food, film, etc. will be stowed, followed by flight crew ingress.

The vehicle will then be transferred by an advanced OMV to the propellant depot for cryogenic loading, and then deployed by OMV to the stand-off position for the trans-lunar injection burn.

Lunar Vehicle Processing Operations.



Propellant Tethered to Space Station Freedom

An option for the refueling of reusable Space Transfer Vehicles in the vicinity of the Space Station involves the use of a propellant depot which is tethered to the Space Station. The propellant tanks are tethered away from the Space Station in either the zenith or nadir directions. Having the tanks attached to the station allows the tanks to be under station control, but decreases the risks of having large amounts of propellant close to the station. The tanks experience a slight acceleration at the end of the tether which can be used to simplify propellant storage and transfer operations. Tether lengths of roughly 200 m provide accelerations at the tanks of roughly 0.0001 g, which is sufficient to allow fluid settling in LOX and LH2 tanks.

Two different tether configurations have been analyzed to determine their impacts on Space Station. The first case, as illustrated in the figure below, deals with using a tether to store and transfer propellant for lunar mission flight 1, which is an expendable cargo flight. The second case, shown in the figure on the following page, shows the use of a tether system to store and transfer propellant during the lunar operational phase, where two reusable LTV's are based at Freedom.

The study assessed the feasibility of locating Transfer Propellant Tank (TPT) platforms remote from the Space Station through the use of tethers. One major objective of the study was to determine the dynamic environment of the Space Station-tethered tank platform system. This included evaluating attitude motion, system center of mass migration, microgravity sensed at the Space Station center of mass, microgravity sensed at the tanks, tether tension, and the impact of a departing vehicle on the motion of an empty tank platform.

For the purposes of the initial study, certain assumptions were made:

1) The tether used was stainless steel, 1 mm in diameter, 200m in length.

2) The Space Station center of mass orbit was at 220 Nm altitude, 28.5° inclination.

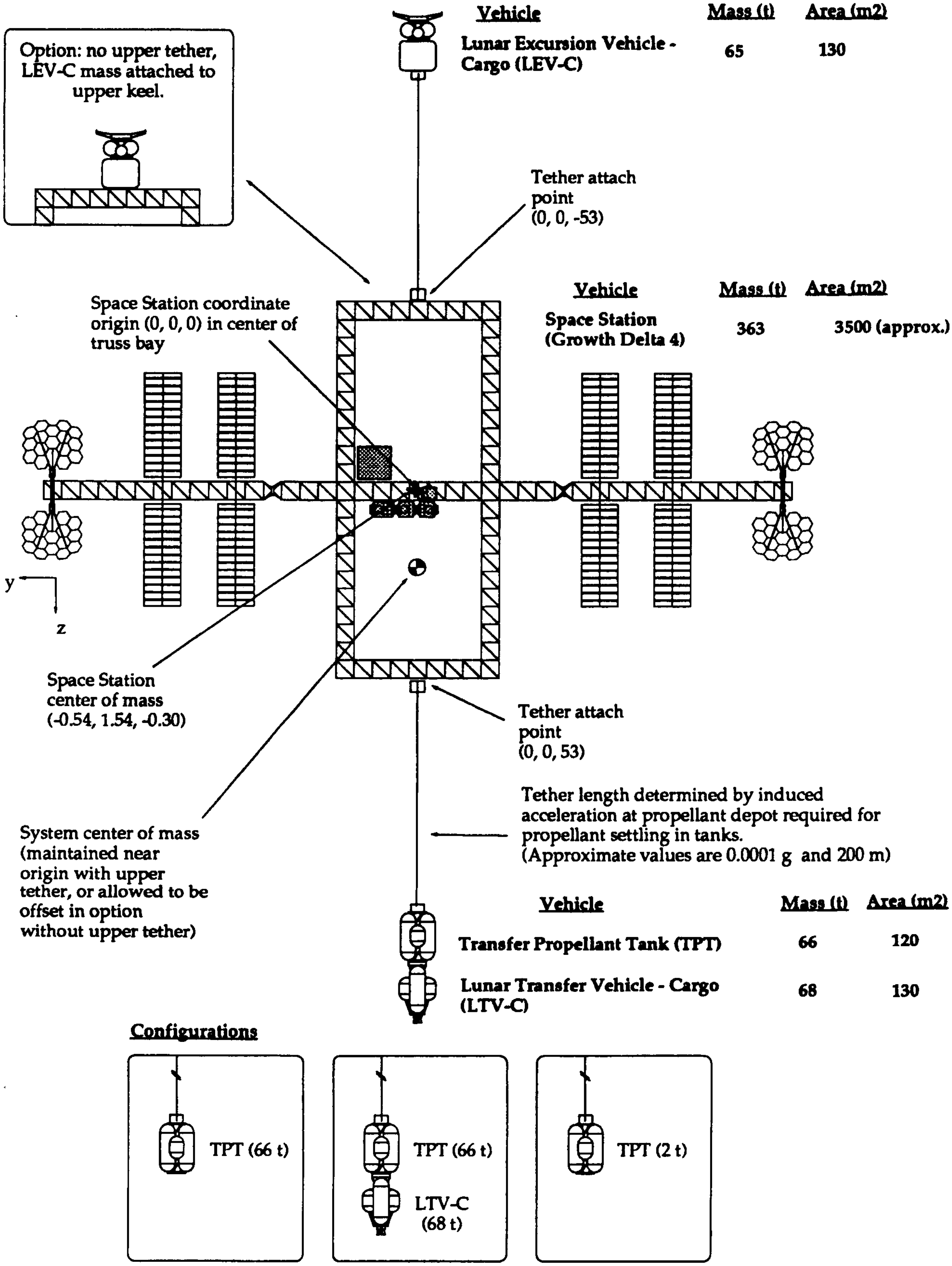
3) The Space Station center of mass (CM) was at (0, 0, 0) in Space Station coordinates and the tether attach points were at ±53m on the Space Station z-axis.

4) Due to software constraints, the Space Station and tank platforms were treated as point masses (except for drag calculations where drag surface areas are included).

5) The mass and drag surface area of the tether were included in the mass and area of the tank platforms in the 2 body simulations (also in the lower platform in the 3 body simulations). The mass and area of the upper tether were added to the Space Station mass and area in the 3 body simulations.

6) Full tank steady state conditions were used as the starting point for the study of the impact of a departing vehicle (released empty tank simulation).

Lunar Evolution Space Station with Tethered Propellant Depot - Flight 1



Propellant Tether to Space Station Freedom (continued)

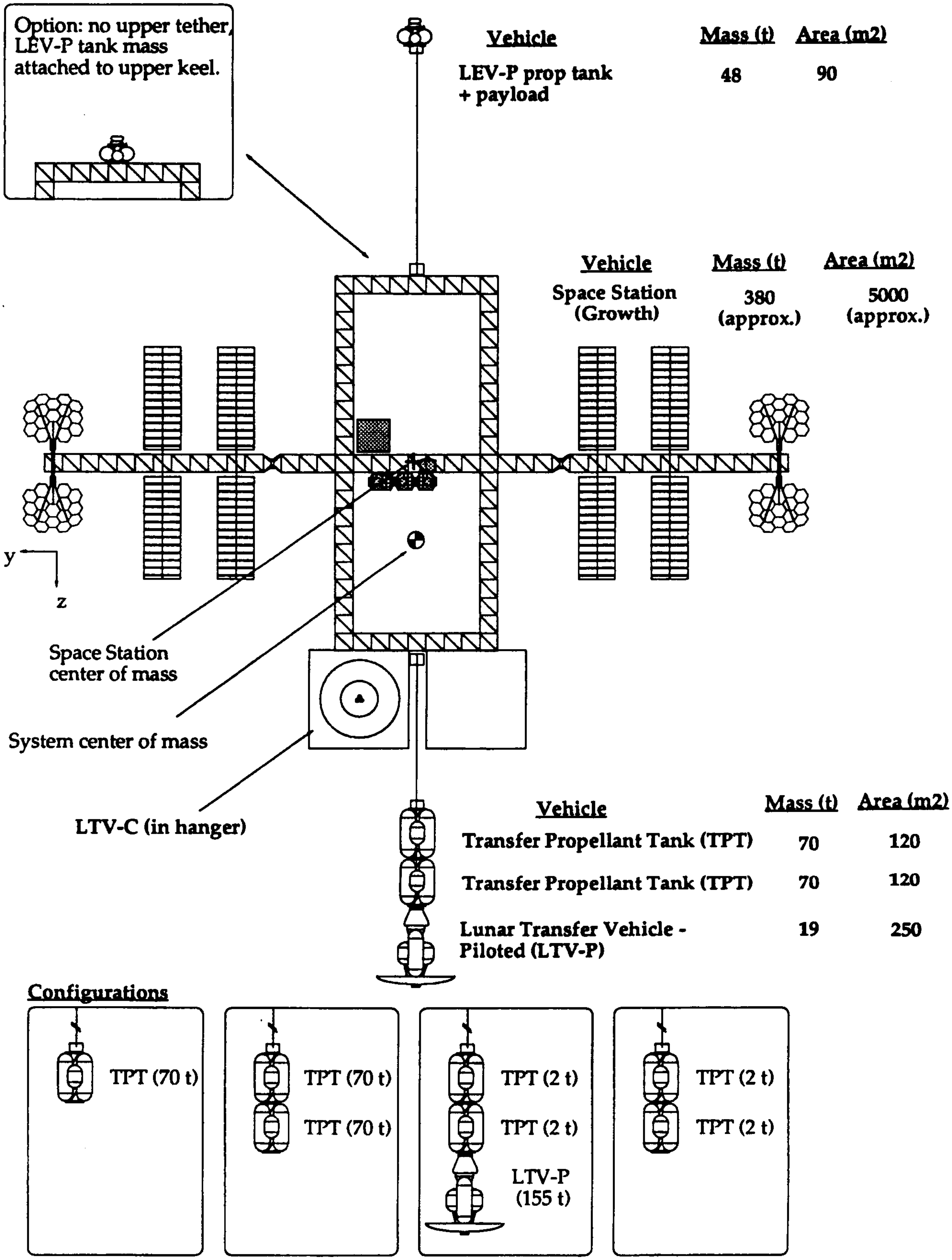
Two Space Station configurations were tested. The first had mass of 363 tons and surface of 3500 m^2 (Figure 7.4-1). The second had mass of 380 tons and surface area of 5000 m^2. For each Space Station configuration, several combinations of propellant tanks, fuel and vehicles were simulated as listed below.

