AN INFRASTRUCTURE FOR EARLY LUNAR DEVELOPMENT

Brand Norman Griffin[1]
Member, American Institute of Aeronautics and Astronautics

ABSTRACT

A complete Earth/lunar infrastructure is presented. All phases necessary to support a return mission to the Moon and achieve permanent occupancy are described. This paper offers design concepts and supporting rationale for a low-risk, low-cost program based on existing technologies and use of the proven Shuttle system.

At the heart of the infrastructure is the Shuttle cargo bay and its payload retention system. The payload sizing and method of structural support is used as a standard throughout the infrastructure, ensuring compatibility and simplifying user operations. Horizontal integration and handling on Earth and the Moon represents a substantial cost avoidance through use of existing Shuttle systems and minimal lunar ground support equipment.

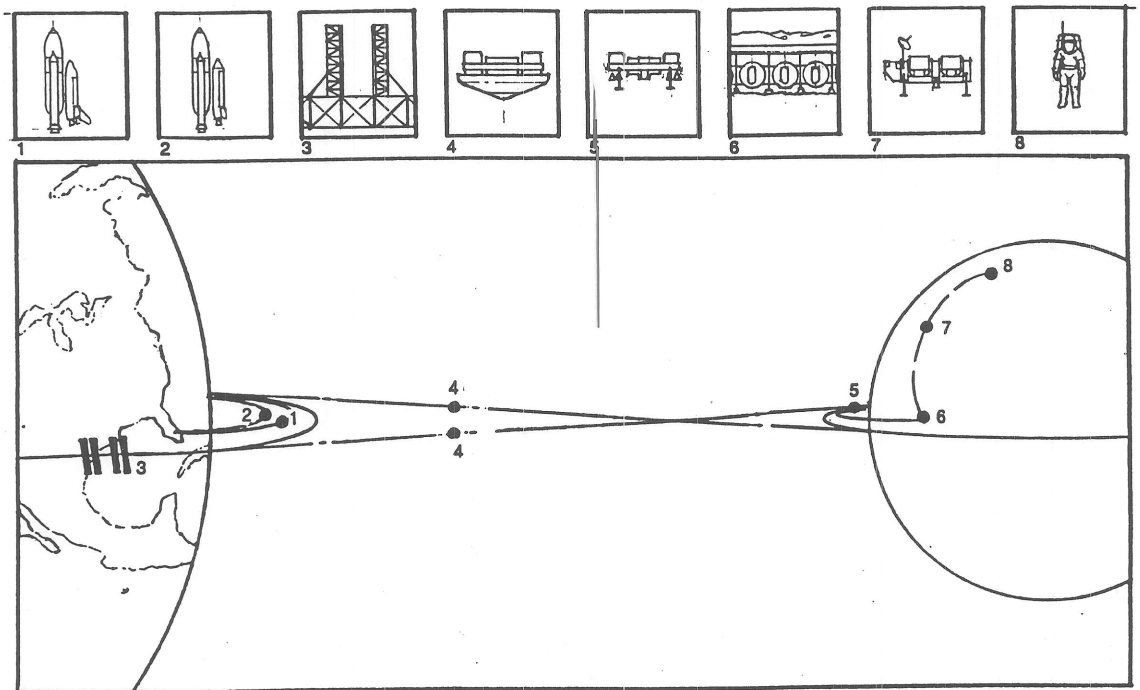
INTRODUCTION

No matter how constrained the program, a return mission to the Moon represents a major national commitment. The Apollo program proved that expendable systems could deliver and execute short-duration, manned lunar missions. The challenge in returning is to create a cost-effective reusable infrastructure that offers eventual permanent occupancy.

Planners must decide whether to adopt an austere approach based on existing systems or to be aggressive and develop new technologies. In light of prudent engineering judgment and traditional Government procurement practices, this paper presents a conservative approach

[1]Griffin, Habitation Module Manager, The Boeing Company, P.O. Box 240002, Huntsville, Alabama 35824-6402

for establishing a low-cost, Earth/lunar infrastructure leading to early settlement of the Moon (Fig. 1). It offers the benefits attributable to such proven operational systems as low-risk, minimal startup, commonality, built-in safety, and known reliability.



