Technology Development Plans for the Mars Sample Return Mission [1,2,3]

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Abstract—Mars Sample Return (MSR), a technology-rich mission, is being planned for possible launch in 2013. Project guidelines dictate all technology be at Technology Readiness Level (TRL)-6 by the PDR scheduled for mid-2009. Funding for MSR focused technology development starts in FY05. Over the last year, a MSR technology planning board has assessed technology needs and developed a plan to be implemented over the next 4 years. This paper describes this plan and how we arrived at it. The plan includes needed technologies that are being developed in other Mars Exploration Program (MEP) technology areas, and flight demonstrations that are required to reduce overall project risk.

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1. INTRODUCTION

Over the last few years, the current architecture for MSR has been developed based on successive studies performed by industry (Ball, Boeing, Lockheed and NGST) and JPL, with participation from NASA Langley Research Center and NASA Marshall Space Flight Center. The basis has roots in design work that was done for a previous start-up of the MSR project, which was cancelled in 2001. An international, multi-agency advisory group – the Mars Exploration Systems Engineering Team (MPSET) – examined and advised direction on major MSR trades. In addition, two separate Science Steering Groups were convened at key crossroads points to advise on science priorities. Another factor that has influenced the architecture of MSR has been the early phases of development of the Mars Science Laboratory (MSL), being planned for launch in '09. MSL will develop the next generation Entry, Descent and Landing (EDL) capability on which MSR has based their design.

Other Mars projects will contribute toward or interact with MSR Implementation. The missions of this decade are shown in Figure 1. Mars Odyssey, the European Mars Express along with their companion orbiter Mars Global Surveyor (MGS) (launched in 1996) have been sending back data that are continuously illuminating new information about Mars, and based on better understandings, effect the direction of further exploration on Mars. While both the Japanese Nozomi Orbiter and European Beagle 2 Lander had mission failures, they both were significant steps in establishing an international program. The Mars Exploration Rovers (MER) currently in operation are teaching us a great deal about landing and operating on the surface of Mars, as well as rover design. More over, MER discoveries have already impacted the nature and architecture of MSR, and was the motivation for convening the second Science Steering Group previously mentioned. The Mars Reconnaissance Orbiter (MRO) will be much more capable than its predecessors and aside from it's high science value, promises to provide high resolution imaging of the surface that will aid future missions in navigating the surface and providing a basis of surface-feature-based pinpoint (<100m) landing. The NASA Phoenix Scout mission will look for subsurface water ice thought to contain organic compounds that are necessary for life, and will provide experience in subsurface sampling that will be of value to MSR. The Mars Telesat Orbiter (MTO) will not only provide a telecommunications relay function for MSR, but will be a back up for tracking an orbiting MSR sample

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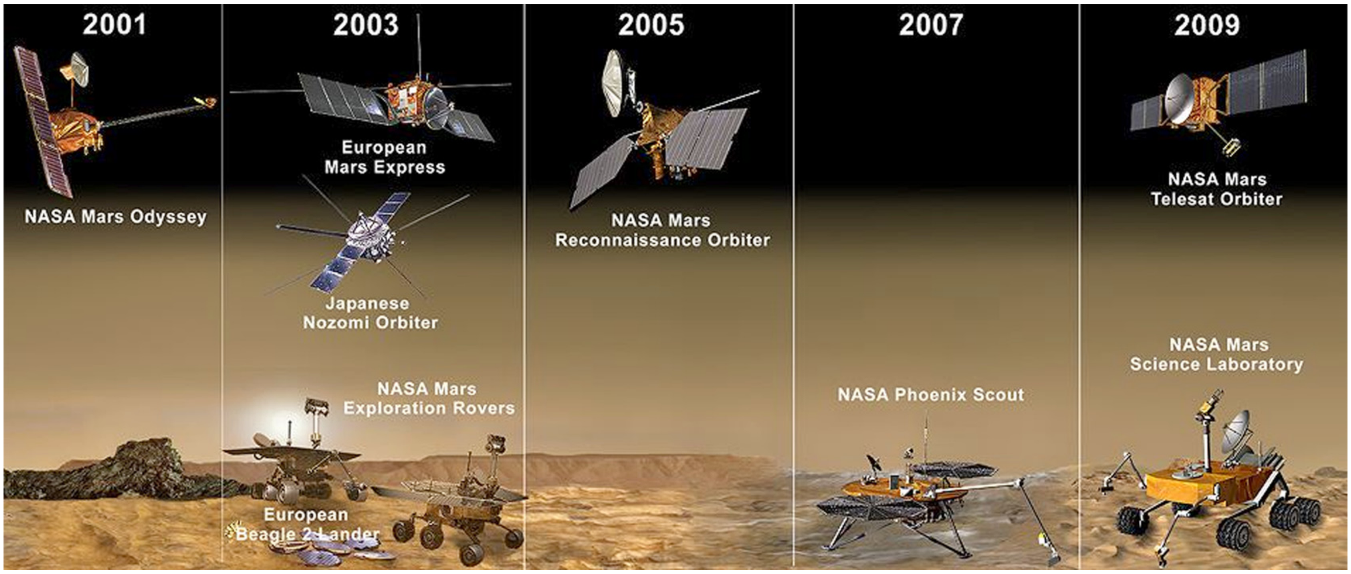

Figure 1 - This decade of Mars Missions will contribute to MSR

container. It will also host an important rendezvous demonstration for MSR to be discussed later. New MSL landing techniques will most-likely provide the basis of landing on Mars needed by the large MSR payload. MSL will also contribute substantially to advanced rover design, sample collection and surface operations plans for MSR. In addition, it will help pave the way for more stringent planetary protection techniques, necessary for MSR and future surface missions.

2. MSR ARCHITECTURE AND CHALLENGES

The reference mission scenario currently being considered is shown in Figure 2. It is annotated such that it should be self-explanatory; thus the reader is encouraged to read through the notations in the figure. A discussion of assessment of the technology in the next section will follow the order of this mission scenario. The high-level requirements on the mission consist of bringing back 1/2 kg of sample consisting of rock, regolith and atmosphere. Access to the Martian surface is moderate in altitude and latitude. Modest mobility is required to get access to stratified layering like that identified by the MER mission. This mobility capability was recently added to baseline as a result of experience from MER. The primary sampling will be performed by a rock corer on a rover, while an arm /scoop/ sieve is used on the lander as a backup (acquiring a contingency sample). No in-situ science is currently in the baseline.

There are a number of areas that MSR would need to implement, and rather than try to list them here, they will be pointed out in the next section as part of the technology assessment. There is one area that is particularly challenging that cuts across mission segments – planetary protection, for both Mars and Earth.

