IAA-L-0407

RETURN TO THE MOON: THE GREAT BASIN LUNAR SAMPLE RETURN MISSION

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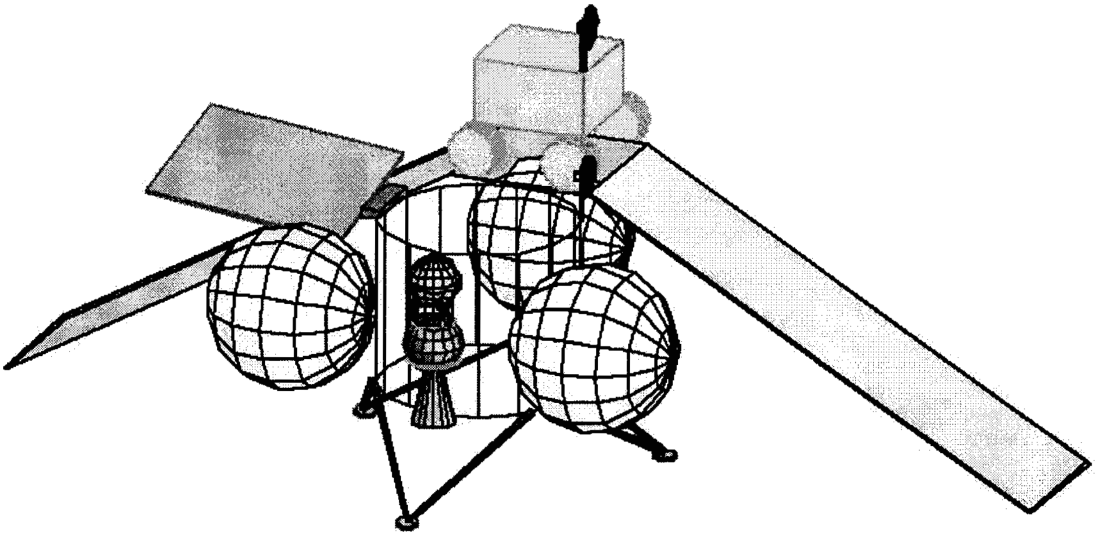

Figure 1: Simple CAD rendering of Lunar Lander, Rover (pink box on top), Ascent Vehicle (red and blue spheres sitting on the cone center left)

Abstract- In cooperation with NASA's Solar System Exploration Subcommittee and its working groups, JPL is investigating the feasibility of planetary science missions proposed for launch toward the end of the next decade. One of these studies was the Lunar Giant Basin Sample Return mission. This mission would use a combination of a lander (shown above), rover, lunar ascent vehicle, and orbiter/sample capture and return vehicle to reach and return samples from the South Pole-Aitken Basin (see figure below) on the far side of the Moon, providing opportunities to develop new insights into the formation of planetary systems. This mission is particularly challenging as large amounts of delta-V are required to land and return a sample to Earth. While the lander and orbiter are launched together and follow direct trajectories to their destinations, this study uses a different sample return scenario than many previous studies. Instead of a direct Earth return or rendezvous in lunar orbit, both very costly in terms of energy, this study employed a rendezvous in Earth orbit.

