Section 4I
Lunar Robotic Precursor Missions

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Robotic Precursor Missions

Robotic missions to the Moon should be undertaken prior to human return to the Moon for several reasons. Robotic missions can collect strategic knowledge that permits safer and more productive human missions. Such data includes information on lunar topography, geodetic control, surface environment, and deposits of largely unknown character, such as those of the polar regions. This information can be collected by a variety of spacecraft, including orbiters and soft landers.

In addition to collecting important precursor data, robotic missions can deliver important elements of the surface infrastructure to the eventual outpost site. Such deliveries include exploration equipment (i.e., rovers) and scientific instrumentation (i.e., telescopes). Additionally, since the extraction of resources will be an important activity of humans on the Moon, robotic precursors can deliver elements of the resource processing infrastructure, including digging, hauling, and extraction equipment. It is likely that NASA will want to experiment with various processing techniques and methods of extraction, and robotic missions can demonstrate process techniques at small scales in advance of the requirement to put large amounts of infrastructure on the lunar surface.

Strategic Knowledge Requirements

Before humans can successfully return to the Moon, gaps in our knowledge of the surface, environment, and nature must be filled. Robotic missions provide a way to cost-effectively answer these questions; but, in addition, offer the opportunity for early accomplishment, asset emplacement, and long-term risk reduction.

Strategic knowledge consists of those facts about the Moon and its environment that can affect the design and operation of systems that will ultimately make up the lunar outpost. For the Moon, this consists of its physical environment and nature of its deposits at a variety of scales. The latter qualification means that both orbital and landed robotic missions are required to provide the information needed to let humans safely return and then effectively operate on the Moon.

Because one of the principal objects in lunar return is to learn how to use space resources, much strategic knowledge revolves around the nature of lunar materials, especially materials from environments and areas on the Moon for which we have little or no data. This includes the vexing problem of water ice at the lunar poles, an issue whose resolution should come as soon as possible in a program to return humans to the Moon. Thus, much of the discussion below deals with this problem. However, the types of measurements done and equipment delivered to the Moon as described below are applicable to a landing at any site on the Moon, although the strategic knowledge requirements vary depending upon which sites are chosen for consideration as the outpost site (Table 4I-1).

A General Robotic Strategy

The ESAS team identified a general strategy that systematically fills in the most pressing knowledge gaps first, but is flexible enough to adapt to changing circumstances in the architectural structure of the return to the Moon. The strawman presented below has been chosen to illustrate the possible evolution of the robotic program (summarized in Table 4I-2).

The Lunar Reconnaissance Orbiter (LRO) is the first NASA mission in the lunar return. It will collect global and local data on the Moon's surface morphology, topography, and surface make-up to give us a first-order understanding of the Moon and to complete the global reconnaissance started by the Clementine and Lunar Prospector missions. The principal database of exploration significance from LRO will be a well-controlled map of the Moon's topography and morphology, via the laser altimeter and surface camera. In addition, the LRO will measure the environment and nature of lunar polar deposits, including characterizing surface temperatures, particularly in the cold traps which have never been measured, the volatile-rich deposits in these zones, and mapping the location of quasi-permanently lit regions as possible exploration targets (length of illumination, times, and durations of eclipses, etc.). From the data provided by the LRO, we should get a good first-order understanding of the nature of the polar environment and its deposits.

After this mission maps the Moon in detail, it is desirable to land on these newly mapped polar volatiles and characterize them in detail. Specifically, we need to understand the nature of the volatiles, their physical and chemical make-up, and their setting and occurrence. This information is only accomplished via a landed mission that is capable enough to rove across the putative polar deposits, make in-situ measurements of their physical, chemical, and isotopic composition, have enough lifetime and range to map the scale and extent of such deposits, and have a way to get this information back to Earth (the polar cold traps are permanently out of both Sun and Earth view).

