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Mars Sample Return Conceptual Mission Overview

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Abstract

This talk will provide an overview of an overall Mars Sample Return campaign architecture, and the current concepts and options for the architecture and design of a Mars Sample Retrieval Lander (called Sample Retrieval Lander, SRL). The overall SRL mission concept and key mission objectives will be described, including the mission's concept of operations and a notional timeline from launch to entry, through surface operations, to delivery of the samples to Mars orbit. The overall lander vehicle concept will be described, including current options being evaluated. Key lander element options will be discussed, including a Mars Ascent Vehicle (MAV), Fetch Rover, Orbiting Sample container (OS), and tube transfer robotics systems. Details of the notional Fetch Rover functions, constraints and operations will be discussed. Specific challenges and approaches for addressing those challenges will be discussed, including key technical margins and planetary protection. Major trade studies and implementation approaches and a proposed schedule will also be discussed.

The information provided about possible Mars sample return architectures and concepts is for planning and discussion purposes only. NASA and ESA have made no official decisions to implement Mars Sample Return.

Keywords: Mars Sample Return, Sample Retrieval Lander

Acronyms/Abbreviations

Break-the-Chain (BTC), Capture/Containment and Return System (CCRS), Delta Velocity (DV), Earth Return Orbiter (ERO), Entry Descent and Landing (EDL), European Space Agency (ESA), Gross Lift Off Mass (GLOM), In-Situ Resource Utilization (ISRU), Jet Propulsion Laboratory (JPL), Mars Ascent Vehicle (MAV), Mars Returned Sample Handling (MRSH), Mars Sample Return (MSR), Marshall Space Flight Center (MSFC), Mars 2020 Rover (M2020), Mixed Oxides of Nitrogen (MON), MAV Payload Assembly (MPA), Model-Based Systems Engineering (MBSE), National Environmental Policy Act (NEPA), Orbiting Sample container (OS), Probabilistic Risk Assessment (PRA), Propulsive Platform Lander (PPL), Project Implementation Plan (PIP), Quantification of Margins and Uncertainties (QMU), Sample Fetch Rover (SFR), Sample Retrieval Lander (SRL), Sample Transfer Arm (STA), Sky Crane Delivered Lander (SDL), Ultra High Frequency (UHF).

1. Introduction

This paper is an overview of the current architectural elements for a potential Mars Sample Return (MSR) campaign, and the concepts and options for the architecture and design of a MSR lander, called the Sample Retrieval Lander (SRL), which has been under study since 2017 [1]. Key mission concept objectives and the overall mission design are described, including the mission's concept of operations and a notional timeline from launch to entry, through surface operations, to delivery of the samples to Mars orbit. The two current lander vehicle options being evaluated will be discussed, including the key lander element options of a Mars Ascent Vehicle (MAV), Sample Fetch Rover (SFR), Orbiting Sample (OS) container, and the Sample Transfer Arm (STA) tube transfer robotics systems. Details of the Fetch Rover constraints and operations will be discussed.

Specific architecture level challenges and approaches for addressing those challenges are discussed, including key technical margins and backward planetary protection. Major trade studies and implementation approaches and a proposed schedule are also included.

2. Mars Sample Return Campaign

2.1 Functional Objectives

The functional objectives for a potential MSR campaign include the following:

- Acquire and return to Earth a scientifically selected set of Mars samples for investigation in terrestrial laboratories.
- Select samples based on their geologic diversity, astrobiological relevance, and geochronologic significance.
- Establish the field context for each sample using *in situ* observations.
- Ensure the scientific integrity of the returned samples through contamination control (including round-trip Earth contamination and sample-to-sample cross-contamination) and control of environments experienced by the samples after acquisition.
- Ensure compliance with planetary protection requirements associated with the return of Mars samples to Earth's biosphere.
- Achieve a set of sample-related scientific objectives including: life, geologic environments, geochronology, volatiles, planetary-scale geology, environmental hazards, and In-Situ Resource Utilization (ISRU)

