NASA FREEDOM

Evolution Design Requirements and Design Strategy

Space Station Evolution Beyond the Baseline – 1991

August 7, 1991

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Overview

Drivers for Growth / Evolution

Evolution of Space Station Freedom is justified for reasons which vary from more effectively utilizing the manned base to providing a means for incorporating new technologies as they come become available. Increasing or, more importantly, balancing the resources that are provided to the users is very critical to effectively utilizing the station. At permanently manned phase of the program, there will be four crew members that will be supporting and monitoring three laboratories. Accepted user mission databases have shown a demand for more crew, power, and volume than is provided by the baseline. As the work done in space by NASA continues to expand, the station will take a more active role in the missions. New functionalities for its operation and support of other missions will be required. One important driver for growth, particularly in the area of structures, is the inability of the baseline configuration to store all the ORU spares that will be required on–orbit. New technologies drive growth by providing a means of streamlining operations and possibly reducing the demand on EVA. They will also ensure that the station does not become plagued with obsolete equipment.

Drivers for Growth / Evolution

- **Increase resources for users**
  - Reduce time–sharing of critical resources at PMC (particularly power and crew)
  - Increase utilization by expanding user volume (LAB B)
  - Provide balanced resources for expanded user volume
- **Provide new functionality for users and station operations**
  - New classes of user payloads (e.g., large external payloads)
  - New functionality within station–provided services
    - GN&C and procedures for ELV–delivered cargo
    - Free–flyer servicing
- **Incorporate new technologies**
  - Reduce operations costs and increase utilization
  - Decrease EVA requirements
  - Avoid obsolescence

Design for Growth

If growth is not considered during the initial design process, implementing the follow–on and evolution phase plans could prove to be very complicated. More specifically, it could be either too costly or operational complex. Follow–on and evolution phase configuration design features that fall into these two categories need to be “flushed–out” promptly. Scars for all element and system growth need to be identified as soon as possible such that the impact to the baseline design is minimized. The farther along the design is, the more difficult changes will be. As will be shown in the following pages, there are certain scars that need to be installed on the baseline to permit growth beyond PMC.

Design for Growth

- **Potential impacts of not considering growth in the baseline design process include:**
  - Prohibitive costs for growth retrofit
  - Increased operational complexity for on–orbit upgrades

- **Impact of accommodating future growth in baseline design will be minimized if acted upon now**
  - Many "scars" have minimal cost and weight
  - Restructuring detailed design is in progress
  - As CDR approaches, requirements changes will carry significant costs

- **Although SSF is designed to provide phased capability, design features in the first configuration (MTC) are required to enable growth to the follow–on and evolution phases**

Follow–on Phase "Design–to" Strategy

The Space Station Freedom follow–on phase has been addressed in several forms throughout the program. A commitment to achieving 75 kW power generation capability and 8 crew capability, at some point in the program, is contained within the international MOUs. The Integrated Systems Preliminary Design Review, the SSF Restructuring Directive and the WP–02 White Papers all provide information concerning systems and elements that will most likely be included during this phase of the Space Station. Those items required to fulfill the international MOUs commitments will have to be placed in orbit during the buildup to this phase.

The precise configuration for this phase is currently being identified and analyzed in the Space Station Freedom Office at the Langley Research Center. As a result of the program having some understanding of what the follow–on phase entails, the scarring approach should minimize hardware replacement and retrofit, ensuring a smooth transition from the Permanently Manned Configuration.

Follow–on Phase "Design–to" Strategy

- ISPDR and SSF restructuring directive (BB000986R1) provide basis for follow–on phase
- Follow–on phase elements represent high probability, early growth additions; particularly those items required to fulfill the international MOUs (75 kW and 8 crew)

Baseline scarring approach should minimize hardware replacement and retrofit for the follow–on phase

Evolution Phase "Design–to" Strategy

The design strategy for accommodating the evolution phase of Space Station Freedom is one that supports some degree of flexibility within the design. This requires that growth be considered in, but not drive, the initial design of the station. This also requires that critical scars be identified and incorporated in the initial design such that show–stoppers to general growth flexibility are avoided. At the Permanently Manned Configuration phase of the program, there should remain within the design some option as to which evolution path will be pursued. The method of scarring for the evolution phase, however, shall be one that minimizes the impact to the baseline design.