The planetary protection requirements — forward, back and round-trip as follows:

- The need to control the amount of sample contamination by round-trip Earth organisms to avoid false positives in life detection tests (for the purposes of this study we assumed a goal of sterilization of the entire Lander to Viking levels, or proof of <10e-2 chance of a single Earth organism in the sample).
- Sample containment assurance: The requirement that the integrated probability of back contamination be kept below a specified level (with a lack of a specific requirement, for the purposes of this study we assumed a goal of probability of release of Mars material to the Earth's biosphere to being less than 1 in a million).

Planetary protection and the technology program necessary to satisfy the goals are discussed in depth in a separate paper presented in this session (Gershman, IEEEAC Paper #1444).

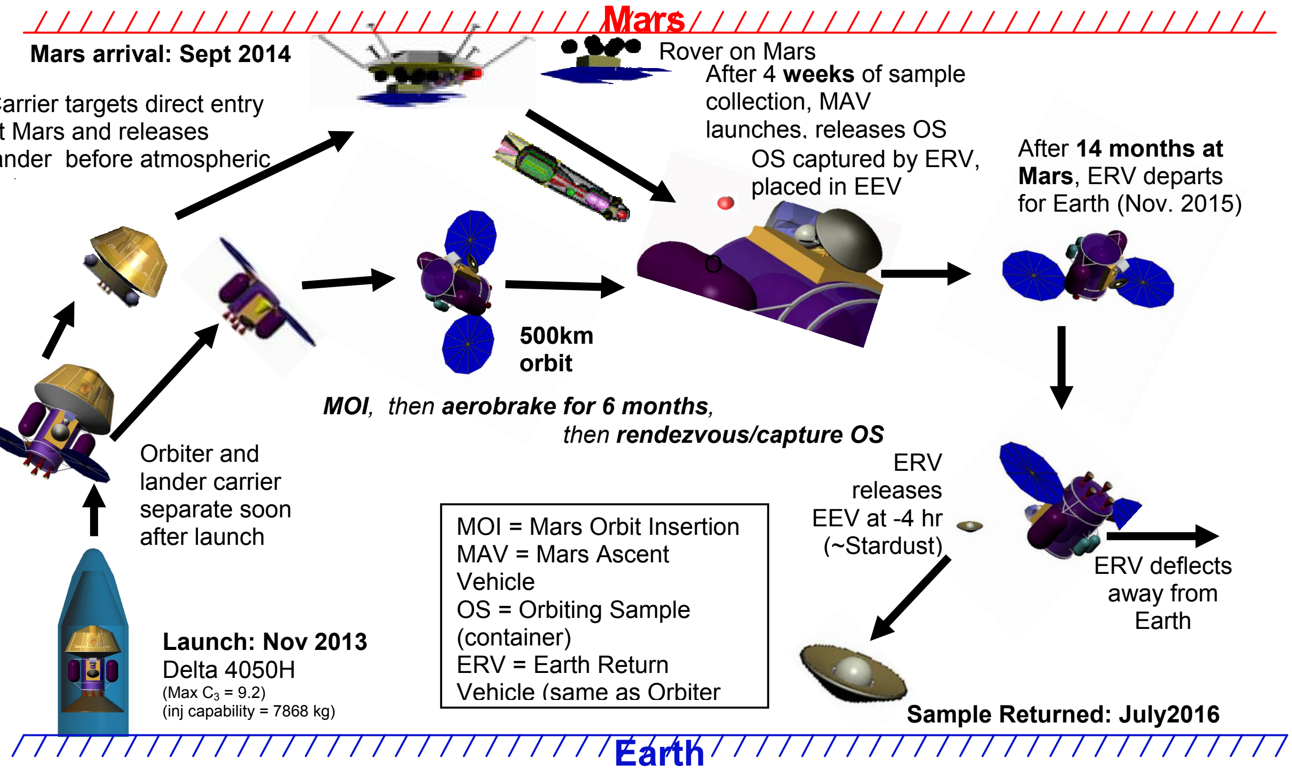

Figure 2 - Current MSR notional mission architecture

3. Technology Planning

Technology Development Schedule

The nominal MSR project schedule is shown in Figure 3. In order to have technology at TRL 6 by Preliminary Design Review, technology planning had to start in 2004 with a serious funding starting in 2005 to fill the technology gap.

Technology Assessment (and TRL Levels)

Technology Readiness Level Achievement schedule constraints that MSR has accepted are specified as follows (see Technology Readiness Level Definitions, Figure 4):

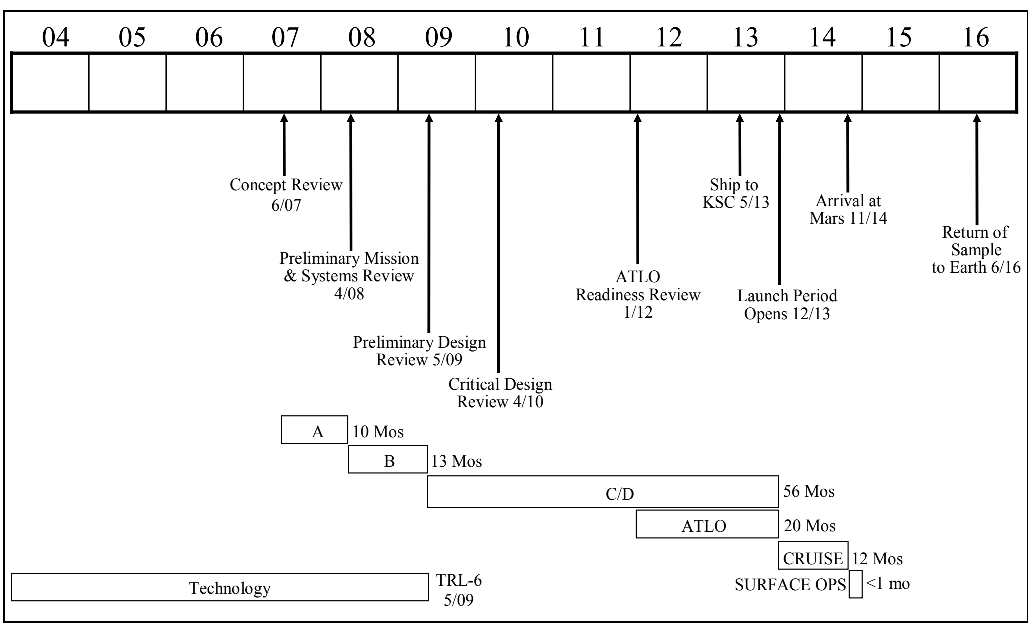

Figure 3 - Nominal MSR Project Schedule

- TRL 5 — by Preliminary Mission System Review (before Phase B start).
- TRL 6 — by Preliminary Design Review (before Phase C start).
- TRL 7 — by Critical Design Review (if required) (before Phase D start).

