HIGH PERFORMANCE MARS ASCENT VEHICLES, EARTH RETURN VEHICLES AND "ALL-UP" LAUNCH STRATEGY FOR LOW COST SAMPLE RETURN.

L. G. Lemke[1], C. R. Stoker[1], B. J. Glass[1], J. S. Karcz[1], J. V. Bowles[1], A. A. Gonzales[1], S. Davis[2]. [1]NASA Ames Research Center, [2]SpaceX Company.

Introduction: Robotic missions to return carefully selected samples of Mars atmosphere, regolith, and rock have been actively studied and advocated by NASA for at least the last 15 years and remain a very high priority objective of both the Science Mission Directorate (SMD) and the Human Exploration and Operations Mission Directorate (HEOMD) programs. As a practical matter, such missions are intrinsically among the most complex robotic planetary missions that can be engineered. The current Decadal Survey Architecture (DSA) incorporates virtually every technical capability in the robotic spaceflight repertoire—atmospheric Entry Descent and Landing (EDL) at Mars, Mars surface mobility, subsurface sample acquisition, autonomous sample handling for planetary protection, Mars surface rendezvous with rovers, launch from Mars' surface to orbit, Mars Orbit Rendezvous (MOR), and Earth EDL from high speed approach (≈ 12.5 km/s). The need to utilize all or nearly all, these capabilities to return just one sample container is undoubtedly a major driver for the risk and cost of sample return architectures. Even a minimal Mars sample return mission will necessarily have a large number of moving parts, each one of which must be designed, developed, launched, operated, and therefore paid for. On multiple occasions--including the present--the high perceived technical risk and cost risk has prevented a NASA sample return campaign from starting. We argue that a Mars Sample Return (MSR) architecture that eliminates the need for MOR may reduce the cost of returning carefully selected Mars samples by a factor of two or more relative to the DSA, and thus allow an MSR campaign to start. Moreover, we argue that spacecraft transportation systems currently being planned for development and funded by HEOMD may be utilized for implementing such an MSR architecture without the need for large, expensive, new spaceflight hardware investments.

Benefits of Eliminating MOR: It is important to recognize that the reference DSA was not crafted and makes no claim to be, the least costly method possible for returning carefully selected samples from Mars. Rather, the DSA is crafted to satisfy at least three important external constraints. First, all mission elements must fit within the mass and volume constraints of existing launch vehicles. Second, all mission elements sent to Mars' surface must fit within the mass and volume constraints of Viking-heritage EDL landers. Third, mission costs must be able to fit within a given (relatively level) funding profile. Together, these constraints force a complex architecture to be fractionated into smaller pieces and implemented over a longer time than might otherwise be desireable. One consequence of this mission fractionation is that the DSA uses a small (≈ 300 kg) Mars Ascent Vehicle (MAV) with a ΔV of ≈ 4 km/s—just enough to attain low Mars orbit. This, in turn requires MOR to place the sample container in a hermetically sealed Earth Return Vehicle (ERV) before departure toward Earth. The Mars Orbiter in the DSA is itself a large and highly capable spacecraft requiring a dedicated launch and mission control.

A Johnson Space Center (JSC) study conducted by the then Office of Exploration [**1**] examined the cost and risk benefits of MSR alternatives not requiring MOR. One of the conclusions is that an architecture involving MOR is likely to be one of the more expensive and risky choices compared to an architecture that does not. In order to implement an MSR mission without MOR, it is necessary to land a highly capable MAV + ERV spacecraft stack—one capable of carrying the sample container all the way from Mars' surface to Earth orbit (an "Earth-Direct" architecture). Given a fixed level of technology, such a highly capable MAV + ERV stack will necessarily be more massive than an equivalent MAV designed to go only to Mars orbit. Thus, everything else being equal, Earth-Direct architectures seem to require the ability to land larger single payloads on Mars than does the DSA. This, in turn requires larger individual launch vehicles to inject larger landers on trajectories toward Mars.

With this in mind, [**2**], JSC studied an Earth-Direct MSR point-design mission utilizing a human exploration heavy lift launcher. In that mission, a mid L/D entry vehicle flies a guided hypersonic entry to execute a precision landing with terminal hazard avoidance in order to place a 4.5 ton lander in proximity to surface features determined to be of high scientific interest. The lander acquires a regolith sample with a robotic arm, places it in a container on an ERV located on top of a 2 stage MAV. The MAV + ERV combination returns the sample cannister to Earth orbit where it is retrieved by the Shuttle. The MAV utilizes a storable bi-propellant propulsion system and the ERV utilizes Solar Electric Propulsion (SEP). The ERV has a wet mass of ≈ 350 kg and the MAV + ERV combination has a wet mass of ≈ 2300 kg. Architectures of this type not only seek to reduce risk and cost, but also to capitalize on investments by, and achieve objectives for, the human exploration enterprise. In this case, the architecture demonstrates use of high ballistic coefficient, guided hypersonic EDL and precision landing with hazard avoidance—capabilities which have frequently been identified as enabling for human exploration of Mars.