Evolution Phase "Design–to" Strategy

- **Flexibility rather than rigid point–design**
  - Multiple options for evolution paths
  - Generic design features

- **"Design–for–growth" focusing on minimal impact approach**
  - Consider growth in initial design
  - Incorporate a few critical scars to avoid *show–stoppers* to general growth flexibility
  - Do not use life–cycle cost as a justification

Scarring approach for the evolution phase should minimize impact to the baseline design (weight, power, and cost)

Evolution Requirements Background

Evolution requirements have impacted the design of Space Station Freedom to varying degrees during the past seven years. The Program Requirements Document (PRD) has always included a set of evolution requirements. This set has been kept current by continually updating the requirements based upon the results from the element and distributed systems studies funded through the Advanced Studies Program. The Program Definition and Requirements Document (PDRD) included a set of evolution requirements until the 1989 program rephasing.

The *disconnect* between the PRD evolution requirements and the PDRD was brought to light during the ISPDR. All Review Item Discrepancies (RIDs) concerning evolution were assigned to the traceability team and disapproved with an action to resolve the PRD/PDRD disconnects via deletion or modification of the existing requirement.

Level I Advanced Programs Office and the Langley Research Center SSFO worked through the action, and a preliminary Level I / Level II meeting to discuss evolution requirements was held January 31, 1991 at Reston. The results of the evolution requirements work performed by Level I and LaRC were then presented to the Director for SSF on March 1. A PRD CR with follow–on and evolution phase requirements was signed out–of–board by the Director for SSF on June 14, thus baselining a limited set of critical requirements in Rev D of the PRD. The Level II Manager of Distributed Systems was briefed on the evolution requirements and the ongoing studies that support the requirements on June 14. Subsequently, a draft PDRD CR that "flows down" the evolution requirements from the PRD has been developed by Level I and Level II.

Evolution Requirements Background

- **Evolution requirements originally were included in the SSF Program**
  - Scrubbed from PDRD during 1989 rephasing
  - Retained in PRD and updated based on results of Advanced Studies Program

- **Lack of flow–down of evolution requirements from PRD to PDRD was recognized during ISPDR**

- **A reduced set of critical evolution requirements was baselined in the PRD Rev D**

- **A draft PDRD CR that flows down evolution requirements from the PRD has been developed between Level I and Level II**

Requirements, Approaches, and Baseline Impacts

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Critical Evolution Requirements

Since the ISPDR, the evolution requirements contained within the PRD have been reduced from 45 to six. The six *critical* requirements are as follows: 1) the ability to increase the total power generation and distribution capability of the station, and the ability to distribute growth power to the baseline elements; 2) the ability to increase the Thermal Control System heat rejection capacity commensurate with power growth; 3) the ability to increase data processing, transfer, and storage capability of the Data Management System; 4) the ability of the station to accommodate an advanced Extravehicular Mobility Unit; 5) the ability to augment the transverse boom with growth structure; and, 6) the ability to add pressurized volume. When considered during the initial design process, these six requirements will provide a basic flexibility for Space Station Freedom to evolve, independent of the specific evolution path (e.g., SEI, expanded R&D, etc.).

Critical Evolution Requirements

- **Ability to add power**
  - Total power generation and distribution capability
  - Power distribution to baseline elements (modules)
- **Ability to increase thermal rejection capacity commensurate with power growth**
- **Ability to increase data processing, transfer, and storage capability**
- **Accommodation of an advanced EMU**
- **Ability to add structure**
- **Ability to add pressurized volume**

These six requirements are needed to provide basic flexibility for Space Station Freedom evolution independent of the specific evolution path

"Design–for–Growth" Strategy

The requirements presented here identify the method of scarring that will be pursued for both the follow–on and evolution phases. Scarring for the follow–on phase shall be "installed up–front" in the baseline configuration. The elements and distributed systems which are slated to be part of the follow–on phase are summarized in Table 3.3–2 of the PRD. The scarring approach for the evolution phase is identified as one that "minimizes the impact on the baseline design in the areas of weight, power, and development cost." Identification of growth elements and distributed system upgrades that will be included in the evolution phase configuration of Space Station Freedom is currently underway at the Langley Research Center SSFO.

"Design–for–Growth" Strategy

PRD Rev D Requirement(s)

- **Program Summary PRD 1.3**
  - ...All systems shall be scarred to accommodate all the Follow–on Phase requirements specified in this document
  - ...The approach to meeting requirements for the Evolution Phase shall be one that minimizes the impact on the baseline design in the areas of weight, power, and development cost.