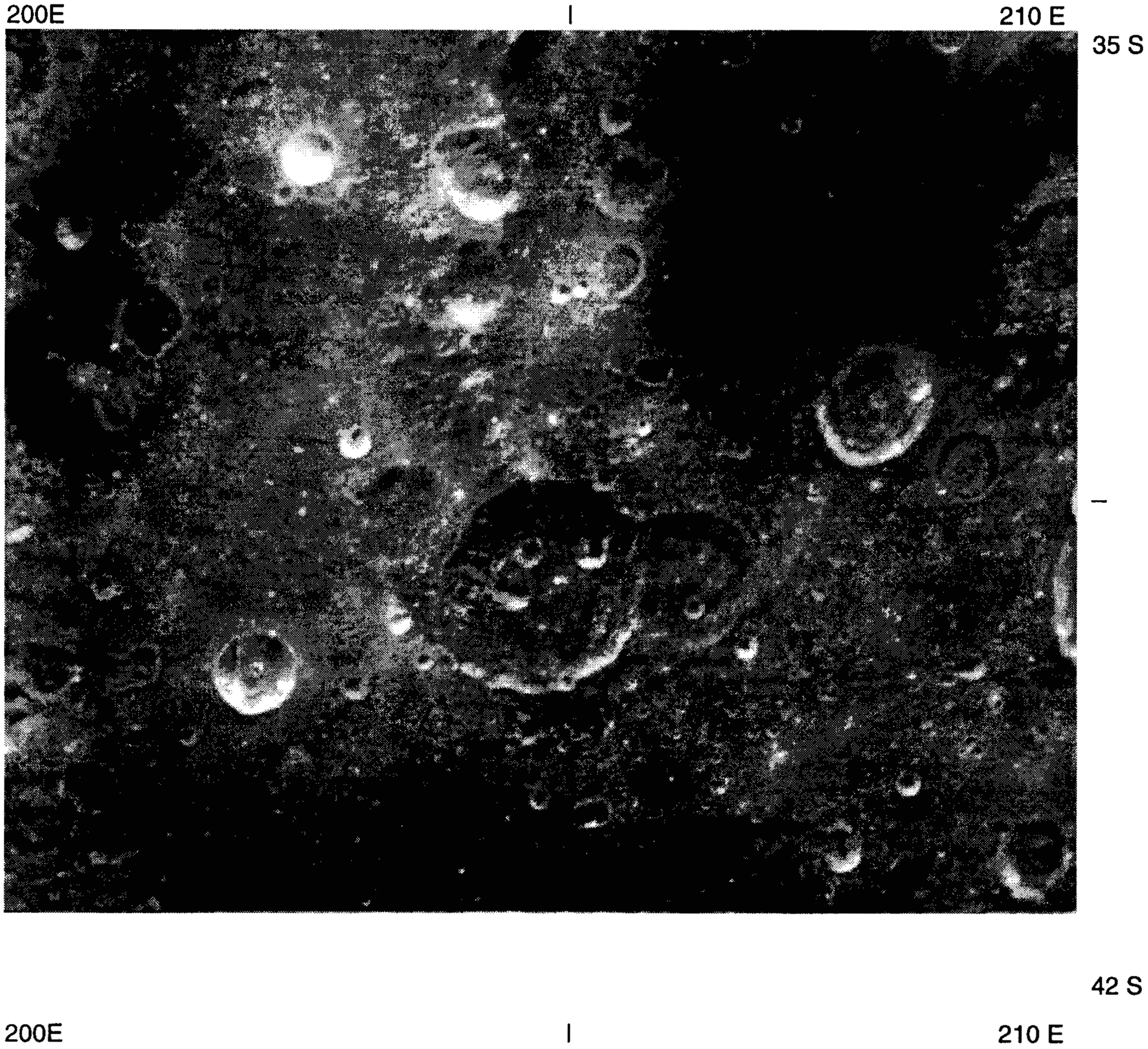

**Figure 2: Landing Site at 38.2 S 206.7 E in the South Pole–Aitken Basin
Image scale ~260 km × 210 km**

I. SCIENCE OBJECTIVES AND MEASUREMENTS

Science Objectives

The goal of the Lunar Great Basin Sample Return mission is to collect samples of lunar mantle and other material associated with an ancient and very large impact basin (located far away from areas of the moon previously sampled) and to return these to Earth for petrological, geochemical, chronological, and other analyses. These returned materials will address several outstanding lunar questions: 1) the composition of the stratigraphic column to the lunar mantle and the differentiation processes that produced it from the early magma ocean; 2) the early impact history of the moon; 3) the character and age of any early basalt differentiates associated with an ancient basin; and 4) the nature of lunar highland crust far removed from other large impact basins. These data may further help elucidate models of lunar formation, the character of the early primary crust and mantle of the Moon and its relation to other silicate bodies, and the nature of large impactors that formed giant basins.

The proposed landing site for this mission is at 38.2 S 206.7 E on the floor of the South Pole–Aitken Basin. The South Pole–Aitken basin is centered at 56 S, 180 E on the lunar far side (Figure 2.) It is 2500 km in diameter and over 12 km deep, making it the largest known impact basin on the Moon (or in the Solar System).

The amount of material proposed to be acquired for the Lunar Basin Sample Return Mission totals 4.6 kg, including:

- One regolith core 2 m deep by 1.5 cm in diameter with a mass of 1 kg.
- Selected rocks in the 1- to 4-cm size range totaling 3 kg.
- Bulk regolith samples totaling 0.6 kg.

Measurement Objectives

Measurement requirements for this mission cover two areas: (1) selection of a specific type of sample and (2) establishing sample context. The most important goal is sample selection—collecting a variety of samples. As rocks are collected at the surface, a preliminary analysis will be performed to determine if they are likely candidates. For context, descent imaging is required to accurately determine the location of the landing site. Additional imaging of the surface is required for rover navigation and identifying samples, but sample context is of lesser importance than sample selection.

