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Paper Session II-A - Space Station Freedom Accommodation of the Human Exploration Initiative

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SPACE STATION FREEDOM ACCOMMODATION OF
THE HUMAN EXPLORATION INITIATIVE

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ABSTRACT

In his July 20th speech commemorating the 20th anniversary of the first Apollo Moon landing, President Bush proposed "...a sustained program of manned exploration of the solar system...and the permanent settlement of space." The President's plan for the future of America's manned space program calls for Space Station Freedom to be operational in the 1990's followed by a return to the Moon for the new century, "this time to stay", and then a manned mission to Mars. Space Station Freedom is a fundamental part of this long-range, evolutionary, human exploration initiative. It will support continuous human presence in Earth orbit for the purposes of scientific research and the development of technologies critical to the exploration missions. In addition to serving as a research and development facility in space, Freedom will be used as a spaceport or transportation node to support the assembly, servicing and checkout of space transfer vehicles which will ferry crew and cargo to the lunar surface and on to Mars. A study conducted by NASA during the Autumn of 1989 identified exploration accommodation requirements for the Space Station and formulated plans to implement mission-supporting capabilities. It was determined that the initial Space Station Freedom configuration (termed Assembly Complete) must be augmented to provide additional resources and capabilities. Increases will be required to Freedom crew, power, pressurized volume and truss structure. New capabilities will be required such as spacecraft assembly and servicing. A significant conclusion of the 90-day NASA study was that Space Station is capable of accommodating the necessary additions due to the evolutionary nature of the design.

INTRODUCTION

The National Aeronautics and Space Administration, in response to the President's space policy speech of July, 20 1989, organized a task force to conduct a study of

manned Lunar and Mars exploration [1]. The objectives of the 90-day NASA study effort were to develop mission approaches, derive mission requirements and define infrastructure requirements to a level which allowed cost estimates to be made for each mission strategy. Langley Research Center, working with the Office of Space Station at NASA Headquarters, was responsible for identifying impacts on Space Station Freedom and accommodation requirements for the support of, what is now termed, the Human Exploration Initiative (HEI). Station support of HEI encompasses two critical functions. It will serve as a transportation node providing facilities and resources (e.g., crew, power, communications) for space vehicle assembly, testing, processing and post-flight servicing. Secondly, Freedom will be an orbiting laboratory for research and technology development. Life science research will be conducted on Space Station to develop countermeasures to long-duration exposure of humans to weightlessness. Technology experiments will be accommodated to demonstrate and verify mission-critical technologies in the space environment. A phased evolution of Space Station Freedom was defined during the NASA study consistent with its functional roles and the HEI mission milestones and required augmentations and system capabilities were identified for each phase.

Human Exploration Initiative Requirements and Assumptions for Space Station Freedom

The top-level mission requirements imposed on Space Station by the Human Exploration Initiative state that Freedom: (1) shall be used as a source of technology, hardware and software for lunar and Mars vehicles and systems; (2) shall act as a testbed for validation of lunar and Mars systems and technology elements; (3) shall be used as a laboratory for determination of acceptable long-term human spaceflight microgravity and radiation countermeasures, and self-sufficient life support systems; and (4) shall accommodate assembly, test, launch, recovery and turnaround of lunar and Mars vehicles.

Several basic assumptions relevant to Space Station were established at the start of the HEI accommodation study. The first assumption was that the Space Station program and its capabilities would be fully augmented to meet the requirements identified for HEI. Secondly, the resources allocated for this support (e.g., power, crew, lab space) would be provided from the U.S. resource allocation, i.e., the Space Station international partners receive their fixed percentage of resources as agreed upon in the Memoranda of Understanding. Lastly, Freedom would accommodate concurrently multidiscipline research and development for other U.S. experimenters as well as for the internationals.

The baseline Freedom configuration, which was the point-of-departure for the analysis, is illustrated in figure 1.

