Paper Session I-B - The Lunar Campsite Mission Concept

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THE LUNAR CAMPSITE MISSION CONCEPT

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Abstract
This paper presents an overview of the lunar Campsite concept. The Campsite uses the lander as a platform for the habitat and systems needed to support a crew on a planetary surface. It is integrated and tested on the ground prior to launch. It is self-contained, requires no pre-existing surface infrastructure, and does not rely on in situ construction or assembly. This paper also identifies potential Campsite mission and subsystem requirements, provides an overview of a potential Campsite configuration, and develops initial sizing estimates for Campsite elements and the transportation systems required to get them to the Moon. The concept can be implemented to provide a significant, early, visible manned exploration milestone. It is suitable for lunar near-side, far-side, equatorial or polar missions, and can support intermittent or continuous occupation. Campsite hardware developed to support an early mission or missions, could also be used as contingency and remote support elements in a more advanced architecture.

Introduction
Future manned space exploration is envisioned as a series of related missions each building upon previous missions and exploiting knowledge and capabilities established in a stepwise fashion leading to and facilitating the development of an infrastructure capable of supporting and enabling the manned exploration and utilization of large regions of the inner solar system. An early evolutionary step in this process will consist of emplacement on the Moon of a minimal system to provide crew habitat and life support for up to seventy days (three lunar days and two nights). We call this minimal manned support system a lunar Campsite. It will follow short duration missions with small crew sizes that can be accommodated in the crew compartment of a lander/return vehicle such as the Apollo LM. Missions lasting longer than 60-70 days, or those with larger crews, will require significant surface support infrastructure and larger, more complex habitats than can be provided by the basic Campsite concept.

In the NASA 90-Day Study manned lunar missions were envisioned as following at least two cargo missions which would land a rover, site preparation equipment, payload handling equipment, a habitat, an airlock, a power system, and other support equipment. The initial manned habitat would be tele-robotically placed on the surface in a prepared location and covered with lunar regolith for radiation protection. A manned crew of four could then be sent to check out the habitat and stay for as long as 30 days. This approach requires a significant early investment in lunar infrastructure prior to the arrival of the crew. It would be too costly for use at multiple remote outposts such as exploration sites, astronomy facilities, or mining locations.

A simpler approach would be to use the lander as a platform for a pre-integrated base. This avoids having to first establish infrastructure needed for: 1) site preparation, 2) unloading elements from the lander, and 3) assembling modules and utility systems on a planetary surface. It also allows deferring development of a separate Lunar Excursion Vehicle (LEV), which provides transportation between the lunar surface and low lunar orbit, with the Lunar Transfer Vehicle (LTV) being used to land the campsite. Deferring infrastructure and minimizing the number of flight elements is expected to reduce initial program cost and allow earlier manned missions.

In addition the campsite utility is relatively broad. It could be used as an initial exploration base, a

Acronyms

C&T Communication & Tracking System
CRV Crew Return Vehicle
DMS Data Management Subsystem
ECLSS Environmental Control and Life Support System
EPS Electrical Power Subsystem
ETO Earth to Orbit
EVA Extra-Vehicular Activity
H/W Hardware
kg Kilograms
kw Kilowatts
LEO Low Earth Orbit
LEV Lunar Excursion Vehicle
LLO Low Lunar Orbit
LM Lunar Module
LTV Lunar Transfer Vehicle
m Meters
ORU Orbital Replacement Unit
SSF Space Station Freedom
t Tons
TCS Thermal Control Subsystem
TLI Translunar Injection
W/S Work Station

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construction shack for permanent base emplacement, a
man-tended science station (near-side, limb, or far-side),
an emergency shelter, or the first part of a permanent base
facility. It could be designed for a single visit, for
multiple visits, and for one time, contiguous, or
intermittent habitation. Alternately, a Campsite could be
designed to land and remain at its landing site, be capable
of moving or being moved to a nearby permanent base
location, or be capable of “hopping” to successive
utilization sites or to the location of an emergency.