1. Shuttle
2. Shuttle-C
3. Space Station Freedom
4. Orbital Transfer Vehicle
5. Lunar Landing Vehicle
6. Lunar Base
7. Lunar Utility Vehicle
8. Lunar Suit

Figure 1. End-to-End Earth/Lunar Infrastructure Based on Existing Technologies

POINT OF DEPARTURE

The existing National Space Transportation System (NSTS) offers a complete Earth-to-orbit system. It provides integration, launch, flight, reentry and processing capabilities, and is the product of many years of development and refinement. The Shuttle, part of the NSTS, is the backbone for Space Station Freedom. Its performance and cargo bay dimensions sized the major U.S. and international modules.

Payload accommodation is the key to this system. With its cargo bay, the Shuttle offers simple horizontal integration while retaining a conventional vertical launch. Ordinarily the structural engineer would not volunteer half a tube as a fuselage cross-section; however, payload handling requirements drove the Shuttle configuration. The result is a pair of structural sills running the 60-foot length of the cargo bay. Structural loads are transferred through trunnions to the sill, keeping the payload secure during all phases of the mission (Fig. 2). This system provided the first inspiration for the Earth/lunar infrastructure.

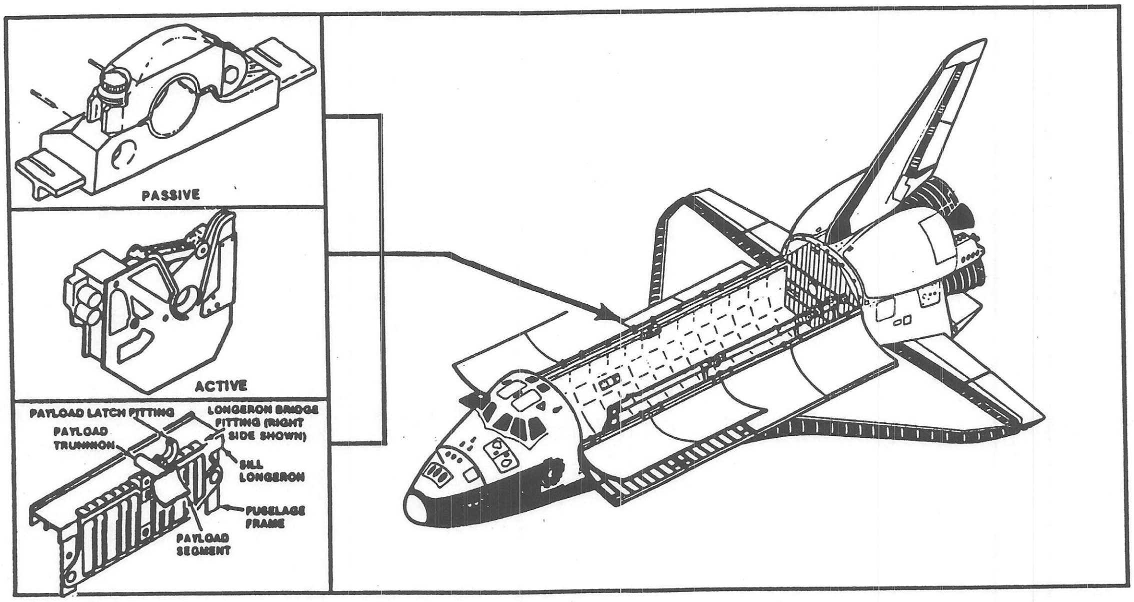


Figure 2. Shuttle Payload Restraint System - Used For All Mission Phases

The second strong motivation was a vehicle orientation for simple payload handling. Union of these two objectives produced a design that offers easy user operation while minimizing both development costs and lunar payload support hardware.

INFRASTRUCTURE DESCRIPTION

The Earth/lunar infrastructure considers all major aspects of the mission from ground operations, through orbit transfer, to lunar base architecture, including space suit design. Shown in Fig. 3 are concepts that translate the mission stages into point-design and create an integrated, end-to-end system for sustaining a permanent lunar base.

EARTH SURFACE

Space exploration is actually Earth based. Engineering, manufacturing, development, qualification, training, and integration are done by people on Earth in facilities on Earth. Existing trained personnel and facilities represent a cost-effective, low-risk point of departure for the Earth/lunar infrastructure. By using the NSTS, current jobs evolve into careers with a productivity payback in the lunar-mission era. Compatibility with NSTS means that growth to meet the increased traffic can be achieved by replicating existing facilities rather than by designing and building structures for a new system. This avoids the cost of developing new transportation systems, integration and checkout facilities, launch complexes, or major ground support equipment.

