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Paper Session II-A - Space Station Requirements and Transportation Options for Lunar Outpost

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Space Station Requirements and Transportation Options for Lunar Outpost

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Abstract

The 1990’s and Space Station Freedom are the next critical steps in our space endeavors which will be stepping stones for the new century permanent exploration of the moon and the solar system. Freedom Station and transportation requirements for the lunar outpost are partitioned into three phases - the emplacement phase, the consolidation phase, and the utilization phase. The Earth-to-orbit transportation system must ferry vehicles, cargo, crew, and propellant to low Earth orbit (LEO) to support these lunar outpost phase requirements. The lunar transportation system is designed to move crew, science instruments, and support equipment from LEO to the surface of the moon. The lunar transportation system consists of the lunar transfer vehicle (LTV) and the lunar excursion vehicle (LEV). These reusable and highly reliable vehicles provide multiple mission utility through common vehicle usage for cargo and crew delivery. Mission analyses and the lunar payload model have established vehicle design and sizing requirements. A 300-km circular orbit is assumed for the low lunar orbit (LLO) staging point for the lunar surface base. Freedom is used as the LEO transportation node. The LEV is sized to deliver 15t to the lunar surface for the first piloted flight. The LEV can deliver 33t to the lunar surface in the cargo expendable mode. Different transportation system options are designed and sized to compare and show sensitivity of the initial mass required in LEO to determine the most effective and efficient transportation concept.

Introduction

In his July 20, 1989, space policy speech, President Bush proposed a long-range continuing commitment to space exploration and development, and outlined a three-phase program. First, for the decade of the ’90’s — Space Station Freedom, our critical next step in all our space endeavors. Next, for the new century and the new millennium, back to the Moon, this time to stay. And then, a journey to tomorrow — a journey to another planet, manned missions to Mars.

The Space Station Freedom requirements are based on supporting the space transportation systems to move humans and support equipment (e.g., habitats, supplies, and science and exploration equipment) from Earth to the surfaces of the Moon and Mars. Space Station Freedom is fundamental to completing President Bush’s program. The space transportation system is divided into three logical parts. Transport to and from Earth orbit is accomplished by the NSTS (space shuttle), expendable launch vehicles (ELVs), and a new heavy-lift vehicle capable of 55t to 150t cargo delivery each flight. Space transfer vehicles provide transportation between Earth orbit and lunar orbits. The excursion vehicle provides transportation between lunar orbit and the lunar surface.

This paper describes results of preliminary design studies conducted by NASA and its contractors that defined Space Station Freedom requirements and transportation systems options for the lunar component of President Bush’s initiative. The paper presents an understanding of Freedom Station requirements, transportation requirements/options, and design solutions to meet the requirements.
Lunar Outpost Program Approach

A firm program for lunar exploration has not been selected. NASA studies have considered a range of program approaches that focus on the issues of technology, schedules, and budget. This paper describes an approach dealing primarily with the issue of schedule for return of humans to the Moon. The approach is based on the earliest feasible date for return to the Moon, with a rapid buildup to a permanent human base on the Moon.

The lunar outpost approach is characterized by three, generic program phases: emplacement, consolidation, and operation. The emplacement phase places facilities and equipment on the lunar surface and puts them into initial experimental operation. The consolidation phase adds facilities, especially for local resource utilization, and develops a degree of maturity in planetary surface operations. This maturity qualifies surface operations for the more difficult Mars missions. The operation phase exploits lunar surface systems and operations for scientific benefit as well as for farther-reaching exploration benefit. These phases of lunar exploration are described in Figure 1. The figure also includes descriptions of the principal activities during each phase.

Missions to the Moon fall into two categories: piloted and cargo. Figure 2 illustrates the typical mission profile for delivering crew and cargo to the lunar surface. A piloted mission delivers a crew of four and some cargo to the lunar surface and returns a crew of four and limited cargo to Freedom. A cargo mission delivers only cargo, and the vehicle is either expended or returned empty. The missions use common transfer and excursion vehicles: the piloted missions add a crew cab for personnel transfer, and cargo missions use only a cargo pallet. The vehicle for cargo missions can be expended, which increases the payload delivery capability to the lunar surface. For piloted flights, the transfer vehicle employs an Earth-to-Moon trajectory that allows the crew to return safely to Space Station Freedom if necessary.

Reference Lunar Transportation System

The transportation system needed for the sustained lunar program as currently envisioned will require that Space Station Freedom become an important element of the overall transportation architecture. This important role of Space Station Freedom becomes obvious when the lunar transportation system and the requirements placed on that system are examined. The transportation system consists of two vehicles, a lunar transfer vehicle (LTV) and a lunar excursion vehicle (LEV). The LTV transports the LEV, payload, and crew to lunar orbit and brings the crew back. The LEV transports payloads and crew between lunar orbit and the lunar surface. The role of the Freedom is derived from two basic sets of requirements placed on the transportation system. The first is the lunar surface payload requirements, and the second is the lift capabilities of the launch vehicle that will be used.