Point Design Assumptions

In order to evaluate a system concept it is necessary to
apply the concept to a total mission scenario and size the
resulting vehicle systems utilizing a representative point
design. The mission that we selected for this analysis
required the Campsite to serve as a manned habitat
supporting a remote science base on the limb of the
Moon. Summary top level mission requirements
assumed are shown in figure 1. The mission was
assumed to require intermittent support from a crew of
four with stay times of 42 days. It was assumed to
require pressurized science and maintenance work areas,
and 2.5 tons of external science and operations equipment
including two rovers. The mission was assumed to
require a capability to support a two person eight hour EVA
every 24 hours. We further assumed that the
campsite lander would be capable of landing at an
unprepared lunar site, and that it would be capable of self-
leveling the campsite module.

We assumed that a 100 t payload capacity launch vehicle
with a 10 m shroud would be used to carry all elements
into low Earth orbit. It was clear that the Campsite
mission could be accomplished with a very large 200-250
t launch vehicle, but we reasoned that the mission would
be more affordable if it could be accomplished by a
smaller vehicle. On the other hand, operational
complexity increases significantly with more launches
required to assemble a mission vehicle. We felt that
something at the high end of the Saturn V or Energia
class range was a reasonable compromise, and wanted to
see how well such a launch vehicle could be made to
work.

Derived Requirements

A pre-integrated lunar base requires power, thermal
control, and communications systems that can be
packaged efficiently and deployed on landing. It requires
an internal storm shelter to protect from solar flare
radiation, an efficient airlock to allow quick and
covenient crew ingress and egress with minimal resource
expenditure. It requires a habitat to support the crew
through the planned mission duration, a lander which is
large enough to carry all of this equipment, and a
transportation system to get it to the Moon. In addition,
the Campsite must have efficient dust removal systems,
it must be readily reprovisioned, and it must
accommodate changing mission needs.

Operational Scenario

Early system concept design trades led us to adopt
separate two staged vehicles for both Campsite and crew emplacement. In
evaluating potential mission profiles it
became clear that a two stage vehicle
would be required, and that landers would
be only slightly larger than the boost
stages. Further study led us to conclude
that Campsite and crew landers had
relatively similar landed mass
requirements. So we concluded that
Campsite and crew landers had
relatively similar landed mass
requirements. So we concluded that
campsite lander hardware
common boost andlander stage hardware
could be used to minimize development
cost. The boost stage would use the
same tanks as the lander stage, but they
would not be filled to capacity. This
eliminated the need for development of a
separate lander stage. Further, our
analysis indicated that a single 20,000 lb
thrust, throttleable, restartable engine
could be used on all four stages. This led
to the mission profile is shown in figure
2.

The mission conveniently breaks down
into four launch elements, two landers
and a transfer vehicle for each. A LTV is
Step 2:

Crew Vehicle Mission (repeated as required)
- LTV booster launched into LEO
- Crew vehicle stage launched into LEO
- LEO rendezvous and dock
- LTV booster enters elliptic orbit; expended.
- 2nd stage goes to LLO for checkout & alignment; after a few orbits, it proceeds to surface.
- 2nd stage returns intact from lunar surface.
- 2nd stage expended, crew module recovered with direct entry.
- Booster TLI total $\Delta V = 2450$ m/sec.
- 2nd stage total landing $\Delta V = 3822$ m/sec.
- 2nd stage total return $\Delta V = 2750$ m/sec.

Step 1:

Campsite Enhancement
- LTV booster launched into LEO
- Campsite launched into LEO
- LEO rendezvous and dock
- LTV booster enters elliptic orbit; expended.
- 2nd stage goes to LLO for checkout & alignment; after a few orbits, it proceeds to surface; not returned.
- Booster TLI total $\Delta V = 2450$ m/sec.
- 2nd stage total $\Delta V = 3822$ m/sec.

