LUNAR BASE MISSION TECHNOLOGY ISSUES AND ORBITAL DEMONSTRATION REQUIREMENTS ON SPACE STATION

N93-17416

Charles P. Llewellyn

Analytical Mechanics Associates
17 Research Drive
Hampton VA 23666-1398

Deene J. Weidman

NASA Langley Research Center
Hampton VA 23665

The International Space Station has been the object of considerable design, redesign, and alteration since it was originally proposed in early 1984. In the intervening years the station has slowly evolved to a specific design that was thoroughly reviewed by a large agency-wide Critical Evaluation Task Force (CETF). As space station designs continue to evolve, studies must be conducted to determine the suitability of the current design for some of the primary purposes for which the station will be used. This paper will concentrate on the technology requirements and issues, the on-orbit demonstration and verification program, and the space station focused support required prior to the establishment of a permanently manned lunar base as identified in the National Commission on Space report. Technology issues associated with the on-orbit assembly and processing of the lunar vehicle flight elements will also be discussed.

INTRODUCTION

In early 1987, the Office of Aeronautics and Space Technology, NASA Headquarters, requested that the Langley Space Station Office perform a study to assess the impact of a manned lunar base mission on the Critical Evaluation Task Force (CETF) IOC space station. An agency-wide team was formed to investigate the space station support necessary to accommodate such a mission, with emphasis on precursor research requirements, lunar mission support requirements in low Earth orbit (LEO), concurrent science applications, technology requirements and issues, and station resource requirements including crew, power, and volume. The results of this study are published in *Weidman et al.* (1987).

From a review of recent studies conducted by NASA and in concert with the Civil Space Leadership Initiative (CSLI) activities, a baseline lunar base mission scenario was postulated, and the top-level technology requirements and issues needed to support such a mission were identified. These top-level issues were then analyzed to determine technology areas needing early or accelerated emphasis, and a statement of near-term and far-term requirements was formulated in terms of applicability to the lunar base initiative. From this analysis, the systems-level technologies that were considered enabling were identified, and an orbital demonstration and verification program for the major flight hardware elements of the lunar vehicles was developed.

Key lunar base mission technology implications are summarized in terms of the space station requirements and on-orbit support activities. Technology areas requiring additional study are identified and include in-space processing and serviceability, space-storable cyrogenics, automation and robotics, automated rendezvous and docking, etc. Some basic requirements for an orbital maneuvering vehicle (OMV) -type vehicle with increased capability and operational flexibility are presented.

LUNAR BASE ACCOMMODATION STUDY OVERVIEW

Before addressing the specific technology issues and on-orbit demonstration program requirements, a brief overview of the study results presented in *Weidman et al.* (1987) will be discussed.

The overall study objective was to establish and, where possible, quantify all the lunar base mission impacts on the IOC space station (on resources, interfaces, science, technology DDT&E, and configuration) resulting from accommodation of the lunar base mission. Of particular importance to the study were the on-orbit resource requirements in terms of crew, power, and volume, the impacts to the station science, and the enabling and enhancing technology requirements.

The basic assumptions and ground rules that were used in the study were (1) the CETF IOC configuration is the study baseline; (2) there will be an early manned lunar mission; (3) there will be lunar sample return and rover precursor missions with expendable launch vehicles (ELVs); (4) the Johnson Space Center (JSC) lunar base scenario is the primary basis for space station mass flow; (5) lunar mission vehicle buildup will take place in LEO; (6) a hydrogen/oxygen chemical proplusion system will be used; (7) orbital transfer vehicles (OTVs) and OMV will be man rated and space based; (8) heavy lift launch vehicles (HLLVs) will be operational; and (9) the study does not consider a post 2010 timeframe.

