Development of a NASA 2018 Mars Landed Mission Concept

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ABSTRACT

Fundamental to NASA's Mars Exploration Program (MEP) is an ongoing development of an integrated and coordinated set of possible future candidate missions that meet fundamental science and programmatic objectives of NASA and the Mars scientific community. In the current planning horizon of the NASA MEP, a landed mobile surface exploration mission launching in the 2018 Mars launch opportunity exists as a candidate project to meet MEP *in situ* science and exploration objectives. This paper describes the proposed mission science objectives and the mission implementation concept developed for the 2018 opportunity. As currently envisioned, this mission concept seeks to explore a yet-to-be-selected site with high preservation potential for physical and chemical biosignatures, evaluate paleo-environmental conditions, characterize the potential for preservation of biosignatures, and access multiple sequences of geological units in a search for evidence of past life and/or prebiotic chemistry at a site on Mars. Candidate science measurements and payload sizing implementation options for this concept are identified and described for the purpose of identifying overall rover mass and power scenarios for such a mission. A description of plans for use and possible modification of NASA-developed entry, descent and landing capabilities will be included and is fundamental to meeting the budget and landing site access goals for this mission concept.

This mission concept also intends to make concrete steps towards a possible future mission to return Martian samples to the Earth. This latter objective anchors the potential 2018 mission in a sound Mars exploration strategy that is also consistent with NASA's primary goals for the subsequent decade of exploration (2020 – 2030), namely; a potential international collaboration for the return to Earth, and subsequent detailed analysis, of carefully selected Martian samples.

The proposed 2018 Landed Mission concept includes near sub-surface access and acquisition of sample cores, as well as encapsulation and caching of cores for possible recovery by a potential future mission. Here we describe the mission concept and the technology planning and development efforts underway to enable meeting the proposed mission objectives. Potential international collaboration opportunities and implementation strategies for this mission concept and potential launch opportunity are also outlined.

INTRODUCTION AND MISSION DEVELOPMENT BACKGROUND

Program planning for concepts that have evolved to the current 2018 landed mission concept began in 2003, when a follow-on landed mission after the Mars Science Laboratory (MSL) was first being sought. The first concept was the Astrobiology Field Laboratory (AFL) mission, which sought to expand significantly the capability of MSL and would carry a new 200 kg life detection scientific instrument payload on an enlarged mobile platform to a special, hydrothermal or polar region on the Martian surface (Steele 2006, McCleese 2006, Beaty 2006, Beegle 2007). A combination of technical and fiscal problems led to a descope of this concept in 2007. What emerged in program planning efforts was a second MSL-type rover landed mission concept with a new 100 kg instrument payload, again aimed at life detection in special designated regions.

In 2007, a National Research Council Committee released a report on An Astrobiology Strategy for the Exploration of Mars (National Research Council, 2007). The committee found that "The greatest advance in understanding Mars from both an astrobiological and general scientific perspective will come from laboratory studies conducted on samples of Mars returned to Earth." In addition, the committee found that "Identification of appropriate landing sites for detailed analysis can be done with the data now available or imminently available from currently active missions." Thus, the Academy both endorsed the sample return as the next key step in Mars exploration and announced our scientific readiness to begin this endeavor.

Again, technical and fiscal constraints forced a delay in a possible Mars Sample Return (MSR) mission and led to the development in 2008 of a precursor landed rover concept called Prospector. That mission would carry an approximate 10 kg of science instruments on a mobile platform to a newly selected site and demonstrate sample acquisition, including rock coring, and encapsulation of individually selected samples. The science payload, deemed appropriate by a succession of science advisory sub-groups (Borg, 2008; Murchie, 2008) of the Mars Exploration Program Analysis Group (MEPAG) included measurements for visual site reconnaissance, mineralogy, organic carbon identification, bulk elemental abundance determination and sedimentary texture identification. The Prospector mission concept included a scaled-up Mars Exploration Rover (MER)-heritage rover.

In 2009 the Prospector concept evolved into the Mars Astrobiology Explorer-Cacher (MAX-C) current mission concept, proposed for launch in 2018. The proposed MAX-C is now envisioned as the first leg of a potential sample return mission set (Pratt et. al., 2009). This mission concept would carry a mid-sized (much smaller than MSL but significantly larger than MER) rover with 15 kg of science instruments, and increased mobility performance to perform - not just demonstrate - the sample acquisition, encapsulation, and caching roles for a potential sample return effort. The science instrument payload concept has been expanded from the Prospector concept to perform more definitive *in situ* astrobiological measurements on the Martian surface (Pratt, 2009). The rover concept has design heritage from both MER and MSL.

Recent high level discussions between NASA and ESA (see for example McCuistion, 2009, or Taverna, 2009) have begun to explore the idea of delivering an

ESA ExoMars rover (Vago, 2006 and Amos, 2009) and the proposed NASA MAX-C rover to Mars together in 2018 on a single launch using an MSL-type Entry, Descent and Landing system. This combined mission concept has been evaluated only briefly thus far. For discussion purposes only, the proposed implementation outlined in this paper reflects a proposed NASA-only concept for the MAX-C mission, but would not be expected to change significantly for a potential joint mission architecture.

SCIENCE DEVELOPMENT, OBJECTIVES AND IMPLEMENTATION CONCEPT

The proposed MAX-C mission would primarily address Goal I of the Mars Exploration Program Analysis Group (MEPAG): "to determine if life ever arose on Mars". MAX-C's envisioned role also includes objectives that would enable it to be the first mission in a potential multi-mission sample return campaign focused on seeking evidence of past life or prebiotic chemistry on Mars (Pratt et. al., 2009).

Sample return is regarded as an essential step in the search for life, as detecting potential signatures of past microbial life (the most likely kind of biosignature to be found on Mars, if any), would almost certainly require analyses that could only be performed on Earth (Jakosky, 2009). Importantly, however, vital information required to interpret potential traces of biological activity also lies in the broader outcrop context from which the samples would be acquired. Gathering samples without gathering this contextual information represents extremely high scientific risk. The proposed MAX-C mission would reduce the science risk of a sample return endeavor by gathering this vital contextual information during the course of selecting, acquiring and caching samples.