These requirements imply a fairly capable landed mission, one that includes the ability to land with some precision, assets to permit long-life (enabled by landing in a permanently lit area near the pole), and the capability to traverse, measure, and survive long enough to characterize the polar deposits. Moreover, it further implies the presence of a communications infrastructure that, at a minimum, enables periodic and predictable contact with the vehicle in the cold traps such that data can be retrieved and commands for future work can be uploaded. This will likely require a communications relay in lunar orbit, either an extended capability of the LRO spacecraft or a dedicated system of communications satellites that will support not only this mission, but future missions to these areas and other far side or limb areas as well. Additionally, robotic precursor missions offer the opportunity to demonstrate technologies that will be used on future human landed missions. Technology demonstrations such as propulsion and guidance systems will reduce the eventual risk to human missions.

Following the mapping and characterization of polar deposits, it will be necessary to fly to the Moon demonstration experiments that evaluate different techniques and processes to extract usable resources. A likely target resource is water, present on the Moon either in the form of water ice in the cold traps or synthesized from the hydrogen-reduction of iron in the lunar soil. Water is valuable not only as a life-support consumable, but also as a convenient form of propellant for transport. The type of occurrence of hydrogen on the Moon will dictate the method of processing and we may want to experiment with several different processing methods. Thus, a likely set of payloads that could follow the initial mapping and prospecting lander might include a variety of bench-scale experiments designed to evaluate the relative efficacy of water production methods. Such experiments would allow us to test various processing schemes prior to the landing of people. The needs of such experiments need to be defined; at a minimum, they will involve collecting regolith feedstock, grading the feedstock to eliminate rocks and other non-useful components, processing the ore to extract the product, and transferring and storing the extracted water.

The payloads and missions of future landers need to be defined after the basic data collected from these missions has been evaluated. They may contain additional resource processing experiments and equipment, specialized resource and outpost civil engineering experiments, scientific packages (e.g., demonstration telescopes and small geologic rovers), and other pieces of outpost infrastructure. The definition of such payloads should be deferred until more information on their requirements has been collected.

Table 4I-1 Strategic Knowledge Requirements as a Function of Type of Outpost Site

Sites	NavCom	Precision topography and local terrain	Surface deposit characterization	Site environment
Equatorial and low latitude sites	No	Probably not	No	No
Limb sites	Yes	Yes	No	No
Polar sites	Yes	Yes	Yes	Yes

Table 4I-2. Summary of Proposed Robotic Mission Campaign

Mission	Type	Information	Duration	Other/Comments
LRO	Orbiter	Lunar geodetic model, polar deposit characterization, radiation of near-Moon environment	1 year mapping; 4 years extended	Needs communications relay capability
NavCom system	Multiple Orbiters	Enable near-Moon navigation for precision landing (within 100 m); comm. relay for far side and limb landings	3-5 years	Can be implemented with 4-6 microsats in a variety of orbits
Lander 1	Soft lander	Characterize polar environment and deposits; rove to cold traps to make in situ measurements; conduct other site characterization as required	2 years	Emplace long-lived beacon and demonstrate key subsystems for human return; demonstrate precision landing and other spacecraft systems that are extensible to human landers
Lander 2	Soft Lander	ISRU experiments, bench-scale water production, map mining prospect	1-2 years	Demonstrate reproducibility of lander design
Lander 3	Soft Lander	Additional ISRU experiments, scientific packages, outpost infrastructure	Indefinite	Material and information as needed to build up outpost (e.g., power systems)

Table X-3 Robotic precursors and human lunar return

Key knowledge needed for human safety and mission success

- Detailed topography, physical environment, polar deposit states and compositions, terrain, geotechnical properties

Technology demonstrations

- Precision landing, propulsion, ISRU demonstration experiments

Infrastructure elements for eventual human benefit

- Landing beacons, communications relays, cislunar and surface navigation and geodetic control, earth-moving equipment, paving machines, diggers, thermal processing, power system deployment

Scientific information to guide human exploration

- Remote sensing data of site, pre-outpost sampling traverses, demonstration experiments (e.g., robotic telescope), geophysical package deployment