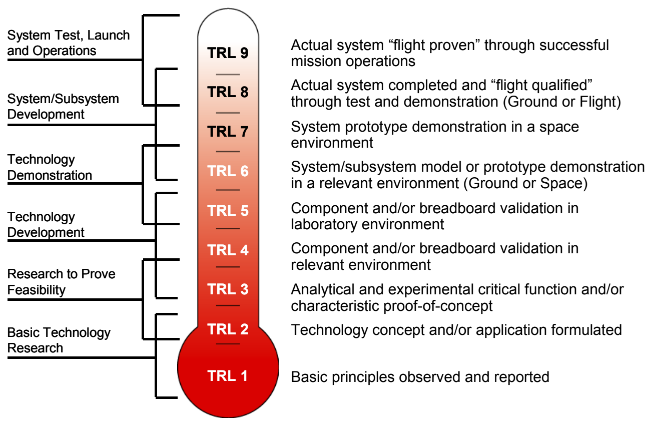

Figure 4 *- Technology Readiness Level Definitions*

Technology Board Formed

In recognition of the need to start preliminary MSR technology development in 2005, a MSR Technology Board was formed to solidify the plans required. The Board consists of representatives from JPL, NASA LaRC, and NASA MSFC covering each of the key areas identified. During 2004, the Board examined the current state-of-readiness, defined the gaps and developed technology task plans to fill-in those gaps as necessary. As part of that activity, the board was also the basis of the continuing assessment of architectural and implementation issues.

Workshops

As part of the technology assessment, four workshops were held during 2004 in key multidiscipline mission segment areas, all dealing with parts of the process of handling the acquisition of the samples and the subsequent handling.

The first was sample collection and handling including filling a sample container for return. This requires two sessions, dealing with the difficult issue of collecting pristine samples in the presence of contamination. It was identified that technology tasks were necessary for this area.

The second area was transfer of a sample container into an Orbiting Sample (OS) container and releasing in orbit. The assessment was that advanced engineering was involved, but based on previous work that was done, no new technology was required.

The third area was OS detection and rendezvous. The workshop included representatives from Draper labs, NASA MSFC and NASA JSC. The variety of experience recommended a multiple-sensor approach to detection and tracking be used. This, however, is beyond the current plans and further assessment, as indicated below, indicated an all-optical approach is adequate.

The fourth area was capture of the OS and transfer to the Earth Entry Vehicle (EEV). Here is another area where prior design work led to a conclusion that it is difficult engineering, but with one exception not needing technology development. The one exception is the need to understand contact dynamics of a capture cone with the OS. Work in this area is currently ongoing.

Mini-MPSET Guidance

As mentioned in the Introduction, the Mars Exploration Systems Engineering Team (MPSET) was used to examine and advise direction on major MSR trades. During this period of technology planning, a subset of that group, we called the mini-MPSET, was used to advise on a couple issues of technology funding priorities. It examined and recommended paths in three areas. The first was whether other means of detecting/tracking an orbiting sample container beyond optical should be funded. It was recommended to stick with optical cameras, but be able to explore and test other sensors in the future. The Second was whether to pursue Gel technology for the Mars Ascent Vehicle, and it was recommended to not invest Mars technology funding in that area and that a solid propellant implementation is low risk and adequate. The third area was whether a developmental flight test of the earth entry vehicle was required. It was recommended that if a moderate cost test program was available, that such a test would be of value, and should be considered for inclusion in the technology program.

4. Assessment of Technology and Gaps

Entry/Descent/Landing

One of the premises of keeping the cost and risk down for MSR is to use the landing system developed by the Mars Science Laboratory (MSL). Developed under the MSL focused technology program, MSL plans to demonstrate precision landing, robust/safe landing and delivery of higher usable landed mass than previous missions. The MSL landing system evolved from a traditional legged platform to support the rover laboratory to one where the landing system suspends the rover from above and lowers the rover to the surface via a 10-meter tether system. This landing system is coined the "skycrane". Figure 5 depicts this current MSL landing concept.

Figure 6 depicts an MSR platform being lowered by the skycrane.

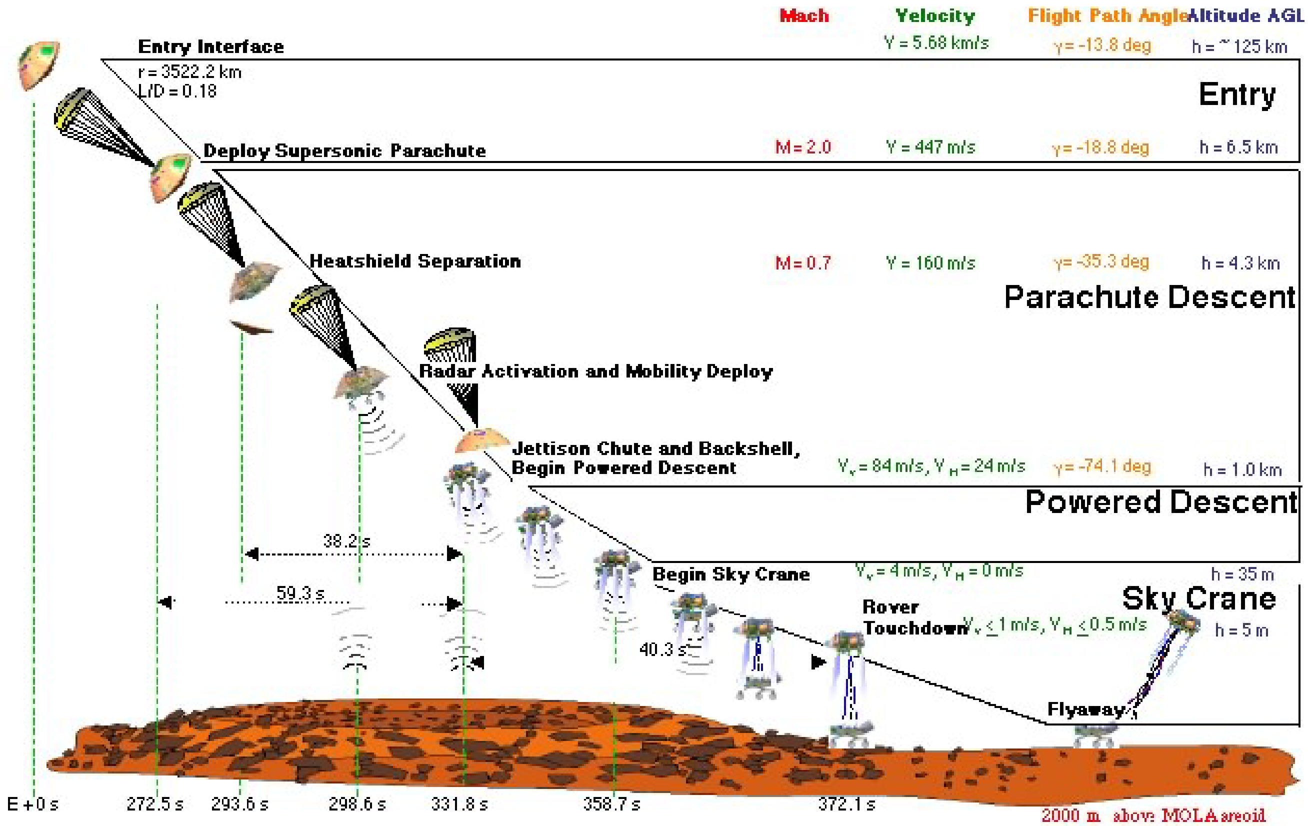

Figure 5 *- MSL EDL concept*

Figure 6 - MSR lander lowered by skycrane

The MSR Skycrane concept is shown in Figure 7. The system is monopropellant, and utilizes engines inherited from Viking flown in 1970's. The MSL Technology Program has upgraded and re-qualified those engines and, by the end of 2005, will have demonstrated feasibility of the skycrane concept.