Figure 1. Lunar Base Evolution Phases

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Conceptual configurations of the two lunar vehicles are shown in Figure 3. The LTV consists of a propulsive core stage connected to two sets of drop tanks which carry propellant. An aerobrake is attached to the core stage for missions returning to S.S. Freedom and a crew module is attached to the core for piloted missions. The first set of two drop tanks is jettisoned shortly before or after the trans-lunar injection burn is completed. The second set of drop tanks carries propellant for lunar orbit insertion plus additional propellant which is transferred to the LEV in lunar orbit. The aerobrake is used to brake the LTV into Earth orbit upon return from the Moon. The lunar excursion vehicle consists of a single propulsive stage, used for both descent and ascent. The surface payload is attached to two outboard platforms which tilt downward for payload removal. The LEV used for piloted missions has a crew module permanently attached.

Space Station Freedom will be required to fulfill two roles, one as a “transportation node” and the other as an “assembly node.” The advantages of having a reusable lunar transfer vehicle are greatly increased if the LTV can remain in orbit rather than return to the Earth’s surface between missions. Space Station Freedom provides an excellent orbital base from which lunar missions can embark and vehicles can be checked out or even refurbished. The role as an assembly node is even more important due to the lunar surface payload requirements imposed on the transportation architecture. The assumed lunar surface payloads for the first eight missions are listed in the upper part of Figure 4. These payloads range from 15 metric tons for piloted missions to 33 metric tons for cargo missions. The lunar surface payload is the primary driver of the propellant loading and total mass that must be delivered to orbit. These values are also shown in Figure 4. The total delivery requirement for any one mission greatly exceeds the capability of the launch vehicles that will be available. Therefore, multiple launches are required for each mission. Space Station Freedom provides an ideal orbital facility where vehicle elements can be assembled and checked out prior to each mission. The lower portion of Figure 4 shows how the vehicle elements would be delivered to the Freedom for each of the five possible mission modes. The elements that would be included in each launch are listed inside the representative payload shrouds.
**Lunar Excursion Vehicle (LEV)**
- Payload to Surface: 15t Plus Crew Module or 27t Cargo Only
- Single Stage Design
- Liquid Hydrogen/Liquid Oxygen Propellant
- 4 Engines @ 20k Thrust Each
- Vehicle Mass: 31t

**Lunar Transfer Vehicle (LTV)**
- Core Stage w/Drop Tank Design
- Liquid Hydrogen/Liquid Oxygen Propellant
- 4 Engines @ 20k Thrust Each
- Aeroassist Earth Orbit Return
- Vehicle Mass: 127t

*Figure 3. Lunar Transportation System*

**Lunar Outpost Launch Manifest Summary**

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<th>Flight No.</th>
<th>Date</th>
<th>Mission Type</th>
<th>Payload to Surface</th>
<th>Total Propellant</th>
<th>Mass Delivered to LEO</th>
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<td>2001</td>
<td>Cargo</td>
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</table>

*Figure 4. Lunar Outpost Launch Manifest Summary*
Assembly and Basing at Space Station Freedom

The reference lunar transportation system configuration is presented in Figure 5. This figure depicts the vehicles, both LTV and LEV, as they would be initially flown for a piloted mission with crew modules and cargo. Using expendable drop tanks reduces the vehicle’s propellant load by approximately 10 percent compared to a single-stage reusable lunar transfer vehicle.

![Initial Vehicle Delivery Mode](image1)

**Figure 5. Lunar Transfer/Excursion Vehicles**

On initial crew delivery flights, the vehicles are packaged and launched to Freedom on a single heavy-lift launch vehicle as depicted in the lower left corner of Figure 5. Packaging includes the fully fueled core propulsion/avionics module, the aerobrake central core and peripheral segments, transfer vehicle crew module, excursion vehicle crew cab, and partially fueled excursion vehicle. At Freedom, the eight peripheral segments of the aerobrake are attached to the aerobrake central core, and the combination is checked out for structural integrity (Figure 6). Two additional heavy-lift vehicles launch four fully loaded expendable main propellant tanks to Freedom for mating to the transfer vehicle. The shuttle delivers cargo modules and crew to Freedom, where the cargo modules are added to complete the integrated lunar transportation vehicle.

![Aerobrake Packaging](image2)

**Figure 6. Aerobrake Packaging**
Figure 7 shows the evolution required of S.S. Freedom to support the lunar vehicle assembly, refurbishment, and tests. A lower keel will be added to provide real estate for an assembly area and a hangar site. The power will be increased from 75 to 125 kilowatts to support additional power for the vehicle as well as assembly and testing operations. Two additional crew members will be added to the Freedom to support lunar vehicle processing. This S.S. Freedom configuration will support the LTV verification flight.

