LOW-COST ATHLETE-BASED MARS LANDER/ROVER. C. McQuin[1] and B. Wilcox[2], [1]Jet Propulsion Laboratory, California Institute of Technology, email: christopher.mcquin@jpl.nasa.gov mail: 4800 Oak Grove Drive, M/S 82-110, Pasadena, CA 91109, [2]Jet Propulsion Laboratory, California Institute of Technology, email: brian.h.wilcox@jpl.nasa.gov mail: 4800 Oak Grove Drive, M/S 301-420, Pasadena, CA 91109.

Introduction: A low-cost Mars lander/rover is proposed based on technologies developed or perfected at JPL that may enable a highly capable Mars lander/rover to be flown in the near term at a reasonable cost. These technologies include the throttleable descent engine (Mars Landing Engine or MLE) used for the Mars Science Laboratory (MSL) now en-route to Mars and the All-Terrain Hex-Limbed Extra-Terrestrial Explorer (ATHLETE) wheel-on-limb mobility system that could be packaged into a Mars Exploration Rover-sized aeroshell and would self-deploy as "outriggers" for an air-bag-cushioned landing and subsequently to provide the lander with robust surface mobility.

Affordable, Near-Term Surface System Capabilities: The concept is to utilize the 2.65 meter diameter aeroshell developed for Pathfinder and Mars Exploration Rover (MER), packaging the ATHLETE wheels-on-limbs folded into the rarely-used annular volume around the circumference of the heat shield (Figures 1a and 1b). ATHLETE limbs would function as outriggers during the landing event, preventing overturning while air bags at the base of the launch adapter ring would cushion the final impact. These ATHLETE limbs would provide mobility post-touchdown (Figures 1c and 1d), and also have quick-disconnect tool adapters which would allow all manner of tools (e.g. drills, grippers, scoops) to be used to feed and maintain a payload (e.g. for drilling, including deep drilling, as well as sample acquisition and handling), which would otherwise require a substantial investment in special-purpose sample-handling-chain hardware. Because a hybrid rolling/walking vehicle could escape entrapment in soft soil by walking, it could have a higher ground pressure. This higher ground pressure would greatly reduce the mass of the wheels and wheel drive assemblies, so that these hybrid vehicles would have a significant mass advantage at larger scales needed for human exploration as well as slight mass advantages at the scale proposed here.

In addition to the MLE (the only small throttleable engine developed since Viking in the 1970s) and ATHLETE, JPL has other technologies which make this approach attractive. JPL's experience with air-bag

