REDUCING THE RISK, REQUIREMENTS, AND COST OF THE HUMAN EXPLORATION PHASE OF THE CONSTELLATION PROGRAM WITH ROBOTIC LANDERS AND ROVERS.

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Introduction: The Lunar Orbiter, Ranger, Surveyor, and Apollo missions demonstrated the utility and overall program success that can be generated by integrating robotic and human exploration of the Moon. In a strategy study for the new U.S. space exploration policy [1], Garriott, Griffin (now the NASA Administrator), and their colleagues concluded a similar type of synergism is prudent and that the initial reconnaissance missions should “involve extensive robotic and remote sensing activity.” The report further concluded that “human-robotic synergism is expected to play an essential role in the scientific, engineering, and new technology aspects of emerging human exploration of the solar system.” The advantages of that type of integration and synergism is further explored here, based on the science and exploration objectives articulated recently by the Lunar Architecture Team (LAT [2]) and the National Research Council (NRC [3]).

Reducing Risk, Requirements, and Cost of Polar Operations: Specific elements of the exploration initiative require polar operations [4]. This is an environment with which we have no prior experience. Although we can extrapolate from our experiences in the near-side equatorial region, uncertainties in several physical parameters and their effects over longer duration missions than those of the Apollo program are increasing engineering requirements for the Constellation Lunar Lander and supporting infrastructure. Some of those uncertainties can be addressed with robotic missions, so that the risk, requirements, and cost of human exploration are reduced. For example:

(1) The ionizing radiation environment in cis-lunar space has been measured repeatedly and is fairly well understood. The interaction of that radiation with the lunar surface in a polar region can be modeled, but those models have not been confirmed with in situ measurements, particularly during peak activity of a solar cycle. Robotic missions can (a) measure ionizing radiation in sunlit and shadowed regions at a pole, (b) test habitat and astronaut radiation monitoring devices, and (c) test the effectiveness of regolith for shielding by deploying detectors in trenches and beneath reworked regolith. If a robotic mission is flown in 2010, then it can make those measurements during solar maximum, providing a better measure of potential risk and requirements needed to mitigate that risk.

(2) Ambient dust and particles produced by impact cratering processes are potential hazards for long duration mission activities. The mobility of dust and its effect on mechanical systems can be tested robotically over multiple lunar days and, thus, resolve the putative effects of passing terminators. Any special effects that might be associated with polar environments that are either shadowed or dominated by sunlit conditions can also be evaluated.

(3) In the current LAT design, polar operations involve landing and habitation zones that are separated by >1 km. This separation requires the transport of significant amounts of material over the lunar surface. Apollo and Lunokhod missions demonstrated that vehicles can become stuck in soft soils, particularly where they form unconsolidated deposits around impact craters. Also, once disturbed, consolidated regolith cannot be mechanically recompacted to its original density. For those reasons, a robotic survey of potential routes between a landing zone and habitation area will greatly reduce risk and narrow the requirements for transportation designs suitable for the human operations phase.

(4) The sunlit regions of polar environments are being targeted to exploit solar power, yet the nearby shadowed interiors of impact craters may need to be exploited to meet other resource and safety objectives. Shadowed craters are difficult terrains for humans to explore and may be best characterized initially by robotic systems. Preliminary designs of robotic landers and rovers suitable for both the sunlit rims and shadowed interiors of polar craters have been developed [5] and are ready to be implemented.

Integrating Robotic and Human Exploration: Although exploration activities may be concentrated in a polar environment, the recent LAT and NRC studies [2,3], plus a previous Lunar Exploration Science Working Group (LExSWG) study [6], require global access (Fig. 1). For that reason, landers and rovers are being designed that can be deployed anywhere on the lunar surface, including shadowed craters [e.g., 5]. A robotic rover system, for example, can be deployed in several modes to facilitate human exploration:

(1) As a mobile experiment platform that can accomplish the science objectives of LAT, while also accomplishing the exploration objectives that must be

met in preparation of future human operations. Several examples are described in the previous section.

(2) As a transport vehicle that can deploy static science and exploration platforms, both during the robotic and human exploration phases.

(3) As a scout deployed prior to a human flight. For example, one of the highest science priorities is to determine the impact flux in the Earth-Moon system [3,7,8], which will require a diverse set of samples from multiple impact craters. A robotic lander-rover system can survey potential sampling sites and determine routes to them in advance of human collection during an astronaut-led mission. Furthermore, it can expand the geographic coverage of human-led sorties by collecting, caching, and potentially returning samples from other lunar locations.

(4) As an astronaut assistant during the human exploration phase. A rover will augment surface operations so that an astronaut has more time to explore the geology of the lunar surface and conduct other exploration activities. This strategy will maximize the time available for astronauts to utilize their unique human capabilities by assigning many mechanical and analytical tasks to a robotic rover.