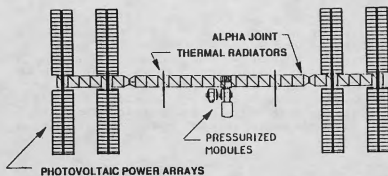


Figure 1. Space Station Freedom Baseline Configuration

It is referred to as the "Assembly Complete" configuration within the current development program and features 75 kilowatts of photovoltaic electrical power, 8 crewmembers, 1 U.S. habitation module and 3 pressurized laboratory modules (1 U.S., 1 Japanese, 1 European) and accommodations for 2 attached payloads.

Exploration Accommodation Milestones

The first mission milestone which Space Station Freedom is required to support as a transportation node is a test flight of the Lunar Transfer Vehicle or LTV. The LTV is the spacecraft which will ferry crew and cargo between Freedom and the lunar surface. This initial flight serves as an unmanned, end-to-end verification test of the LTV; however, it will deliver some limited payload to the lunar surface. Next, a series of expendable LTV flights occur from Freedom. This expendable mode of operation maximizes payload mass which can be delivered to the lunar surface in order to implace critical systems for life support (e.g., power generation, pressurized living quarters). Subsequent to the expendable flight operations phase, reusable Lunar Transfer Vehicles are introduced as a cost-effective alternative to expending spacecraft systems after each mission. Space Station will be required for post-flight servicing of the reusable LTV's and each vehicle is projected to have a lifetime of 5 missions. The final operational phase of the initiative combines manned and cargo missions to Mars with steady-state support of the lunar outpost. Freedom serves as the in-space, assembly site for the Mars vehicle (minus the propulsion stages) as well as providing continued turnaround operations for the LTV. Concurrent with each of the operational phases for HEI is the research and technology verification activities at Space Station which focus on mission enabling issues.

Research and Technology Verification

Space Station Freedom is an ideal base to support many of the research and technology development activities for the Human Exploration Initiative. This

research must be conducted in Earth orbit since no terrestrial laboratory can adequately simulate the characteristics of the space environment in which the spacecraft systems and crew must operate. Research and technology development areas that are mission enabling and require the utilization of Space Station are broadly categorized as In-space Operations, Humans in Space, Spacecraft Design Technology and Lunar and Mars Mission Simulation. The elements of each category are listed in Table 1.

In-Space Operations

- In-Space Assembly
- In-Space Vehicle Processing
- Robotics / Teleoperations Technology
- Guidance, Navigation, & Control
- Communications
- EVA / Suit R&T
- Cryogen Fluid Management / Tank Handling

Humans in Space

- Human, Plant, & Animal Physiology
- Space Human Factors & Performance
- Closed Life Support Systems (CLLS)

Lunar / Mars Mission Simulation

- LTV Verification Flight
- High Energy Aerobrake Test
- Mars Mission Crew Simulation

Spacecraft Design Technology

- Space Materials
- Space Hardening of Electronics

Table 1. Research and Technology Elements

The HEI-focused, research and technology program at Freedom is phased to coincide with the operational intervals described in the previous section. The initial R&D phase begins as soon as Space Station is permanently manned and continues until the LTV verification flight. It focuses on the in-space operations necessary to prepare for the test flight (e.g., element mating, aerobrake assembly) and life science research. Life science research will concentrate on developing procedures to guarantee safe and productive crew operations during extended stay times on Space Station. The goal is to achieve stay times of 180 days.

The second R&D phase takes place during the interval between the LTV verification flight and the LTV reusable operations phase. In-space technology development continues with a focus toward spacecraft servicing operations required to process and recertify a reusable LTV. The life science research during this phase will address the development of effective countermeasures to microgravity exposure for the extended durations associated with the trip to Mars.

In the third R&D phase, human life science research will be emphasized in an effort to confirm the effectiveness of microgravity countermeasures prior to beginning the design and development efforts for the Mars Mission Vehicle. Selected countermeasures must be

verified at this time in order to continue the design process for a zero-gravity vehicle. In addition, life support system technologies will be tested and verified for use on the Mars vehicle. Experience gained processing LTV's will serve as a basis for the subsequent Mars operations.