Cases involving Space Station tether configuration 1 (363t, 3500 m^2) with downward deployed tethers included:
1a) Full Tank Platform (66t, 120m^2);
1b) Full Tank Platform and Lunar Transfer Vehicle Cargo (LTV-C) (134t, 250m^2);
1c) Empty Tank Platform (2t, 120m^2);
1d) Empty Tank Platform at time of "release" by LTV-C (2t, 120m^2).
Cases with upward deployed tethers included:
1e) Lunar Excursion Vehicle-Cargo (LEV-C) (65t, 130m^2);
1f-h) combined upward deployed tether with each downward deployed tether case, except "released" platform.

Cases involving Space Station tether configuration 2 (380t, 5000m^2) with downward deployed tethers included:
2a) One Full Tank Platform (70t, 120m^2);
2b) Two Full Tank Platforms (140t, 240m^2);
2c) Two Full Tank Platforms and Lunar Transfer Vehicle Piloted (LTV-P) (159t, 490m^2);
2d) Two Empty Tank Platforms (4t, 240m^2);
Cases with upward deployed tethers included:
2e) Lunar Excursion Vehicle - Prop Tank and payload (LEV-P) (48t, 90m^2);
2f-i) combined upward deployed tether with each downward deployed tether case, except "released" platforms.

The various downward deployed configurations were simulated in a 2 body system with the space station. These simulations showed a stable system, even though beginning in an artificial state (i.e., deployed mass directly below Space Station CM, at full deployment length). During the course of the study, it was observed that small initial relative velocity errors between the deployed tanks and the Space Station resulted in large amplitude oscillations; further studies are needed to determine control parameters to accomplish actual deployment of the platforms.

Lunar Evolution Space Station with Tethered Propellant Depot - Flight 8



•Propellant Tethered to Space Station Freedom (concluded)

The steady-state gravity gradient sensed acceleration at the platform ranges from 70-97 micro-g in the various 2-body simulations, and from 2-29 micro-g at the Space Station CM. In addition, there is a cyclic tether acceleration sensed at the tank. This acceleration is a damped elastic effect with peaks of 5-56 micro-g, depending on the mass deployed. The tether/space station system had a steady state in-plane oscillation of less than 2 degrees. This motion is depicted in the figure below, which shows radial displacement of the tank from the station versus in-plane position of the tank relative to the station for the 66 ton platform. The upper symbol in the figure represents
the space station, while the lower represents the tank platform. The movement of the space station is an arbitrary representation of the plotting program which allows a better visual representation of the in-plane motion over a period of time (in this case, 10,000 seconds).

Similar results were obtained in the upward deployed 2 body simulations and the 3 body (upward and downward deployed) simulations. The steady state gravity gradient sensed acceleration at the tank platforms ranged from 80-114 micro-g, while those at space station CM ranged from 0.2-19 micro-g.

All tether tensions are well within the stainless steel capacities at the tether diameters studied.

Meteoroid and Orbital Debris Shielding for Hangers

The protection of space transfer vehicles from meteoroids and orbital debris while at the Space Station involves balancing the benefits of additional protection against the costs of adding significant mass to the hanger walls. A hanger wall thickness was selected to provide some additional protection to EVA astronauts while operating in the unpressurized hanger. An aluminum alloy hanger wall and bumper with a (combined) thickness of 1 mm was selected. This wall is capable of stopping the small, paint flake size particles and would provide roughly ten times more protection than an astronaut in the current EMU. The amount of protection is not large, yet it involves a significant addition of mass to the hangers - 2.8 metric tons for 1000 square meters.

The SRD requirement states that "SSF shall provide debris protection for space transfer vehicles and mission equipment while resident at SSF". The Lunar transfer vehicles will have some shielding themselves. For example, the current Lunar vehicle tank design has a 30 mil (0.76 mm) Al-Li alloy wall and a 15 mil (0.38 mm) bumper with multi-layer insulation (MLI) in the gap. The protection requirements for the vehicle components, such as the aerobrake, must be determined. Since the specific requirements of the space transfer vehicles for additional protection while in LEO were not available, a hanger wall design was selected to protect the EVA crew servicing the transfer vehicle.

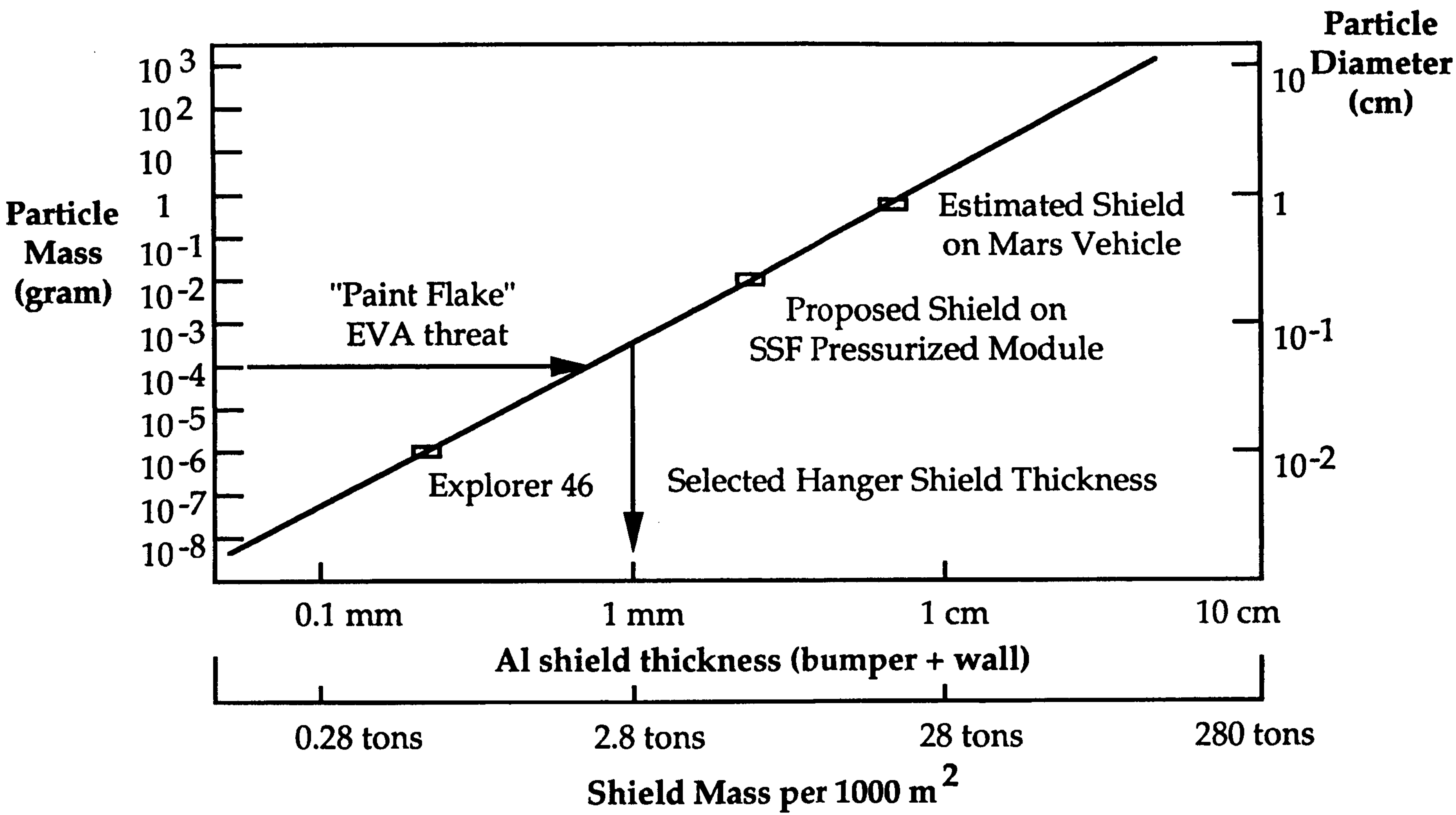
The protection requirements for SSF EVA astronauts is stated as: "..the SSPE should be designed and operated in a manner such that the individual crewman would not be exposed to a risk of more than 0.0005 (1 per 2000) accidental deaths per year as a consequence of meteoroid and debris strikes." (Space Station Program Natural Environment Definition for Design, JSC 30425, Sec. 13.1) The above requirements place a specific limit on the risk to an EVA astronaut. In the absence of additional protection, this requirement would limit the total amount of time a crew member could spend on EVA.