<u>*Objectives:*</u> The proposed MAX-C rover would investigate a site that – based on detailed analysis from orbit – has high potential for past habitability and preservation of ancient biosignatures, as well as the opportunity to sample diverse geological units. The rover would conduct a detailed geological investigation of that region; seek evidence of past life and/or prebiotic chemistry; and select, document and cache a diverse suite of samples that could be collected by a potential future sample return mission.

In doing these tasks, the proposed MAX-C mission would achieve two goals. On the one hand, it would make definitive technical and scientific steps towards the potential return of samples to Earth. On the other hand, importantly, the mission would also conduct significant *in situ* science, attaining high impact science returns even if samples are not returned or evidence of past life is not discovered. These science returns arise because the geological investigation that is required to select a high quality, well-documented suite of samples relevant to the search for possible traces of past life would also yield significant insights to the geology, geochemistry, past climates and habitability of Mars – whether or not evidence of past life or prebiotic chemistry is found.

Implementation: To implement the proposed investigation, a suite of measurements is envisioned that focuses on arm-mounted contact instruments capable of high resolution micro-mapping of rock composition and texture, in addition to mast-mounted instruments for gathering larger scale contextual information. In order to seek signs of past life on Mars, basic requirements include comprehensive characterization of the macroscopic and microscopic fabric of sedimentary materials, detection of organic molecules, reconstruction of the history of mineral formation as an indicator of preservation potential and geochemical environments, and determination of specific mineral compositions as indicators of oxidized organic materials or coupled redox reactions characteristic of life (Pratt et. al., 2009). Accordingly, it is anticipated that the envisioned MAX-C measurements would be able to gather and integrate detailed information on visual appearance and the mineralogical, chemical and organic geochemical composition of outcrops from the large scale (meter scale and larger) to the microscale (centimeters to micrometers). An example strawman measurement strategy concept is presented in Figure 1. It should be noted that this envisioned measurement strategy, and example strawman payloads capable of providing these measurements, are only used during the advanced concept development phase to illustrate the measurement goals and to assist engineering development teams in sizing an example system capable of meeting such goals. It is anticipated that standard NASA competitive processes will be used to define and select appropriate instrumentation to achieve the yet-to-be-defined scientific objectives.

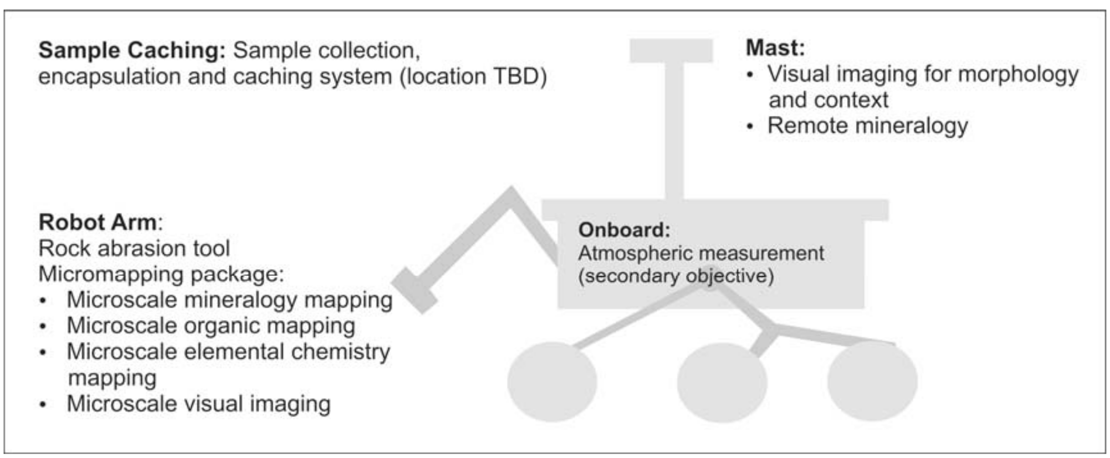


Figure 1: Example strawman payload measurements for the MAX-C mission concept

The example measurement suite takes a similar approach to the highly successful MER, being focused on investigation via mast-mounted and contact instruments. However, the contact instruments envisioned for the proposed MAX-C mission represent an important advance beyond the 'bulk measurement' approach taken by MER, instead achieving some higher degree of spatially resolved measurements of rock composition. In addition, an instrument capable of detecting and mapping organic compounds *in situ* (i.e., without sample handling or processing) would be included. Such instruments would offer significant scientific advantages through the ability to relate variations in rock composition to rock texture and microstructure. The combination of petrography and geochemistry would allow better constraint of the origin and significance of minerals or organics that may be detected. A significant technical risk would also be reduced by obviating the need for onboard sample handling and processing, and the measurements envisioned would likely require significantly less instrument mass than typical onboard analytical laboratory instruments.

In addition to these measurement capabilities, the proposed MAX-C rover would require access to outcrops, as well as the ability to traverse some distance among different outcrops to allow robust mapping and interpretation of local geology. This could be achieved by landing close to outcrops and/or by having a long traverse capability. Three different types of high priority landing site are identified in the MRR-SAG report (Pratt et. al., 2009). One type of site would be 'Early Noachian terrain', where the proposed MAX-C rover could seek information regarding the habitability (and potential inhabitation) of Mars at a critical period in early solar system history when life may have first appeared. Another type of site would target the Noachian-Hesperian boundary, to understand the transition in surface conditions that occurred near the boundary of the Noachian and Hesperian epochs and to assess the geologic, biologic, and climatic implications of this transition. A third type of site, 'Astrobiology: New Terrain', would target a type of astrobiologically significant terrain that has not yet been investigated, such as Noachian craters containing acid-saline lake and/or clay-rich deposits, evaporite sites containing chlorides or carbonates, mud diapirs that may expose minimally-altered samples from depth, and gullies that show evidence of recent water flow. The MER or MSL landing sites would be considered if a significant discovery were made there in time for proposed MAX-C landing.