The study concluded, however: "…that if the Viking heritage heatshield and parachute continue as the only available Mars delivery system, a MSR mission will always be limited to using Mars Orbit Rendezvous due to limitations of landed mass …."

Moving Toward All-up Launch: Currently, the ideal all-up launch strategy is is not attainable, due to the limited capacity of existing launchers and Mars landers. However, progress in that direction is scheduled to occur in the mid-term (post 2018) if either or both SLS or the SpaceX Falcon Heavy become operational. The SpaceX Falcon Heavy can launch approximately 10,000 kg on a Mars trajectory with a C3 of 10 km^2/s^2. In a companion abstract [**3**], it is shown that a suitably modified SpaceX Dragon capsule ("Red Dragon") can perform all the EDL functions necessary to land on Mars with a contained payload mass of ≈ 1,000 kg. We believe that progress in small spacecraft technology will allow the design of a combined MAV + ERV spacecraft stack more than 2x smaller than the JSC design, and therefore be capable of fitting into a Red Dragon capsule. By itself, this would allow the return of a so-called "grab sample" acquired from the immediate vicinity of the lander that bypasses MOR and returns a sample directly to Earth orbit. This case is discussed in a companion abstract [**4**].

However, a grab sample does not satisfy the full objectives of the DSA. But, the Falcon Heavy (or SLS) can accommodate a secondary payload of ≈ 1,000 kg on the same launch, inside the interplanetary cruise stage. The secondary payload could be an additional lander (carrying, for example, a small rover and using a proven landing system) or a communications relay orbiter, or some combination of the two. If the rover is landed days or weeks before the Red Dragon arrives, the hypersonic maneuvering of the Red Dragon may be used to perform a precision landing in the vicinity of the rover. In this architecture, because the rover arrives at Mars at the same time as the MAV, the MAV may depart for Earth with a sample delivered by the rover after about 500 days. This eliminates the need for a separate "fetch rover" and approximately 3 years of operations. We estimate that the combined effect of these changes could reduce the cost of a sample return to less than half the DSA cost.

Technological Readiness: This cost saving architecture is enabled by both the ability to throw and to land large integrated masses to Mars, and the ability to manufacture a high performance MAV + ERV within a mass budget of < 1,000 kg. Plans are currently in place to develop the heavy Mars delivery systems, both within the NASA SLS program and the CCDev program. Currently, there is no integrated program to develop technology for a high performance MAV + ERV.

The dry mass of a high performance MAV or ERV is < 100 kg, which defines them as small spacecraft. Although it is unclear whether the expected evolutionary improvement in performance of small spacecraft subsystems may be sufficient to allow an all-up sample return in the post 2018 era based on use of Red Dragon, a modest investment in technology development would assure it. Earth-Direct architectures using chemical rockets require a relatively large ΔV (≈ 6.7 km/s, or more), implying that the propellant mass fraction will be high. Because propellant mass dominates the MAV + ERV system mass budget, improvement in propulsion system performance for either the MAV or ERV (or both) would have a high payoff in minimizing the technical risk of committing to an Earth-Direct architecture. Current state of the art in small bi-propellant systems yields a specific impulse in the range of ≈ 340 seconds. Calculations from as early as 1969 showed that diborane based storable propellants for example, could reach a theoretical specific impulse in the range of ≈ 425 seconds. As the JSC study showed, SEP for the 350 kg ERV was the preferred technical approach. For a 100 kg class ERV, an SEP upper stage may also be superior in mass performance. However, a small ERV SEP stage would likely make use of a Hall-effect thruster in the 600 W category. For such small systems, the mass of the expellant (Xenon) storage tanks becomes a disproportionately large fraction of the mass budget. Thus, a focused technology program to develop small spacecraft SEP propulsions system components would also contribute significantly to risk reduction of a small, Earth-Direct architecture. One such advanced expellant is Iodine, which has high specific performance and the advantage of not requiring a heavy pressure vessel for storage.

A program of focused investment in high performance MAV propulsion (chemical and SEP) and other subsystem technology could enable an affordable Mars sample return architecture.

References: [**1**] Connolloy, J. F., Exploring the Road Less Travelled: a Comparison of Unique Mars Sample Return Architectures. 53rd International Astronautical Congress, Oct. 10-19, 2002, Houston, TX. [**2**] Connolloy, J. F., et. al., Direct SEP Mars Sample Return: A Mission Study Using Solar Electric Propulsion and Direct Return Trajectories. Exploration Office publication EX-13-00-020, Sept. 2000. [**3**] Karcz, et. al., 2012. *Concepts and approaches for Mars exploration (this meeting)*. [**4**] Marinova, et. al., 2012. *Concepts and approaches for Mars exploration (this meeting)*.