Lunar Vehicle Operations

Since the size and weight of the Lunar Transfer Vehicle preclude its delivery to space via a single Earth-to-orbit launch, it must be delivered in pieces and assembled at Space Station Freedom. The launch concept calls for three heavy-lift vehicles (HLV's) to be launched to Space Station. One delivers the LTV along with its Lunar Excursion Vehicle (LEV) and the aerobrake segments and two HLV's are required to deliver the loaded LTV fuel tanks (liquid oxygen/hydrogen). Therefore, Space Station must be capable of accommodating HLV delivery of LTV/LEV hardware and must support the mating of wet propellant tanks to the vehicle. In addition, the aerobrake must be assembled on-orbit and verified for operation. Finally, Freedom will provide an integrated checkout of the spacecraft prior to launch. This functional capability is required in its entirety to support the initial exploration milestone, the LTV verification flight. To meet these requirements, Space Station must be augmented with additional power, crew, truss structure and unique facilities. The Space Station configuration required to accommodate the LTV verification flight is shown in figure 2. The LTV operations (defined in greater detail by Troutman and Ganoë [2]) require a special facility called a service track assembly to provide a fixture for mounting and manipulating the vehicle, equipment storage and to guide robotic arms to all portions of the LTV.

50 kW Additional
Solar Dynamic Power

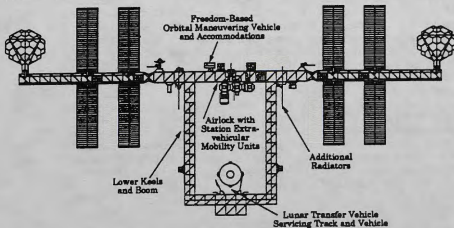


Figure 2. Lunar Operations Configuration (LTV Verification)

To provide a location for the service track assembly and for the support of technology experiments, additional structure must be added to the Assembly Complete, Space Station configuration. This augmentation is implemented by attaching the lower keels and lower boom to the transverse boom of Freedom.

Crew-time requirements associated with the LTV operations, research and technology verification, concurrent science, station maintenance and international support calls for two additional crew members beyond that of the baseline capability. By the time of the LTV verification flight, power requirements on Freedom will have increased to about 100 kw. to support the assembly and checkout and the increased level of life science research. To provide this power, a pair of solar dynamic systems will be added, bringing the total power generation capability to 125 kw. (average). Other key augmentations include a second airlock and station-based, high pressure EVA suits to support assembly operations; station-based Orbital Maneuvering Vehicle (OMV) accommodations and enhancements to Space Station Freedom distributed systems.

Following the LTV verification flight, Space Station Freedom enters the operational phase of the lunar outpost support. Initially, this involves mating, assembly, checkout and launch of LTV's operating in the expendable mode. Since Freedom must provide temporary housing of the 4-person LTV crew on the trips to and from the lunar surface, a second habitation module is added to Space Station prior to the first piloted mission. The two crew members added in the previous phase to support the verification flight will be relocated into this second habitation module. The service track assembly is enclosed during this phase to provide debris protection for the LTV. The enclosure will be designed so that it can be retracted as vehicle operations demand. Additional elements and activities at Space Station will increase the power requirements; however, the power demand remains within the power generation capability.

As lunar operations mature, Space Station will be required to process reusable LTV's. The servicing and refurbishment functions and increased life science research which occurs during this phase will result in power requirements that exceed the 125 kw. station capability. Therefore, a second set of solar dynamic generation units will be added to Freedom to bring the total capability to 175 kw. The permanent crew increases from 10 to 12, but this growth can be accommodated by the habitation module added in the previous phase. A comparison of key growth elements added to Freedom to accommodate the three principal lunar operation phases and the subsequent lunar and Mars operations is summarized in Table 2.