Unmanned precursor missions, which include lunar orbiters, sample return vehicles, and surface rovers, will be delivered by ELVs launched directly from Earth. From the onset of the early manned lunar missions to the establishment of a permanent lunar base, all lunar mission elements will pass through the space station. The mass-to-LEO necessary to support the flight rates assumed for the program dictated the need for an HLLV. The station-based OTVs and OMVs were assumed to be available early in the program from the vehicles' on-orbit verification and man-rating programs beginning at station IOC.

In the study four possible on-orbit basing options for vehicle preparation and maintenance were considered: (1) all vehicle accommodations are based on the space station; (2) the vehicle hangar is based on the space station but propellant is located on a co-orbiting facility; (3) all vehicle accommodations except the crew habitation module are based on a co-orbiting facility; and (4) all vehicle accommodations including the crew module are based on a co-orbiting facility.

Only options 1 and 2 were analyzed in any detail for their impacts on the station configuration, control characteristics, and static microgravity profiles. In option 3 the major impact would be increased traffic to and from the station to accommodate the support crew shift changes. Option 4, by definition, would produce little or no effect on the station.

The station configuration shown in Fig. 1 shows option 1 with the vehicle hangar/service facility above the transverse boom and attached to the upper keel, while the propellant tanks are below the boom and attached to the lower keels. The JSC lunar base scenario, which provided the fundamental definition of the total mass flow through the station, consists of three phases and is shown in Table 1.

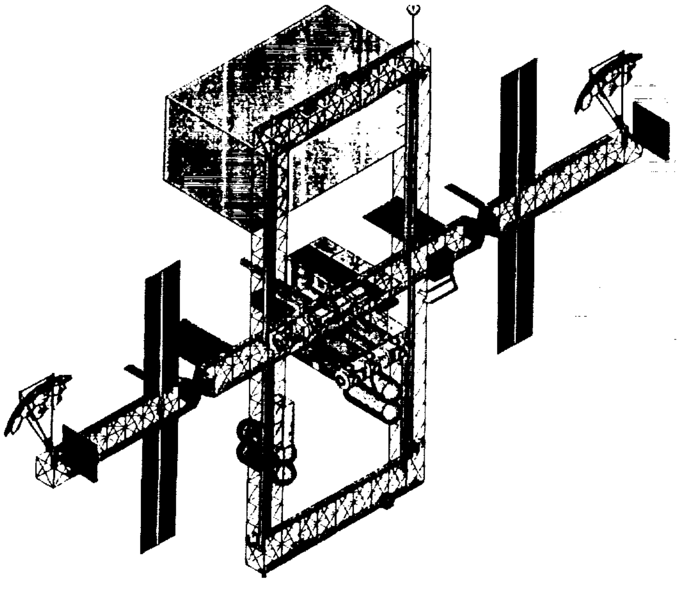


Fig. 1. Space station configuration—option 1.

TABLE 1. Lunar base scenario.

Phase I: Preparatory Exploration (Robotic)
- Lunar orbiter explorer and mapper
- Site selection
- Possible automated site preparation

Phase II: Research Output (0-4 Personnel)
- Man tended
- Habitat module
- Total Earth supply
- Science module
- Lunar oxygen pilot plant
- Surface mining pilot operation
- Power unit

Phase III: Operation Base (4-12 Personnel)
- Permanently occupied facility
- Additional habitats and laboratories
- Expanded mining facility
- Oxygen production plant
- Additional power

The first phase begins in 1994 with the primary objective being to assess and select a candidate landing site. This phase would commence with a lunar orbiting satellite to provide detailed mapping of the entire lunar surface. This would be followed by sample return missions and delivery of unmanned rovers for detailed landing site evaluations. The final step in this phase could be delivery of automated construction equipment to the surface for initial site preparation.

The second phase of the scenario establishes a man-tended research outpost and begins with the delivery of a small power plant, a habitat, an unpressurized rover, and various scientific experiments. A crew of four will operate the outpost for up to two weeks at a time during the first two years. As more facilities and equipment are delivered, stay times will increase and small-scale mining operations and oxygen production experimentation will commence.