Electrical Power System Growth

The requirement for power generation states that the station shall allow for evolution to a capability of 150 kW orbital average power. This growth power level resulted from multiple utilization analysis iterations using varying allocation assumptions. The requirement that the Power Management and Distribution (PMAD) design shall allow for the distribution of *growth* power (power generated by additional power modules brought to orbit during the buildup to·the evolution phase) to the baseline loads will be added by directive to the PRD. This requirement was inadvertently dropped from the CR during the final editing process.

Replication or retrofit of the baseline EPS hardware (i.e., MBSUs, power modules, SPDAs, etc.) constitutes the minimum impact approach of achieving the growth power generation and distribution requirement. Installation of the associated growth electrical utility lines can be deferred until they are needed for distributing growth power. Deferral of these two aspects of the EPS growth is necessary because of the weight associated with the equipment and the current state of the baseline weight allocations.

The Solar Alpha Rotary Joint provides the following three functions: 1) sun tracking rotational movement of the PV arrays; 2) structural load transfer between the inboard and outboard truss members, and; 3) transfer of 160 VDC power and 1553B data across the Alpha Joint. Increased load transfer capability could be attained by replacement or retrofit of the SARJ trundle bearing packages, and, subsequently, the drive motors and Rotary Joint Motor Controllers (RJMCs). The impact on non–ORU components of this method of structural upgrade is currently being investigated. Power and data are transferred across the alpha joint by means of the Utility Transfer Assembly (UTA), which is an ORU. The baseline UTA design contains 18 power "roll rings" (4, 4 wire channels) and 24 data "roll rings". The minimum impact approach to power and data transfer upgrades would entail changeout of the baseline UTA with the UTA designed previous to Restructuring (24 power roll rings and 48 data roll rings). A study is underway which addresses the details of the evolution requirements for the SARJ and the means of satisfying them.

Electrical Power System Growth

- **PRD Rev D Requirement**
  - 3.4.5.4.4 The Electrical Power System (EPS) shall allow for growth to provide up to 150 kW orbital average power (Table 3.3–3)

To be added by Directive to PRD:
  - 3.3.2.3.5 The Power Management and Distribution (PMAD) design shall allow for growth to accommodate the distribution of power during the Evolution Phase to the baseline loads

- **Minimum Impact Approach**
  - Replicate or retrofit EPS hardware for growth
  - Defer growth electrical utility lines
  - Upgrade SARJ utility transfer assembly (UTA)
  - Replace or retrofit SARJ trundle packages, drive motors, and Rotary Joint Motor Controllers (RJMCs)

Electrical Power System Growth (Cont.)

A "growth" inertia requirement is being levied upon the design of the drive system. Analysis is underway to determine whether the equipment to be located outboard of the alpha joints during the evolution phase of the station has inertia properties that exceed the capability of the motors. The rotation capability can be upgraded by replacing the drive motors and RJMCs, as was presented on the previous chart. However, the design–limiting factor of this upgrade is the load carrying capability of the race bull gear, which, as an integral part of the bearing assembly structure, is not an orbital replaceable unit (ORU). Similarly, replacing or adding trundle packages on–orbit will allow for greater load transfer, but could also cause the race ring and "skirt" (non–ORU) to buckle.

There are several potential impacts to the baseline that result from these minimum impact solutions, although the degree of impact varies. One impact that is common across all distributed systems is reserving volume/access for growth hardware. A prime example of this impact is the identification of volume required for additional or upgraded MBSUs (required because there is a minimal number of spare RBIs within the baseline configuration). Placement of the electrical utility lines associated with the growth of the EPS will need to be identified. As a result of being a non–ORU, the SARJ bearing assembly, which consists of the skirt, race ring, ribs, T–rings, and hubs, will need to be sized for growth loads.

Electrical Power System Growth (Continued)

- **Installed Capability**
  - Structural capability of non–ORU SARJ components (skirt, race ring, ribs, T–rings, and hubs) must be adequate for growth
- **Potential Baseline Impacts**
  - Reserve volume/access for growth hardware (e.g., MBSUs)
  - Room for the addition of growth electrical lines
  - SARJ bearing assembly designed for growth loads

Thermal Control System Growth

The intent of the growth Thermal Control System (TCS) requirement is to ensure that the design of the system allows for upgrading the heat rejection capability consistent with the increased heat loads generated by the power system, crew, and equipment during the evolution phase. An initial assessment of the endpoint heat rejection capability during the evolution phase results in a growth load of ≈ 165 kW.

Placement of "growth" radiators on the station has been severely constrained as a result of the the Pre–Integrated Truss (PIT) design which came out of restructuring. The location of the MT prohibits growth of radiators in the +X direction, and the PIT prevents growth in the +/– Y direction. The option of extending the radiators in the –X direction at the current baseline location is being investigated.