MISSION DESIGN DESCRIPTION

The proposed MAX-C mission would be launched from the Cape Canaveral Air Force Station (CCAFS) in Florida during the 2018 Earth-to-Mars opportunity using a Type 1 ballistic trajectory (i.e., the heliocentric transfer angle between launch and arrival is less than 180°). The proposed 2018 MAX-C launch period extends from 14 May 2018 through 6 June 2018. This launch period has a maximum Earth departure C_3 (i.e. energy) of 10.2 km^2/s^2 and a maximum Mars atmosphere-relative entry speed of 5.8 km/s at Mars arrival. The characteristics of the proposed MAX-C launch period are shown in Table 1. The launch/arrival trade space is illustrated in Figure 2.

Table 1: Proposed MAX-C Launch Period Characteristics

Launch Day	Launch Date	Arrival Date	Time Of Flight (day)	C_3 (km^2/s^2)	DLA (deg)	VHP (km/s)	DAP (deg)	Atmosphere-Relative Entry Speed (km/s) 25°N	5°S	15°S	Ls (deg)	SEP (deg)
1	05/14/2018	01/14/2019	245	7.870	-14.980	3.376	-1.319	5.737	5.768	5.793	323.8	75.2
2	05/15/2018	01/14/2019	244	7.827	-14.619	3.375	-1.619	5.736	5.767	5.792	323.8	75.2
3	05/16/2018	01/14/2019	243	7.798	-14.450	3.372	-1.815	5.734	5.765	5.790	323.8	75.2
4	05/17/2018	01/14/2019	242	7.782	-14.396	3.369	-1.949	5.733	5.763	5.789	323.8	75.2
5	05/18/2018	01/14/2019	241	7.778	-14.415	3.366	-2.044	5.731	5.761	5.787	323.8	75.2
6	05/19/2018	01/14/2019	240	7.787	-14.483	3.363	-2.112	5.730	5.760	5.785	323.8	75.2
7	05/20/2018	01/14/2019	239	7.807	-14.587	3.361	-2.162	5.728	5.758	5.784	323.8	75.2
8	05/21/2018	01/14/2019	238	7.840	-14.716	3.359	-2.198	5.727	5.757	5.782	323.8	75.2
9	05/22/2018	01/14/2019	237	7.885	-14.863	3.357	-2.223	5.726	5.756	5.781	323.8	75.2
10	05/23/2018	01/14/2019	236	7.942	-15.023	3.355	-2.240	5.725	5.755	5.780	323.8	75.2
11	05/24/2018	01/14/2019	235	8.012	-15.192	3.354	-2.251	5.724	5.754	5.780	323.8	75.2
12	05/25/2018	01/14/2019	234	8.096	-15.367	3.353	-2.256	5.724	5.754	5.779	323.8	75.2
13	05/26/2018	01/14/2019	233	8.192	-15.547	3.353	-2.257	5.724	5.754	5.779	323.8	75.2
14	05/27/2018	01/14/2019	232	8.302	-15.728	3.354	-2.254	5.724	5.754	5.779	323.8	75.2
15	05/28/2018	01/14/2019	231	8.426	-15.909	3.354	-2.247	5.725	5.754	5.780	323.8	75.2
16	05/29/2018	01/14/2019	230	8.564	-16.089	3.356	-2.238	5.725	5.755	5.780	323.8	75.2
17	05/30/2018	01/14/2019	229	8.717	-16.267	3.358	-2.226	5.726	5.756	5.781	323.8	75.2
18	05/31/2018	01/14/2019	228	8.884	-16.441	3.360	-2.212	5.728	5.757	5.783	323.8	75.2
19	06/01/2018	01/14/2019	227	9.067	-16.612	3.363	-2.196	5.729	5.759	5.784	323.8	75.2
20	06/02/2018	01/14/2019	226	9.265	-16.777	3.366	-2.178	5.731	5.761	5.786	323.8	75.2
21	06/03/2018	01/14/2019	225	9.479	-16.937	3.370	-2.158	5.733	5.763	5.788	323.8	75.2
22	06/04/2018	01/14/2019	224	9.709	-17.091	3.375	-2.137	5.736	5.766	5.791	323.8	75.2
23	06/05/2018	01/14/2019	223	9.956	-17.239	3.380	-2.114	5.739	5.769	5.794	323.8	75.2
24	06/06/2018	01/14/2019	222	10.220	-17.380	3.385	-2.089	5.742	5.772	5.797	323.8	75.2
		MAX	245	10.220	-14.396	3.385	-1.319	5.742	5.772	5.797	323.8	75.2
		MIN	222	7.778	-17.380	3.353	-2.257	5.724	5.754	5.779	323.8	75.2

The launch/arrival strategy was optimized for maximum entry mass and satisfies all recommended key mission requirements:

- Launch period shall be at least 20 consecutive days.
- Launch period shall accommodate landing site latitudes between 25°N and 15°S.
- Atmosphere-relative entry speeds shall be less than 5.9 km/s (MSL-like).
- Longitude of the Sun > 320 deg to avoid arrivals deep in the dust storm season.
- Communications coverage during the Entry, Descent and Landing (EDL) phase shall include an X-Band direct-to-Earth link.
- Launch period shall have a constant arrival date to simplify mission operations, DSN deep space tracking support and proximity relay overflight during EDL by other Mars orbiting assets (e.g., proposed 2013 MAVEN (see NASA, 2008) and 2016 ExoMars orbiter (see Taverna, Oct 2009) missions). For this concept the arrival date was selected to be 14 January 2019.