Natural meteoroids include low density cometary material in periodic meteor showers, and higher density asteroidal material. Meteoroids have high velocities (10 - 60 km/s) and would arrive at SSF with directions randomly distributed across the hemisphere above the horizon.

Artificial orbital debris consists of large objects - which are tracked optically and with radars, and the more numerous small objects and particles. There is limited data on the number of small objects. The model distributions are extrapolated from the numbers of larger objects and are uncertain by a factor of ten for the current environment. In the coming decades, the amount of debris is projected to increase by a factor of 2 to 10 depending of future space activity and debris countermeasures. Orbital debris impact directions are concentrated in the x-y (horizontal) plane. Typical impact velocities of orbital debris (10 km/s) , while lower than meteoroids, are more capable of penetrating shields since particle fragments may survive impact with the bumper shield. A retrieval of the Long Duration Exposure Facility (LDEF) satellite would significantly add to the understanding of the current environment.

The current space suit can be penetrated by particles as small as 0.5 mm diameter at orbital velocities. The probability of such an impact on an EVA astronaut in the current environment is roughly $2x10^{-6}$ per hour of EVA time. Without additional protection, the SSF risk limit would require an operational limit of 3-5 EVA days per month for an astronaut.
The selected meteoroid/debris includes a main wall of 0.8 mm of Al alloy, an exterior bumper wall of 0.2 mm at a distance of 3 cm, with the gap between the walls partially filled with layers of multilayer insulation (MLI). The effectiveness of shields of various thicknesses is illustrated in the figure below. The figure compares the thin shield of the Explorer 46 satellite, able to stop microgram size particles, to the heavier shields for SSF modules. The 1 mm shield selected would stop particles just under 1 mm in diameter and reduce the threat to EVA astronauts by roughly a factor of ten. This would remove the debris risk as an operational limit to EVA time in the hanger. The resulting mass penalty for the hanger walls is 2.8 metric tons per 1000 square meters of hanger wall.

Selection of 1 mm Al Shield for Vehicle Hanger Wall



Mars Evolution Case Study Assessment

Mars Evolution Case Study Outpost Capabilities*

The emplacement of a permanent, self-sufficient outpost on the surface of Mars is planned to follow an evolutionary path as illustrated. The outpost will develop through a series of phases, each with its own distinct objectives. Just as in the Lunar Evolution case study, the three mission phases for the Mars Evolution are (1) emplacement, (2) consolidation, and (3) utilization. The objectives and characteristics of each phase are:

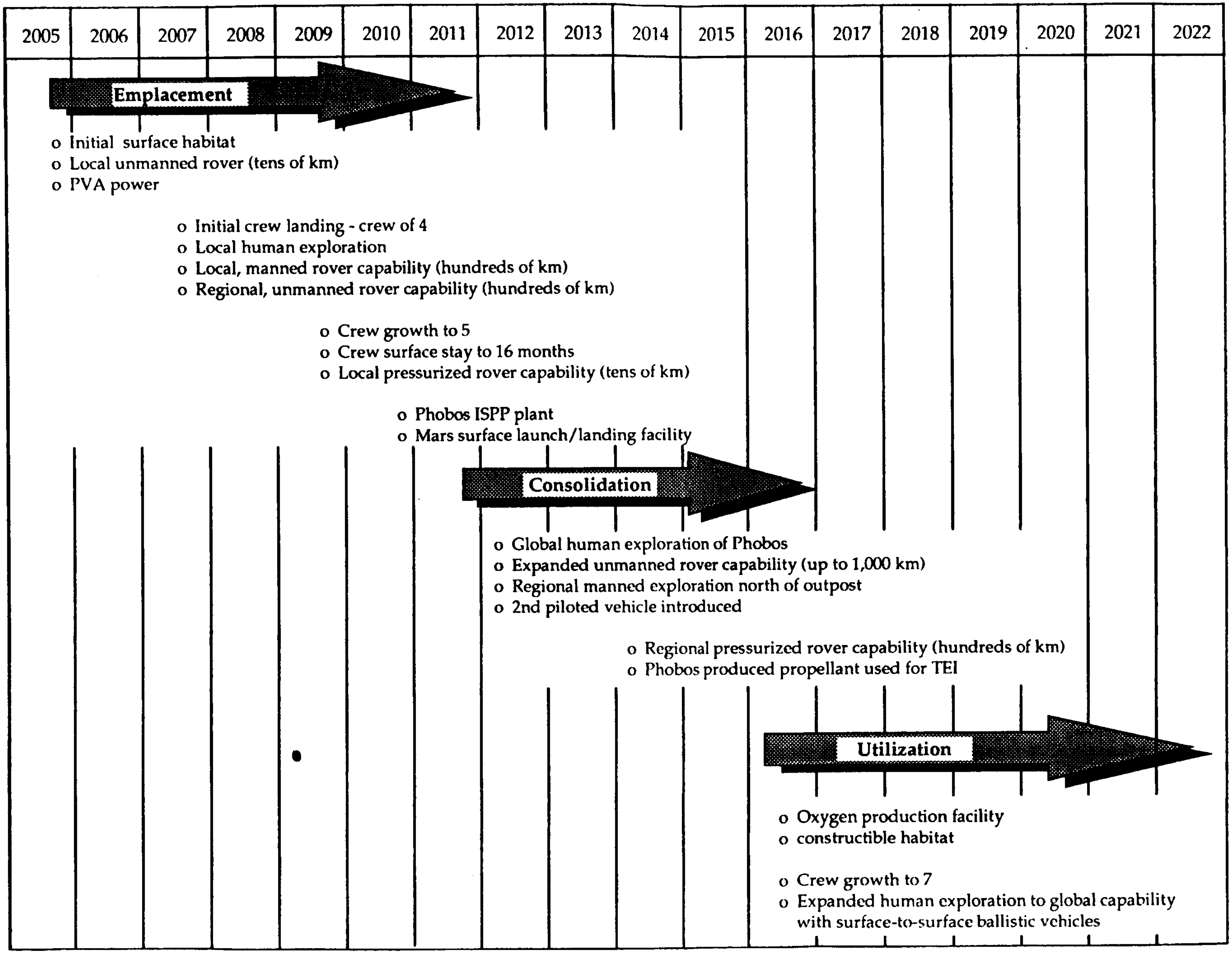
Emplacement Phase. Accomplish the initial human landing, deployment, and check-out of the surface habitat module. Initiate local human exploration activities and regional semiautonomous exploration capability.

Consolidation Phase. Begin to exploit local resources with the introduction of a gateway propellant plant to produce oxygen for outpost and vehicle resupply. Expand the surface crew size and stay time, and increase both human and robotic exploration capabilities.

Utilization Phase. Establish outpost permanence with expanded surface facilities, greater use of Mars resources, and advanced space transfer vehicle propulsion technologies. Demonstrate global exploration of Mars.

* This overview of the Mars Outpost was taken from an Office of Exploration FY89 Annual Report draft.