The lunar vehicle hangar is added to the Freedom to support expendable LTVs. The hangar is required to protect the vehicle from debris during the long stretches of time that it is located at LEO. A habitation module is added to accommodate the lunar mission crew of four.

To support the reusable LTVs, a second RMS and additional solar dynamic power units are added. The power generation capability will then increase from 125 to 175 kilowatts. Two additional permanent crew members are added to support lunar vehicle processing and normal Freedom Station activities.

Figure 8 itemizes the required changes to be made to Freedom in support of the lunar mission. Other S.S. Freedom facility changes required to support the lunar mission include accommodations for an upgraded OMV and control system impacts. Space Station Freedom safety may be impacted by increased proximity operations, contamination, and propellant transfer and storage. The Freedom's normal operations may be impacted by Earth and sky viewing occlusion, decrease in available EVA/crew-time/crew-skill mix, down logistics, and international agreements.

Impacts on the lunar vehicle, because of Space Station Freedom processing, include venting restrictions, proximity operations restrictions, as well as data, software, and communications compatibility.
### Figure 8. Space Station Freedom Growth Elements for Human Exploration

#### Orbit Debris Protection Requirements

The lunar transportation elements will be based at the space station for extended periods of time - either for assembly or storage awaiting the next mission. During this period of time, they will be exposed to the meteoroid and orbital space debris environment. These elements, having quite large surface areas, are fairly likely to receive an impact which will cause a penetration. The man-made orbital debris is the primary problem. The amount of space debris is increasing every year at the rate of about 5 to 10 percent. By early in the next century it has been estimated that an unprotected LTV would receive a penetration every 2-1/2 years on the average. Obviously, some type of protection must be provided. In the past, spacecraft have provided their own protection through the use of shields of various designs. The LTV can ill-afford the added mass that this would require. The space station, therefore, must provide a protected area in which to do assembly operations and storage.

The standard way of protecting against the smaller (and much more numerous) debris objects is to provide a double-walled shield. The outer wall is called a bumper. When a debris particle strikes the bumper, a strong shock wave will rapidly travel through the particle, liquifying or vaporizing it. To achieve this, the thickness of the bumper should be from 0.1 to .25 times the diameter of the debris particle. The rear wall, which is some separation distance behind the bumper, must then stop the resulting spray of liquid or vapor.

Figure 9 shows schematically the application of this concept to the protection of the LTV by a “hangar” at the space station. To provide a moderate amount of protection, such a hangar would have a mass of about 20,000 lbs.
Freedom Proximity Operations

The Lunar Exploration Initiative proximity operations is shown in Figure 10. The HLLV is launched to a point co-orbital with SSF and 20 nmi behind it. At this point the vehicle will be on the boundary of the SSF control zone and rendezvous zones. After it arrives at this point the HLLV will go into a station keeping mode and await the arrival of the Orbital Maneuvering Vehicle (OMV) for cargo transfer operations.

OMV Moves to HLLV

Figure 10. Space Station Freedom Proximity Operations.
The OMV, based at SSF, will depart SSF and will rendezvous with the HLLV. It will dock with cargo elements in the HLLV payload bay. When the elements are released, the OMV will move the elements to SSF and within grappling range of the Space Station Remote Manipulator System (SSRMS). Once the SSRMS has grappled the cargo elements, the OMV will release from the elements and return to the HLLV for another load. A maximum of three trips are possible without refueling the OMV.

After the last cargo elements have arrived at SSF, the HLLV is free to deorbit. It is assumed that the HLLV can deorbit from the SSF rendezvous zone as soon as safe deorbit zone is reached.

Transportation Options

As mentioned earlier, the LTV design consists of a core stage with an attached aerobrake plus two sets of drop tanks. The LEV consists of a single cryogenic stage. These choices resulted from a comparison of several vehicle options. These options included a single-stage reusable LTV, an LTV with only one set of drop tanks, and an LTV with no aerobrake. An alternative LEV that would use space-storable propellants was also evaluated and compared with the cryogenic LEV. Figure 11 shows a summary of this comparison. It can be seen that the selected LTV configuration results in less mass required in low Earth orbit. Also shown is the lunar surface payload capability for each of the five mission modes for the selected LTV, using Earth-produced or lunar-produced liquid oxygen.

![Figure 11. Lunar Outpost Mission Analysis (Performance Calculations)](image)

**Conclusion**

Space Station Freedom requirements and transportation systems have been defined to satisfy the lunar outpost part of President Bush’s exploration initiative. Different transportation system options were designed and sized to compare and show sensitivity of the initial mass required in LEO to determine the most effective and efficient transportation concept.