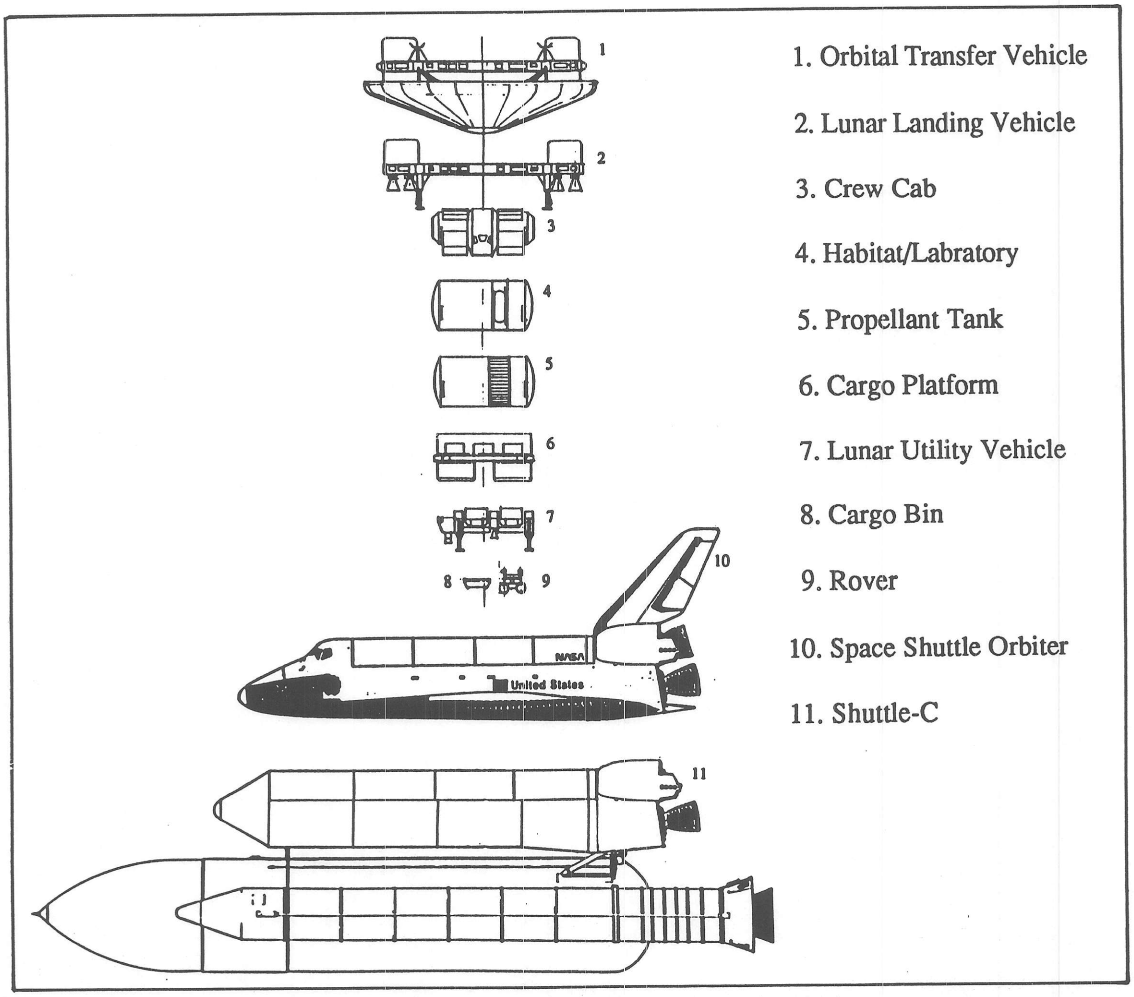


Figure 3. Vehicles and Cargo Feature Modular Design

LAUNCH AND REENTRY

The Earth/lunar infrastructure is derived from the Shuttle cargo bay; therefore, it allows for standardization of payload integration and handling. Because the planned Shuttle-C (Fig. 4) has the identical payload attach system, cargo delivered by this vehicle is also compatible with the infrastructure. The Shuttle/Shuttle-C cargo bay commonality allows interchangeability, thus creating a flexible and resilient system.