Mars Evolution Case Study Outpost Capabilities



SRD Specified Mars Evolution Case [redacted] Freedom Requirements

As in the Lunar Evolution Case Study, Space Station Freedom will be required to support advanced development of base and space transportation systems. In addition, life science research will be conducted to investigate long-duration crew exposure to a mico-gravity environment. It is important to note that for the Mars Evolution Case Study no space transfer vehicle processing activities are done directly on Space Station Freedom. Iinstead, a separate free-flying assembly fixture is used to assemble, process, and fuel the Mars Transfer Vehicle (MTV).

Mars Evolution Case Study Resource Requirements

The magnitude of effort needed to support the Lunar and Mars Evolution case studies requires that the Space Station provide increased resources and capabilities. This expansion of the performance envelope includes such basic resources as crew, power, interior volume, and exterior work space. The plan for accommodating the case studies called for using the requirements specified in the Office of Exploration (OEXP) Study Requirements Document (SRD) to establish evolutionary Freedom resource and facility requirements. These requirements were initially submitted as part of the baseline Preliminary Requirements Review (PRR) that was held in May and June of 1988. The transportation node growth requirements are presently being refined and combined with the Multidisciplinary Research and Development reference configuration growth requirements into a set of composite evolution growth requirements. This composite set of growth requirements will be submitted to the Space Station Freedom Preliminary Design Review (PDR) in 1990. The specific resource requirements for the Mars Evolution case study are shown in the accompanying figure.

Additional habitable volume will be required on Freedom to accommodate the Mars transfer vehicle (MTV) mission crew , MTV processing crew, and the life science research crew. In order to mate the additional habitat module to the existing module cluster, two resource nodes, greater in length than the presently designed node, are required. The extended resource node is required to satisfy the current Freedom requirement of maintaining enough clearance (2.1 meters) between Freedom modules to allow an EVA astronaut to pass inbetween and make repairs if necessary.

In addition to the habitat module, an addional life science laboratory module is required to conduct research into long duration crew exposure to a micro-gravity environment, along with a plant and animal vivarium. Also, 3 pocket laboratory modules (short labs) are required to conduct research on advanced chemical-physical life support systems, artificial gravity effects on animals and humans, and possibly a quarantine facility for Mars sample returns.

100 kW of dynamic power is required to provide the additional power for the habitat, resource nodes, and LTV processing facilities.

The ability to evolve to these levels of capabilities preserves the option to accommodate, at a top level of functionality, the OEXP Mars Evolution case study which requires Space Station Freedom as a part of the overall infrastructure.

MARS EVOLUTION CASE STUDY
TRANSPORTATION NODE RESOURCE REQUIREMENTS

Station Configuration	Current Recommendation
Power	
Average	175 kW
Peak	NA
Crew	18
Pressurized Modules	
US Habitation	2
US Laboratory	2
ESA Laboratory	1
JEM Laboratory	1
Pocket Laboratory	3
Resource Nodes	8
Transverse Boom	
Dual Keel	Scar for distributed systems
Servicing Facility	Scar for all possible locations
Power Modules	SD array growth on extensions of boom ends
Payloads	
APAE	TBD
Location points for APAE	TBD
Tether Payloads	2

Mars Evolution Time-Phased Space Station Freedom Growth Deltas

The time-phased Space Station Freedom growth augmentations, or growth deltas, are shown. These growth deltas reflect major incremental increases in various resources including power, habitable volume, truss, payload attach points, etc. The growth deltas do not reflect the actual hardware manifesting on a flight-by-flight basis, but instead illustrate major incremental increases in various resources including power, habitable volume, structure, etc. The growth increments are shown in this manner because the time-phasing of the additional Space Station hardware elements are directly related to the amount of transportation support that Space Station receives after assembly complete.

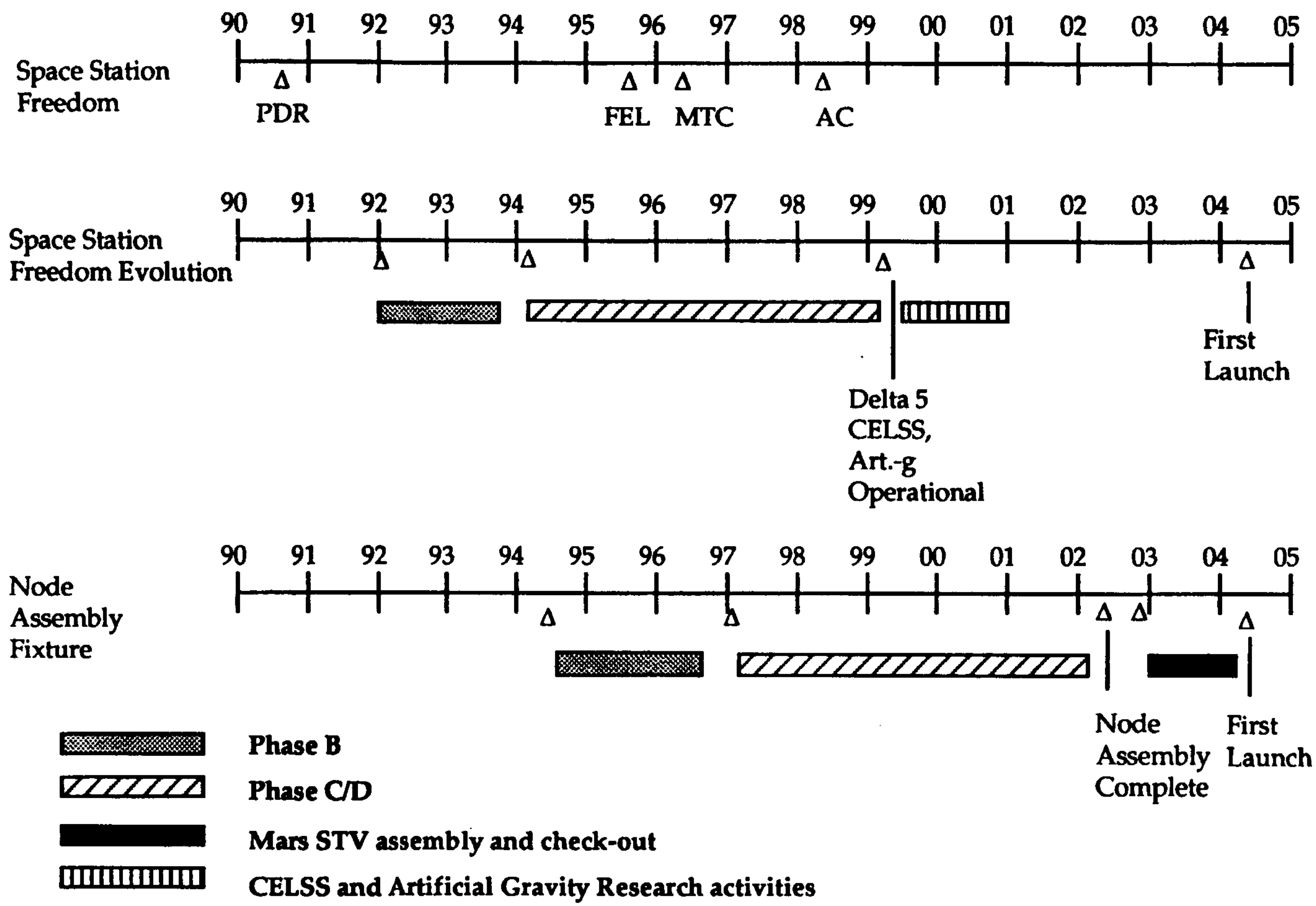
MARS EVOLUTION CASE STUDY
TIME-PHASED SPACE STATION FREEDOM GROWTH DELTAS

$\Delta 1$	(2 - 25 kW) Solar Dynamic Modules; (2) 25 meter Transverse Boom Extensions; Space Based OMV & Space Based OMV accommodations
$\Delta 2$	Upper/Lower Keels & Booms
$\Delta 3$	(1) Habitat Module; (2) Resource Nodes
$\Delta 4$	(2 - 25 kW) Solar Dynamic Modules; Servicing Facility Phase 1
$\Delta 5$	(1) Large Pocket Laboratory (Art-g); (1) Large Pocket Laboratory (CELSS); Servicing Facility Phase 2
$\Delta 6$	Life Sciences Laboratory Module; (2) Resource Nodes
$\Delta 7$	Phase 3 Servicing Facility (Completed CSF);
$\Delta 8$	(1) Large Pocket Laboratory (Quarantine Facility)

Mars Evolution Case Study Programmatic Schedule

Based on the currently proposed Mars Evolution case study mission description a Space Station evolution programmatic schedule has been developed. It is important to note that with an initial manned Mars launch date in 2004 and the fact that Space Station Freedom will not reach assembly complete until 1998, there is probably not sufficient time to grow the Space Station to support life sciences and technology research required to influence the design of the Mars Transfer Vehicle. Additional understanding of the life science program timelines and resource requirements must be established before a final integrated Mars mission schedule can be established.