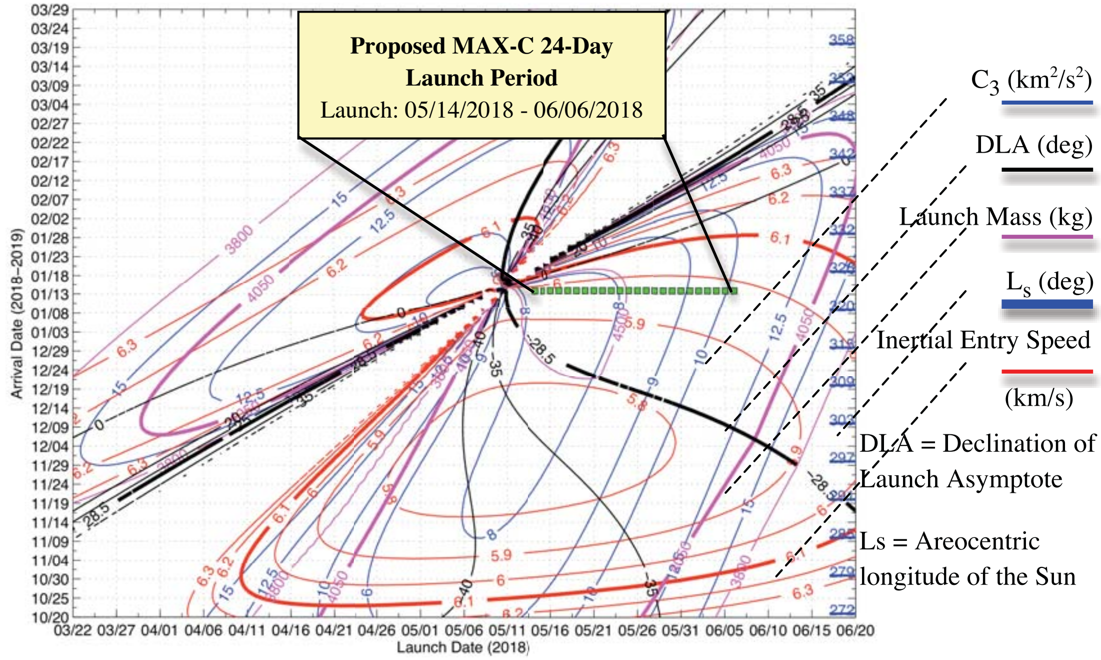


Figure 2: 2018 Earth to Mars Launch/Arrival Space

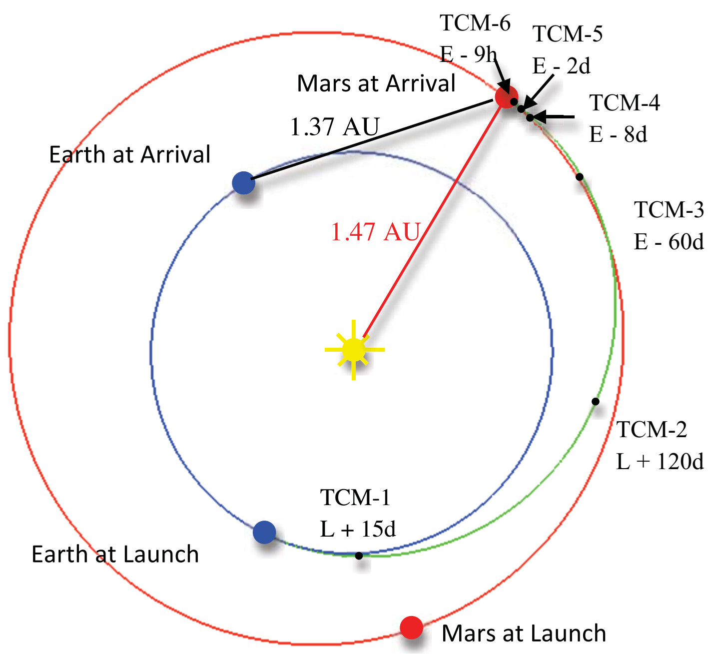


Figure 3: Proposed Interplanetary Trajectory - Type 1 (Open - 05/14/2018)

The launch of the proposed MAX-C flight system would be conducted onboard an Evolved Expandable Launch Vehicle (EELV) class vehicle, such as Atlas V or Delta IV. The actual vehicle for such a mission would be determined through a competitive launch services activity conducted by NASA. Six Trajectory Correction Maneuvers (TCMs) are part of the mission design plan and would correct launch vehicle dispersions, remove planetary protection trajectory biases, and control the cruise and approach trajectory to Mars, enabling delivery of the flight system to precise entry conditions for the entry, descent and landing phase. A plot of the interplanetary trajectory is shown in Figure 3. The spacecraft would enter the Martian atmosphere approximately eight months after launch. The proposed MAX-C mission expects to use the same entry, descent and landing architecture as that under development for the 2011 Mars Science Laboratory (MSL) mission. The proposed MAX-C flight system would follow a guided hypersonic entry trajectory before it enters the supersonic parachute deploy regime. Following a safe heatshield separation, the powered descent vehicle would reduce the vehicle vertical speed to approximately 0.75 m/s before the Sky Crane system lowers the rover to the surface of Mars (Mitcheltree, 2006).

CRUISE, ENTRY, DESCENT and LANDING

The proposed MAX-C flight system, as currently conceived, would consist of three major components that are modeled after the MSL system currently under development for launch in October 2011 (Mitcheltree, 2006, Prakash, 2008). The fundamental characteristics of the proposed system include an Earth-Mars cruise stage, an atmospheric EDL system, and the MAX-C rover with an integrated instrument and sampling package. Variations of this concept could either use the proposed MAX-C mobility system as a touchdown impact attenuation system (MSL-like) or might instead augment the system above with a lander pallet and egress system to perform that same touchdown and deploy functions.

Following launch and during the interplanetary transfer to Mars, the cruise stage would provide the necessary functions to deliver the entry system to the atmospheric entry interface at Mars. The cruise stage would have minimal capabilities (e.g., power, propulsion, telecommunication, etc.) and take advantage of the rover's systems to implement many of its data handling and commanding functions. The cruise stage propulsion system would be separate from the EDL system and would be used for spin-rate control (if the same MSL/MER spin stabilization architecture is adopted), attitude control, and all TCMs on approach to Mars (see Figure 3). The proposed MAX-C cruise stage, as currently conceived, would be modeled as a direct heritage design from MSL with some design updates to better take advantage of improved attitude determination systems for improved landing accuracy.

The Entry, Descent, and Landing (EDL) phase would begin when the cruise stage separates just prior to the Mars atmospheric entry interface point (see Figure 4). The design would employ an aeroshell/heatshield and a parachute to guide and decelerate the lander through the martian atmosphere. The diameter of the parachute is expected to be the same as that of MSL at approximately 21.5m and is expected to be robust to the shift in atmospheric modeling conditions (i.e., from those conditions consistent with an MSL arrival in September 2012, to those consistent with an arrival at Mars in January 2019).