Phase III begins about 2005 with the goal of establishing a permanently manned lunar base. During this phase the number of crew will increase to 12 with the habitats, facilities, and equipment necessary to support large-scale oxygen production. A lunar orbiting support facility will have been established as a storage/transfer depot for the lunar-produced oxygen and as a staging area for the arriving and departing lunar mission crews.

The major development milestones necessary for implementing the phased lunar base program are shown in Fig. 2. Key space station events are indicated. As mentioned earlier, OTV and OMV development and orbital verification should start at station IOC, as well as the orbital assembly and outfitting of the OTV and lunar vehicle and hangar/service facility. The milestones for the lunar vehicle elements reflect a very ambitious and success-oriented schedule considering that all the flight hardware elements must be assembled on orbit, tested, and verified in two years!

The space station support requirements that need to be addressed in order to successfully meet the schedule milestones are shown in Table 2. In this table, the primary activities required by the station to support a lunar base are shown as a function of time and include all the program phases discussed. The early activities, 1997-2000, affecting the station requirements support are primarily the on-orbit technology development and demonstration program, the on-orbit facility support buildup, and the lunar vehicle testing and verification program. The station support requirements in the 2000-2010 timeframe include (1) the capability to support routine vehicle servicing, refurbishment, and missions operations and (2) the advanced technology development programs necessary to establish the permanent manned facility on the lunar surface. These advanced programs and their implications on the evolutionary growth of the LEO and lunar orbit infrastructures will undoubtedly be challenging topics for future study activities such as those emerging from NASA's Office of Aeronautics and Space Technology's Project Pathfinder. Also, during this latter time frame, the orbital activities and mass-to-orbit requirements necessary to support the lunar base (and quite possibly the manned Mars initiative) will most likely have established the need for an LEO transportation node as part of the in-space infrastructure.