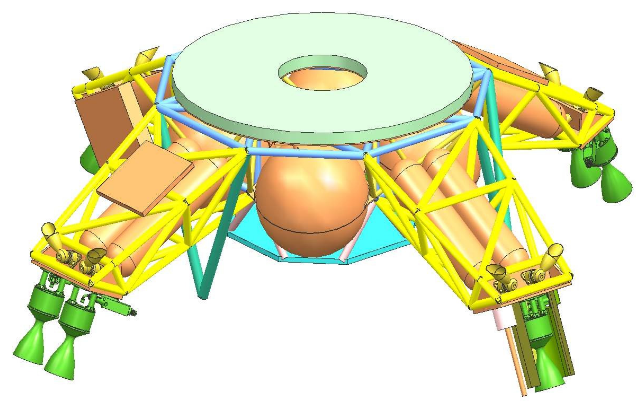

Figure 7 - MSR skycrane

The Skycrane and Lander are packaged in a heatshield (bottom) and backshell as shown in Figure 8. The shapes of aeroshell and backshell are similar to those used on Viking, preserving that heritage. The aeroshell is currently 4.5 m in diameter to take advantage of the full dynamic envelope of heavy-lift launch vehicles (5-meter fairings). If MSL ends-up not requiring the full 4.5m size entry system, MSR would be able to readily scale-up to their needs, with no new technology required.

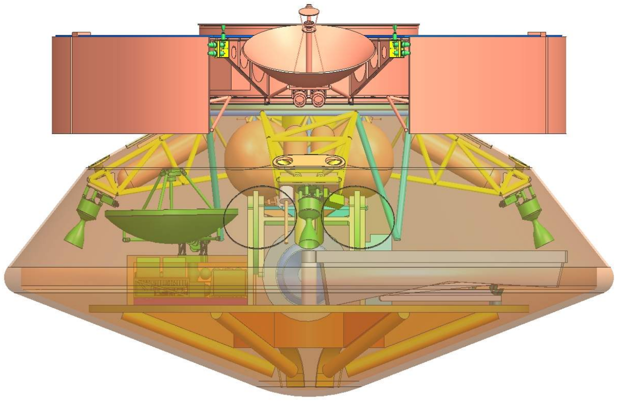

Figure 8 - EDL system with Cruise Stage

Also packaged in the aeroshell are supersonic and subsonic parachutes used for descent. The supersonic chute has been qualified by previous missions, most recently MER. The subsonic chute is a new design that requires qualification. The MSL Focused Technology program (IEEEAC paper #1471) has taken that chute development through initial flight testing. The MSL Project has de-scoped their EDL system to not include a subsonic chute. The remainder of the qualification of that chute will now be picked-up by the MSR Focused Technology program (since MSR does need it to handle a higher lander mass) and is identified in the tasks listed in the next section.

Figure 8 shows the cruise stage attached necessary for Earth-Mars transit. The design of the cruise stage is expected to be inherited from MSL, and may incorporate the optical navigation capability that will be demonstrated on MRO '05. No new technology is needed.

While the MSL landing system is being developed to land with an error of 10km, new technology may have been demonstrated that would allow MSR to land within 100 meters of a geological feature. This would allow the project to reduce the requirements on a rover that would be required to access specific features that have been previously identified by MRO, MSL, Phoenix or MER. This would entail an optical sensor, matching maps from images taken by MRO, and additional control authority and fuel to compensate for entry and descent errors and the effects of wind. A separate technology program (identified in the next section) is being funded to develop this capability).

The Lander shown in Figure 9 is a new design, but assumes some MSL heritage. The planned avionics, including telecom, are all existing technology, with high-heritage from MSL or early programs. The Skycrane implementation is able to lower the lander to the surface with very low impact forces. While the design will be challenging, we anticipate that there is no new technology required; thus have not included any tasks in the MSR technology program. The lander carries a rover (see Figure 10), used to collect and cache samples remotely; sample acquisition equipment for collecting contingency samples at the lander; a mars ascent vehicle (MAV) to launch the collected sample into orbit around Mars; and the equipment to perform the transfer of sample and sample containers.

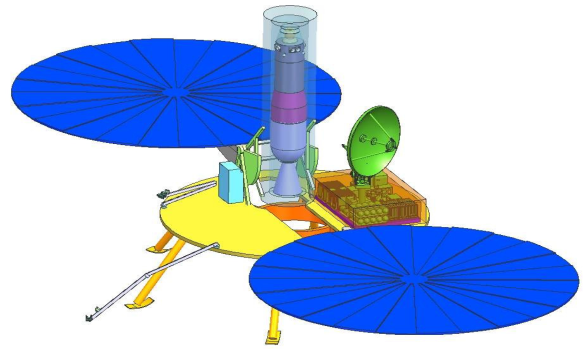

Figure 9 - MSR Lander – deployed, MAV ready to launch

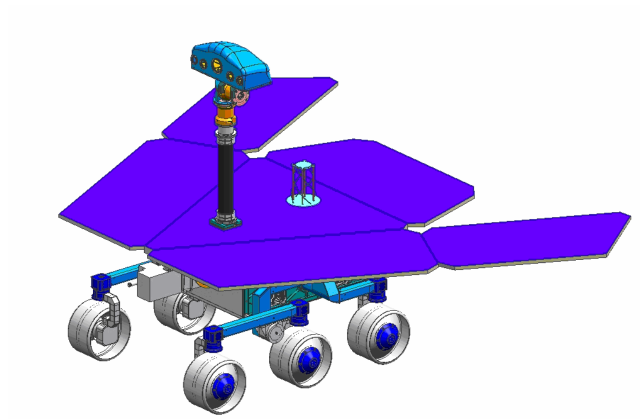

Figure 10 - Fetch Rover

Sample Acquisition for the Lander`

Redundant arms (about a meter long), each with a scoop and sieve, are used to acquire samples from the immediate area. Trenching to a few tens of centimeters will be required to obtain sample free from lander contamination and natural surface oxidation. While previous contemporary landers use a stereo camera on a mast to view the trenching and collection area, we believe that simple arm-mounted cameras can be used effectively. Acquiring the sample would utilize experience and inheritance of hardware from both Phoenix and MSL. Phoenix will utilize a 1-meter arm with a scoop that should be directly applicable to MSR. Autonomous testing using this arm has demonstrated its trenching capability in Mars-like terrain. This process of acquiring a sample from the lander may be adequate to get below the surface contaminated by landing. A Technology task has been identified to further develop methods of acquiring the sample without introducing earth-originated contamination to the sample. Software for visualization needed for planning and monitoring the trenching operation interactively with mission planners will have been well established and proven by Phoenix and MSL and to some extent is currently being used on MER. The new challenge for MSR would be methods of sorting through bulk sample and measured methods of transferring sample to the sample container. This needs to be done without introducing earth microbes. Experience will be gained with Phoenix and