Like MSL, the proposed MAX-C mission would use an offset center-of-mass to generate an aerodynamic lift vector during the hypersonic entry phase (Mitcheltree et al. 2006). The entry vehicle lift vector would be modulated through use of roll-control thrusters to guide the vehicle and compensate for unpredictable vehicle performance, navigation accuracy, and environmental variations that ultimately affect surface targeting accuracy. Lift-vector modulation would be the primary means for meeting the landing accuracy needs, which are currently estimated and approximated by a 7 km radius footprint on the surface of Mars. This is an improvement over that expected for MSL (i.e., a 20 km by 25 km ellipse) and would be enabled by a more precise attitude update strategy for EDL phase initiation. This version of the proposed MAX-C mission does not attempt to guide the vehicle to impact or avoid specific ground features. Such a capability would be warranted if future analyses and mechanical configurations indicate an unacceptably high probability of landing on a hazard (e.g., large rocks or steep slopes). When investigating a specific landing site, the necessary landing accuracy requirement would be driven by terrain and mobility considerations. If the highest priority landing sites supporting science and mission objectives require increased landing accuracy, this technology would need to added to the technology development trade space for this mission, and the vehicle design modified to support this capability.

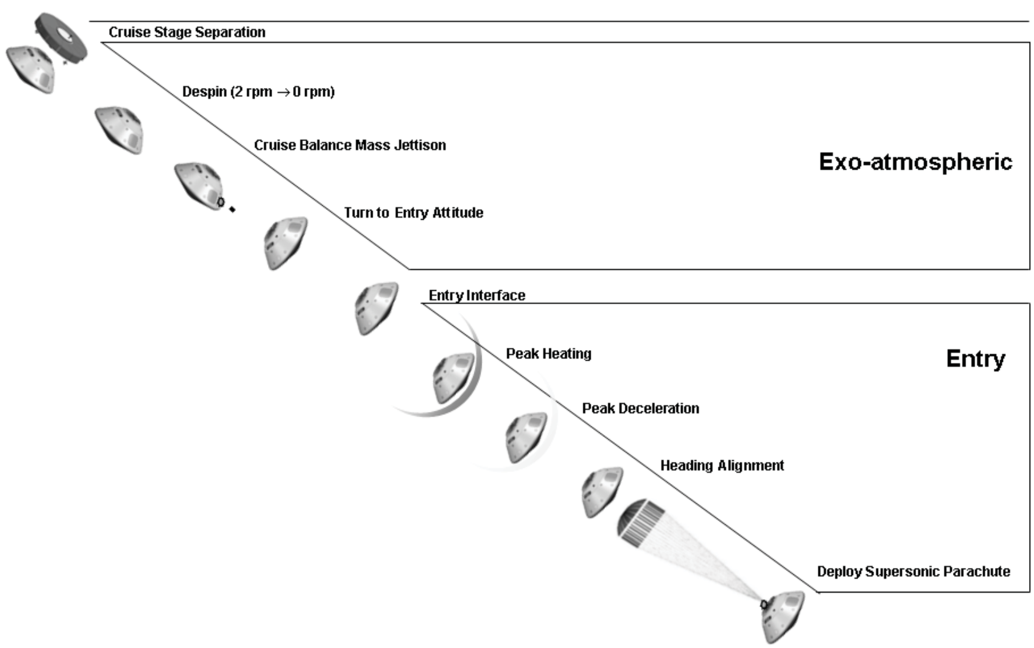


Figure 4. MSL Heritage Design for Entry and Descent

Following the parachute phase, the vehicle would employ the same skycrane architecture as MSL for shedding the remaining velocity of the system and deploying the rover on the surface (see Figure 5). No modifications to the MSL skycrane phase (as implemented by the MSL Descent Stage) depicted in Figure 5 are anticipated for this concept, although a pallet concept might be desirable if other constraints are introduced into the design.

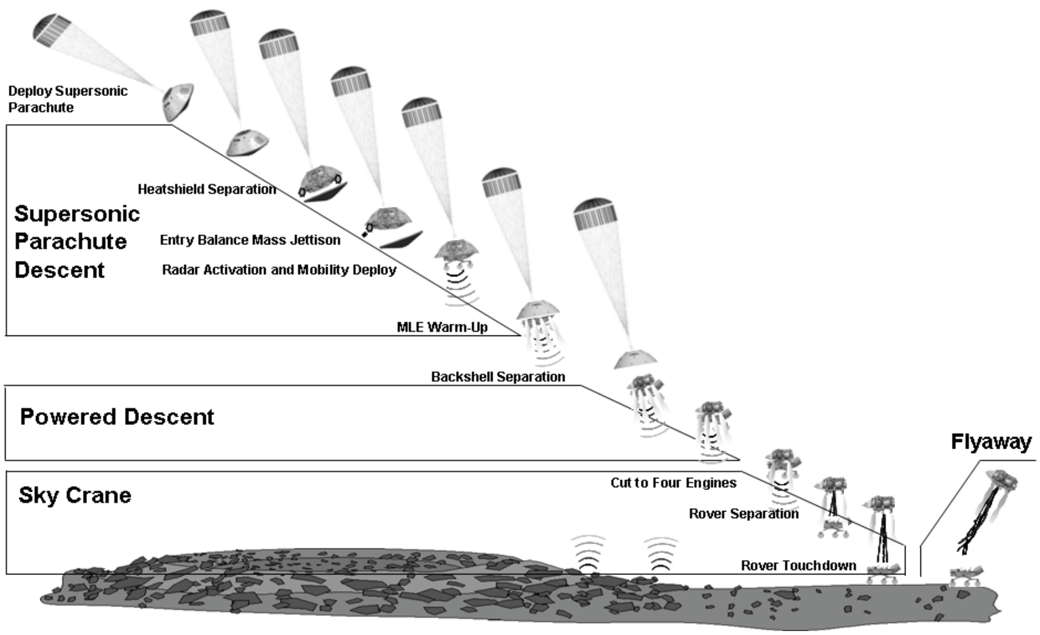
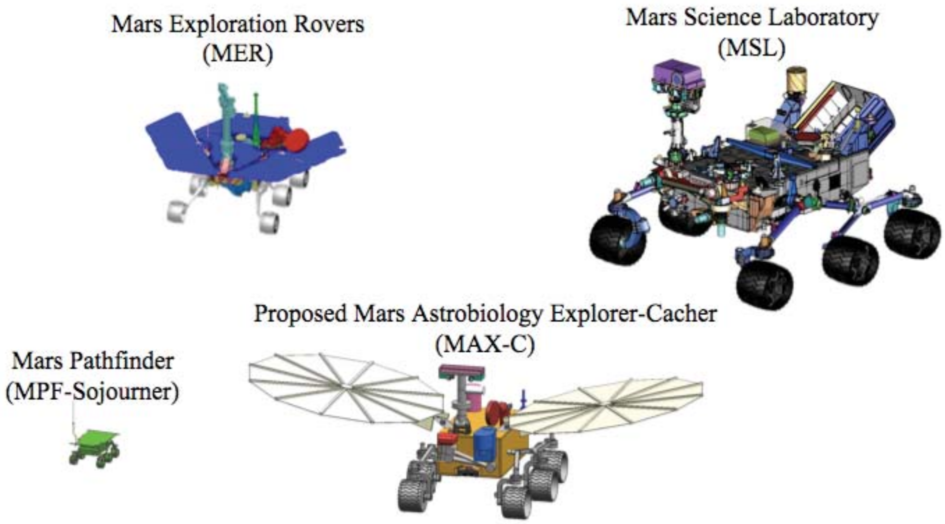