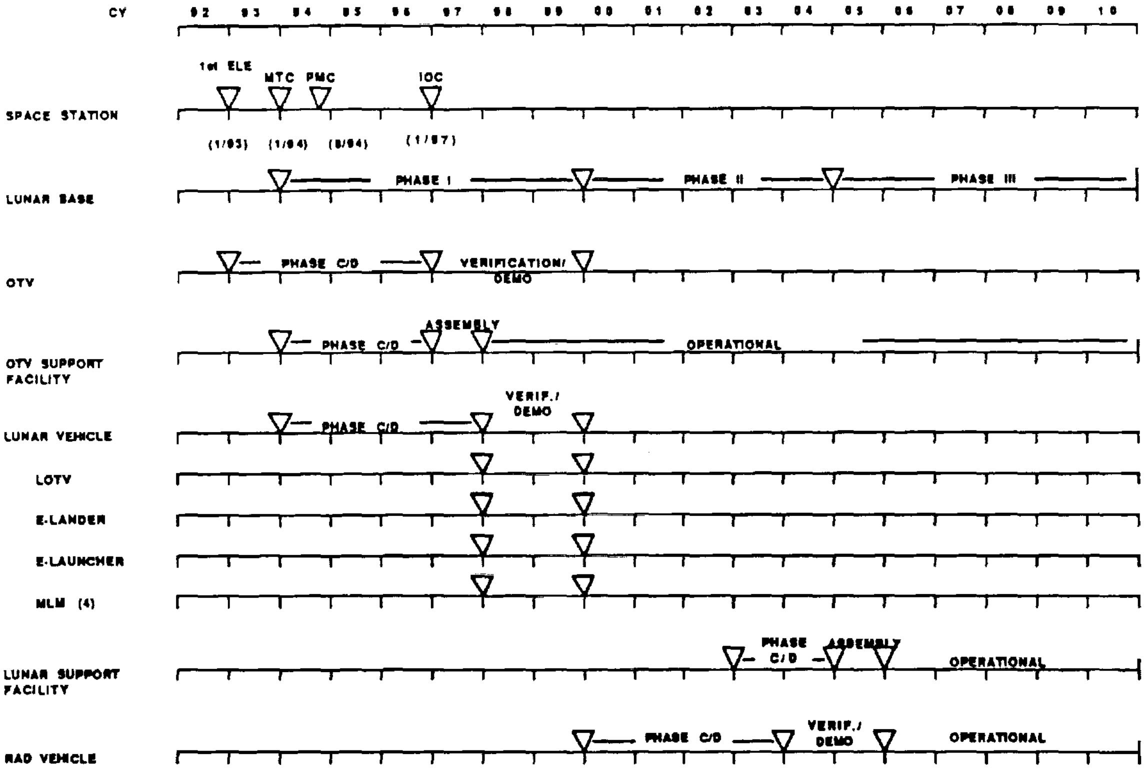


Fig. 2. Major milestones for the lunar base.

TABLE 2. Space station support requirements.

1997-2000
- On-orbit facilities buildup
- Technology development/demonstration
- Lunar vehicle demonstration/verification

2000-2010
- Lunar vehicle servicing
- Lunar base mission support
- Advanced technology development/demonstration
- Advanced lunar vehicle development/verification

To summarize the lunar base overview, the majority study accomplishments are (1) mission and mission vehicle are defined; (2) detailed operations analysis are concluded; (3) strawman Kennedy Space Center (KSC) flight schedule is developed; (4) space station accommodation options are identified and analyzed; (5) space station science effects are analyzed; (6) technology requirements for lunar base support are examined; and (7) on-orbit development program requirements are developed.

The remainder of this paper will concentrate on the last two items, the overall development of the technology requirements and the on-orbit technology demonstration and verification programs necessary to support this initiative.

TECHNOLOGY REQUIREMENTS/ISSUES

In order to assess the specific technology requirements and their impacts on the station, it was necessary to first identify the top-level technology issues that must be addressed in order to establish a permanently manned presence on the Moon. These technologies, shown in Table 3, are "across the board" or generic in nature, and are relevant to the entire initiative.

TABLE 3. Top-level technology issues.

- Advanced Environmental Control and Life Support System (ECLSS)
  - Air, water, waste management, food processing
- Crew Systems
  - Advanced EVA suits
  - Habitability considerations
  - Health care and maintenance considerations
- Surface Transportation
  - Rovers (unmanned, manned)
- Automation and Robotics
  - Cargo handling
  - Assembly
  - Remote site exploration
- Structures
  - Aerobrake/aeroshell
  - Assembly and handling
- Power/Thermal
  - Solar
  - Nuclear
  - Chemical
- Long-life Mission Systems/Subsystems
  - Radiation/temperature effects
  - Propellant storage
  - Maintenance/activation

The technologies indicated on the table were not prioritized or time-phased, but do serve as a basis for a point of departure in the study to determine areas of specific emphasis for the space station support. For example, the structures, automation/robotics, and life-support technologies being developed under the space station program are directly transferable to lunar base applications. Technology areas such as surface transporation, power generation, and thermal protection could best be done on the ground with prototype and final hardware demonstration and verification being done on the lunar surface.

In the following discussion, only those technologies that needed the space station for direct support will be considered at any depth. These "station focused" technology issues are shown in Table 4. The first five technology issues listed were those the study identified as needing early or accelerated emphasis. These may be looked at as enabling technologies, whereas the items listed under "Space Station Supporting Technology and Development" could be considered as enhancing and would be accommodated by the station in any event.

TABLE 4. Technology issues—space station focused.

