Accessing the Lunar Poles for Human Exploration Missions

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The National Vision for Space Exploration calls for an American return to the Moon in preparation for the human exploration of Mars and other destinations. The surface environment of the Moon is a challenge for human operations, but recent findings from robotic and Earth-based studies have indicated that the polar regions of the Moon may offer advantages in terms of thermal conditions, availability of solar energy, and access to local resources. While accessing these regions represents a challenge due to orbital dynamics and propulsive performance, methods for accessing the regions with humans are being actively pursued, and environmental data gathering is planned through future robotic missions.

THE NATIONAL VISION FOR SPACE EXPLORATION

The National Vision for Space Exploration (NASA, 2004) as laid out by President Bush in January 2004, calls for an American return to the Moon in preparation for the human exploration of Mars and other destinations. The Moon is to provide an operational environment where we can demonstrate human exploration technologies and capabilities within the relatively safe reach of Earth. New sustainable exploration techniques such as the utilization of space resources, and human-scale exploration systems such as power generation, surface mobility, and habitation and life support are examples of these capabilities. In addition, these missions are to pursue scientific investigations on the Moon, such as geological records of the early solar system.

ENVIRONMENT OF THE LUNAR POLES

The Moon is a "slow rotator." Its rotation rate is tidally locked to its revolution about the Earth giving a diurnal period of 29½ days. This, combined with the lack of a lunar atmosphere leads to large surface temperature variation, from 117°C (243°F) to -170°C (-272°F) near the equator (Heiken et al., 1991). While these are the regions explored during the Apollo Program, the missions landed early in the lunar day, and departed before the challenging thermal conditions of lunar noon were experienced. In addition to the severely cold temperatures experienced during the long lunar night, the lack of solar illumination for almost 15 days would likely require any extended human exploration mission to rely upon non-photovoltaic (i.e., nuclear) power sources.

The polar regions of the Moon were essentially unexplored by the Apollo Program and the Lunar Orbiter robotic missions of the 1960s. Theses areas were never considered as targets for the Apollo landings due to constraints of orbital mechanics (high propulsive requirements and no "free return" abort capabilities). However, recent robotic and Earth-based observations of the Moon have revealed exciting new information about these previously unexplored regions. Both the 1994 Clementine spacecraft and the Goldstone Solar System Radar have indicated the existence of permanently shadowed and nearly permanently lit areas in the vicinity of the lunar poles (Bussey et al., 1999; Margot et al., 1999). These exist due to the very low inclination (only 1½°) of the lunar equator with respect to the ecliptic plane resulting in very shallow solar incidence, combined with significantly rough surface topography. Illuminated areas of the poles are thought to have surface temperatures of -53°C (-63°F), while the permanently shadowed regions would be only a few degrees above absolute zero (perhaps around -233°C or -387°F).