The main objective of sample context is the determination of the exact location of the landing site. High-resolution images of the landing site will also be useful for planning rover traverses. Images showing the locations where the samples are collected are desired but not required. Context information for samples sifted from the lunar regolith, which are scattered from impacts, are not as important as they are for samples collected in other geologic contexts.

Science Implementation

- Chemistry, by X-ray fluorescence (XRF) spectrometry, on the rover.
- Mineralogy, by visible/NIR spectrometry, on the rover.
- Monochrome imaging on the descent stage and the rover.
- Multispectral imaging on the lander.

The XRF spectrometer should have the capability to measure FeO in the range from a near zero to 30 wt % with 0.5 wt % accuracy. TiO_2 should be measured in the zero to 20 wt % with 0.5 wt % accuracy plus the ability to show <0.1 wt % TiO_2. Other elements of interest include Mg, Si, Al, Ca, Na, Cr, Mn, and K.

The visible and NIR point spectrometer should cover the range from 0.4 to 2.5 μm at 10-nm resolution.

Science Operations

The lander collects descent imaging as it approaches the surface, beginning at 200-m resolution and continuing in factor-of-2 steps down to the surface, yielding 10 to 12 images of 1024 × 1024 pixels at 10- to 12-bit image depth.

The lander will then make a multispectral panorama of the landing site (similar to that of the Mars Pathfinder, aka Sagan Memorial Station). The lander obtains a bulk regolith sample and bulk rock rake sample of about 0.5 kg each. It then obtains a regolith core sample. This will provide a minimum science return in case of rover failure.

The rover loops out from and back to the lander, at least once each day during surface operations, each loop more ambitious than the last, and collects image data for both teleoperation and sample context. The rover traverses will vary in length from a few hundred meters to a few kilometers. The rover rakes soil to collect 1- to 4-cm rocks, then performs chemical and mineralogical analysis to determine candidates for return. The candidates are placed in a documented sample bag and stored in a temporary sample cache on the rover, then transferred to the sample return container on the lander.

II. MISSION DESIGN

While the lander and orbiter are launched together and follow direct trajectories to their destinations, this study uses a different sample return scenario than many other studies. Instead of a direct Earth return or rendezvous in lunar orbit, both very costly, this study employs a rendezvous in Earth orbit. The Lunar Ascent Vehicle (LAV) and sample return container (SRC) portion of the lander launches in a western direction from the lunar surface and enters a high-altitude Earth orbit. (Eastern launches, while providing a small ΔV advantage, tend to rapidly leave Earth orbit). The relay and sample return orbiter, on station at lunar L_2 to provide a link to the lander and rover, will rendezvous with the SRC anywhere from 2 weeks to possibly a month after lunar escape.

Three options are available for tracking the sample return canister:

-One-way Doppler in S-band from the Deep Space Network (DSN) 34-m antenna: requires oscillator stability on the order of 1 part per billion.

-Two-way Doppler in S-band from DSN 34-m BWG: requires transponder-like receiver and clock

-Radar from Arecibo or Goldstone: radar was used for the SOHO recovery, with Arecibo transmitting and Goldstone receiving, to obtain very high-fidelity data such as attitude and spin rate.

Proximity sensors will be needed for terminal rendezvous. Options include radio direction-finding relying on a low-power, one-way beacon on the sample; laser range finder; and optical (stereo helps). When the orbiter is within 0.5 to 2 km, feedback and accuracy of proximity sensors becomes the dominant information source. Quasi-autonomous terminal rendezvous technology has been in use since Apollo.