Roles and missions are better defined by inclusion of the Shuttle-C vehicle. The unmanned Shuttle-C provides transportation to low Earth orbit for heavier, longer cargo. The manned Shuttle, on the other hand, transports crew up and down and provides a sheltered return to Earth for Shuttle-compatible payloads. Infrastructure elements, such as crew modules, are designed to return for major overhauls. This relieves the Space Station astronauts from EVA servicing in weightlessness and allows trained technicians to use extensive test

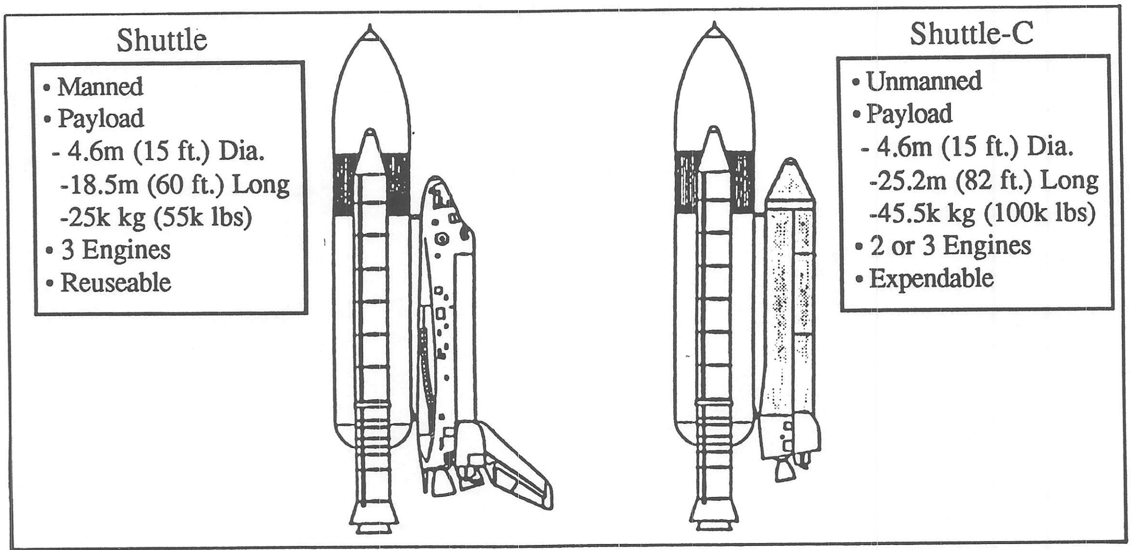


Figure 4. Payload Interchangability Improves Access to Orbit

equipment to repair, upgrade, and recalibrate the vehicle in a gravity environment with all systems off.

SPACE STATION FREEDOM (SSF)

Space Station Freedom is the waypoint for traffic to and from the Moon. For outbound missions, the station is a platform for vehicle assembly, payload integration, propellant transfer, and systems verification. Traffic returning from the Moon aeromaneuvers through the Earth's atmosphere to rendezvous with SSF. The lunar crew then returns to Earth aboard the Shuttle. Similar to a zero-g wharf, SSF provisions include sill-like piers for restraining transfer vehicles, propellant tanks, and cargo (Fig. 5). The same Shuttle payload attach points are used to restrain all elements between the piers. However, unlike the enclosed Shuttle cargo bay, access to payloads is improved because only the side trunnions are secured.

ORBITAL TRANSFER VEHICLE (OTV)

The Orbital Transfer Vehicle ferrys crew and cargo between SSF and low lunar orbit. The OTV reduces procurement and operations costs through (1) compatibility with trunnion points, (2) commonality within the infrastructure, and (3) simple operations for cargo integration and vehicle servicing. The configuration is based on a structural frame with three openings (Fig. 6). A large, central opening serves as a cargo hold with Shuttle-like attachments for payload trunnions and the two outboard openings for vehicle propellant tanks. Because the OTV returns to SSF, it carries an aeroshell used to brake against the Earth's atmosphere. The aeroshell experiences considerable thermal loading and has a limited life. Therefore, the