MSL, but we expect to have residual issues for MSR. Technology funding may be needed for lab mock-up of processes to assure ourselves that no new technology is needed. Included is evaluating the ability of an arm-mounted camera to provide enough context to plan and monitor the sample collection. The method of filling the Sample Container is yet to be definitized, but is believed to be easily within current technical capabilities.

Rover Sample Acquisition

The experiences learned from MER have led to the current MSR concept adding a rover to obtain samples, particularly cores, from stratified material some minimal distance from the lander. The rover currently planned has the capability to traverse about a km and communicate both through the lander and directly to an orbiting asset. The rover is similar but smaller than MER, and is based on the same developmental rover, FIDO, that MER based their design on. The Rover carries a rock corer, that is also capable of picking-up regolith, and the mechanisms needed to fill a canister with cores. The operational capabilities have been demonstrated on MER. The corer may be high heritage from MSL but, if not, technology tasks are planned to develop it further. Again, sample acquisition without introducing contamination is essential. This will require technology development in conjunction with the lander based sampling discussed above.

Orbiting Sample Concept and Breaking the Chain with Mars

The OS concept calls for a 16 cm diameter sphere. It contains the sample container that would be filled and sealed prior to insertion into the OS. The OS contains an internal structure that locks the sample container in place and protects it (see Figure 11). The outer surface is a smooth spectular surface for efficient detection with a visible camera. Current plans include a UHF beacon in the OS for detection backup.

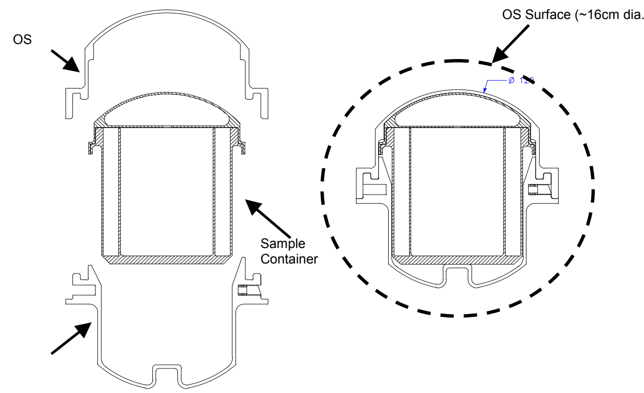

Figure 11 - Sample Container inside OS structure within the OS shell

Back planetary protection (of the earth) is a difficult process. A separate paper in this session addresses this topic (Gershman, IEEEAC Paper #1444). Key to our current concept is what we term "breaking-the-chain" of contact with Mars.

Breaking-the-chain occurs in two places in our current mission concept. The first is to arrange for the sample canister to be placed in the OS without carrying any contamination to the OS or MAV which would have remained in an earth clean environment since launch. An ingenious scheme has been devised that would not only allow for a clean transfer, but would also effect a series of seals (one being welding or brazing the lid to the container). The process is depicted in Figure 12. The scheme calls for the exterior of the sample canister to be kept isolated from the Mars environment by an outer shell (like a thermos bottle) until it is sealed shut and inside the earth-clean environment. This transfer process requires technology development but initial testing indicates that it is doable. The second place where the chain is broken is in Mars orbit. The OS is ejected from the MAV and captured by the ERV.

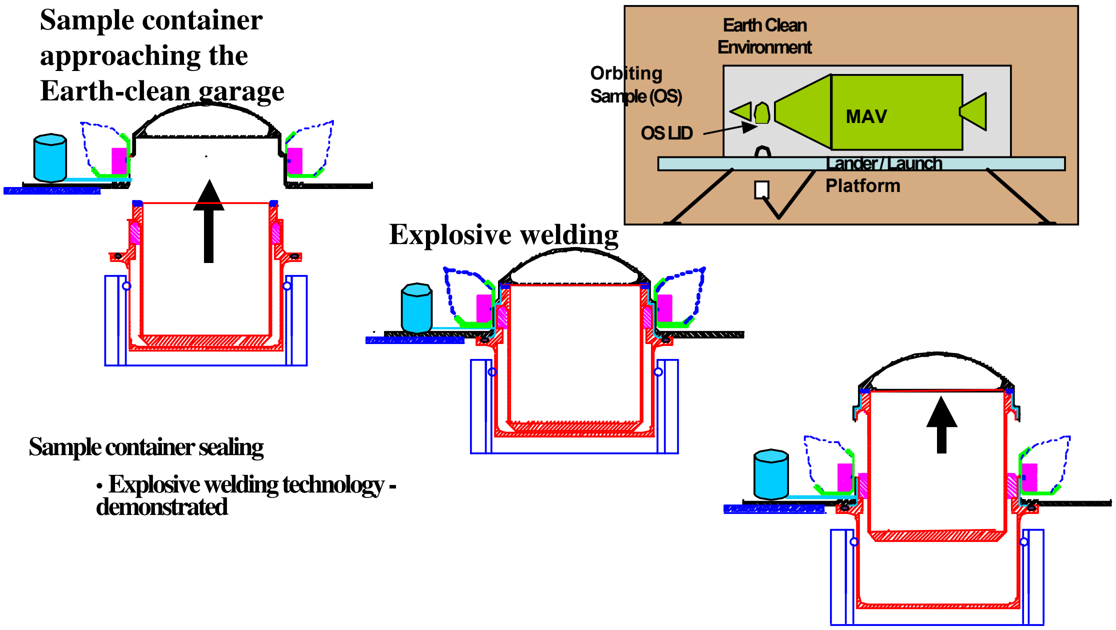

Figure 12 - Breaking the chain of contact with Mars

The OS is clean, and the potential of contaminating the OS from atmospheric dust that the outside of the MAV might have picked up is minimized. Analysis of potential migration of any dust is underway. Probability is high that further steps will not have to be taken, such as using a pyrolytic paint on the MAV fairing that would burn off any residual. Except for the OS, nothing that was in contact with Mars would be in contact the ERV. Additional measures would be taken as "belt-and-suspenders" including placing the OS inside a Kevlar soft containment vessel in the EEV which is sealed shut with enough heat to sterilize the seams, and designing the shape of the EEV so that all exterior surfaces will reach temperatures high enough for sterilization (>500 C).