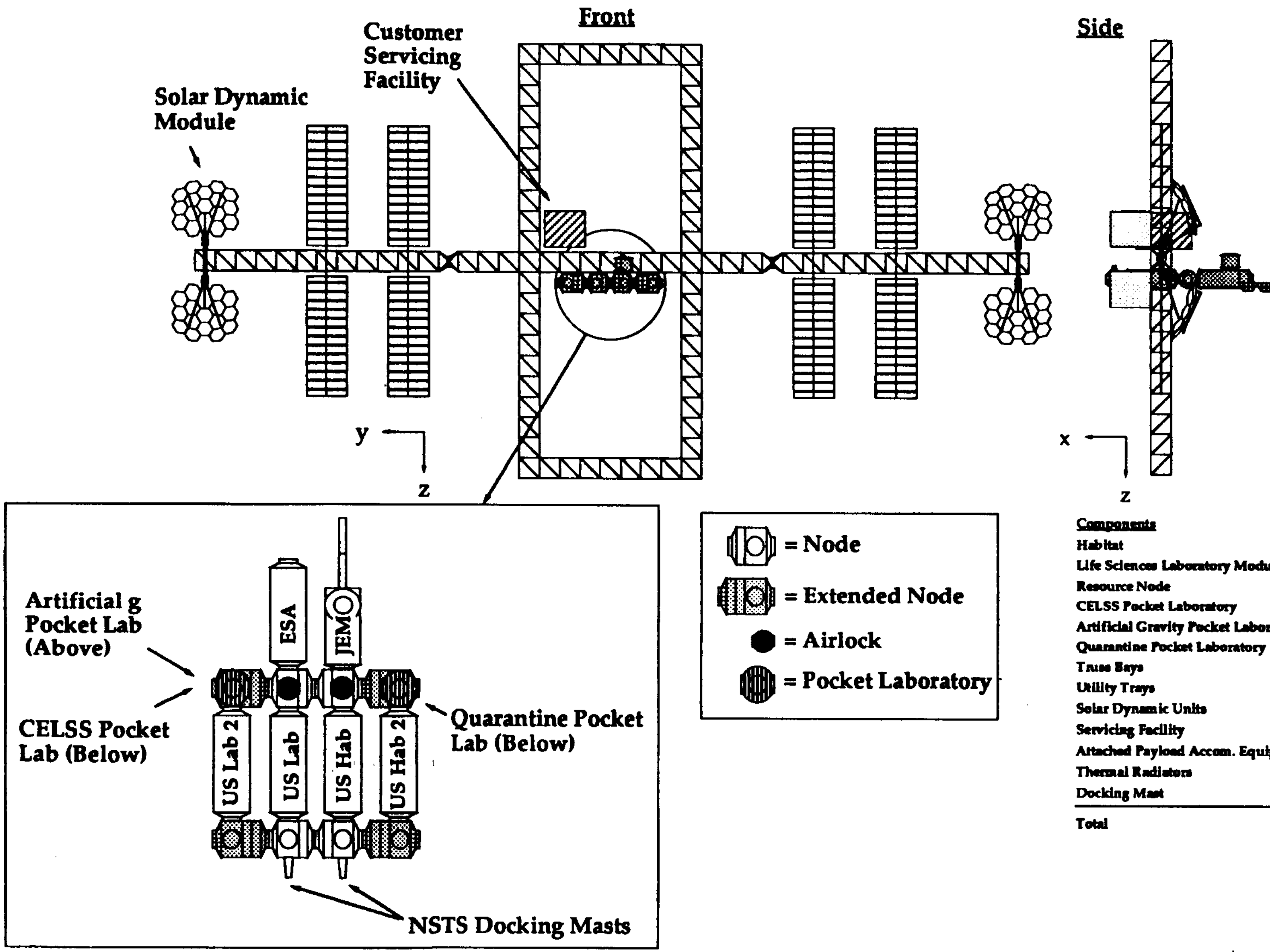
Mars Evolution Case Study Programmatic Schedule



Mars Evolution Space Station Growth Configuration (Delta 8)

The recommended Mars Evolution Case Study growth configuration to support life sciences and technology research is pictured. It is important from a Space Station Freedom programmatic point of view that the proper hooks and scars be maintained in the baseline SSF program. Several important SSF scars are the alpha joint (175 kW), Power Management and Distribution (PMAD) system (175 kW), and the Active Thermal Control System (ATCS) (175 kW). Configutationally, it is important that the Reaction Control System has the capability to be relocated on the upper and lower keels, and that the module pattern has sufficient room for growth along the transverse boom. In addition, the radiators must be located such that there is ample clearance with the upper and lower keels.

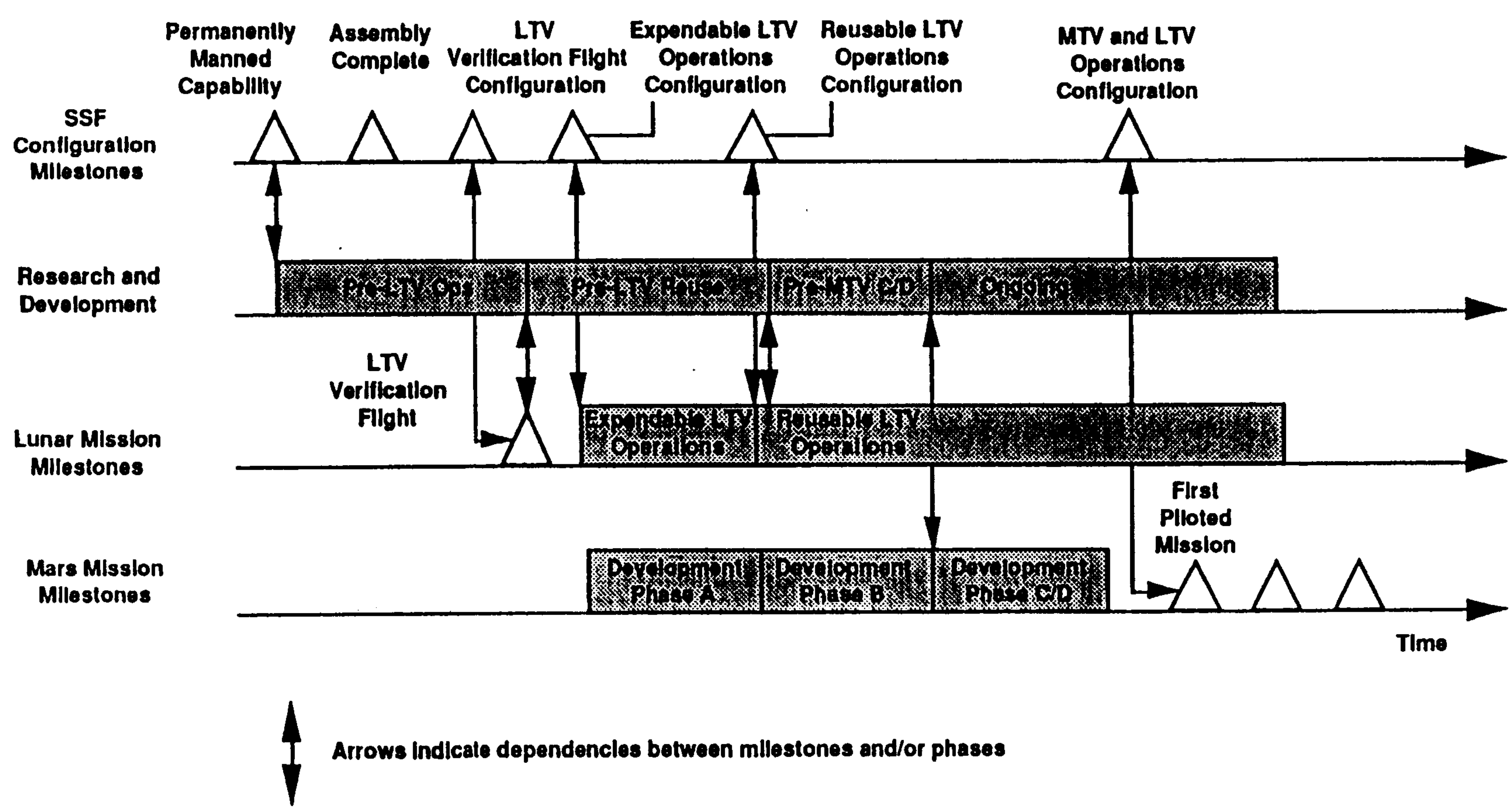
Mars Evolution Space Station Growth Configuration (Delta 8).



