DELIVERY OF LUNAR SURFACE PAYLOADS ON A COST-SHARED COMMERCIAL ROBOTIC EXPEDITION. D. P. Gump, Astrobotic Technology Inc. 4551 Forbes Avenue, Suite 300, Pittsburgh, PA 15213, david.gump@astrobotictech.com

Introduction: The agenda for robotic activity on the moon is sufficiently broad and the expense of mounting a commercial mission is now sufficiently affordable to close the business case for repeated private-sector expeditions that sell payload accommodations on a per-kg basis to all interested parties.

Astrobotic Technology Inc., a spin-off from Carnegie Mellon University's Field Robotics Center, is exploiting both the University's deep technical expertise and its tradition of internally fabricating advanced robots for hazardous and challenging environments using modest budgets.

In addition, Astrobotic Technology has signed a launch contract with SpaceX to use the economical Falcon 9 to inject its single-stage spacecraft/lander into trans lunar trajectory. This will be the first mission of the Falcon 9 for beyond-Earth destinations.

The mission will be able to deliver up to 110 kg of payload for space agencies, academic researchers, and the media/marketing industries. Both lander and rover provide power and communications to payloads. Payloads on both have access to the regolith less than a half-meter away from their mounting locations.

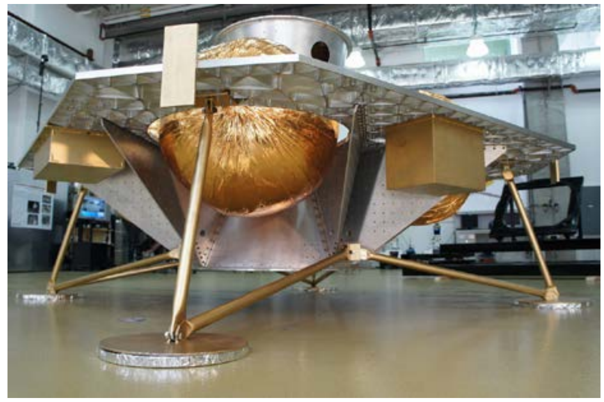
The initial mission will launch in the April-July 2014 period, with the date and lunar desintation dependant primarily on customer preferences.

Mission design. A Falcon 9 launches and injects the spacecraft through TLI with second stage re-ignition. The single-stage lander cruises for four days, orbits, descends and lands. Pinpoint landing near a feature of interest is achieved by optical registration of images captured during orbit and descent to stored images from LROC. The lander detects hazards during approach of the final landing site and diverts to safely land within 200 meters of the target. The rover departs for a 12-day trek until local sunset, when it enters hibernation until the next dawn..

Ground Operations: Launch ops occur at SpaceX's Cape Canaveral facility. Surface operations are centered in Pittsburgh at CMU. To maintain continuous 24/14 surface operation, operators are rotated every six hours.

Cruise, Orbit and Landing: Mission trajectory has been designed through Satellite Toolkit through partnership with AGI. Control of descent and in-flight attitude maneuvers will be evolved from autonomous vehicle control systems developed at CMU.

Lander design: The lander is a pallet structure, which delivers the rover and stationary payload to the lunar surface. The lander hosts payload and provides 500W of persistent solar power during daylight. It is solar powered with rechargeable



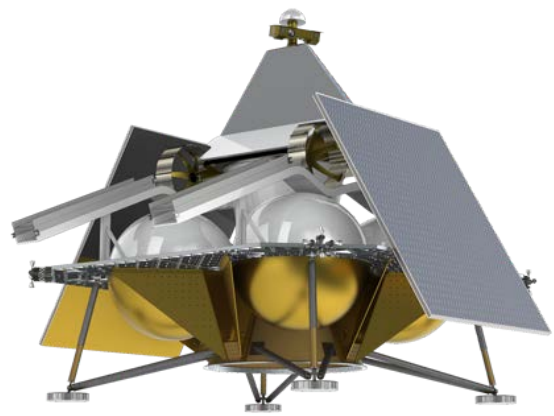


Figure 1. Top photo is lander primary structure after shake table testing; bottom image is full lander with rover mounted on top.

batteries for storage and surge power. Baseline communication is a pointed antenna with omnis as backup.

Lander solar arrays generate 500 watts average power. The 28V 54Ahr battery incorporates lithium iron phosphate cells. Battery packs have been developed, prototyped and tested for power draw and thermal.

Rover Design: Three rover prototypes already have been fabricated and field tested. Rover structure is primarily composite. Structure components are manufactured at Carnegie Mellon's Advanced Composites Lab and critical components have been manufactured and tested to verify process and quality. Rover structural analysis has been performed for loads from launch and roving.