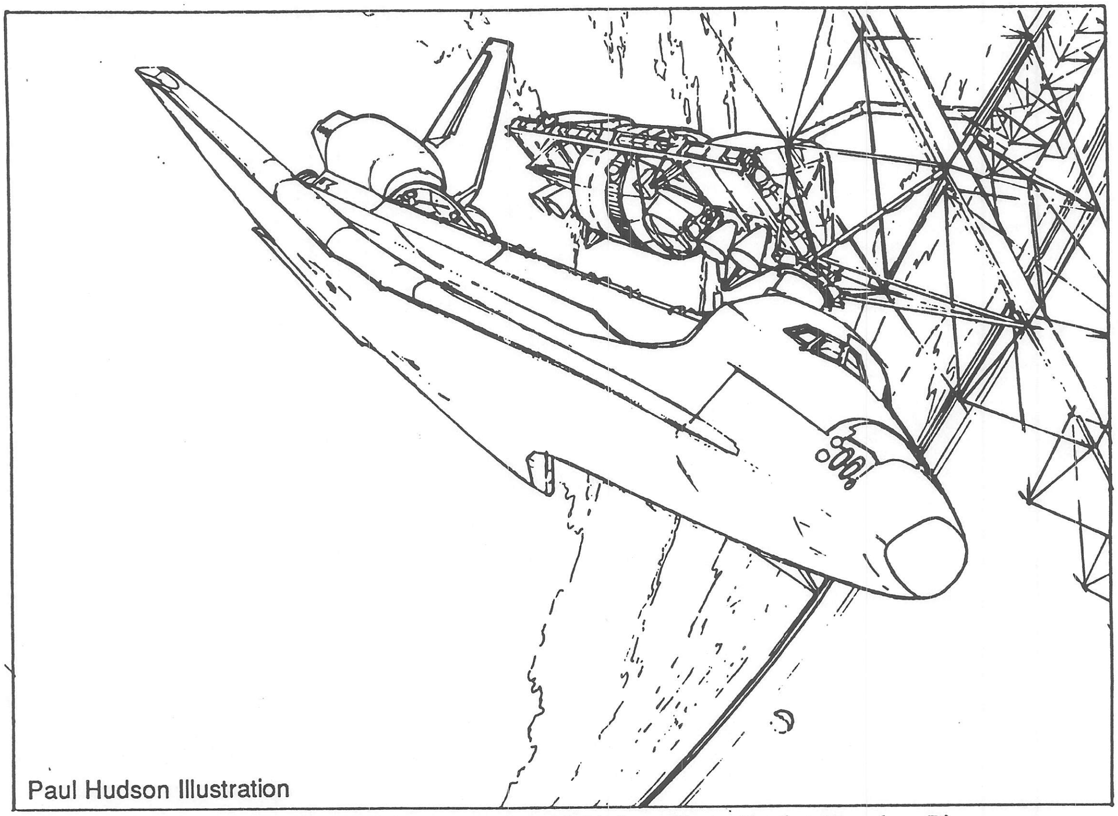


Figure 5. Transfer of Lunar Landing Vehicle to Space Station Freedom Piers

OTV is designed for easy inspection before reuse and, if required, simple aerobrake removal.

The OTV is considered a space-based vehicle; however, it can be returned to Earth in the Shuttle. Typically, servicing is done at SSF using either suited astronauts or a robotic device. All subsystems are modular and orbital replacement units (ORU) are attached one layer