(5) As an extended mission partner with human sortie efforts, deployed to further explore the lunar surface around a sortie landing site after astronauts have returned to Earth. Post-human mission processing of lunar surface materials might also be accomplished with a robotic component.

(6) As a surrogate explorer deployed by astronauts on extended (e.g., 180-day-long) missions, particularly during lunar nights and when hazardous conditions exist.

Conclusions: Robotic missions are a low-cost, science- and exploration-rich method to initiate a lunar exploration program. Under tight budget constraints, robotic activities can be accelerated, because they deliver large returns for relatively small dollars. They also have the capacity to reduce risk, engineering requirements, and cost of a human exploration phase. Like the human phase of exploration, a robotic phase will drive technology and, thus, support an underlying goal of space exploration. An integrated robotic and human exploration program will likely be the most cost efficient and productive means of exploring the Moon and other targets of the Constellation Program.

References: [1] Garriott O. K., Griffin M. et al. (2004) Extending Human Presence into the Solar System, The Planetary Society, 35 p. [2] http://www.nasa.gov/pdf/163560main_LunarExplorationObjectives.pdf. [3] Paulikas G. A. et al. (2007) *The Scientific Context for Exploration of the Moon: Final Report*, National Academies Press, 112 p. [4] http://www.nasa.gov/pdf/163896main_LAT_GES_1204.pdf. [5] Kring D. A. and Rademacher J. (2007) *LPS XXXVIII*, Abstract #1595. [6] LExSWG (1995) Lunar Surface Exploration Strategy, Final Report, 50 p. [7] Kring D. A. et al. (2005) Space Resources Roundtable VII, Abstract #2017. [8] Kring D. A. (2007) NASA Advisory Council Workshop on Science Associated with the Lunar Exploration Architecture, http://www.lpi.usra.edu/meetings/LEA/whitepapers/Kring_NACLunarMtg_2007_Invited.pdf.

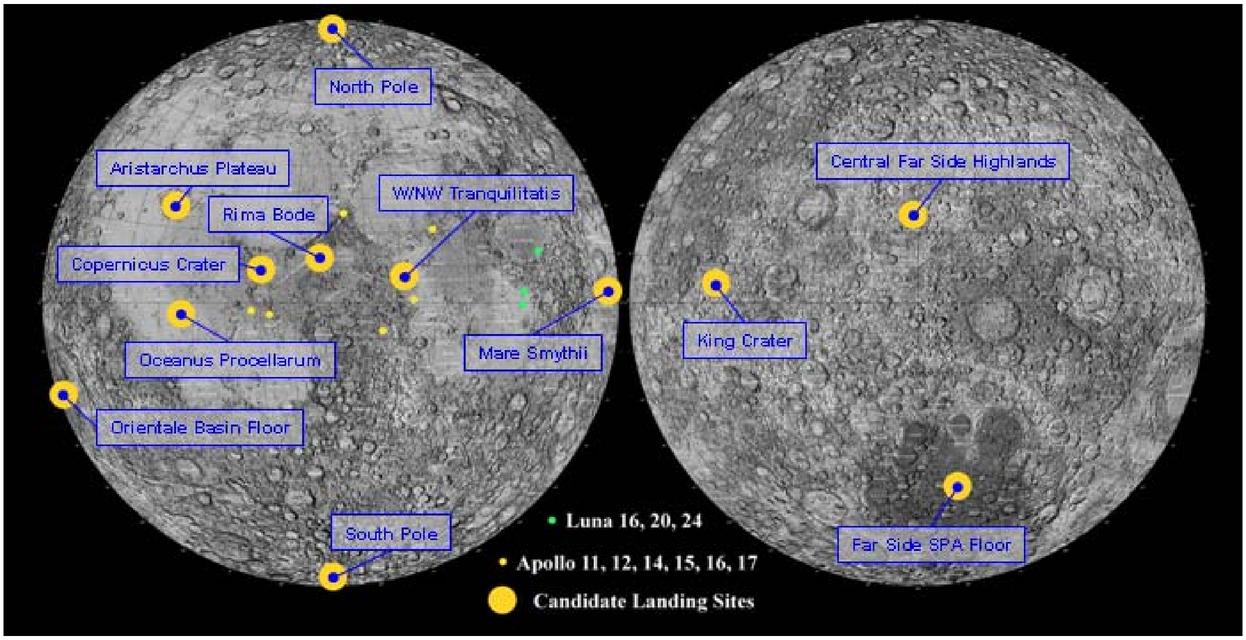

Fig. 1. Map showing the locations of several candidate landing sites on the Moon [5].