The rover is a skid-steered vehicle with passive suspension. Two actuators propel and steer the rover. Roller chain transmits torque from shoulder actuators to the wheels; chain

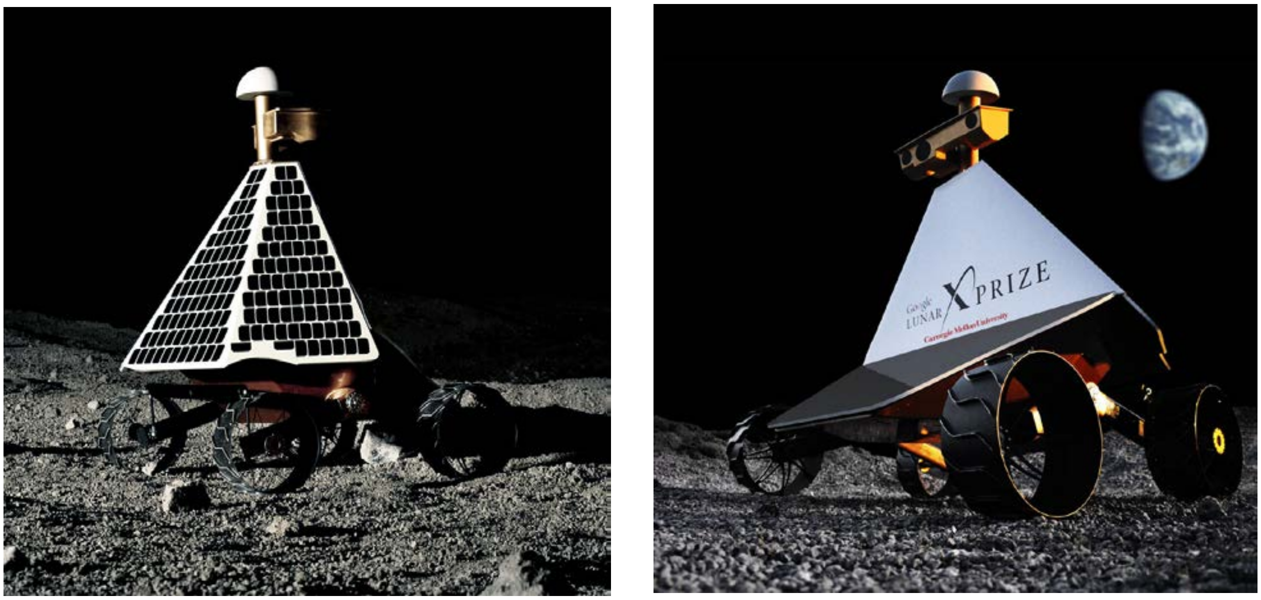


Figure 2. Prototype lunar rovers shown above have been field-tested in lunar-like slag heaps near Pittsburgh, demonstrating an ability to surmount steep obstacles during teleoperation. The camera head rotates 180 so that the rover can move toward or away from the sun while keeping its solar panels fully illuminated and its slanted radiator pointed to black sky to dump excess heat.

enables high torques with minimal mass and complexity. Placement in the shoulders insulates actuators from lunar dust and extreme temperatures of the lunar surface and eliminates wire flexure or steering through the suspension. Each shoulder actuator transmits torque to both wheels on one side. Extensive testing on mobility prototypes has validated system performance under thermal and mechanical load.

Alliances with Harmonic Drive and International Rectifier provides robust space actuation. Actuation stacks are developed by CMU and Harmonic Drive are driven by OM9373 motor drivers from International Rectifier. All actuation stacks have been detailed, prototyped and tested including functional field testing and thermal vacuum tests.

The rover is powered by a fixed faceted conical solar array avoiding complex, mass intensive deployments. The rover operates much like a sailboat tacking to keep the sun on the solar array and off the radiator. Full motion is achieved with a bidirectional drive train and rotatable camera head. The power system electronics mimic that of the spacecraft. A battery identical to the spacecraft battery provides surge power for drive actuators and payloads.

An asymmetric, composite structure with dual structural and thermal function, achieves passive thermal regulation for the hot lunar equatorial day. Critical robot components are thermally isolated from the solar panels and chassis with MLI. Motors, avionics, batteries, and other electronics which generate heat are connected to a radiator which faces away from the sun either directly or through high conductivity thermal pathways. The result is a robot that absorbs little heat from its surroundings and efficiently dumps self-generated heat.