Figure 5. MSL Heritage Design for Descent, Touchdown and Flyaway

ROVER and SURFACE OPERATIONS

The proposed MAX-C Rover would draw upon the experience base of past NASA rovers in terms of general functionality, electronics, configuration, structural/thermal design, and mobility capabilities. The proposed MAX-C Rover, like MSL and MER, would form the core of the spacecraft for all mission phases. It is where the main avionics, most of the radio equipment, and all the payload would reside. Driven by a notional set of payload requirements, the proposed MAX-C Rover would be much smaller than the MSL Rover, but larger than the MER Rovers. Figure 6 shows a comparison of rover sizes and science instrument and payload support masses for the family of NASA rovers. In this context, items like robot arms, abrasion or coring tools, masts and the like are book kept as payload support to the science instruments.



Payload + Science Support Equipment Mass			
MPF (Sojourner)	MER	MAX-C	MSL
~1 kg total	5+16 kg	~15+55 kg	82+155 kg

Figure 6: Family of NASA Mars Rovers

Figure 7 shows an example of the proposed rover configuration. The ~2m diameter solar arrays are shown as lightweight deployed “wings” on either side of the rover top deck. Prominent appendages are the imaging/science mast and the sampling/science arm at the front of the rover. Remote sensing science instruments and some of the engineering cameras would be located on the mast, while contact or close-up instruments and the coring/abrading tool(s) would be located on the end of the arm. The Sample Handling Encapsulation and Containerization (SHEC) equipment would also be located at the front of the rover, accessible by the arm. The various antennas for X-band and UHF communications are shown in the aft portions of the top deck. The proposed MAX-C rover’s 6-wheel drive rocker-bogie mobility system, similar to that of its ancestors, would allow it to approach science targets of interest in varied terrain using either 4-corner steering, or full 6-wheel steering.

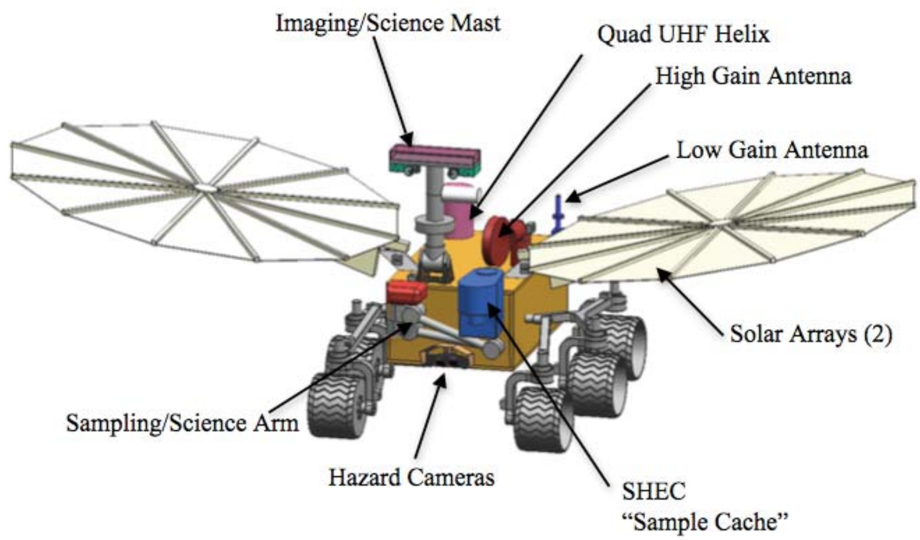


Figure 7: Example MAX-C Rover Illustration

The proposed surface mission would include an initial checkout period, followed by a combination of long traverses and reconnaissance to locate specific targets of interest for the science investigations. Once regions of rich targets are identified, short traverses could be used to position the rover for using its instrument suite and acquiring cores for caching. Notional operational timelines can be described as combinations of long and short traverses, reconnaissance, and science/coring operations, but the actual ordering of such activities and balance of, for example, driving distance to sampling activities would be heavily dependent upon the particulars of a given landing site. A broadly distributed science target-rich site would require less total traverse distance to access desired targets, and a more discretely located spread-out set of science targets would require more total traverse distance. A preliminary look at an example mission timeline which includes traversing outside of the landing ellipse, assessing and acquiring a cache of rock cores, documenting the context of the sampled rocks, and dropping off the sample cache in an appropriate location for possible future return results in a surface mission duration, with margin, of about 500 sols.

A "day in the life" of the rover is strongly influenced by power, thermal, and communications considerations. The power design of the rover and the related operability characteristics would be similar to those of the MER rovers. A solar array (~4x larger than MER) would provide electrical power during daylight hours and a rechargeable battery would be used to augment the solar array for peak loads and nighttime power needs. To save energy, the rover would generally go into a low activity, low power mode (i.e., "sleep" mode) through most of the night and for some parts of the day, allowing the batteries to charge from the solar array. Higher power activities (e.g., driving, coring, transmitting) would only be conducted for a few hours each day, depending upon energy available due to such factors as seasonal effects, and dust accumulation. The majority of science activities would be conducted while the rover is awake, but some instruments with low power and long duration activities would be designed to allow that instrument to conduct its operations while the rest of the rover sleeps, to avoid the energy overhead of the rover's infrastructure.