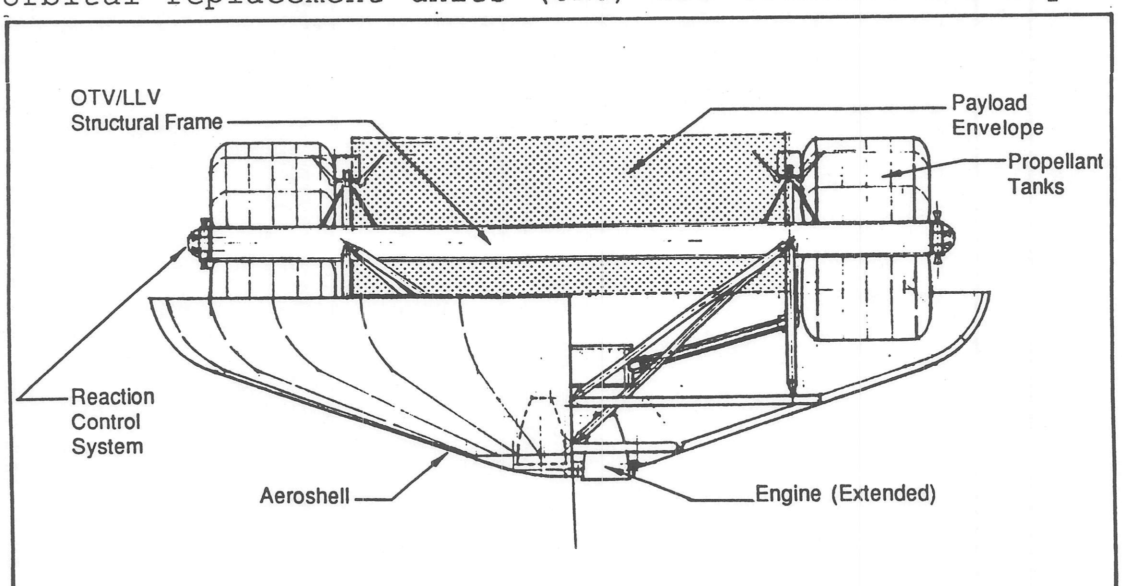


Figure 6. The OTV Adds an Aeroshell to LLV Systems to Provide Orbit Transfer

deep to the frame's exterior. This arrangement affords direct access without having to remove another ORU, thus simplifying servicing operations in weightlessness.

Steady state operations require at least two operational OTVs in the fleet, including a supply of critical spares at SSF. This provides an added measure of safety and allows simultaneous cargo integration and delivery.

LUNAR LANDING VEHICLE (LLV)

A good transportation system assumes the responsibility for end-to-end movement of cargo. An efficient infrastructure minimizes support equipment used to accomplish this task.

The LLV configuration, like the Shuttle, responds by placing the user first and providing simple cargo handling (Fig. 7).

The LLV carries its cargo amidship attached to the underside of the structural frame. This provides an efficient arrangement for managing the payload center of gravity. Its horizontal configuration offers excellent crew visibility for landing and easy cargo off-loading without the use of overhead equipment. Additionally, the cargo is delivered in a useable orientation minimizing the difficulty handling of large payloads.

Compromises are made in design. The price of a horizontal LLV is off-centerline thrust. However, this does not represent a significant problem because the LLV is equipped with four engines, two of which are required for landing. The remaining run at idle and are available

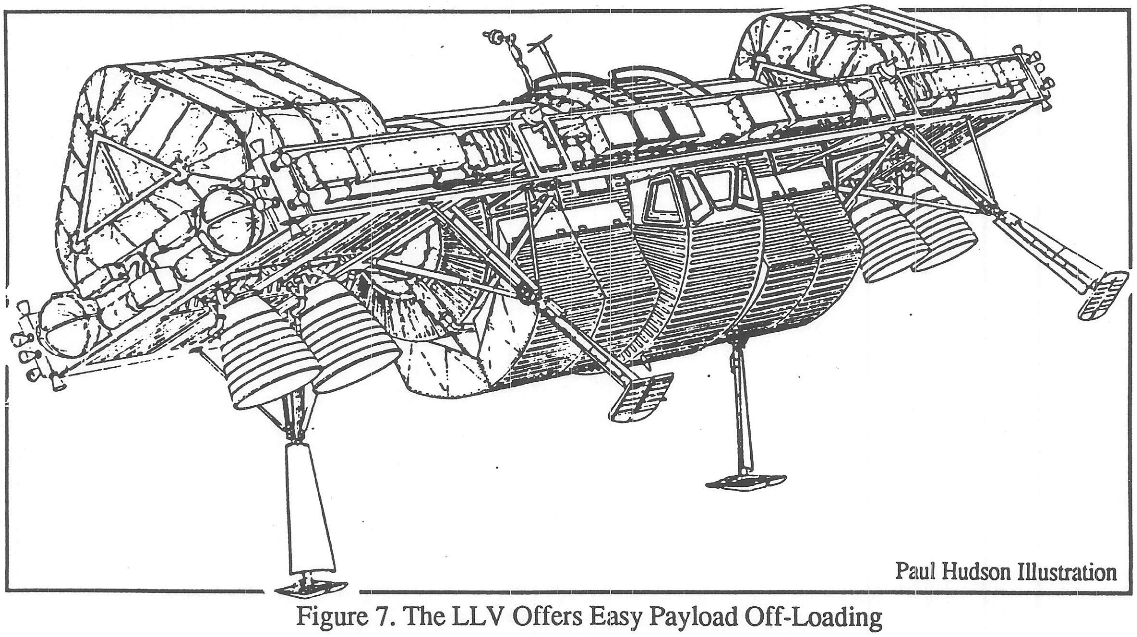


Figure 7. The LLV Offers Easy Payload Off-Loading

to compensate for an engine-out during critical periods of flight. This procedure, coupled with proven control technology, provides a low-risk alternative to vertical, centerline thrust configurations.

