GRiffin: Industry-led development of robotic lunar landers. S. Huber, K.M. Peterson, J. Thornton, and W. L. Whittaker, steven.huber@astrobotic.com, kevin.peterson@astrobotic.com, john.thornton@astrobotic.com, red@cmu.edu, Astrobotic Technology, Inc., 2515 Liberty Ave, Pittsburgh, PA 15222.

Introduction: This paper describes a financial and technical model for industry-led public/private partnerships in development of lunar landing capability. The paper discusses the public/private partnership, our model for payload services, and Griffin, a lunar lander that is core to the model.

Public/Private Partnership: Astrobotic envisions an industry-led partnership with NASA to co-develop a lunar lander. Each partner provides personnel effort, support services, equipment, expertise, information, and facilities to attain the best from a public/private partnership. The objectives of the proposed model are to:

- implement U.S. Space Exploration policy with investments to stimulate the commercial space industry,
- facilitate U.S. private industry development and demonstration of robotic lunar landers to deliver small (30-100kg) and medium (250-450kg) class payloads, and
- create a market environment in which commercial lunar payload delivery is available to Government and private sector customers.

In this model the commercial partner is responsible for development and demonstration of lunar landing capabilities under commercial funding. NASA provides inputs in relevant data; systems engineering; process for build, integration, and test; technical expertise; collaborative design, development, and testing of lander systems; use of test facilities; and specific hardware and software elements. NASA contributions to the project target items that have significant risk or cost reduction potential and are needs that NASA is uniquely qualified to satisfy.

Payload Services Model: In the nominal mission revenue model, Astrobotic sells payload to one or multiple customers to fill a manifest, and generates revenue from sponsorships and other commercial activities, NASA could buy all or part of the available payload capacity. The pricing strategy is to charge a nominal price per kilogram of $1.2M/kg for delivery to the Lunar surface. Payload can be deployed in cruise or orbit with alternative pricing structures. Further details about pricing can be found on www.astrobotic.com.

Services available: Standard prices cover basic power, data, and engineering support. Astrobotic offers options other than landed payload delivery, including commission of an Astrobotic rover for on-surface mobility and drop off in lunar cruise or in orbit (potentially for satellite delivery).

Griffin Lander: The Griffin lander precisely delivers small and medium class payloads to any destination on the Moon. Griffin’s flexible payload mounts can accommodate a variety of rovers and other payloads to support robotic lunar missions like lunar polar volatile prospecting, sample return, geophysical network deployment, skylight exploration, regional prospecting, and mining. Details such as size of launch vehicle and solar arrays, orientation of high-gain antennas, and sizing of thermal radiators are customized for destination and purpose, while structure, propulsion, power, avionics, communications, and guidance, navigation, and control are invariant.

Griffin launches on a third-party launch vehicle. A SpaceX Falcon9 is currently under contract for launch in October-December of 2015. Medium-class payload capability in future missions is obtained with a larger launch vehicle, such as a Falcon Heavy or SLS. After achieving Low Earth Orbit, the launch vehicle second stage reignites for trans-lunar injection. Following a 4.5-day cruise, Astrobotic’s lander establishes a 100km circular orbit, corrects its state estimation errors, and initiates deorbit by entering a 15km periplanet orbit. Deorbit is followed by a 20-minute powered descent

phase. During powered descent, Griffin autonomously aligns real-time data from cameras and LIDAR with existing satellite imagery to navigate to a precise landing location and maneuver past hazards to safely touchdown.

Structure: Griffin’s aluminum frame is stout, stiff, and simple for ease of payload integration. The main isogrid deck accommodates flexible payload mounting on a regular bolt pattern. Thermal control is available through cruise and on the surface. Four legs absorb shock and stabilize Griffin on touchdown. Rover missions can use deck-mounted ramps for rover egress. Protoflight lander structure has been qualified for launch loads through vibration testing.

Guidance, Navigation, and Control: During orbit and landing, cameras register Griffin to lunar terrain for precise landing, while LIDAR constructs 3-D surface models of intended landing zone to detect slopes, rocks, and other hazards. This technology enables Griffin to safely land within 100m of any targeted landing site, even in complex and hazardous terrain.

Propulsion: Nine continuously-throttled Nitrous Oxide Fuel Blend (NOFBX) 100lbf engines perform primary braking and attitude maneuvering. This propellant and engine have been developed in cooperation with NASA for over a decade. The engines are arranged with five in a tight star pattern coincident with the central axis of the lander and four additional engines located around the perimeter of the lander clocked 90 degrees from each other, which enables single engine-out capability. Depending on the mission phase, it is possible to lose more than one engine and still succeed in landing. The engines are throttleable 100:1. For additional attitude maneuvering, Griffin incorporates cold gas thrusters for roll control and sources the fluid from the gas phase of its propellant.

Avionics: Griffin’s computing platform is a combination of Field Programmable Gate Arrays (FPGAs) and a general-purpose processor. Computationally expensive operations like feature detection and hazard analysis occur on FPGA-based computational accelerators. The processor marshals data and orders computational operations. This system enables high performance and the efficiency necessary for the real-time data processing during landing.

Night Survival: Unique battery, power system, avionics, and engineering enable Griffin to hibernate during the lunar night, then revive the following lunar day. Astrobotic’s testing campaign has identified battery chemistry, power system, and electronic components that enable hibernation. Nominally, primary mission operations are completed in the first lunar day and additional days support reach goals, until night survival is verified on the 2015 mission.

Rover Deployment: A Griffin design option provides deployable ramps for rover egress. Once on the surface, deployable ramps enable egress of large rovers mounted to the top of the Frustum Ring. Ramps stow for launch and are spring-deployed upon release, accommodating both third-party rovers and Astrobotic surface rovers for payload delivery. Astrobotic rovers can support missions for any latitude – equatorial to polar. Griffin supports medium-class rovers up to 500kg.

Payload Accommodations: Griffin supports payload operation with thermal control, power, and data transmission. Deck mounting locations are thermally regulated during all mission phases. Thermal regulation is by radiation dissipation from the topside of the deck and heaters. An average of 150W of power is available to payloads during cruise and on the surface. The lander downlink can support an average of 200kbps of payload data when on the surface. A Griffin design option provides wireless surface radio to act as a communication relay for mobile rovers.