LOW COST HIGH VALUE MARS SAMPLE TO ORBIT. M. Adler, C. Guernsey, S. Sell, A. Sengupta, L. Shiraishi, mark.adler@jpl.nasa.gov, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena CA 91109.

Introduction: This concept addresses Challenge Area 2 with a low cost approach to collecting a Mars surface sample with a roving vehicle and caching that sample in Mars orbit for later capture and return to Earth.

The key characteristics of this approach are:

- Star 48 upper stage on a Falcon 9 launch vehicle
- Scaled-down Mars Science Laboratory (MSL) Cruise-EDL system (guided 10 km miss distance)
- Mars Exploration Rover (MER) class rover for rock core collection and context documentation
- Reduced sample mass and storage requirements (~100-gram sample mass, single container)
- Small two-stage solid rocket motor Mars Ascent Vehicle with guided first stage and spin-stabilized second stage
- Acceptance of larger orbit insertion dispersions using a Solar Electric Propulsion return orbiter able to change its orbit across those dispersions

Launch: Starting with the launch vehicle, the current Falcon 9 Block 2 promises very low cost, but has limited performance to escape velocity due to the fact that it is a two-stage vehicle. Adding a third stage can significantly improve that performance. The same third stage used on the Delta II for many planetary missions, the PAM-D Star 48, allows a 1000 kg increase in escape performance. (Figure 1) A PAM-D would add $5M to $10M recurring cost, plus a non-recurring cost.

Lander: The Mars Science Laboratory project has developed a highly capable Mars entry, descent, and landing (EDL) system that delivers high mass efficiency and precision landing with very low impact velocities. However the MSL launch mass of 3800 kg is too great for even the three-stage Falcon 9.

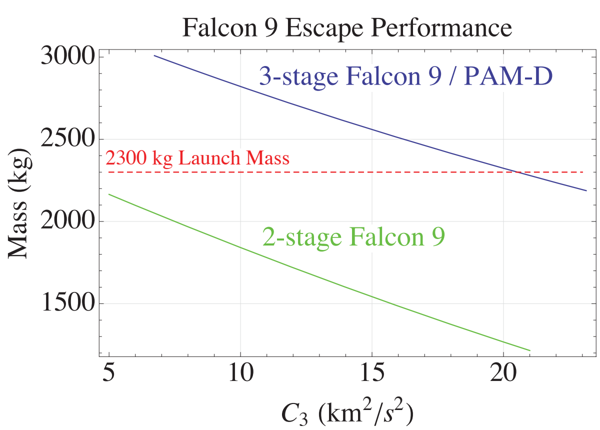

Figure 1. Falcon 9 Escape Performance

The MSL Cruise-EDL system can be scaled down for this application (Table 1). Not all elements were scaled in order to arrive at a realistic assessment. For example, the descent stage avionics and mechanisms have the same mass as on MSL. The result is a scaled system that would fit on a three-stage Falcon 9 that can deliver 500 kg to the surface. (Table 1) A generous margin is applied resulting in a 350 kg delivered mass to be used here for planning purposes.

Table 1. Mid-Lander Attributes

Attribute	MSL	Mid-Lander
Aeroshell Diameter	4.5 m	3.5 m
Entry Mass	3300 kg	2000 kg
Ballistic Coefficient	130 kg/m^2	130 kg/m^2
Landed Mass (hung)	900 kg	500 kg
Launch Mass (w/cruise)	3800 kg	**2300 kg**

Mars Ascent Vehicle: A similar scaling can be performed on the Mars Ascent Vehicle (MAV). A two-stage MAV concept was developed in Phase B of the 2003/2005 Mars Sample Return Project. This concept minimizes the mass of the MAV by having no active guidance on the second stage, which is spin-stabilized. The first stage would be fully guided with thrust vector control and a cold gas system for attitude control after the first stage burn. The first stage guidance was found to be necessary in order to achieve orbit with high probability. That 130 kg MAV could launch a 3.6 kg Orbiting Sample (OS), where the 3.6 kg OS carried a 0.5 kg sample.

The 2011 Planetary Science Decadal Survey [1] has as its highest priority a Mars sample caching mission, but stated “It is likely that a significant reduction in mission scope will be needed to keep the cost of MAX-C below $2.5 billion. A key part of this reduction in scope is likely to be reducing landed mass and volume.” Such a reduction for an end-to-end Mars sample return mission must start at the sample.

For this concept, the sample mass is reduced to ~100 g and the OS to 0.5 kg, where the ratio assumes limited partitioning of the samples. Many anticipated sample analyses operate on milligram and microgram quantities of sample. Sample cores provide their own isolation from other samples, where sectioning of the samples and grains on Earth exposes the pristine rock. This *first* of several low-cost Mars sample returns will return far more science than equivalent-cost in situ investigations. Subsequent MSRs will improve on the sample mass and isolation.