The minimum impact approach to increasing the capabilities of this system consists of ORU replacement and retrofit of the TCS equipment (i.e., pump module assembly, thermal radiator rotary joint, radiator panels). One "brute force" option that is under consideration would place growth radiators and equipment on growth structure. The specific details of the options available are currently being investigated through an advanced study at JSC. The main potential impact to the baseline is, once again, preserving volume for the growth equipment and structure.

Thermal Control System Growth

- **PRD Rev D Requirement**
  - 3.4.5.4.5 The thermal distribution system shall allow for growth compatible with heat rejection requirements from EPS plus parasitic and metabolic loads (Table 3.3–3)
- **Additional radiators on the baseline PIT is not a viable option**
- **Minimum Impact Approach**
  - Upgrade Pump Module Assembly (PMA)
  - Retrofit Thermal Radiator Rotary Joint (TRRJ) / radiator panels and (optionally) add heat pump, or;
  - Install additional TCS radiators and equipment on growth structure
- **Potential Baseline Impacts**
  - Accessibility and fluid disconnects for TRRJ, PMA, and radiator panel upgrades (all ORUs)
  - Fittings for structural augmentation to PIT
  - Room for the addition of growth fluid lines

Pressurized Volume Growth

The intent of this requirement is ensure that the Space Station design allows for the expansion of the module pattern via laboratories, habitats, resource nodes, airlocks, ACRVs and log modules. The need for this requirement is driven by the results from numerous utilization analyses based upon accepted user mission data.

The minimum impact approach to implementing growth of the module pattern would defer the work until post–EMC. This is true not only for the pressurized canisters, but also the common berthing mechanisms and utilities required for installation of the elements. The critical impact to the baseline design is the reservation of volume, both internal and external, for the elements and supporting utility lines. More specifically, for the elements, node ports need to be made available for future use as a module path. The utility line issue is somewhat more complicated. Not only is volume required for the growth lines, but also a means of connection to these lines.

Pressurized Volume Growth

- **PRD Rev D Requirement**
  - 3.4.5.4.1 The SSMB design shall allow for the addition of pressurized elements such as laboratories, habitats, resource nodes, airlocks, ACRVs, and logistics modules
- **Minimum Impact Approach**
  - Add pressurized volume for growth post–EMC
  - Defer installation of growth common berthing mechanisms for module interconnect
  - Defer installation of utility lines to resource node ports for growth pressurized volume
- **Potential Baseline Impacts**
  - Ensure availability of resource node ports via equipment relocation (e.g., logistics module relocated to growth nodes)
  - Reserve internal volume in nodes/standoffs for growth utility line runs and provide a means of connection to these lines

Truss Structure Growth

The intent of this requirement is to ensure that the baseline Pre–Integrated Truss can accommodate the addition of growth structure along and orthogonal to the transverse boom. It also allows for the addition of the growth utilities associated with the increase in resources.

Structure added *along* the transverse boom will be required for accommodating growth power modules. Structure will be added *orthogonal* to the transverse boom to accommodate additional subsystems, spares storage, utilities, technology payloads, and EOS and/or spacecraft servicing facilities. All structure will be added only when needed after PMC.

Truss Structure Growth

- **PRD Rev D Requirement**
  - 3.4.5.4.2 the SSMB structural design shall allow for addition of power generation capability along the transverse boom, addition of truss orthogonal to the transverse boom, and for utility distribution associated with growth resources
- **Minimum Impact Approach**
  - Add structure orthogonal to the transverse boom post–EMC
  - Augment the transverse boom along the Y–axis for power system growth post–EMC
  - Defer utility lines for growth

Truss Structure Growth (Cont.)

The addition of structure in either mode will be possible only if fittings and connectors, as well as volume, are provided in the baseline configuration. Langley is currently identifying the configurations for the phases of the station beyond PMC. Studies are also underway that are addressing the issues of transition structure, loads analysis, and growth utility placement and support.

Truss Structure Growth (Continued)

- **Potential Baseline Impacts**
  - Provide fittings at specified locations to allow the attachment of structure orthogonal to the Pre–Integrated Truss (PIT)
  - Provide fittings and connectors at the ends of transverse boom for power augmentation
  - Reserve room along faces of the transverse boom for utilities
- **Structural loads analysis has not been completed (baseline or growth)**

EVA Systems Growth

The EVAS growth requirement states that "the SSF design shall allow for upgrade to a station–based EVA capability using an on–orbit serviceable EMU". Work is being done through the advanced studies program that will trade competing EMU life support technologies and candidate configurations, and identify highly probable growth paths. Potential growth paths include support of an on–orbit serviceable high pressure (3500 psia) oxygen system, on–orbit hydride–based heat rejection systems, and data interfaces necessary to support automated checkout and servicing of an advanced EMU.