Accelerated Emphasis
- Automation/robotics
- Aerobraking
- Autonomous rendezvous and docking
- Space propulsion systems
- Space cryogenics

Space Station Supporting Technology and Development
- Environmental Control and Life Support Systems (ECLSS)
- Guidance, navigation, and control (GN&C)
- Communications and tracking (C&T)
- Extra vehicular activity (EVA)
- Data management system (DMS)

Table 5 shows the technology issues just discussed with a brief statement as to their application to the near-term and long-term lunar program requirements. For example, the automation/robotics technology, while key to the success of the lunar vehicle on-orbit servicing/refurbishment requirement, is also an essential technology necessary to support the lunar base surface operations. This is equally true for the automated rendezvous/docking issue, where sophisticated systems are required to support both the numerous LEO and lunar orbital operations that have been identified. Guidance, navigation, and control and Comm/Tracking are also key technology issues when the amount of traffic that can be expected in the space station and the lunar vicinity is considered.

As mentioned earlier, the handling of space cryogenics needs early emphasis in that the transfer, storage, and management of space-storable propellants is critical to mission success. This becomes even more apparent later in the program when lunar oxygen production becomes a reality. Fuel-related issues include (1) fuel transfer (tank to tank/tank to vehicle), (2) fuel storage/boil off; (3) on-orbit tank handling (automated rendezvous/docking and OMV capabilities); and (4) robotic/teleoperator servicing/operations. Solutions to these issues are also keyed to the supporting automation/robotics and the automated rendezvous/docking technologies.

TABLE 5. Near-term and long-term lunar program technology requirements.

Automation/Robotics
- Lunar vehicle preparation/servicing in LEO
- Lunar base surface operations

Aerobraking
- OTV LEO operations

Automated Rendezvous/Docking
- OTV, OMV, HLLV, LEO operations
- Lunar vehicle lunar orbit operations

Space Propulsion Systems
- OTV, E-lander, E-launcher engine development
- OTV, OMV propulsion systems reusability, maintainability, refurbishment

Space Cryogenics
- Propellant transfer and storage

ECLSS
- Manned lunar module (MLM)
- LEO/LO support operations
- Lunar base operations

GN&C
- Traffic control in LEO
- OMV, OTV LEO operations
- Lunar vehicle translunar and lunar orbit operations
- Lunar orbit system

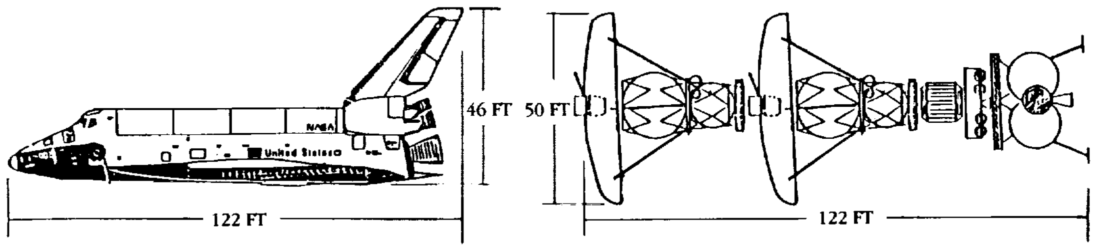
Comm/Tracking
- Traffic control in LEO
- OMV, OTV LEO operation
- Lunar vehicle translunar and lunar orbit operations
- Lunar orbit systems

EVA Systems
- Lunar surface operations
- LEO support operations

DMS
- LEO support operations
- Lunar base support
- MLM support

Technology issues include (1) space-based diagnostics/prognostics (in-space systems checkout, onboard/orbit decision making for safe systems operations, and systems health prediction/status; (2) in-space shelf life of lunar-base hardware/spares inventory in LEO, lunar vicinity; (3) in-space processing of hazardous (wet) systems; and (4) pressurized transfer of mission crew to fueled lunar vehicle. These issues evolved from the analysis of the lunar vehicle in-space processing and turnaround requirements developed by the KSC study participant.