The second stage tracking beacon and some small non-propulsion hardware on the second stage would be reduced to 2.5 kg, of which 1 kg is avionics. A conservative approach is used to scale the MAV, assuming that all of the remaining non-propulsion hardware mass remains the same, scaling only the rocket motors' propellant and dry mass. This reduces the 130 kg MAV to 95 kg. A non-guided second stage results in larger orbit dispersions than a guided second stage, which can be compensated for by an Electric Propulsion return orbiter that can reach those orbits. Commercial Hall thrusters are well suited to round-trip Mars missions, offering significant mass and cost benefits.[2][3] Such concepts for Mars sample return orbiters using Hall thrusters have been developed with masses on the order of 700 kg with five-year round trip times.

A 100 kg MAV is assumed, plus 50 kg for the platform, communications, erection system, and thermal control. That leaves 200 kg for the rover.

The MER and MSL rovers have demonstrated a 15% to 25% science payload fraction, where the remainder is the mobility system, power, data handling, and communication. The 200 kg rover would be solar powered, where a 20% payload fraction — a 40 kg science payload is assumed. A 40 kg payload developed for other concepts [4] is assumed, which has MER-class science and a rock coring and transfer system [5], and which includes 10 kg of margin with the removal of a caching system for this concept.

Work on taking further advantage of the reduced OS mass for further reduced MAV mass will be conducted before the presentation of this paper. If further studies can reduce the MAV size sufficiently and increase the rover payload fraction, the ultimate objective would be to carry the MAV on the rover. This would eliminate the risk to the mission of failed rover once a few samples have been collected. The MAV could be launched by an immobilized rover, or launch itself off of a failed rover. Using the full 350 kg of delivered mass for a rover would allow a 70 to 85 kg payload including the MAV.

Cost: The MSL development cost divided by the dry mass is the metric used for this concept. The $1.8B MSL development costs (which includes a two-year delay), not including launch or operations, with a 3350 kg dry mass, results in a development metric of $0.54M/kg. The metric applied to this concept's dry mass of 2050 kg results in a development cost of $1.1B.

MSL was a new development across all elements. No credit is taken in the above estimate for extensive MSL heritage on the Cruise-EDL system, or for MER heritage for the rover used in this concept.

Available data for the Falcon 9 suggest launch costs on the order of $0.1B, resulting in $1.2B plus operation costs, in approximately year 2009 dollars.

Conclusion: A mid-size lander, rover, and MAV using the MSL CEDL architecture and a three-stage Falcon 9 can collect scientifically high-quality Mars surface samples consisting of rock cores collected by a roving platform, and deliver those samples to Mars orbit in a single mission at potentially much lower cost and lower risk than previous architectures with much larger vehicle, multiple missions, and very long traverses. Further work on this concept may offer the potential to carry the MAV on the rover, simplifying the system and reducing the risk even further. A separate, comparatively small, 700 kg return orbiter using solar electric propulsion would locate, capture, and return the orbiting sample to Earth. The small size of the lander and return systems promise much lower development costs, which are approximately proportional to dry mass. The use of the Falcon 9 with a third stage has the potential to greatly reduce launch costs as compared to the current stable of EELVs. The total cost of a Mars sample return mission with one lander and one return orbiter could be on the order of $2B to $2.5B in FY15 dollars. A series of small Mars sample return missions would reduce risk and significantly increase the science return over one large Mars return mission, by virtue of multiple landing sites and learning from previously flown MSR missions. Making use of MER rover and MSL lander heritage, such a system to put a sample into Mars orbit could fly as early as 2018, would make a giant leap towards Mars sample return, and would maintain and strengthen NASA competencies for Mars landing, roving, and launching technologies.

References: [1] Committee on the Planetary Science Decadal Survey; National Research Council, "Vision and Voyages for Planetary Science in the Decade 2013-2022" (2011). [2] Oh, D. Y., et al, "Benefits of Using Hall Thrusters for a Mars Sample Return Mission" (2009) *International Electric Propulsion Conference, IEPC-2009-217*. [3] Oh, D. Y., et al, "Commercial Electric Propulsion Enables Innovative and Practical Mars Sample Return Missions" (2012), abstract submitted to *Concepts and Approaches for Mars Exploration*. [4] Ehlmann, B. L., et al, "A 2018 MER Caching Rover for Exploration of Noachian Mars" (2012), abstract submitted to *Concepts and Approaches for Mars Exploration*. [5] Backes, P., et al, "Demonstration of Autonomous Coring and Caching for a Mars Sample Return Campaign Concept" (2012), *IEEE Aerospace Conference, paper #1480.*