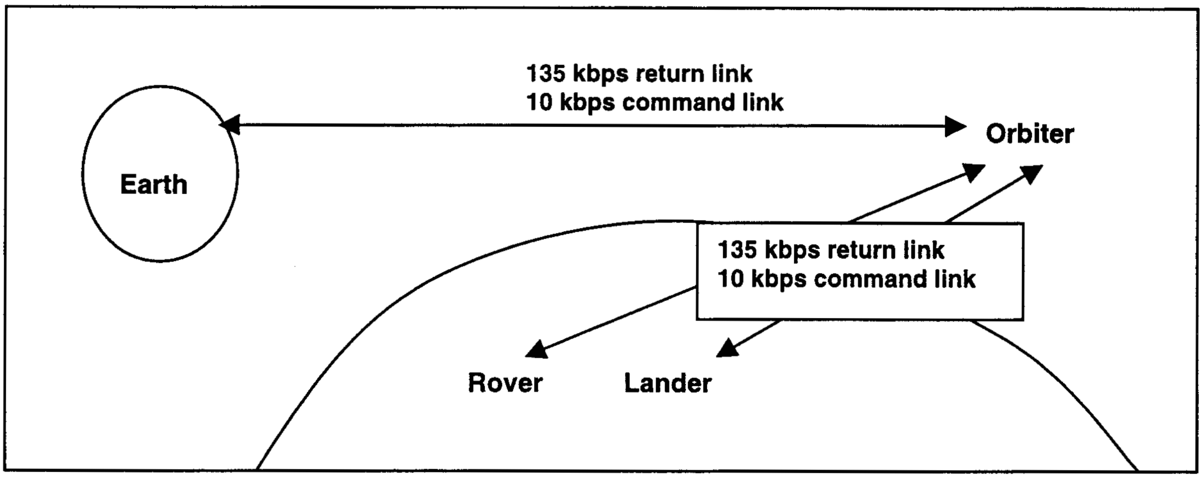

Figure 3: Earth-to-Orbiter, Orbiter-to-Rover, and Orbiter-to-Lander Command and Data Links

Once captured by the orbiter, the SRC will be transferred to the Earth Entry Vehicle (EEV). The orbiter will place the EEV on the proper trajectory for Earth return before releasing the EEV. Descent of the EEV will be managed by a combination of heat shield and ballute.

III. FLIGHT SYSTEM

This study has four distinct elements: the Lunar Ascent Vehicle (LAV), the Lunar Lander, the Lunar Rover, and the Relay Orbiter. All elements were designed to be launched together on a single Atlas IIIA (Figure 4.) The Lunar Rover volume and mass were based on currently planned rovers. New instrumentation and additional thermal control were added to the rover. The relay orbiter functions as both a communications relay to earth while the rover and lander are collecting samples on the far side of the moon and as a rendezvous vehicle for returning the samples to Earth. The lunar lander functions as a platform for spinning and launching the LAV and as a platform for drilling for lunar samples. The LAV has been simplified as much as possible to return the samples to the relay orbiter. This resulted in a total system mass estimate of 2585 kg. which provides a launch vehicle margin of a little over 200 kg. with respect to the Atlas IIIA.

The telecommunication system relies on the orbiter to act as a relay for the rover and lander. By positioning the orbiter near Lunar L2, a direct communications link can be maintained with the Earth during science operations (Fig. 3).

The LAV propulsion system uses a single-stage, solid rocket motor (SRM) to boost the 4-kg lunar sample into orbit. The SRM is a derivative of the Thiokol Star 13A.

The propulsion systems for both the lander and relay orbiter are similar dual-mode systems, with the lander requiring the development of a new-design, throttleable, main engine valve.

The power subsystem for the rover was derived from a previous study. Power subsystems for each of the other three mission elements were designed to minimize mass and use technology readily available for a 2008 launch date.

Table 1 – Spacecraft Mass and Power

	Mass (kg)	Power (W)
Sample Ascent Vehicle	**56.4**	**1.5**
Payload total	9.7	
Canister	4.4	
Beacon, Solar Cells	0.70	
Sample	4.6	
Lift System total	9.7	1.1
Mass/Power contingency	4.4	0.3
Propellant	32.6	
Lander (wet)	**1913.0**	**666.9 (Core Drilling)**
Payload total	167.4	430.0
Instruments	26.1	430.0
Rover	68.0	
Ascent Vehicle	56.4	
Ascent support eqpt.	16.9	
Lander Bus total	386.7	122.1 (descent/landing)
Mass/Power Contingency	128.9	153.9
Propellant and Pressurant	1230.0	
Lunar L2 Orbiter (wet)	**591.0**	**209.6 (TCM)**
Payload total	90.0	
Sample Capture	50.0	
Earth Entry Vehicle	40.0	
Orbiter Bus total	159.5	161.2 (TCM)
Mass/Power Contingency	74.9	48.4
Propellant and Pressurant	266.7	

IV. TECHNOLOGY

The following technology items contribute significantly to this mission.

For the Lander:

The drill system and the sample arm and containment elements require validation and testing of the selected designs.

The specific technology issues for the lander propulsion system are the development of a main engine throttle valve, and the continuing development of lightweight components. Without a throttle valve available, there would be a significant mass penalty incurred to move to the multiple engine configuration required to perform a soft lunar landing.

For the Rover:

The integrated visible and near infrared point spectrometer and the X-ray fluorescence spectrometer (XRFS) are input at mass targets that assume technology development.

The sampling system and sampling container elements also require technology development.