The LLV's horizontal configuration and externally mounted ORUs combine to create a vehicle that is easily serviced in weightlessness or in a gravity environment. An emphasis on modularity affords rapid changeout of subsystems while minimizing downtime. Furthermore, this concept provides refueling options. The tanks can either be fueled in place or installed full, offering alternatives for managing propellant boiloff.

The LLV structural frame is identical to the OTV and shares most of the same subsystems. The LLV, on the other hand, transports crew and cargo between lunar orbit and the lunar surface, thus requiring landing gear. The OTV uses the same LLV landing gear attach points for the aeroshell supports. This results in a common design for reacting the structural loads or aerobraking and landing.

OTV cargo transfer and integration are made simple by using the standard trunnion attach system and by having the same basic configuration as the LLV. Cargo from the SSF piers is easily transferred and secured to the OTV, and the cargo exchange with the LLV in lunar orbit is simplified by the commonality of vehicles.

More words on commonality: On each mission, the OTV and LLV rendezvous in lunar orbit and exchange arriving or departing payloads. This encounter, along with the high level of vehicle commonality, offers cost savings and contributes to the reliability and safety of the man-rated transportation system. For example, by having identical and interchangeable critical ORUs, the integrity of a failed redundant system can be restored in lunar orbit by exchanging components between LLV and OTV. This procedure means one vehicle is operating at risk until serviced; but the capability is built in and ensures a safe system with an overall reduction in spares.

LUNAR BASE

Consistent with preceding mission stages, the lunar base architecture uses the same trunnion attach system. The habitable modules that join together to form the pressurized living/working space are moved from the LLV to the base superstructure (Fig. 8). The modules are carried and positioned beneath parallel sill-like trusses. They are then raised into place and secured to cargo bay attach fittings on the underside of the preassembled truss work. This procedure automatically aligns and levels the modules within the base superstructure.

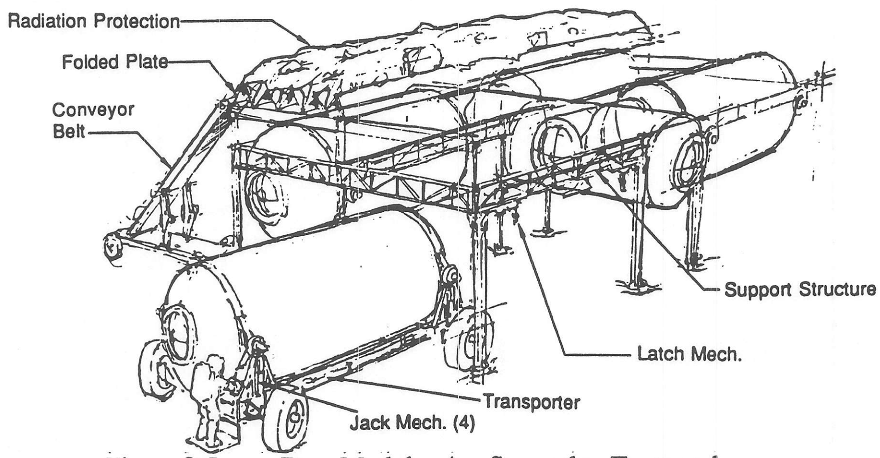


Figure 8. Lunar Base Modules Are Secured to Trusswork

The overhead trusswork, which makes up the super structure, establishes a precision reference platform above the irregular and unpredictable lunar surface. This arrangement ensures accurate assembly and minimizes the ground equipment and EVA exposure time required for site preparation. Additionally, by having separate and independent radiation protection above the modules, the crew can can inspect, service or repair externally mounted equipment. Also, this offers easy removal and replacement of entire modules with minimal disruption to system integrity.

LUNAR UTILITY VEHICLE (LUV)

EVA on the lunar surface will be limited by crew fatigue and radiation exposure. Therefore, to capitalize on useful work at the job site, wheeled rovers and the LUV are used to minimize transit time (Fig.9). Sized to fit within the LLV cargo hold, the LUV flies a two-man crew and 4600-kg payload over impassable terrain. Modular stacking bins are slung beneath the vehicle for easy surface operations and serve as standardized transportation containers for samples and equipment.

