FURTHER DEVELOPMENT OF SMALL ROBOTIC LANDERS FOR PLANETARY MISSIONS. B. A. Cohen[1], J. A. Bassler[1], D. G. Chavers[1], D. S. Eng[2], M. S. Hammond[1], D. W. Harris[1], L. D. Hill[1], T. A. Holloway[1], S. Kubota[2], B. J. Morse[2], B. D. Mulac[1], and C. L. B. Reed[2]. [1]NASA Marshall Space Flight Center, Huntsville AL 35812 (Barbara.A.Cohen@nasa.gov); [2]The Johns Hopkins University Applied Physics Laboratory, Laurel MD 20723.

Introduction: The Robotic Lunar Lander Development (RLLD) office at NASA Marshall Space Flight Center, in partnership with the Johns Hopkins University/Applied Physics Laboratory (JHU/APL), has developed several mission concepts and capabilities to address high-priority lunar science objectives uniquely met with landed missions to the Moon [1]. In the last several years, the team completed detailed pre-Phase-A studies for the Robotic Lunar Exploration Program Mission #2 (RLEP-2) as a human-exploration precursor mission to demonstrate precision landing and definitively determine if there was water ice at the lunar poles, and for the International Lunar Network (ILN) Anchor Nodes Mission, as a possible contribution to a multi-national lunar geophysical network. In addition, the team has been conducting risk-reduction tests and activities in areas that are common to all lander concepts. Engineering tasks include propulsion thruster testing; propulsion thermal control testing and demonstration; composite lander deck design and fabrication; landing leg stability and vibration; and demonstration of landing algorithms in a lander testbed.

Lander design and risk reduction activities for these missions has had significant feed-forward to other missions to the Moon and, indeed, to other airless bodies such as Mercury and near-earth asteroids, to which similar science objectives are applicable. In this abstract we will detail several studies conducted in 2010 and the continuing risk-reduction activities taking place in the Robotic Lunar Lander Development office.

Lunar Polar Volatiles Explorer: The Planetary Science Decadal Survey commissioned the RLLD and APL team to conduct a concept study for a Lunar Polar Volatiles Explorer mission [2]. The overall science goals and objectives were provided as guidelines by the Decadal Survey Inner Planets Panel, with the goal of determining whether such a mission could be accomplished within a Principal Investigator (PI)-led mission cost cap.

The Lunar Polar Volatiles Explorer concept involves placing a lander and rover (with an instrument payload) in a permanently sun-shadowed lunar polar crater. The rover will carry a suite of science instruments to investigate the location, composition, and state of volatiles by direct in-situ measurement. A prospecting strategy is employed to enable lateral and vertical sampling only where higher hydrogen concentrations are detected, thus eliminating the criticality of statistically significant numbers and distributions of samples required by stochastic approaches.

The spacecraft is launched on a single Atlas V 401 Launch Vehicle. In order to ensure mission cost caps would be met, this mission concept utilizes a lander to deliver either a battery or Advanced Stirling Radioisotope Generator (ASRG)-powered rover to the surface. The lander is of a minimal capability, making use of a high-pressure, high thrust-to-weight ratio propulsion system for landing but relying on rover-based avionics and sensors to the maximum extent to enable precision landing in a permanently shadowed crater's Earthshine zone. The lander would be nonfunctional after the rover departs with the instrument suite to prospect for volatiles. A case was developed for an instrument suite and operations duration that fully met the science objectives within the New Frontiers cost cap, but total mission costs vary with the power system and instrument configurations.

Mercury Lander: Also for the Planetary Science Decadal Survey, the APL and RLLD team worked with Glenn Research Center to conduct a rapid, low-maturity concept study for a Mercury lander mission [2], focusing on feasibility trades and options for concepts with a goal of determining whether such a mission could be accomplished within a Principal Investigator (PI)-led mission cost cap. The mission focuses on fundamental science questions that can be best, or only, achieved by surface operations such as determining Mercury's bulk composition, the nature of the magnetic field, surface history, internal structure, and surface-solar wind interactions.

A landed mission to Mercury is extremely challenging from a launch energy and ΔV point of view. To address this primary challenge several concepts were explored to determine the trade space of feasible solutions. A three-stage vehicle (e.g. Atlas V 551) is likely the most mass-efficient approach to meet the cost requirement. In addition, the primary braking stage for landing would likely need to be a solid rocket motor to provide the best combination of Isp, high mass fraction, and volume for integration with the other stages.