Figure 2. Campsite and Crew Vehicle Mission Profile

mated to a lander in low Earth orbit (LEO) prior to each lunar flight. To avoid excessive propellant boil-off this requires two Earth to orbit (ETO) launches within a time period of a month or two. First a LTV is launched to LEO, followed by a Campsite lander ETO flight. The two stages are joined in LEO, and the LTV is ignited to place the stack into a lunar transfer orbit. The lander then separates from the LTV, coasts to the lunar vicinity making course adjustments as required, and makes a direct landing at the selected surface location. After landing, the Campsite lander deploys its solar arrays and high gain communications antenna, extends its thermal surface shields, activates the remainder of its internal systems, and performs diagnostic checks.

The Crew Vehicle flight occurs after the Campsite lander is in place and thoroughly checked out. The Crew Vehicle flight scenario is similar to that of the Campsite. A LTV is launched, followed by launch of the Crew Vehicle lander. The two vehicles dock in LEO, and the LTV is ignited to place the stack into a lunar transfer orbit. The Crew Vehicle lander then separates from the LTV, coasts to the lunar vicinity making course adjustments as required, and makes a direct landing at selected surface location - about 500 m from the Campsite lander. The crew then transfer equipment and supplies from the Crew Vehicle lander to the Campsite lander and utilize the Campsite as a base of operations for 42 days. When the surface mission is completed, the crew return to the Crew Vehicle lander which blasts off from the moon for a direct Earth return. The crew capsule separates from the Crew Vehicle lander enroute and returns to the Earth. The Crew Vehicle lander is expended.

Concept Description

Analysis indicated that the landed campsite would consist of a self leveling vehicle frame with engines and associated tankage and control systems, a habitat module with airlock and integral storm shelter, deployable
systems (external photovoltaic array, communications antenna, and radiator panel shields), fixed external equipment (fuel cells and navigation beacons), and exchangeable external equipment such as make up gases. A representative Campsite lander configuration is shown in figure 3. The habitat module is placed between the engines and propellant tanks to lower the vehicle center of mass, reduce ladder heights, and allow the tankage to provide additional radiation shielding. This configuration reduces likely dust contamination of radiators and solar arrays by placing them high on the vehicle. Additional design insights are described in a separate paper.

The frequency of Extra-Vehicular Activity (EVA) requires an airlock to minimize gas loss. The module sits on the lander vehicle above the engines and below the propellant tanks. The Campsite habitat module provides approximately 120 cubic meters of pressurized, conditioned volume for crew and equipment. An integral storm shelter was seen as necessary to allow the crew to survive a solar flare, while avoiding the operational complexities in use of lunar regolith for shielding. The storm shelter is centrally located in the habitat, under the propellant tanks and makes maximum use of vehicle structure for shielding. It uses up to 3000 kg of water for additional protection. Because of the relatively short (42 day maximum) surface stay time of any single crewman, additional dedicated protection from galactic cosmic rays was deemed unnecessary.

High bandwidth communication with the Earth uses a steerable dish antenna located on top of the solar array mast. Low data rate communications utilize omnidirectional body mounted antennas. Deployable solar arrays are sized to provide 11 kw average power. A regenerative fuel cell system is provided for peak and night time power use. Thermal rejection systems dissipate the expected heat loads using body mounted radiators assisted by a surface shield and a daytime heat pump. Campsite subsystems mass and power summaries are provided in figure 4. Heat pump operations during the lunar daytime are necessary to maintain adequate heat rejection and account for the additional daytime power usage. Pressurized module equipment mass estimates are based on

![Figure 3. Campsite Vehicle Overall Concept Illustration](image-url)
work performed in a previous study and assume utilization of Space Station Freedom (SSF) subsystems supplemented by regenerative life support systems. It is estimated that a comparable open loop campsite module with external systems would mass 23 t.