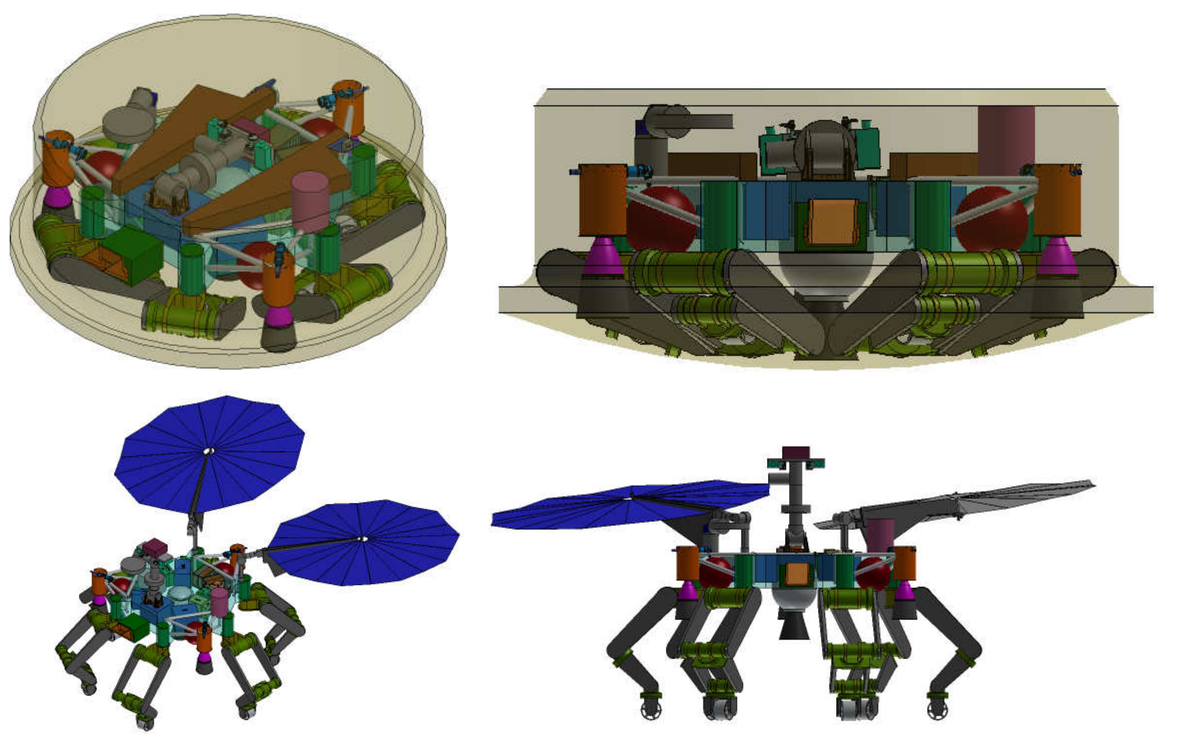

Figure 1: a (upper left) and b (upper right) - Configuration of stowed Lander/Rover in MER-sized aeroshell, c (lower left) and d (lower right) driving pose on Mars surface.

cushioned landings on planetary bodies is well-known. JPL has worked extensively with the vendor to adapt for space and qualify the LN-200 aircraft-grade Inertial Measurement Unit (IMU) as a low-cost alternative for spaceflight (<<$100k/ea), and many have flown on JPL missions over the past 15 years. Also, all flight software and mission operations tools for ATHLETE and MSL come from the same lineage, extending from Pathfinder through Deep-Space-1 and the Mars Exploration Rovers. Software from the HEOMD Advanced Exploration Systems (AES) Autonomous Landing and Hazard Avoidance Technology (ALHAT) Project would be integrated to convert real-time stereo vision (not LIDAR) data to real-time hazard avoidance information. As a result of this heritage, very little software development would need to be done specially for this effort.

The overall approach to creating this system at affordable cost is to trade mass for money. Unlike MER and MSL, which had defined payloads and went through many design cycles to resolve subsystem conflicts, this system would be designed with a "one pass" design philosophy, where each subsystem is given sufficient mass/volume/power reserves to meet a minimal set of mission requirements so that multiple design iterations are avoided. The estimated mass and cost for each subsystem of the proposed Lander/Rover is shown in Table 1. Following a MER-style entry and descent sequence, a STAR-13 solid rocket motor embedded on the centerline would decelerate the system to near-zero velocity, while 3 MLE engines on outriggers would provide attitude control and gently lower the vehicle on top of crushable airbags to the surface where the airbags absorb the impact and the limbs act as outriggers to prevent tipping as shown in Figure 2.