Mars Ascent Vehicle

The MAV is baselined as a solid-propellant, two-stage, three-axis stabilized vehicle, weighing about 285 kg (including the 5 kg OS). Figure 13 shows the MAV configuration, with the smaller second stage with thrusters for 3-axis control and the OS mounted on a spin-eject mechanism inside the nosecone. It launches the OS into a circular orbit of 500 km+/- 100 km and within 0.2 degrees of inclination. The MAV would transmit enough telemetry during ascent to allow reconstruction of events in case of failure. In addition, it carries a UHF beacon for location by orbiting assets to aid in location of the OS. The beacon, both in the OS and the MAV, will be new developments, requiring technology funding.

A focused study on MAVs by three industry teams resulted in a good understanding of the technologies needed (see Reference [10]). The solid propellant vehicle is the baseline, while gel and liquid propellants have been considered. Gel technology developed for tactical purposes by the army is compelling since it allows for lower temperature storage and launch and has potential engine restart capability. We convened a mini-MPSET weigh the priority of Gel technology for MSR, and it was judged not mature enough currently to invest MSR funds. Liquid MAVs do not have the package efficiencies that can compete with solids. The solid MAV technology is readily available, except for the need to further develop a thrust vector control element to operate at cold temperature. The MAV, however, is a new development for the Mars environment. We have chosen to include two Earth-based developmental test flights as part of the project costs. MAV design would be performed early in the project and qualified before CDR. Trying to match dynamic pressure and flight timeline to that of Mars is difficult and requires that the test launches be performed starting from high altitude balloon flights (62,000 ft).

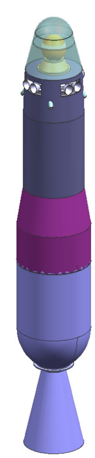

Figure 13 - Mars Ascent Vehicle with OS

Orbiter/Earth Return Vehicle

After transit to Mars, the Orbiter performs propulsive Mars Orbit Insertion (MOI) maneuver, into an elliptical 1-3 day orbit with a 240 km periapsis (apoapsis 35,000 km to 75000 km), setup for aerobraking. For this maneuver and the departure from Mars, the orbiter would require over 3000 kg of mono-propellant. Aerobraking would be used (to save fuel) over the next 6 months to circularize the orbit to 500 km for rendezvous with the OS. Future studies will examine the possibility of eliminating the need for aerobraking, which is viewed as an additional risk for an already complex mission. Depending on the mission scenario, an all-chemical propulsive MOI might be available, with no new technology. The other alternative is aero-capture, which would most likely require a technology demonstration prior to relying on it for MSR. NASA's In-space Propulsion program is helping MSR explore aero-capture options.

The Orbiter/ERV (see Figure 14) carries the Earth Entry Vehicle (EEV), the equipment for detection/rendezvous/capture of the OS and transfer of the OS to the EEV, the spin/release mechanism for the EEV, and the propulsion for earth return. Once in circular orbit, the Orbiter/ERV would maneuver to, rendezvous with, and capture, the OS.

A propulsive maneuver then would initiate a Type-I cruise to Earth. Initially targeted to pass by Earth, the Orbiter would be retargeted in the last few days to release the EEV toward earth entry about four hours out, then would perform a divert maneuver into a non-earth-returning trajectory.

The orbiter itself would be expected to be highly inherited from an industry bus. There are no new technologies envisioned, except in the case if aerocapture were adopted.

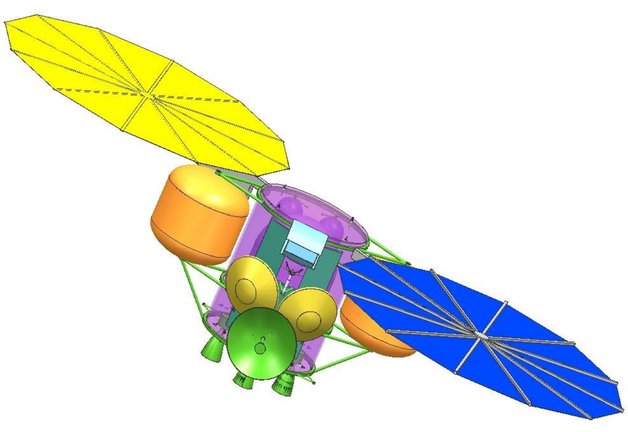

Figure 14 - ERV/Orbiter concept

OS Detection, Rendezvous and Capture

Detection of the OS once in orbit is baselined to be via an OpNav camera being developed for optical navigation from MRO and MTO. Analysis has shown that locating a lost OS from a medium altitude orbit can be achieved within a few days. If MSR in fact uses aerobraking, the relative orbital configurations may make that process difficult. As discussed previously, the OS may be kept attached to the upper stage of the MAV with a UHF beacon for an extended period of time. It is desirable to also have a UHF beacon on the OS that could last a couple of years; miniature designs are being investigated which may be already close to available commercially. Operating an OS beacon on battery is desirable since population of the OS surface with solar cells will degrade the optical detectability

A wide angle visible camera (already flown on MER for other purposes) is planned for close proximity operations

Semi-autonomous rendezvous algorithms have been extensively studied by both JPL and Draper Laboratory, and solutions are available.

Designing the capture of the OS has been through many concepts. JPL has converged on a capture basket concept with which the technology program can move forward (Figure 15). Payload Systems (Cambridge, MA) has a SBIR contract to develop and build a capture mechanism test facility for the International Space Station as part of an augmentation to the SPHERES formation flying testbed. A free-flying OS, which is an adaptation of one of the SPHERES test articles, would be flown in controlled trajectories into a capture mechanism to study contact and capture dynamics. We are currently evaluating whether testing these articles in aircraft hyperbolic zero-gravity flight might be adequate.

The Mars Technology Program is funding MTO to fly a OS detection and tracking demonstration that would release an engineering version of the OS and track the OS in orbit using their already existing OpNav camera. In addition, MTO would serve as a second asset to detect and track the OS during the MSR mission. MTO's Electra communications payload would have the capability to also track the UHF beacons on the OS and MAV.

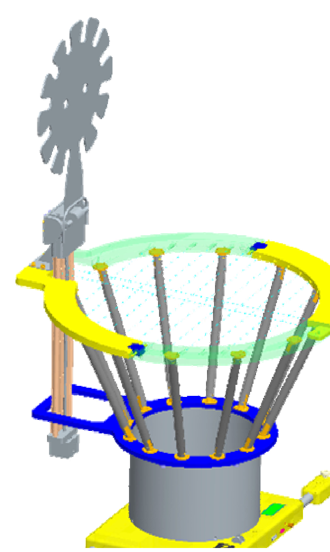

Figure 15 - Capture basket concept

Earth Entry Vehicle Concept

Reliable earth entry is key to sample containment, and LaRC has completed significant development of an Earth Entry Vehicle (EEV) to date. The EEV is a self-righting, 0.9 m diameter, 60-degree sheer-cone blunt-body atmospheric entry vehicle. The cross-section is shown in Figure 16. The central cylinder is the sample container, inside a spherical OS. Aside from another sealed container (essentially a Kevlar bag) around the OS, called Containment Vessel, the remainder of the spherical part of the EEV is crushable material and carbon-carbon composite shells. The EEV is completely passive, except for self-contained beacons used as a backup tracking aid.