Figure 5 shows a potential module layout which is judged to be minimal accommodations for a 42 day mission with 4 crew. Science and operational equipment and work stations are located on the forward end of the module, while sleeping and hygiene facilities are located aft. Low access subsystems are located in the ceiling, and spares are found in the floor. High access items are located on the walls. Equipment is assumed to be mostly packaged in SSF type racks which are 80 inches high, 42 inches wide, and 36 inches in depth. The windows are located in module end domes to provide surface visibility. Ingress and egress are normally accommodated via the module airlock, with a second hatch provided for contingency operations.

During solar proton events the crew enters the central shelter area repositioning peripheral racks into aisle areas to provide additional radiation protection. A data input/output terminal is available in the storm shelter area so that the crew can communicate with the ground and monitor Campsite systems from within the sheltered area. If the duration of the flare is long, the crew may choose to make quick trips outside the shelter for food and hygiene, although emergency supplies are available inside the shelter area.
The Crew Vehicle, illustrated in figure 6, is very similar to the Campsite vehicle which minimizes hardware development cost and risk. It carries a crew module which is similar and comparable to an Apollo command module instead of a habitat module. It also carries Campsite provisions, experimental equipment and a second rover. The Crew Vehicle landing/return stage uses the same engines and systems as the Campsite lander and both LTVs. The LTV boost stage for the crew vehicle is identical to the Campsite LTV. We elected to utilize a cryogenic return system because of its low cost and significant performance benefits. In making this selection we saved the weight and complexity of a second propulsion system, and maintained commonality between Campsite and Crew Vehicle landers. We sized the lander tankage to handle boil-off losses anticipated with such a system. The net result is a system concept that is simpler and much lighter than would be the case with a storable return stage.
Figure 7 provides mass statements for overall vehicle systems for both campsite and crew vehicles. The boost LTV stages shown are expended. However they have enough tank capacity that if refurbishing facilities were available and the tanks were filled to capacity, they could be propulsively recovered.

**Mission Suitability**

Figure 8 provides a range of possible lunar mission types and shows potential applicability of the Campsite approach to each mission in terms of four key mission support parameters: mission duration, crew size, surface transportation, and payload accommodations. The Campsite approach described above meets many of these mission support needs, offering the mission planner considerable flexibility. And the Campsite as an early component of a larger evolving system provides essential support for all identified mission areas.

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<thead>
<tr>
<th>Campsite Mass Statement</th>
<th>Crew Vehicle Mass Statement</th>
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<tr>
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<tr>
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<td>Crew &amp; Supplies</td>
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**Table:**

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<td>• ISRU facilities</td>
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</table>

- *Campsite alone can support most missions*
- *Campsite alone can support some missions*
- *Additions to campsite needed to support mission*

*Figure 8. Mission Suitability Assessment*
The Campsite also has potential for use at Mars. Compared to the lunar environment, a Mars campsite would see an increased surface gravity, lower solar flux, a much shorter local night, weather effects, lower sink temperatures during daylight periods, and an atmosphere that would reduce the need for a storm shelter. The net effect would be to reduce anticipated Mars Campsite module weight. The deeper gravity well however, would require larger propellant masses for the crew return vehicle to achieve Mars orbit. Also the diversity of Mars makes it attractive for early exploration of several widely separated surface regions, rather than focusing on the development of a single manned base complex. These are two good reasons for considering a Campsite approach for Mars.

Conclusions

In summary the campsite concept provides manned lunar surface capability at any latitude without the need for a complex base infrastructure, and without requiring rendezvous and docking or crew transfer in lunar orbit.

The concept is flexible. It can be designed to support a crew of three for up to seventy days, or six people for a week. It can also be used as part of a larger base. The Campsite is suitable for man tended science operations, as a reusable construction shack supporting the emplacement of permanent base facilities, as a mobile base or rescue facility, as a Mars training system, or as an integral initial part of a permanent facility. It supports an affordable, evolutionary program development process with highly visible, early milestones that accomplish significant real science while laying the groundwork and developing components that will be central to accomplishing long term goals.

References