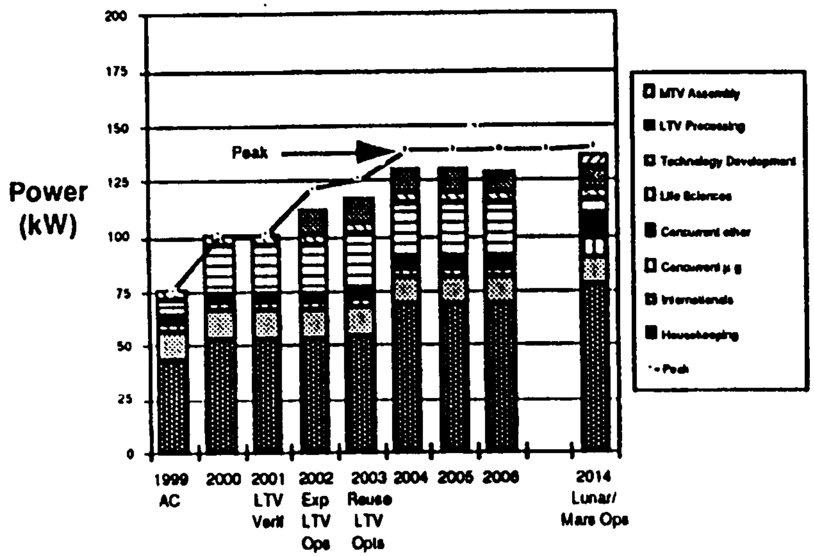
Components	Number	Mass (kg)
Habitat	1	23,500
Life Sciences Laboratory Module	1	34,700
Resource Node	4	31,200
CELSS Pocket Laboratory	1	10,250
Artificial Gravity Pocket Laboratory	1	10,250
Quarantine Pocket Laboratory	1	10,250
Truss Bays	64	5,700
Utility Trays	64	11,300
Solar Dynamic Units	4	27,600
Servicing Facility	1	11,500
Attached Payload Accom. Equipment	4	1,450
Thermal Radiators	2	6,300
Docking Mast	1	1,400
Total		185,400

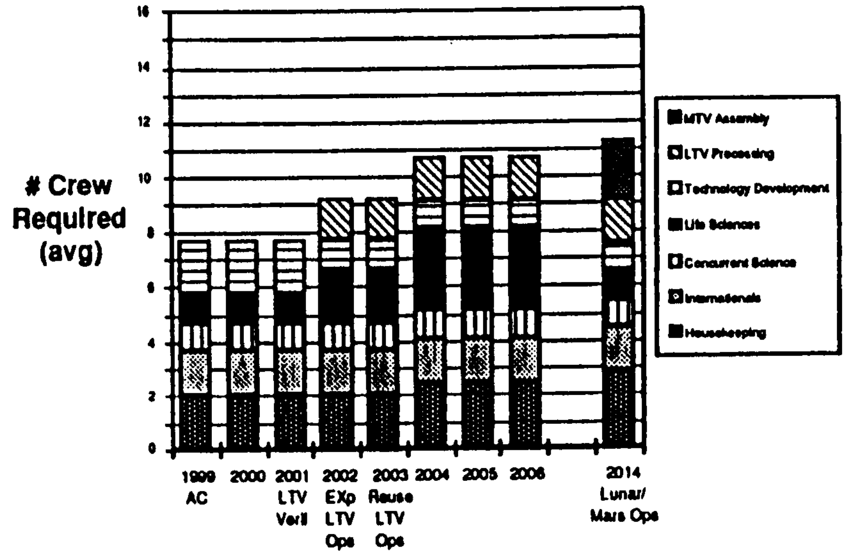
Lunar/Mars Exploration Initiative Assessment

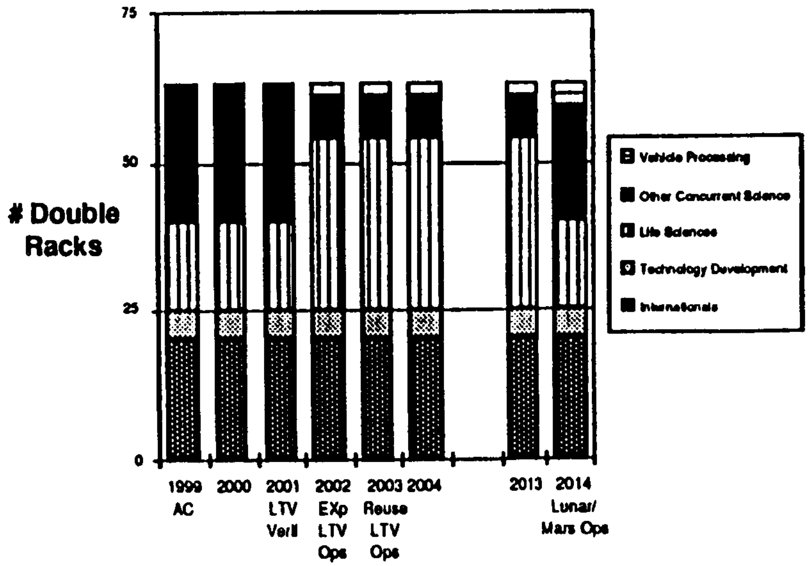
IMPLEMENTATION AGAINST REQUIREMENTS
ACCOMMODATION SCHEDULE



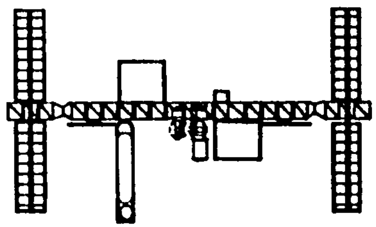
OPTION 5 - PACED DEPLOYMENT OPTION
RESOURCE ALLOCATION



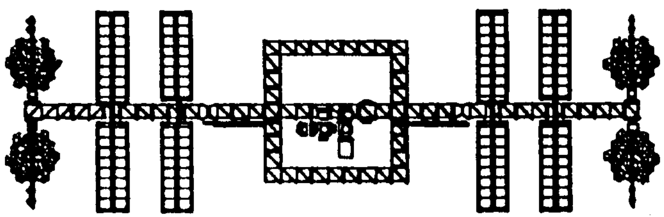




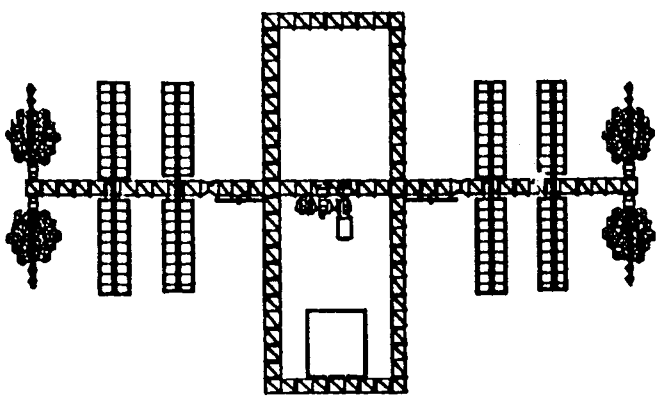
TRANSPORTATION NODE ANALYSIS
EXAMPLES OF CONFIGURATIONS ASSESSED



- Minimum augmentation to rephased program PMC
- Large pitch TEA (pitch TEA > 40 degrees)
- Very large angular momentum (control difficulties)
- Operational and physical interferences (module growth blockages, SSF hydrazine thruster plume impingement, etc.)



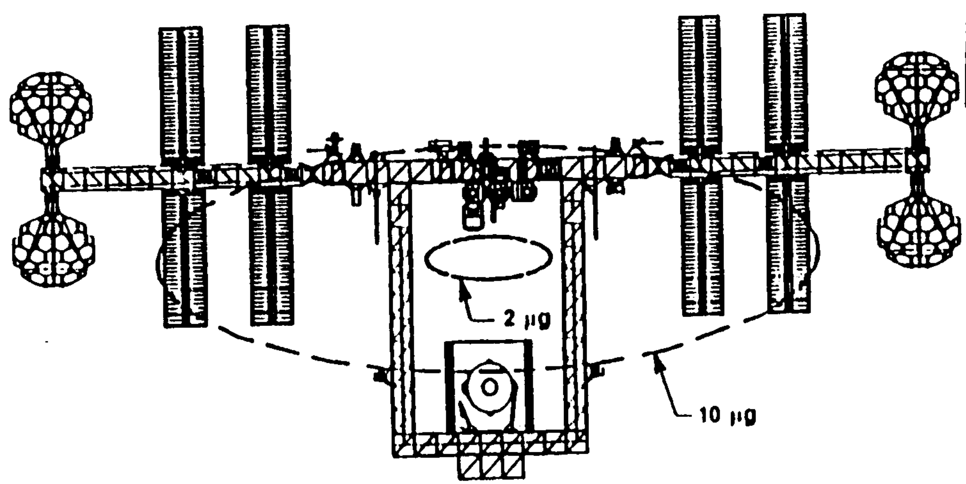
- Minimal augmentation to previous SSF baseline (Phase 1)
- Assembly hangar located behind transverse boom (i.e., offset in the -X direction)
- Large pitch TEA (> 30 degrees)
- Large angular momentum
- Field-of-view blockages (e.g., JEM exposed facility)