The minimum impact approach to fulfilling the requirement is to defer installation of the EMUs and the associated support equipment and hardware. Volume for this growth equipment needs to be identified and reserved during the baseline design of the airlock. More important, however, are the penetrations in the airlock shell and MM/OD shielding that need to be drilled during the initial manufacturing process. Several of the growth scar airlock shell penetrations currently exist in the baseline design (i.e., 900 psia O_2, low pressure H_2 supply, 100–200 psia H_2, 120 VDC, and 1553 data bus), but others remain to be baselined (i.e., 62/35 °F cooling supply and the cooling return).

EVA Systems Growth

- **PRD Rev D Requirement**
  - 3.4.5.4.6 The Space Station Freedom design shall allow for upgrade to a station–based EVA capability using an on–orbit serviceable Extravehicular Mobility Unit (EMU) (Table 3.3–3)
- **Minimum Impact Approach**
  - Defer advanced EMUs and associated support equipment and hardware in baseline airlock
- **Potential Baseline Approaches**
  - Volume and structural interfaces for growth hardware mounted external/internal to airlock (e.g., Advanced EMU, SPCS, O_2 and H_2 compressors)
  - Utility penetrations (O_2, H_2, power, data, thermal) and connectors in baseline airlock shell and fixed MMOD shielding

Data Management System Growth

The purpose of this requirement is to ensure that the Data Management System (DMS) is designed such that future upgrades, either functional or technological, will not require a major redesign of the system. This is the only system which is recognized by the PDRD as being evolutionary in nature. The following sections in the PDRD support this "open architecture" design: 3.2.5.1.1, 3.2.5.1.1.17 and 3.2.5.6.1.

Data Management System Growth

- **PRD Rev D Requirement**
  - 3.4.5.4.3 The SSF design shall allow for growth in data processing throughput and function, data storage capacity and performance, and network communication bandwidth by providing expandable and upgradeable system designs
- **The PDRD recognizes the evolutionary nature of this system**
- **Linkages between the PRD and PDRD have been identified for this requirement by ARMS**

Next Step

An extended version of the *Evolution Design Requirements and Design Strategy* pitch was presented at the Director's Management Review in Reston on June 16. This was the first step towards getting down to the level at which baseline detail design occurs. Meetings to discuss the work that is being done in support of evolution and review the draft CR to the PDRD at the Work Packages have been, or are being, scheduled. One task that needs to be performed by Level III is an assessment of the evolution capability of the baseline design at the Permanently Manned Configuration. LaRC and the Advanced Study task managers will be involved in a supportive role with the assessment and will ensure that there is complete flow–down of the evolution requirements to the Level III documentation.

Next Step

- **Work Package visits to review draft PDRD Evolution Requirement CR**
  - Work Package 1 – August 12
  - Work Package 2 – TBD
  - Work Package 4 – August 20

- **Support WP assessment and flow–down of requirements into Level III documents**
  - Assessments must be performed at the detail design level
  - LaRC and Advanced Studies task managers available for support

Space Station Freedom Evolution Quotes

Numerous statements concerning the capability of Space Station Freedom to evolve are being made both inside and outside the agency. Extensive analysis has been performed in support of identifying those resources that are critical for evolution of Freedom, and work is currently underway that will determine the follow–on and evolution phase configurations for the station. A considerable amount of these studies have been done from outside of the “work package baseline design process”. To ensure Space Station Freedom retains the capability to evolve, the results of these studies need to be factored into the Level III work that is being done on the baseline design.

Space Station Freedom Evolution Quotes

"We realize the value of retaining a growth capability and have done so wherever possible"

– Draft testimony for the FY '92 SSF Budget hearing

"The NASA response to the 90–day assessment will include a capability growth strategy beyond the initial phase"

– 1/91 Lenoir letter to Congress

"The design should not preclude future expansion in structure, power and crew size to enable its evolution..."

– 12/90 Aldrich memo to Lenoir regarding restructuring

" We fully expect that as we build this station we will, in time, meet the requirements of the principal scientific research..."

– 3/91 Fisk statement in response to NRC, SSB criticism of the restructured PMC design