The space-based diagnostics/prognostics issue is key to successfully meeting the rigid turnaround schedule requirements developed in the study and for establishing the high degree of confidence required for safe systems operation. The degree of modularity, the level of component changeout and replacement, engine/tank reusability, spares inventory, etc. will be real challenges to designers to provide "serviceability" to all the lunar vehicle systems. The Lewis Research Center (LeRC) is proposing studies on reusable space propulsion systems that are directly applicable to in-space vehicle processing, especially in the area of expert system intelligence for monitoring, diagnostics, and control. The issues of on-orbit processing of hazardous (wet) systems and the pressurized transfer of crewmen to fueled space vehicles will also require new and innovative "operational philosophies" in order to provide timely and safe solutions to these problems.



SPACE SHUTTLE	
Length	122 ft
Width	78 ft
Height	46 ft
Dry Weight	165,000 lb
On-Orbit Weight	230,000 lb
Engine Systems	
SSME	LOX/LH
OMS	MMH/NTO
RCS	MMH/NTO
Subsystems	
ECLSS	
GN&C	
C&T	
EPS	
DMS	
EVAS	

MANNED LUNAR VEHICLE	
Length	122 ft
Width	50 ft
Dry Weight	56,000 lb
Earth Departure Weight	248,000 lb
Engine Systems	
Space Prop.	LOX/LH
RCS	MMH/NTO
E-Lander	LOX/LH
E-Launcher	MMH/NTO
Subsystems	
ECLSS	
GN&C	
C&T	
EPS	
DMS	
EVAS	

Fig. 3. Comparison of space shuttle and the manned lunar vehicle.

Figure 3 graphically depicts the magnitude of some of the challenges associated with the on-orbit vehicle processing and servicing mentioned above. This figure shows the space shuttle orbiter and the manned lunar vehicle configuration to approximately the same scale. Not only is the lunar vehicle as large, in many ways it is as complex as the orbiter. It has more engine systems and more elements that need to be serviced, integrated, and checked out, all on orbit with limited "hands-on" personnel.

Having identified the key technology areas relative to the station support role, the next step was to define the systems-level technology issues. Tables 6, 7, and 8 address these issues for the major flight hardware elements of the lunar vehicles. Each of the new development items that comprise the manned lunar vehicle is listed along with the major subsystems/functions that make up that element. Table 6 depicts those elements unique to the manned module.

TABLE 6. Systems-level technology issues—manned module only.

Element/Function	SS-Derived	New	LEO Dev. Test STS	 SS
ECLSS	Yes	Some	No	Yes
EPS	No	No	No	Yes
GN&C	Yes	Yes	Yes	Yes
Comm/Tracking	Yes	Yes	Yes	Yes
EVA Systems	Yes	Yes	Some	Yes
DMS	Yes	No	No	Yes
Command/Control Interface	Some	Yes	Yes	Yes

TABLE 7. Systems-level technology issues—orbital transfer vehicle.

Element/Function	SS-Derived	New	LEO Dev. Test STS	 SS
Automated Rendezvous/Docking	Yes	Yes	Yes	Yes
ACS	Yes	No	No	Yes
GN&C	Yes	Yes	Yes	Yes
C&T	Yes	Yes	Yes	Yes
Propulsion System	No	Some	yes	Yes
(Reusability Tech)	No	Yes	Yes	Yes
Aerobrake/Aeroshell	Yes	Yes	Yes	Yes
Command/Control Interface	Some	Yes	Yes	Yes

TABLE 8. Systems-level technology issues—expendable elements.

Element/Function	SS-Derived	New	LEO Dev. Test STS	 SS
E-Lander				
GN&C	Yes	Yes	Yes	Yes
C&T	Yes	Yes	Yes	Yes
ACS	Yes	No	No	Yes
Propulsion System	No	Yes	No	No
Command/Control Interface	No	Some	Yes	Yes
Rover	No	Yes	No	No
E-Launcher				
GN&C	Yes	Yes	Yes	Yes
C&T	Yes	Yes	Yes	Yes
ACS	Yes	No	No	Yes
Propulsion System	No	Some	No	No
Command/Control Interface	Some	Yes	Yes	Yes

In an attempt to define the technology readiness of the flight hardware, an overall assessment was made of the availability of the technology as shown in the first two columns. These technology requirements were identified as being station derived (required by the station program itself), new technology, or some combination of both. As can be seen, over half of those identified were found to be highly dependent on space station heritage. The applicability of using the shuttle and/or space station experience for the on-orbit development and testing for the lunar base elements is indicated in the last two columns of the figure.