Two trajectory approaches were explored. A ballistic/chemical approach was found to be potentially feasible, but current analysis puts it on the edge of being able to fit within the Atlas V 551. Depending on a more optimized mission design, this approach may require a reduction in the instrumentation payload or mass margins. A low thrust option was also explored using a solar electric propulsion (SEP) cruise stage. This option has the potential of offering more payload to the surface. The risk of this concept is its dependency on high-density, high-temperature solar cell technology that has yet to be developed beyond the cell level.

The cost estimates for all options exceeded the PI-led cost cap. A ballistic/chemical option was estimated at $1.2B with a reduced payload, favorable trajectory performance assumptions, and an Atlas V 551 launch vehicle. The SEP option, which includes a robust science payload, is over $1.5B. The same robust payload utilizing the ballistic/chemical option and requiring the Delta IVH launch vehicle is also over $1.5B. However, more detailed study is required to further characterize this challenging mission.

Near-Earth Asteroid Lander: In early 2010, the President outlined his new vision for NASA's space program, including a crewed mission to a near-Earth asteroid (NEA). Knowledge of the candidate human NEA target is required for destination qualification and for mission and systems design, and therefore the Exploration Precursor Robotics Mission (XPRM) office is examining an asteroid rendezvous mission. The objectives of such a mission would focus on identifying human hazards and quantifying engineering boundary conditions for operations in proximity of the object.

The RLLD project examined the utility of the robotic lander design work to a NEA mission by developing a mission concept for lander sizing to address human mission data needs. Assumptions for the study included a launch date in the 2015-2020 to support engineering design trades on the crewed mission, and a targeted total mission cost <$500M, which necessitated assuming a low-cost launch on a Falcon 9 class launch vehicle.

Notional mission objectives for the mission align with needs identified by the XPRM office: 1) obtain critical physical properties of the asteroid necessary to determine target viability and plan a human mission, including precise orbit determination, rotation, gravity and shape models, and surface features and composition; 2) obtain environmental data to ensure crew safety, such as radiation and dust particle sizes and abundance; and 3) support human mission operations planning by determining regolith geotechnical properties and demonstrating anchoring methods. The notional payload to meet these objectives in detail is around 60 kg.

The mission would initially conduct remote observations and make gravity measurements at varying altitudes relative to the asteroid for approximately 6 months. The lander then rendezvous with the surface directly, using visible and IR imagery taken along with nephelometer data to measure thruster interaction with the regolith and dust environment. The spacecraft then descends to the surface using closed loop target guidance and multi-axis thruster control, inserts an anchor, and conducts surface-based measurements of the regolith geotechnical properties. The mission design allows the option to cut anchor and repeat the landing sequence and measurements at a different location.

The mission was designed to a range of bounding characteristics representative of a potential human NEA mission targets. The mission concept is designed to be flexible to accommodate a wide variety of asteroid trajectories and characteristics (size, rotation rate, asteroid composition) consistent with potential human mission targets. The cost of the mission is estimated at $390M for the spacecraft, launch vehicle, ops, schedule margin and cost reserves, with the cost for instruments to be added based on XPRM priorities.

Robotic Lander Testbed: To continue to support development of robotic landers, the MSFC Lander Robotic Testbed was established. The MSFC test facility is currently operational and contains a compressed-air test article that allows demonstration of control software. This test article has a flight time capability of ten seconds and can autonomously descend from three meters altitude. It began flight tests in September 2009 and has completed 142 flight tests. A new MSFC test vehicle is nearly operational, utilizing a hydrogen peroxide propulsion system for longer duration flight (up to 60 s) and descent testing. This more advanced test vehicle will integrate and test other flight-like components and algorithms such as landing cameras, altimeter, instruments, and energy absorbing landing legs for final descent and landing. By spring of 2011, the new lander test vehicle will begin flight tests at the U.S. Army's Redstone Arsenal Test Center in Huntsville, AL. Through the Robotic Lander Testbed and other activities, the RLLD and APL team has significantly reduced technical risks for small and medium class robotic landers.

References: [1] Cohen, B.A., et al. (2010). LPSC 41, #2616. [2] http://sites.nationalacademies.org/SSB/SSB_059331