Space Station Freedom Element	Lunar Transfer Vehicle Verification Flight	Expandable Lunar Transfer Vehicle Operations	Reusable Lunar Transfer Vehicle Operations	Lunar & Mars Operations
Modules	3 Laboratory (1 U.S., 1 European, 1 Japanese) 1 Habitation	3 Laboratory (1 U.S., 1 European, 1 Japanese) 2 Habitation	Same	Same
Truss Structure	Transverse Boom, Lower Keels & Lower Boom	Same	Same	Transverse Boom, Lower and Upper Keels and Booms, Mars Vehicle Support Structure
Power & Thermal	125 kilowatts	125 kilowatts	175 kilowatts	175 kilowatts
Crew	10 Permanent	10 Permanent, 4 Transient Lunar	12 Permanent, 4 Transient Lunar	12 Permanent, 4 Transient Lunar or Mars
Vehicle Processing	Service Track Assembly for Lunar Vehicle	Enclosed Lunar Transfer Vehicle Hangar	Same	Enclosed Lunar Transfer Vehicle Hangar, Mars Vehicle Assembly Facility
Remote Manipulator (Canadian), Mobile Transporter	1 Remote Manipulator, 1 Mobile Transporter	Same	2 Remote Manipulators, 1 Mobile Transporter	2 Remote Manipulators, 2 Mobile Transporters

Table 2. Space Station Freedom Growth Elements for HEI
Lunar and Mars Operations

As the exploration initiative moves into the Mars mission phase, the components of the Mars vehicle, with the exception of the large propulsive stages, will be assembled and checked out at Freedom. Upon assembly of these components (high energy aerobrake, Mars aerobrake, Mars Transfer Vehicle (MTV) and Mars Excursion Vehicle (MEV)), a fully integrated checkout will be performed followed by deployment from Freedom for staging with the propulsive elements. These functions will take place with ongoing lunar outpost support including LTV processing. Space Station will require the addition of upper keels and an upper boom to provide room and support structure for the on-orbit assembly of the Mars vehicle elements (Figure 3). It was assumed that the individual lunar and Mars missions can be scheduled so that no simultaneous operations are required. This results in sequential LTV/LEV and MTV/MEV processing; therefore, no additional Space Station crew is required during the lunar and Mars operational phase. Temporary accommodations will be provided for the four transient Mars crew members within the existing second habitation module. Once again, the key elements added to Freedom at each phase of HEI accommodation are summarized in Table 2.

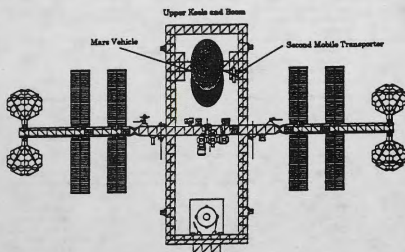


Figure 3. Lunar and Mars Operations Configuration

Conclusions

The Human Exploration Initiative will require an Earth-orbiting, transportation node for processing lunar and Mars transfer vehicles and a in-space laboratory for mission-related research and technology development. Space Station Freedom can accommodate both functions with augmentations to the baseline (Assembly Complete) resources, facilities and operational capabilities. The evolutionary design will permit the on-orbit addition of growth elements such as pressurized laboratories and habitation modules, power generation equipment, truss structure and unpressurized vehicle processing platforms. The capacity to evolve also allows new functions to be added to the baseline, such as the assembly, servicing and checkout of spacecraft.

Fundamental to Freedom's evolutionary potential is the presence of certain features within the initial design which enable future growth in capability. These design features, known as "scars", allow augmentations to be made to Space Station without complex, costly and disruptive retrofits. Critical scars identified for Freedom's accommodation of HEI are those associated with the growth of the power and thermal distribution system, particularly the rotary joints, and those which could be classified as "room to grow" for the addition of the dual keels and the pressurized modules.

References

1. Report of the 90-Day Study on Human Exploration of the Moon and Mars, NASA, November, 1989.
2. Troutman, P.A., Ganoe, G.G., "Lunar Vehicle Assembly and Processing on Space Station Freedom", 27th Space Congress, April 1990.