Subsystem/Component	Qty	Mass (ea, kg)	Extended mass (kg)	Compare Phoenix mass (kg)	Recurring Cost (ea, k$)	Non-Recurring Cost (k$)	Extended Cost (k$, inc. NRE)
Propulsion (dry)			51	53		2,750	5,680
-STAR-13B (@burnout)	1	6	6		500	0	500
-MLEs/valves	3	13	38		600	2,200	4,000
-RCS Thrusters/valves	8	1	4		60	500	980
-Propellant tanks	3	1	3		50	50	200
Liquid Propellant (hydrazine)	1	30	30	67	10	0	10
Solid Propellant	1	41	41				0
Telecom	1	5	5	22	4,000	2,000	6,000
Attitude Control	1	3	3	20	2,000	2,000	4,000
Command and Data	1	15	15	14	4,000	5,000	9,000
Thermal	1	20	20	16	500	1,000	1,500
Power			103	73		2,500	6,300
-Batteries	1	20	20		2,000	1,000	3,000
-Ultraflex solar arrays	2	40	80		400	1,000	1,800
-Power control/conditioning	1	3	3		1,000	500	1,500
ATHLETE limbs & mechanisms	6	20	120		3,000	30,000	48,000
Body structure	1	100	100	72	1,000	2,000	3,000
Payload (including tools)	1	65	65	56	5,000	10,000	15,000
Software	1	0	0	0	0	40,000	40,000
Totals			533	393		97,250	138,490

Table 1: Estimated mass and cost for each subsystem, including non-recurring engineering. The estimated flight system cost is about half that of the Phoenix lander flown in 2007. Entry mass is the same as MER (heat shield, backshell, parachutes, masses not listed). Payload estimated at 65 kg, including tools for manipulation by ATHLETE limbs.

The liquid propulsion system would include 3 of the MLE throttleable engines developed for MSL which have $1M non-recurring engineering and a $1.2M for a delta qualification for each batch of catalysts. The liquid propulsion system would also include 8 Reaction Control System (RCS) thrusters & valves and 3 low-cost, low-performance tanks each containing 10 kg of propellant. The entry mass is the same as MER. The attitude control system would include an LN-200 IMU. The motor controllers would be those jointly adopted by JSC and JPL for the Office Of Chief Technologist (OCT) Human-Robot Systems (HRS) Project from those developed by JSC for Robonaut and already being integrated into the HEOMD AES Multi Mission Space Exploration Vehicle (MMSEV) project. Similarly, the actuators will be adapted from those being jointly developed by JPL and JSC for the HRS project, including those being delivered into the AES MMSEV project. The total estimated cost for the flight system is barely more than half the cost of the Phoenix Mars lander flight system (~$250M). Our projected lower cost is achieved primarily by not attempting to reduce mass, by not using more costly components, and by avoiding expensive non-recurring engineering.

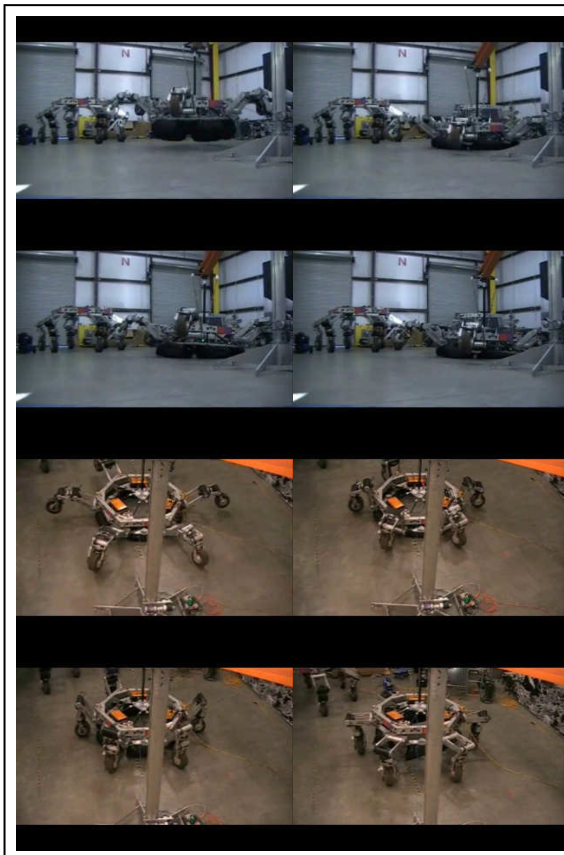

Figure 2: Video still sequence of ATHLETE landing on crushable airbags at APOLLO landing speeds demonstrating terminal landing sequence and drive.