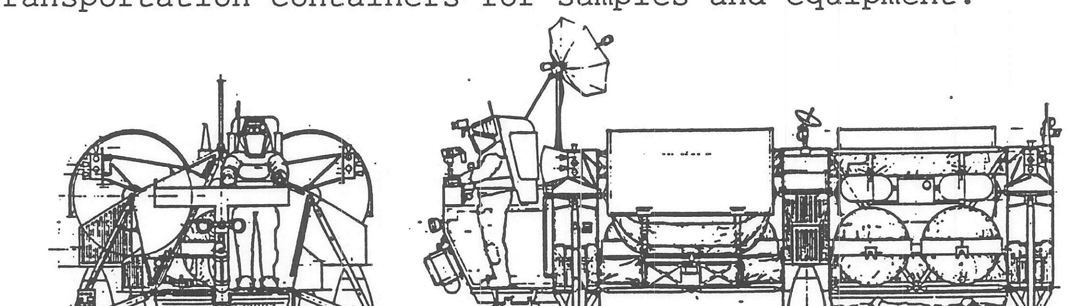
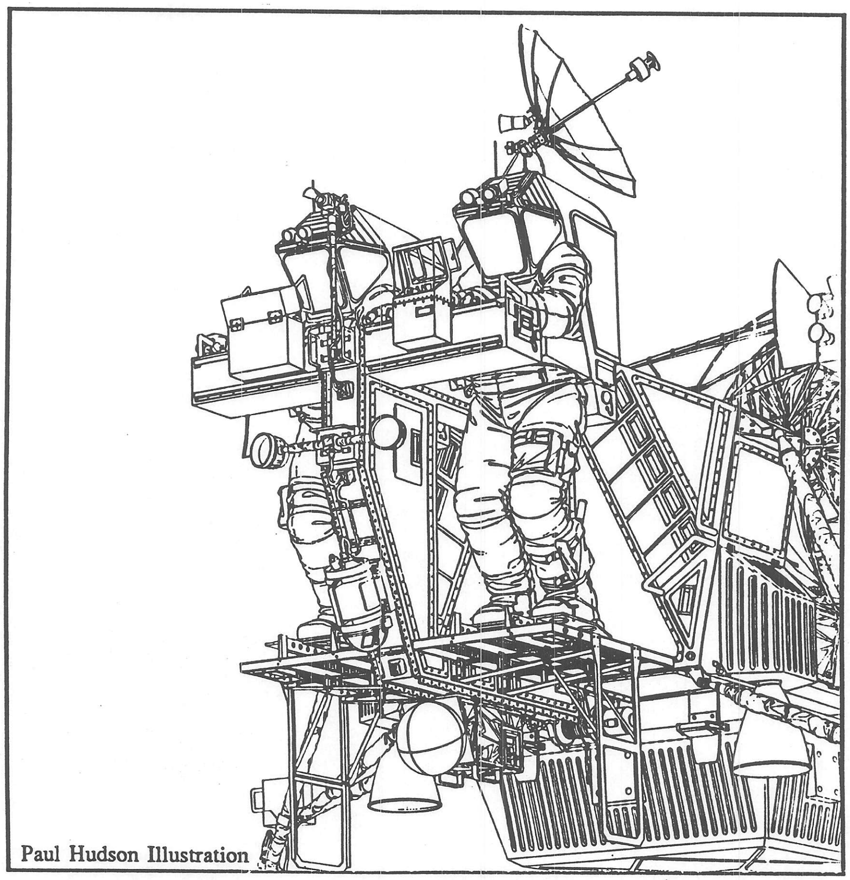


Figure 9. The LUV Transports Crew and Equipment to Remote Sites

LUNAR SPACE SUIT

The lunar space suit and LUV design were considered together to minimize cost and complexity (Fig. 10). The suit's rigid upper torso has extensions that lock into the LUV flight deck. With the feet secured, the suit becomes a structural part of the vehicle with integrated display and control functions.



Paul Hudson Illustration

Figure 10. Integrated Design for Lunar Suits and Spacecraft

SUMMARY

The enabling technologies are in place and the NSTS offers a headstart in building the infrastructure required for permanent lunar habitation. The concept described in this paper uses the Shuttle's proven payload retention system and cargo bay modularity to develop a comprehensive infrastructure stressing simple user operations.

In the 1960's, we demonstrated that we could go the the Moon. This low-risk approach for returning incorporates the dependability of operational systems and offers an integrated end-to-end infrastructure with early emphasis on scientific and engineering objectives.

NOTE: These are the views of the author and do not necessarily represent the views of The Boeing Company.