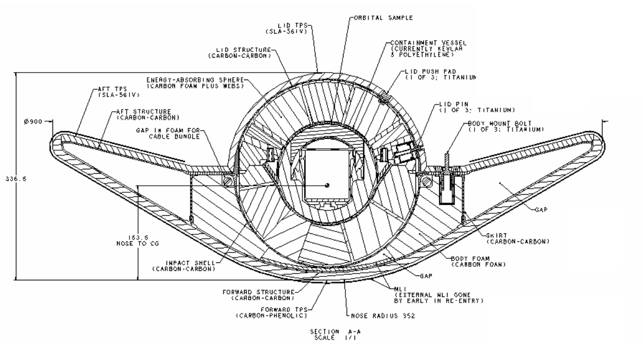

Figure 16 - Cross-section of EEV concept

The aerodynamic characteristics of the design have been analyzed and tested to show that aero-heating is reasonable, even to the extent that soak-back would not cause the sample container to rise above 50 C. While the study considered newer ablative materials for the heat-shield, carbon-phenolic was chosen for test and flight heritage, and knowledge of failure modes. Trajectory entry angles have been selected that limit the heat flux to within well-understood testable regime for verification. In addition high fidelity simulations have shown that if the EEV was released incorrectly (even backwards) or tumbled from a large micro-meteoroid hit, that it would right itself prior to the entry heat-pulse. Micrometeoroid impact protection of the heatshield may be necessary. Design of protective shielding is the subject of current analysis; several concepts look promising. Aerodynamic trajectory analysis has been performed to assure that landing would occur in a safe area of UTTR (the reference landing site used for these studies).

The other function that the EEV has is protecting the sample containment. The sample would be in a multiple-seal container inside a protective OS, now conceived as a pliable sealed Containment Vessel. The landing of the EEV is envisioned to be a direct impact with the surface at a site like UTTR. Referring to Figure 17, the OS/Containment Vessel as conceived is surrounded by a Kevlar and graphite cell wall impact sphere, which deforms to keep the OS loading to reasonable levels. The shell of the EEV is a carbon-carbon composite (the potential benefit of titanium will also be examined). Extensive analysis, verified by testing at the LaRC impact dynamics facility, has verified impact resistance effectiveness. In addition, a full-scale drop test (from a helicopter) of an engineering model EEV reached terminal velocity at UTTR and again validated the design. Figure 18 shows the EEV after impact being held by the LaRC team, and Figure 19 shows the impact area on the ground.

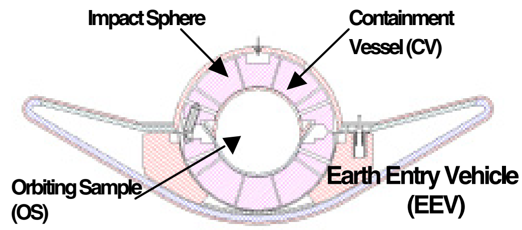

Figure 17 - OS/Containment Vessel

Figure 18 - EEV after impact

Figure 19 - Impact area

Planetary Protection Technologies

Forward Planetary Protection is at this stage believed to be partially consistent with that required by MSL. This is another area where technical feed-forward is assumed. While further understanding and analysis is needed, the MSR requirement to not return earth spores carried to Mars (to avoid false-positives) is roughly consistent with the need to not contaminate measurements made by in-situ missions on Mars. Current MSL and Base Technology Programs are assessing and developing techniques for cleaning and sterilization (including hydrogen peroxide vapor techniques and the effects of heat sterilization on modern (post-Viking) electronics). In addition, validation technologies and procedures to be applied to the spacecraft during assembly need to be further developed. The MSR technology program has funding ear-marked to cover development needed beyond that inherited from MSL. Details of the current plan are discussed in a separate paper presented in this session (Gershman, IEEEAC Paper #1444).

Sample Receiving Facilities

The sample container (most likely the whole EEV) is delivered to a Sample Receiving Facility once arriving at the landing site. This facility needs to:

- Handle samples in a manner as if they are potentially hazardous material.
- Keep the samples isolated from earth-borne contaminates.
- Apply a rigorous protocol to determine whether there is any hazard in potentially releasing samples to other labs outside this facility.

Recently, studies by three industry teams were completed to define the scope of the facility to handle the samples, address issues in the flow of sample analysis, and assess overall issues.

The three industry teams were led by: Flad & Associates in Madison, Wisconsin; IDC in Portland, Oregon; and, Lord, Aeck, Sargent, located in Atlanta, Georgia.

While the needs of a facility was viewed to be within current capabilities, several specific sample handling technologies were identified for funding (discussed in the next section)

5. Technology Plans

Based on the assessment discussed in the previous section, technology development plans have been preliminarily established

The core of the technology development will be accomplished in the MSR Focused Technology Program, starting in 2005. In addition to the MSR Focused Technology Program, MSR is relying on other technology development sources, and they are:

- MSL Focused Technology Program (continuing through FY'05), and is described in a separate paper in this session (IEEEAC paper #1471). This technology program will have developed the Entry/Descent/Landing technology that will be necessary for a vehicle of the MSR class and the Rover technology that will be directly applicable to a MSR fetch Rover. They include hardware items such as extreme environment electronic parts and packaging designs, thermal control systems and mobility technologies; as well as operations technology for rover navigation, instrument placement and streamlined activity planning and simulation. A third area is a integrated sample handling facility including a single manipulator with an end effector, corer/abrader, rock crusher, arm control, biobarrier concepts integration and self-cleaning mechanization for cross contamination.
- The Mars Base Technology Program. Various technologies are being explored in this program that would benefit MSR. Tasks in area of rover navigation, rover-arm coordination, sample acquisition/handling, planetary protection including biobarrier, proximity link technologies, and advanced EDL in support of pinpoint landing.
- Pinpoint Landing Technology Demonstration Program. EDL technologies to enable landing within a 100m geographic feature will be developed and demonstrated with the goal of achieving TRL6 by mid 2008 for identified system components, which include guidance, navigation, and control algorithms for power descent, terrain relative navigation, and approach navigation as well as associated avionics hardware and sensors.
- AFL Focused Technology Program. The in-situ rover-based Astrobiology Field Laboratory is an alternate mission to MSR for the 2013 launch opportunity. This program is developing precision drill, sample acquisition and transfer technologies that could be utilized by MSR.
- MTO Rendezvous and Autonomous Navigation (RAN) Technology Demonstration which develops and demonstrates OS detection, tracking and rendezvous in Mars orbit using an autonomous and self-contained hardware/software package.