The thermal design of the rover would consolidate most of the electronic equipment into a single isolated thermal mass in a warm enclosure that would form the core of the vehicle. The enclosure would incorporate an insulating material or a sufficient gap (filled with the ambient CO_2) to limit loss of heat from the central electronics to the environment. Dissipation of heat through operationally modulating the use of the electronics would keep temperatures within limits. Under the most extreme hot environments, restrictions might be placed on maximum awake time to keep temperatures within bounds. In the cold extremes a minimum awake time would need to be enforced to ensure enough heat dissipation. Survival heaters would form a backstop for the most sensitive components.

Telecommunications provided via X-band and UHF radios would allow control of the proposed rover through periodic upload of sequences (usually daily). The X-band radio system would allow command uplink and telemetry downlink directly from and to Earth, while the UHF system would allow relay of commands and telemetry through orbiting science/relay spacecraft at Mars. The X-band system would provide uplink/downlink generally any time the Earth is in view of the rover, allowing an element of operational flexibility. The much higher performing UHF system would only be used when an orbiter passes overhead, which generally happens a couple times each day. A typical operational cadence that results is to schedule commands using the X-band system such that a few hours of primary activity could be completed shortly before a UHF orbiter overflight provides a path for return of decision-making data to Earth.

SAMPLE ACQUISITION SYSTEM

A key objective in this potential mission concept is the acquisition of samples for possible return to Earth by a future mission. An integrated concept for core sample acquisition and caching with potential application to a mission such as this has been developed (Collins, 2009 and Backes, 2010). The concept would utilize a five degree-of-freedom (DOF) manipulator arm to deploy a rotary percussive coring tool as well as to provide alignment, feed, and preload for the tool. The tool would provide coring, core break-off, core retention, as well as bit capture and release for bit change-out. A sample would be acquired directly into its sample tube in the coring bit and bit change-out would be used to transfer the sample to the caching subsystem where it would be sealed and stored. The sample storage canister could be left on the rover or deposited on the surface for later pick-up by a possible subsequent mission.

A potential set of mission sample acquisition and caching requirements were developed for system technology development and mission implementation sizing purposes only. Some of the key potential requirements used in this development effort are listed below (Note: The actual sample acquisition and caching requirements for a potential MAX-C mission would be defined through standard NASA mission development processes):

- Acquire at least 20 rock cores approximately 1 cm wide by 5cm long (as defined for example in Borg, 2008).
- Acquire rocks of types ranging from Saddleback Basalt to Kaolinite (MSL-like drill requirements).
- Acquire cores in the tool pitch plane through 45 degrees from vertical and with surface normals up to 15 degrees out of the tool pitch plane.
- Seal samples in sample tubes to prevent contamination between samples and prevent material loss.
- Allow sample tubes to be removed from the container for later repackaging (e.g., selective loading of acquired sample tubes into a potential orbiting sample canister for launch into low Mars orbit).
- Fill the sample canister such that it could possibly be returned to Earth.
- Sample from a MER-class rover of mass less than or equal to 300 kg (i.e., the sample acquisition system would be compatible with a rover with significantly less mass than an MSL-class rover).
- Sample on slopes up to 25 degrees, including rock and sandy surfaces.
- Measure mass or volume of each acquired sample with 75% accuracy.

Some related proposed requirements for the sampling rover are listed below.

- Provide bit change-out.
- Deploy contact instruments to the surface with a 5-DOF manipulator arm (see earlier discussion of instrument payload and sample selection operations concept).

Various system architectures were considered. One such system is discussed below and was used to help define the necessary capabilities to fund, develop and deploy such a system on a flight system.

CORING SYSTEM

The coring tool would provide coring, core break-off, core retention, and bit capture/release for bit change-out. The coring tool subsystem concept described is called the Sample Acquisition Tool (SAT). The functions of the coring tool have been identified, but the specific design of the tool has not been completed. An example testbed coring tool used for functional testing is depicted in Figure 8. The coring tool design has linear springs between the turret and coring tool that the deployment arm compresses to provide both preload and tool linear feed motion. The springs also provide the valuable function of suppressing vibration forces from the coring tool to the arm (an important consideration for this mission concept that has sensitive science instruments mounted on the same turret at the end of the arm).

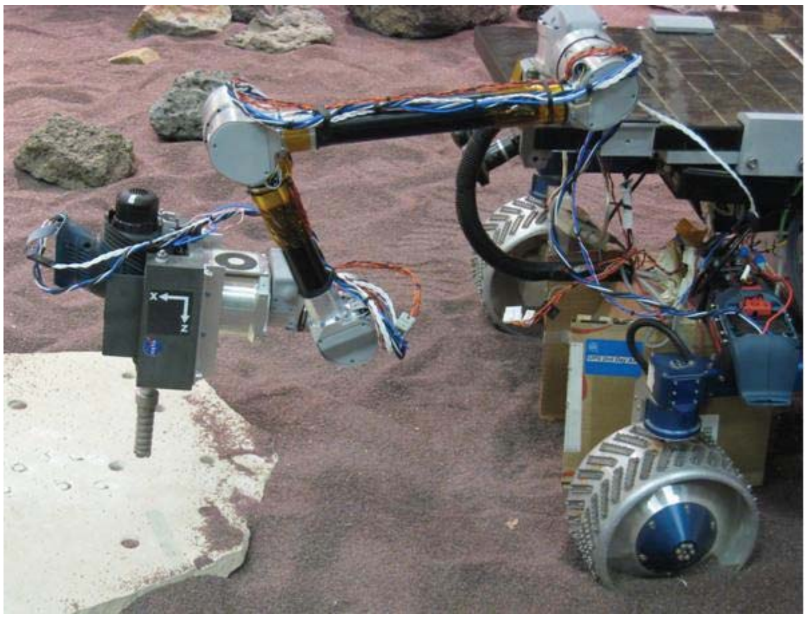


Figure 8: Sample Acquisition Tool (SAT) Testbed

The coring tool, as shown above, is deployed to the surface using the 5-DOF manipulator arm. The arm then provides alignment, preload, and drill feed during the coring operation. The bit-environment interaction forces can be sensed with the six-axis force torque sensor at the wrist. The arm aligns the tool in the hole by nulling interaction forces between the bit and hole as sensed by the wrist six-axis force torque sensor. The arm then preloads the linear spring to the desired weight on bit and is then turned off and its brakes are engaged. It is turned off in order to eliminate the power consumption that would be caused by actuating the arm during the coring process. The tool is then turned on and coring is performed until the weight on bit drops below a threshold. When the weight on bit drops below the threshold, the tool is turned off and the process repeats.