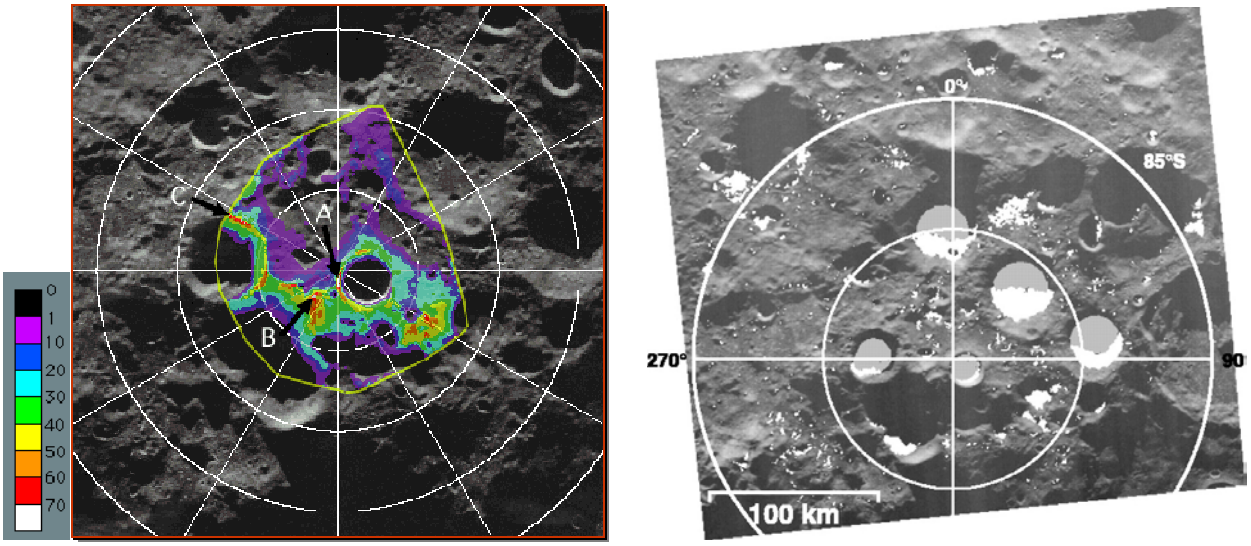

Figure 1 and 2. Lunar South Pole illumination information from Clementine Spacecraft (left, areas with high illumination, [Bussey et al., 1999]) and Goldstone Solar System Radar (right, permanently shadowed areas in white & grey [Margot et al., 1999]).

Both types of terrain, which appear to be in close proximity, hold interest for human lunar exploration missions. The nearly permanently illuminated areas offer moderated thermal conditions and potentially abundant solar power. The permanently shadowed regions have long been hypothesized to harbor "cold traps" enabling the preservation of volatiles such as water ice deposited by millennia of cometary impacts. In fact, in 1998, the Lunar Prospector spacecraft detected trapped hydrogen, possibly in the form of water ice, in these same regions (Feldman et al., 1998). If accessible and in sufficient concentration, water would be a key contributor to sustained human presence on the Moon. Future robotic lunar missions are planned to further refine the topographic information and the true availability of resources.

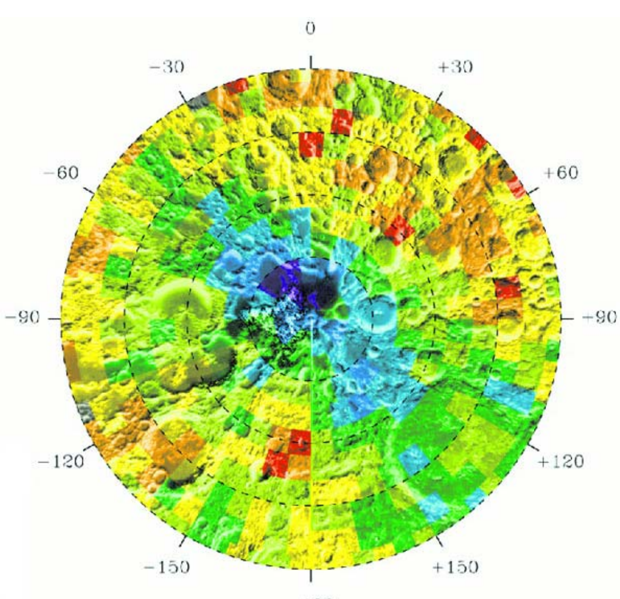

Figure 3. Lunar South Pole hydrogen concentration as measured by Lunar Prospector epithermal neutron spectrometer (Feldman et al., 1998).

ACCESSING THE LUNAR POLAR REGIONS

As mentioned previously, the Apollo missions did not address the challenge of lunar polar landing sites for several reasons. "Free return" trajectories, which allowed the outbound trip to the Moon to be aborted and the spacecraft returned to Earth with little additional propulsion requirement, are not compatible with injection into lunar polar orbit. Also, near-equatorial parking orbits and landing sites allowed the crew to begin the return journey to Earth at nearly any moment with little propulsion performance penalty. However, polar orbits will slowly drift into alignments that are not compatible with a return trajectory. Finally, strict sun angles limits were enforced on the lunar sites during landing so that the crew had good visibility of terrain relief.

Analyses are underway to meet these challenges. Future missions will need to address propulsion system failures though additional levels of system redundancy and reliability rather than "free return" aborts. The orbit alignment issues can be addressed in several ways: 1) the additional maneuvering capabilities can be built into the mission profile (with the associated propellant weight penalties), 2) an alternative to the Apollo "lunar orbit rendezvous" technique can be utilized, perhaps one using Earth-Moon Lagrange points as a staging location, or 3) "safe havens" can be established on the lunar surface, negating the need for return to Earth at any time and allowing more optimal return trajectories. We also expect that automated descent, landing, and hazard avoidance technologies will obviate the need for strict lighting conditions.

CONCLUSION

Lunar polar locations may offer environmental and resource advantages over equatorial sites, and may more closely address the goals laid out in the National Vision for Space

Exploration. The challenges associated with achieving human access to these sites are understood. Data received from future robotic missions along with advanced human mission capabilities and technologies should allow these challenges to be addressed and safely overcome.

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