MSR Focused Technology

After considering the technology issues retired elsewhere, the MSR Focused Technology Program has been planned to retire the remaining areas over the next 4 years. The tasks are aggregated into 7 areas:

- Forward Planetary Protection
- Sample Containment
- Earth Entry Vehicle (EEV)
- Sample Acquisition
- MAV design and flight test
- Detection, Rendezvous and Capture
- Sample Receiving Facility.

Forward Planetary Protection, Sample Containment and Earth Entry Vehicle (which is part of sample containment but split out since it is a major development in itself) are all discussed in more depth is a separate paper "Planetary Protection Technology for MSR" in this session.

Tasks in Forward Planetary Protection include:

- Biobarriers for recontamination prevention
- System/subsystem level sterilization

- Particle transport modeling to understand and allow control of recontamination
- Biodiversity to recognize and understand the bio-organics present for Planetary Protection and Science
- Aseptic assembly approaches to assemble biologically clean hardware
- A Testbed demonstrating the effectiveness of "clean-sampling" tools developed in Sample Handling tasks.

Tasks in Sample Containment include:

- Breaking the chain of contact with Mars after sample collection
- Dust mitigation to ensure that no dust accumulated on the MAV can contaminate the OS
- Containment vessel to maintain containment through impact loads
- Reliable Earth return targeting for Earth avoidance trajectory, EEV targeting, Earth deflection maneuver
- Micrometeoroid protection to prevent EEV damage
- Reliable EEV design

Tasks in Earth Entry Vehicle include:

- Trajectory and aerothermal analysis to calculate confirm landing footprints and worst-case entry heating
- TPS design and testing providing reliable flight-qualified TPS for EEV
- Impact energy absorber development employing crushable energy absorber and demonstrating nominal landing at UTTR (salt clay) and on hard surfaces (gravel road, concrete pad, etc.)
- Structure and mechanical design to support EEV flight test prior to Mission CDR
- Thermal and structural analysis of flight design under launch, entry, and other loads as well as analysis of temperature vs. time profiles of EEV surface, structure, energy absorber, samples in all mission phases from launch through landing
- Systems engineering and trade studies addressing mass/reliability effects of chute vs. no-chute, water landing, different mission scenarios, and varying OS and sample sizes.
- Developmental flight test of prototype EEV to perform one complete pass through the aerothermal and TPS math models to prove their validity and ability to correctly predict the nominal conditions and material performance.

Tasks in Sample Acquisition (which address sampling from both lander-based arm and small rover while satisfying MSR forward and round-trip planetary protection constraints) include:

- Clean sampling tool for acquiring clean sample in dirty environment
- Lander-based sample acquisition and handling providing arm and canister docking system design and imaging/arm control for scooping and contact activities
- Rover-based sample acquisition/handling mechanical system needed for sample acquisition and transfer to canister mechanical system
- Rover-based sample acquisition/handling automated controls providing controls algorithms for automated traverse, approach, and sampling on varied and sloped terrain
- Rover sampling tool for providing clean sample from a small rover platform

Tasks in MAV Design and Flight Test include:

- Solid propellant enhancements to enable delivering OS to Mars 500-km orbit by modifying flexseal, actuator, controller, and exit cone for operations at Mars ambient
- MEMS avionic component utilization needed for reducing MAV mass and power
- Material compatibility consistent with the MSR forward and backward planetary protection approach
- Earth environment flight test in Mars-like dynamic conditions using a high-altitude balloon launch

Tasks to enable robust Detection, Rendezvous, and Capture operations for MSR include:

- Validation of a capture cone design requiring accurate replication of contact dynamics in zero-G
- Autonomous rendezvous validation requiring tight coordination with MRO RAN activities

MTO RAN will develop and validate the MSR wide angle camera (WAC), long-range OS detection, autonomous rendezvous maneuvering, proximity operations, ground-based one-way OS beacon orbit determination:

- 10,000km OS detection range for RF beacon, 7000km for optical detection. Acquire OS NAV data at 10 km, 0.5m/s accuracy.
- Optimized rendezvous and terminal approach maneuvers
- Precision OS-relative position/velocity estimation (50m and 5 cm/s accuracy at intermediate range; 5 cm and 2 mm/s accuracy at short range)
- Capture of a 5 kg, 16 cm diameter OS

Note that MRO will develop and flight test the MSR narrow angle camera (NAC) passive optical sensor (used on MRO and MTO as an optical navigation camera).

Tasks in Sample Receiving Facility established through SRF concept studies with industry teams include:

- Double-walled containment vessels needed for biosafety and minimum sample contamination
- Rapid transfer ports and modules to allow transfers of samples between containment vessels while maintaining cleanliness and biosafety
- Gloves and glove ports incorporating specialized gloves into a double-walled containment vessel to provide a biohazard protection
- Instrument adaptation/demonstration to define special adaptation required for use in SRF and demonstrate functionality

- Robotics demonstrating operations of dexterous ultra-clean robots capable of sample transport and sample manipulation
- Common carriers used to enclose samples for testing, movement, and curation
- Sterilization techniques employing minimum destructive process or combined processes to meet planetary protection requirements

6. SUMMARY

The technology program for MSR has been planned and some tasks have already been initiated. MSR relies on "feed-forward" of technology from a number of earlier missions, yet has a substantial development program of its own required over the next few years.

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ACRONYMS

EDL	Entry, descent, and landing
EEV	Earth Entry Vehicle
ERV	Earth Return Vehicle
JPL	Jet Propulsion Laboratory, California Institute of Technology
MAV	Mars Ascent Vehicle
MEP	Mars Exploration Program
MER	Mars Exploration Rover
MGS	Mars Global Surveyor
MOI	Mars Orbit Insertion
MPSET	Mars Program System Engineering Team
MRO	Mars Reconnaissance Orbiter
MSL	Mars Science Laboratory
MSR	Mars Sample Return
MTO	Mars Telecommunications Orbiter
MTP	Mars Technology Program
NAC	Narrow Angle Camera
NASA	National Aeronautics and Space Agency
OS	Orbiting Sample
SPHERES	Synchronized Position Hold Engage and Reorient Experimental Satellites.

US	United States
UTTR	Utah Test and Training Range
WAC	Wide Angle Camera

BIOGRAPHIES

Richard Mattingly *received a B.S. degree in Engineering from California State University, Los Angeles in 1970. He has been with JPL for more than 20 years. Currently, he is the Program Manager for Advanced Mars Science Missions at JPL and has been the Studies Manager for the MSR Studies. He recently supervised a systems engineering group for JPL's projects implemented in partnership with industry. He has also managed systems engineering groups for instrument and payload development. Richard has been involved in the formulation and development of numerous planetary and Earth-orbiting spacecraft and payloads. His career started with systems integration on the Apollo program for North American Rockwell.*

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