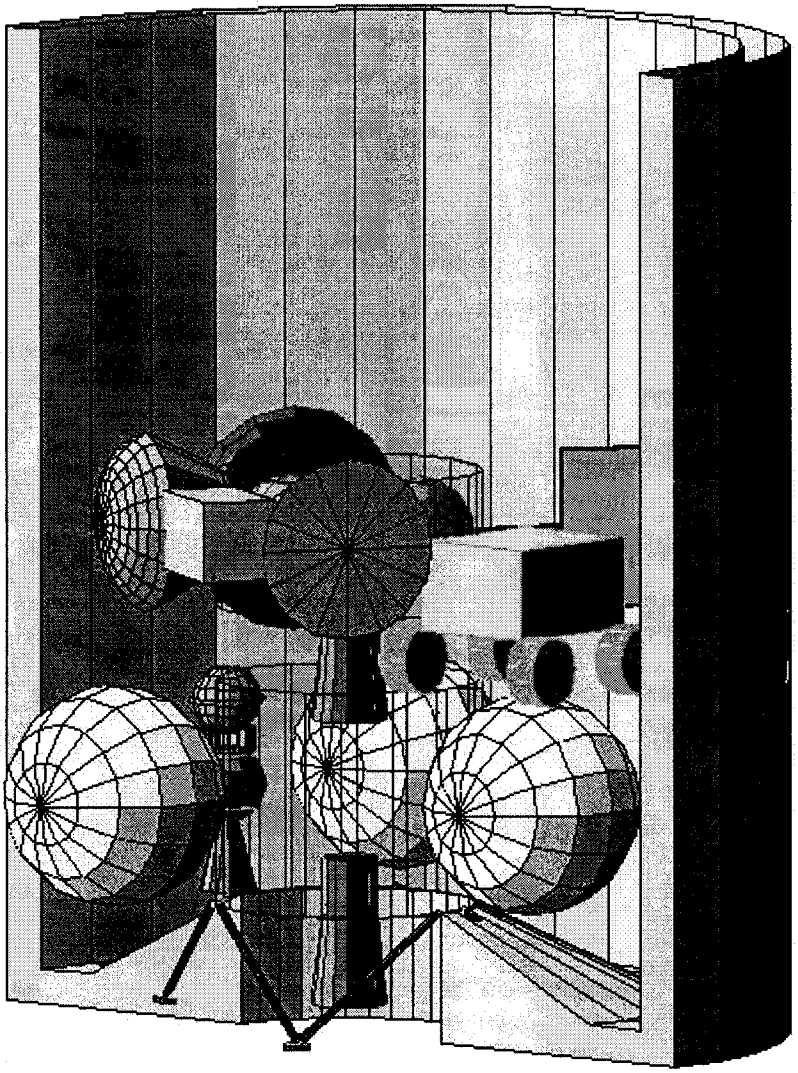

Figure 4 – All elements shown stacked in the Atlas IIIA fairing – Orbiter on top with the lunar lander on the bottom. The ascent vehicel is visible lower left and the rover is visible center right

For the LAV:

The sample aggregation and transfer container requires validation of the selected design.

For the EEV:

A ballute system, even with the current technology status, would reduce the Earth-entry vehicle (EEV) system mass, and with the development of packing technology may reduce the volume of the EEV system.

V. COST

The Team X cost estimate places this mission concept a bit beyond the current upper limit of the Discovery program (end-to-end cost ~ $300M).

VI. CONCLUSIONS

With the novel mission design concept of a relay orbiter at Lunar L2 and the sample return strategy of launching into Earth orbit for rendezvous and return of the sample by the orbiter, a successful sample return from the South Pole-Aitken Basin is finally possible for a reasonable mission cost. (Previous studies had required prohibitively expensive launch vehicles as well as more massive and expensive landers and orbiters.) Detailed examination of possible options for sample collection (e.g., deleting the drill core in favor of additional rake samples, deleting the rover and providing a longer reaching rake for obtaining samples near the lander, etc.) and return could possibly reduce the cost even further. Shared technology development (both for the lunar rover and the sample rendezvous and capture) with the Mars Exploration and Sample Return Program will reduce the risk that would otherwise be associated with this mission.

VII. ACKNOWLEDGEMENTS

The research described in this publication was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The author wishes to thank Robert Gershman for his leadership of the Solar System Exploration Roadmap Study program and the members of the JPL Advance Products Development Team (Team X) for their assistance in this study. In particular, thanks to Robert Oberto (Team X Lead) and Charles Budney (Team X Science and Instrumentation). Thanks also to Richard Welch for his assistance on rover design.