- Dual keel selected as Baseline during Phase B of SSFP
- Low pitch TEA (< +5 degrees)
- Stablized gravity gradient (Ixx >> Izz)
- Room for unobstructed vehicle processing and assembly operations
- Increased structure and utility runs

TRANSPORTATION NODE ANALYSIS
REUSABLE LTV OPERATIONS CONFIGURATON

2 SIGMA JACCHIA ATMOSPHERE
FLUX = 230, AP = 20.7
PITCH DRIFT ERROR = ±0.005 deg/sec
ALTITUDE = 220 Nml



Steady State Microgravity Profile

Mass Properties

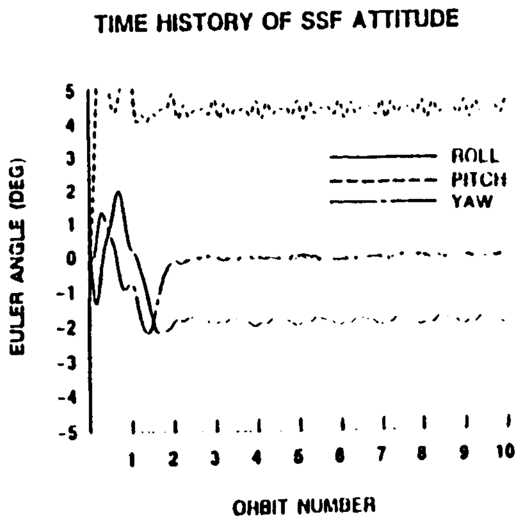
Mass = 488,980 kg

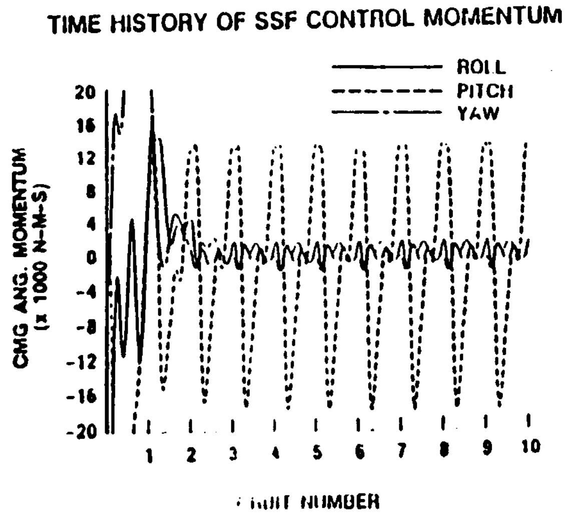
Center of Gravity:
x_{cg} = -1.5 m y_{cg} = -0.2 m z_{cg} = 21.2 m

Inertia Matrix (kg-m^2):

Ixx = 6.06E8	Iyy = 2.71E8	Izz = 3.97E8
Ixy = -7.05E5	Iyz = 4.10E6	Ixz = -8.03E6

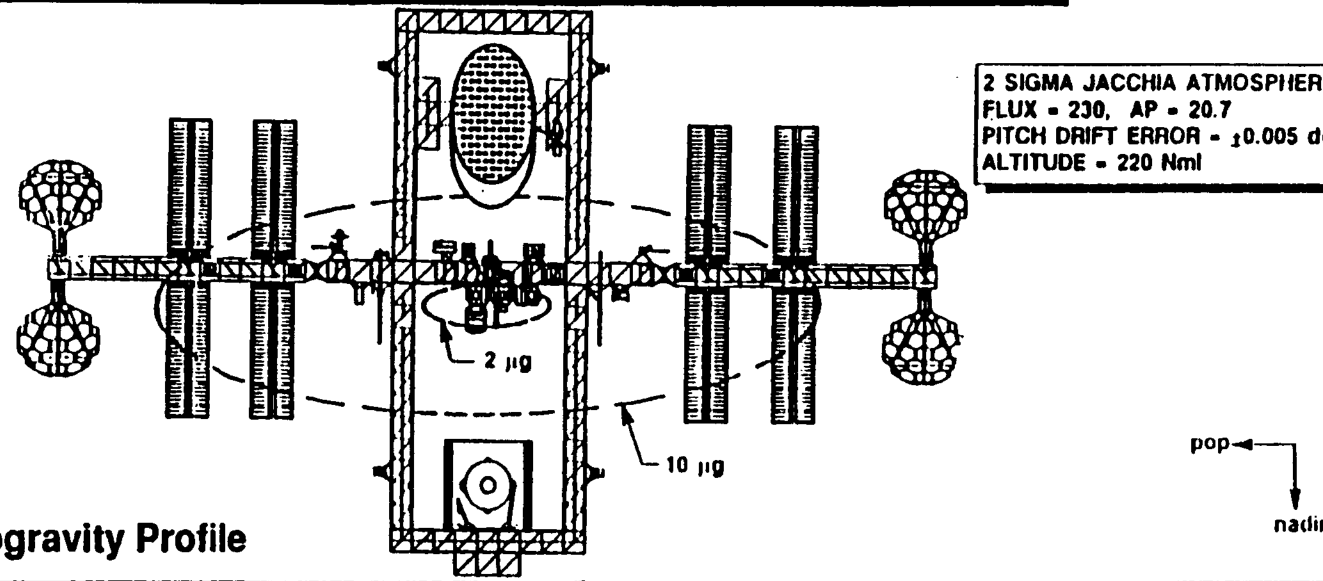
Control Characteristics





NASA — FREEDOM

TRANSPORTATION NODE ANALYSIS
LUNAR AND MARS OPERATIONS CONFIGURATION



2 SIGMA JACCHIA ATMOSPHERE
FLUX = 230, AP = 20.7
PITCH DRIFT ERROR = ±0.005 deg/sec
ALTITUDE = 220 Nml

Steady State Microgravity Profile

Mass Properties

Mass = 644,618 kg

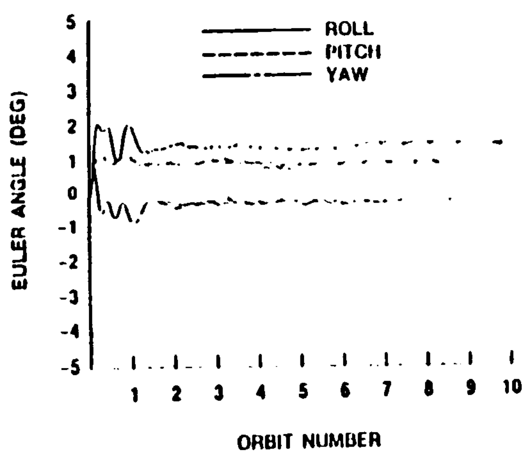
Center of Gravity:
x_{cg} = -1.7 m y_{cg} = -0.25 m z_{cg} = 8.60 m

Inertia Matrix (kg-m^2):

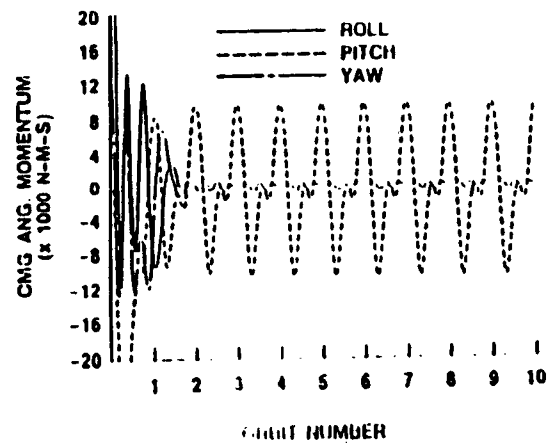
Ixx = 9.41E8	Iyy = 6.10E8	Izz = 4.10E8
Ixy = -1.00E6	Iyz = 4.97E6	Ixz = -2.30E6

Control Characteristics

TIME HISTORY OF SSF ATTITUDE



TIME HISTORY OF SSF CONTROL MOMENTUM



OPTION 5 - PACED DEPLOYMENT OPTION
BUILDUP MANIFEST

Shuttle-only buildup to LTV Verification Flight configuration

	FUNCTIONAL MILESTONE	1995	1996	1997	1998	1999	2000	2001	2002
Shuttle Only to LTV Verification Flight	MAN-TENDED								
	PERMANENTLY MANNED CAPABILITY								
	ASSEMBLY COMPLETE								
	LTV VERIFICATION FLIGHT								
	TOTAL NUMBER OF FLIGHTS	4 assembly	5 assembly	2 logistics 4 assembly	5 logistics 3 assembly	3 logistics 5 assembly	6 logistics 2 assembly	6 logistics 3 assembly	