SAMPLE HANDLING, ENCAPSULATION and CONTAINERIZATION

The caching subsystem for the integrated concept is illustrated in Figure 9. The caching subsystem concept is referred to as the Sample Handling, Encapsulation, and Containerization (SHEC) subsystem. Bit change-out and sample caching are combined in the design.

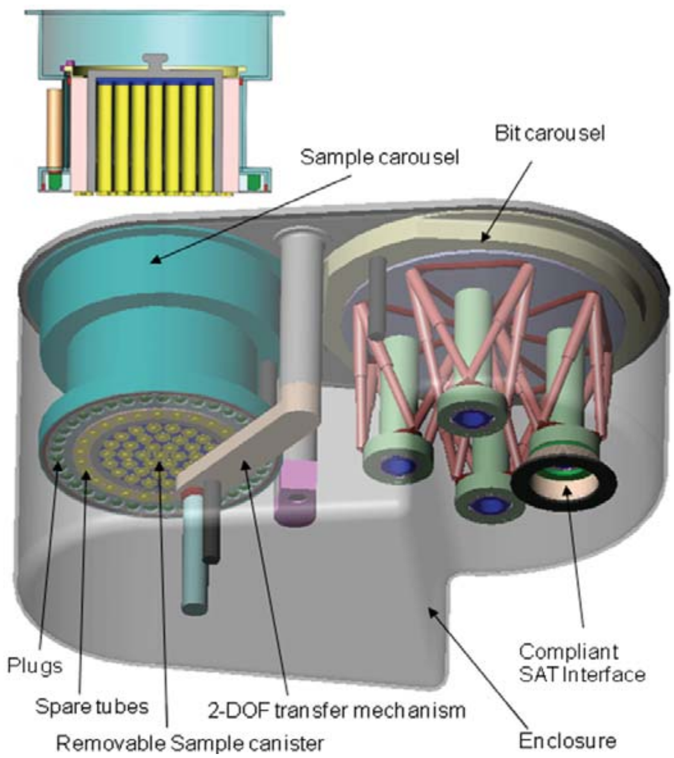


Figure 9: Example Sample Handling, Encapsulation and Containerization (SHEC) Subsystem

There is one opening in the SHEC subsystem design; the compliant SAT interface port for transferring a coring tool bit. The tool bits are stored in compliant bit holders on the bit carousel. Flexures around each bit holder provide passive mechanical compliance to assist in alignment of the rover arm/coring tool during the bit change-out process. For bit change-out the bit carousel is rotated so that a bit holder for the desired bit is aligned with the bit interface port. The carousel rotates to align different bits for exchange with the coring tool on the rover manipulator arm. A 2-DOF transfer arm internally transfers sample tubes between bits on the bit carousel, plugs on the sample carousel, plugging station, and tube chambers in the sample canister. The sample canister is in the center of the sample carousel and could be removed from the top of the SHEC by the rover manipulator arm; this would enable either deposition on the surface for later pick-up by a rover from a possible future mission, or direct removal by that future rover.

The coring tool would insert a bit with its sample into the bit port and release the bit, as depicted in Figure 10. The transfer arm and bit carousel would both rotate to align the transfer arm gripper with the sample tube knob in the bit. The transfer arm would then translate the gripper to the knob, grasp the knob and pull the tube out of the bit. The transfer arm and sample carousel would then rotate to align the sample tube with a plug and the tube would be translated to push a plug into the top of the tube and seal the tube. The tube would then be transferred to a sealing station where the plug is pushed further into the tube to contact the sample, enabling an estimate of the volume of the acquired sample and prevent the sample from moving in the tube. The transfer arm and sample carousel would then rotate to align the sample tube with an empty chamber in the sample canister, and the tube could then be inserted into the empty chamber.

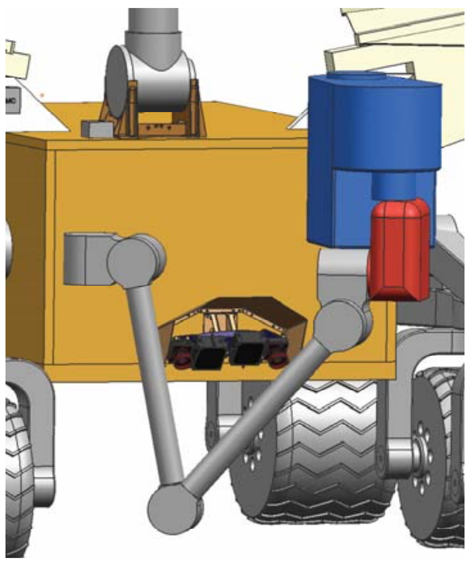


Figure 10: Illustration of Coring Tool Bit Exchange with Sample Handling, Encapsulation and Containerization (SHEC) System Concept

SUMMARY

The development background and a proposed concept for a Mars Astrobiology Explorer and Cacher mission, consistent with a possible launch to Mars in the 2018 mission opportunity, has been described. The proposed MAX-C mission would represent a fundamental step forward in our exploration of Mars, as it would conduct high-priority *in situ* science, collect a suite of well-characterized samples, and potentially become the first element of a possible multi-mission campaign to return martian samples to Earth.

As a final note, the proposed MAX-C implementation described here is depicted as a NASA standalone concept. However, NASA has sought to expand participation and return from its Mars Exploration Program and has embraced a strategy that seeks to develop an international program for the exploration of Mars. A proposed exploration strategy for Mars with the European Space Agency (ESA) has been discussed (see ESA 2009, McCuistion 2009 and Taverna 2009). Alternative mission concepts that adopt this strategy have been proposed and are being investigated.

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