In Table 7, the OTV main propulsion system is an excellent example of capitalizing on the experience base to be accumulated on the space shuttle main engines (SSMEs). This base, along with the proposed LeRC research on reusable space propulsion systems, will be invaluable in finding solutions to the challenges associated with on-orbit processing and refurbishment.

In Table 8 the systems-level issues for the expendable elements are shown. As the program matures into the Phase II timeframe, these elements will be replaced by reusable vehicles. The systems/subsystems technology requirements for these reusable vehicles will have benefited from the early development activities associated with expendable elements.

From this systems-level analysis, the single common thread that ran through all the elements was the command and control interface function. This requirement was due primarily to the "man in the loop," who is an integral part of all vehicle systems. For example, no matter how sophisticated the automated rendezvous and docking system becomes, the crew must have the capability to monitor, assess, and intervene if necessary, to take active, real-time control of any vehicle or situation of which they are a part.

ON-ORBIT TECHNOLOGY DEVELOPMENT AND DEMONSTRATION CONSIDERATIONS

The purpose of the on-orbit technology development and demonstration program was to evaluate and demonstrate the operation of the systems, the techniques, and the components of the mission elements and functions to insure a high degree of confidence in their operations.

Long-term, dependable operation is achieved by high reliability, maintainability, repairability, and/or replacement. The on-orbit technology program must insure that the proper balance of these attributes has been determined for the particular system or subsystem selected. In developing the orbital demonstration/testing program discussed here, the subsystem selection, the development of the operational procedures, and the space asssembly techniques should be made as early in the program as possible, while maximizing the use of space station hardware and operations experience. As much testing and verification as is feasible must be done before flight hardware is committed to orbit.

The primary items that must be considered in the on-orbit demonstration program are identified in Table 9. In this table, the lunar vehicle systems are shown with the major testing and verification requirements listed for each of the flight hardware elements. In addition to those listed, end-to-end testing and all-up mission simulations with the totally integrated lunar vehicle configuration will be required.

TABLE 9. On-orbit program demonstration considerations.

Testing/Verification
OTV
- Rendezvous/docking with OMV
- Rendezvous/docking with MLM
- Separation test—OMV, MLM, cargo module
- Serviceability/turnaround procedures
- Fueling
- Aeroshell performance

OMV
- Rendezvous/docking with HLLV
- Rendezvous/docking with lunar vehicle (OTV/MLM, OTV/cargo)
- Serviceability/turnaround procedures
- Fueling

Manned Lunar Module (MLM)
- Subsystems verification
- Command/control interface verification
- Serviceability, maintenance
- Mission simulations
- Crew transfer, premission/postmission C/O procedures

E-Lander/Launcher
- Separation, rendezvous, and docking demonstration
- Landing and ascent demonstration
- Mission simulation (manned, unmanned)
- Fueling

Aerobrake/Aeroshell
- Assembly
- Serviceability/refurbishment procedures

ON-ORBIT PROGRAM RESOURCE REQUIREMENTS

As stated earlier, the primary thrusts of the paper were the on-orbit technology requirements and the on-orbit demonstration and verification programs with emphasis on station impacts in terms of crew, power, and volume requirements. The on-orbit resource estimates developed for the thrusts are shown in Table 10, and the term "user" refers to those requirements over and above basic station capabilities or allotments.

TABLE 10. On-orbit resource estimates for lunar mission support.

Activity	User Crew	User Power	User Volume
Precursor Program			
Technology development demonstration[*]	4	15 kW	0.5 lab
Mission Support			
Vehicle assembly, servicing, and checkout	6-12	30 kW[†]	1 lab
Mission crew	4-12		

[*] Includes systems testing verification.