Accelerated buildup beyond Assembly Complete using HLLV

	FUNCTIONAL MILESTONE	1999	2000	2001	2002	2003		2013	2014
STS & HLLV beyond Assembly Complete	LTV VERIFICATION FLIGHT								
	EXPENDABLE LTV OPS								
	REUSABLE LTV OPS								
	LUNAR & MARS OPS								
	TOTAL NUMBER OF FLIGHTS	3 logistics 5 assembly	6 logistics 2 assembly	6 logistics 1 assembly	6 logistics 1 assembly	6 logistics 2 assembly		6 logistics 1 assembly	6 logistics 1 assembly

STS Assembly Flight | STS Logistics Flight | HLLV Assembly Flight

OPTION 5 - PACED DEPLOYMENT OPTION
MAJOR ISSUES

- Implementation has potential schedule risk
  - Baseline SSF schedule of AC in 1999 is very aggressive
  - Use of Shuttle only for buildup to LTV verification flight requires very high flight rates (up to 9 per year)
  - Use of HLLV required for buildup to LTV verification flight to provide schedule contingency

Technology Needs Assessment

Preliminary Technology Assessment Review

Top level technology needs have been identified and are shown below. In general, these needs were found to be common to both the LEO node function and the R&D growth evolution station with differences between the two primarily in the "magnitude" of the system or the operational function the need supports.

From an Earth orbital node view point, it was found that the technology drivers identified in this study were relatively insensitive to the particular case study under analysis. The following discussion will apply to all of the case studies' technology drivers unless there was some issue unique to a particular case. Generally, the only major differences in the technology drivers for the case studies were in the particular need dates. That is, the technology readiness requirements were keyed to the particular case study's program schedule.

With the exception of the Mars Expedition Case Study, all of the missions analyzed in the report included multiple missions with varying degrees of reusable mission elements. The Heavy Lift Launch Vehicles (HLLVs) assumed in the studies, were not capable of delivering fully assembled Mars space transfer vehicles to LEO, and the large aerocapture systems used extensively on the Mars transfer vehicles exceeded the payload volume envelopes. Therefore, the HLLV's payload mass and volume constraints drove the requirement for an on-orbit assembly function at the node while the need to service the reusable flight hardware drove the requirement for an on-orbit processing capability.

To accommodate on-orbit assembly at the LEO node, the capability to assemble, handle and mate/demate very large, very heavy and complex space vehicles will be required. A high degree of confidence and reliability must be demonstrated and assembly operations must be conducted with minimum risks and minimum IVA/EVA crew involvement. For the planetary space vehicles (aeroshells, spacecraft, space propulsion systems) and any reusable elements/injection stages, the on-orbit technology program must address handling, assembly and mating techniques using large capacity, highly articulated manipulators and telerobotic/teleoperated aids. The success of providing this capability depends upon major technological advances in the areas of Automation and Robotics, Autonomous Rendezvous and Docking, and control of large structures. Most of the issues mentioned have appeared to be adequately covered in the OAST Pathfinder Program but the need dates and funding levels need to be further evaluated.

A commitment to provide an extensive LEO node on-orbit assembly and vehicle processing capability will require considerable future study effort. However, two important factors will undoubtedly influence the decision to provide this capability. These are the specific mission designs, and the performance characteristics of earth-to-orbit (ETO) launch systems.

The on-orbit vehicle processing function, while requiring many of the attributes needed by the orbital assembly function, i.e., handling, mating, manipulating large and massive mission elements in space, must also be capable of integrating, testing, and the subsequent end-to-end checkout of any and all elements of the space vehicle. To accomplish on-orbit what has traditionally been done utilizing ground based facilities will require a whole new set of in-space operational philosophies, procedures and support equipments - especially where manned systems are involved. From a technology needs standpoint, the orbital test programs for this function (which is yet to be addressed in any of the case studies) must focus on the development and implementation of advanced systems capable of performing automated checkout and systems status interrogations on each element as processed, and on the final flight configuration. In addition to

Preliminary Technology Assessment Review (continued)

the integration and checkout functions, the capability to service, maintain and refurbish all reusable flight hardware elements must be developed.

The successful implementation of the case studies described in OEXP SRD depend on efficiently managing cryogenic fluids in space. From the orbital node viewpoint, the capability to handle, transfer and manage large quantities of cryogenic propellents in space for long periods of time must be developed and demonstrated, on-orbit, before these missions can seriously be considered. The facilities and techniques required to transfer the propellents from tank-to-tank, tank-to-vehicle with minimum boiloff and contamination in and around the LEO node must be available early in the programs.

Autonomous Rendezvous and Docking is another key technology driver in implementing the proposed case study missions. Space based systems must be developed that are capable of autonomous rendezvous and docking with very large, very heavy and passive vehicles such as ELV's, mission vehicles and reusable transfer vehicles and injection stages. The system must be capable of stabilizing and maintaining control of these mission elements for subsequent handoff and transfer to the station, node and/or co-orbiting facilities with a high degree of accuracy. This capability must further be incorporated into an OMV-type system specifically tailored to handle large masses with adequate control authority to deliver and retrieve mission elements to and from staging orbits. This capability is an enabling technology for the lunar and Mars cases where there is extensive use of unmanned cargo/propellant vehicles in the low lunar orbit and Mars orbits.

The introduction of Nuclear Propulsion cargo vehicles will introduce some challenges to LEO node system definition that are more operational than they are technological. The projected orbital operations, which include the Nuclear vehicle assembly, processing, fueling, cargo loading and periodic refurbishment/changeout of its thrusters, must be accomplished with minimum risks to the crew and the LEO node systems. Procedures and techniques must be developed that will insure safe systems operations that will undoubtedly be conducted in a "nuclear safe" orbit and primarily by remote, telerobotic methods.

ORBITAL NODE TOP LEVEL TECHNOLOGY AREAS/ISSUES

- o In-space vehicle processing/refurbishment
  - A&R /telerobotic techniques and aids
  - Automated systems test and check-out
  - Fault tolerant systems
  - In-space servicing/deservicing and check-out of "wet" systems (hypergols)
  - Processing and handling of nuclear stages/power sources

- o In-space assembly/construction
  - Assembly of large aeroshells
  - Assembly of large space transfer vehicles
  - Joining of large structural elements (hangers, propellant storage facilities, etc)
  - Automation/telerobotic principles (precision positioning/handling)

- o Cryogenic fluid management and transfer

- o Autonomous rendezvous and docking

Summary

Issues

- o Significant augmentations to SSF are required to support Lunar/Mars Initiative
- o SSF design must allow power growth to 175 kW average with AC/DC distribution
- o Active thermal control system must be capable of providing heat rejection commensurate with 175 kW power generation
- o SSF-based EVA with advanced suits is required for SSF augmentation and vehicle processing
- o Biomedical Monitoring and Countermeasures (BMAC)/Extended Duration Crew Operations (EDCO) is required (beginning at PMC) to reduce STS flights for crew rotation
- o H2/O2 propulsion is required by SSF to reduce logistics requirements and external contamination
- o Allocation of SSF resources including crew, power, pressurized volume, and attached payload accommodation equipment (APAE) must consider other "non-exploration" users/experimenters
- o Impacts on international/congressional commitments must be addressed

Summary

- o Space Station is capable of evolving to meet requirements of the Lunar/Mars Initiative
  - Augmentation to the SSF program required
  - Requires scar implementation to rephased program
- o Total SSF implementation/cost is relatively insensitive to different options
  - Same augmentation required for range of options considered
  - Lunar/Mars Initiative milestones drive time-phasing of SSF cost
- o Vigorous/early exploration milestones will lead to requirement for accelerated assembly of Space Station Freedom
- o Very high SSF-dedicated STS flight rate or HLLV is required for SSF augmentation to LTV verification flight configuration (in addition to ongoing STS logistics flights)

SRD Specified Mars Evolution Case Study Space Station Freedom Requirements

- Provide capability to support advanced development systems for Mars base and space transportation.
- Provide capability for housing transient mission crew, support crew, and mission equipment.

- Transient mission crew:	Up to 2016 support mission crew of 5 Beginning in 2016 and beyond support mission crew of 7
- Mission support crew:	Accommodate a support crew of 6, for up to 15 months, with 6 month tours of duty
- Mission equipment:	Up to 2014 accommodate TBD metric tons of cargo Beginning in 2014 and beyond accommodate 10 metric tons of cargo

- No vehicle accommodation requirements
- Provide isolation of outbound mission crew and quarantine of Mars crews and samples returning from first 2 missions.