[†] Includes cryo management.

The estimates indicated for the precursor program activity were derived primarily from detailed analysis of the on-orbit demonstration program just discussed. The rather high crew estimates include the personnel requirements for vehicle systems/subsystems monitoring and for crew support, while tests of the rendezvous and docking, fueling, landing/ascent, aeroshell performance, etc. are in progress. Also included is the crew needed for the hangar/service facility and construction and assembly in the 1997 timeframe and for the manpower required to develop, test, and validate the vehicle processing and turnaround procedures during the two years prior to phase II initiation.

The power estimate includes the base load necessary to sustain the systems/susbsystems monitoring functions and an allowance to support a command/control capability on the station. This base load averaged about 6 kW/yr over the 1997-2000 technology development period. The bulk of the power usage, approximately 9 kW, was due primarily to requirements from the vehicle hangar/service facility and to the technology program associated with storage, reliquefaction, and transfer techniques of the space-storable cryogenics. The volume requirements shown represent the pressurized/internal volumes needed to accommodate the monitoring and command/control functions associated with the demonstration and verification support demands.

The mission support activity, which begins at the onset of phase II, puts the most severe demands, in terms of crew, on the basic station resources. Vehicle assembly, servicing, and checkout can require from 6 to 12 additional crewmen depending on the flight rates and turnaround times assumed in the program scenario. If we assume we need to maintain the baseline crew of 8 in order to preserve the basic research mission of the station, there is now an on-orbit crew requirement that ranges from 14 to 20 people. This equates to an additional two habitat modules in order to support routine station and lunar mission operations. The lunar base/mission crew will grow from 4 to 12 by the year 2010. However, these are transient personnel and could probably be accommodated by "doubling up," so to speak, in the additional habitat modules.

The 30-kW power requirement shown for the mission support activity includes the energy necessary to support the vehicle assembly, tests, and servicing functions, as well as providing the power needed for on-orbit space cryogenic management. During the operational time period, a dedicated pressurized service and assembly facility, equivalent in size to a lab module, will be required to manage daily activities associated with vehicle processing and mission control.

SUMMARY

The lunar base program and its attendant requirements can be characterized by long-duration, operationally intense missions. The program's success will depend upon an ambitious flight support schedule requiring a substantial expansion of our current Earth-to-LEO launch capabilities, and significant advances in the automation and robotics technology.

The primary focus on the space station activities in support of the lunar base mission early in the program will be the on-orbit technology development, testing, verification of flight hardware, and some orbital demonstration experimentation. The operational phase will require significant support for the assembly, refurbishment, and maintenance of the lunar mission elements.

If the lunar vehicles and elements are station based, the assembly, servicing, and maintenance functions will require extensive station interfaces such as those for a large hangar/service facility attached to the station.

The OTV and the OMV particularly must be designed to accommodate the massive mission vehicles, and they must be man rated. Traffic control around and at the station, and contamination due to increased vehicular traffic, must be studied to provide workable procedures and solution.

CONCLUDING REMARKS AND OBSERVATIONS

Some of the key conclusions derived from the referenced study and this paper are summarized below.

1. The CETF space station configuration (dual keel) will accommodate the lunar mission.
2. Crew requirements point to the need for a crew carrier.
3. The lunar vehicle size, complexity, and allocated in-space processing time requires it to be of modular design with high reliability and robotic interfaces.
4. Application of automation and robotics principles is required to improve productivity and increase efficiency of operations.
5. On-orbit servicing and refurbishment, space storable cryogenics, and automated rendezvous and docking technologies should be accelerated.

REFERENCES

Weidman D. J., Cirillo W. M., Llewellyn C. P., Kaszubowski M., and Kienlen E. M. (1987) *Space Station Accommodation for Lunar Base Elements—A Study.* NASA TM-100501. 243 pp.