2.2 MSR Architectural Elements

MSR is currently envisioned to be made up of three flight elements and one ground element. The flight elements include: the Mars 2020 mission, a Sample Retrieval Lander (SRL), and an Earth Return Orbiter (ERO) (including its payload). The ground element would be a Mars Returned Sample Handling (MRSH) facility. Mars 2020 is responsible for sample selection, acquisition and caching. The SRL would include a fetch rover to collect the cached samples, the Orbiting Sample (OS) container, in which the samples would be loaded and the Mars Ascent Vehicle (MAV) to launch the OS into Mars orbit. The ERO includes the Capture/Containment and Return System (CCRS), which would capture and contain the OS for return it to the surface of Earth. The MRSH facility would receive, quarantine and curate the samples. It would also be responsible for assessing hazards, and providing the opportunities for the international science community to conduct sample science.

2.3 MSR Mission Scenario and Roles

Based on the joint NASA/ESA Statement of Intent (signed in Berlin on 4/26/18) NASA and ESA are studying how to implement MSR in a partnership. The Mars 2020 rover is being built by NASA/JPL with the planned objective of collecting and caching samples. Per the above agreement, the ERO would be provided by ESA, with the ERO payload provided by NASA. ESA would also provide the SFR and the sample transfer arm (STA) on the NASA provided lander.

Figure 1 shows the current architectural elements, their general interfaces and the currently assumed roles.

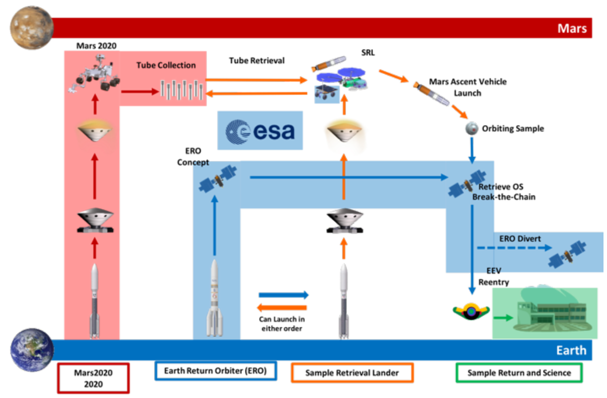

Fig. 1. Potential MSR Mission Scenario.

2.4 Current Operations Timeline

Figure 2 shows what is referred to as the "fast" MSR timeline, which could return samples as soon as three years after SRL and ERO launch.[2] This timeline is very aggressive in terms of surface operations and ERO orbital operations at Mars. Other timelines are being studied that provide greater flexibility and better design and operational margins.

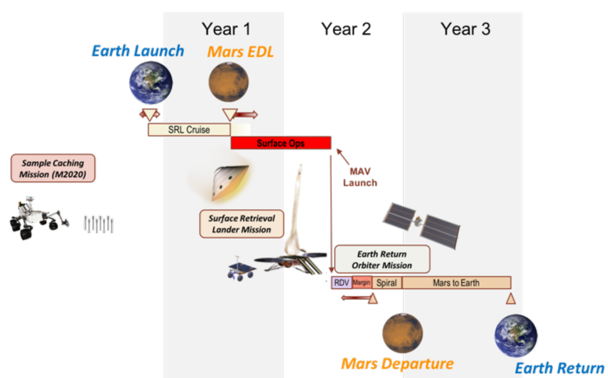

Fig. 2. Notional "Fast" MSR Timeline

2.5 Backward Planetary Protection

The objective of backward Planetary Protection is to prevent uncontained or unsterilized material from Mars from being released into Earth's environment. This involves a strategy for the use of analysis, design, and testing of the elements and systems that would be implemented and validated/certified to deliver Mars surface sample tubes to Earth; while containing, immobilizing and/or sterilizing any other Mars material that might reach the biosphere of Earth. The methodologies used to achieve this objective are referred to as "Break-the-Chain," or BTC. The key elements of the strategy for BTC that would be applied to both the SRL, ERO and the ERO payloads include:

- Establishing requirements definition approach
- National Environmental Policy Act (NEPA) process
- Use of fault trees for element design
- Use of various modeling tools to analyze performance and failure modes
- Use of Quantification of Margins and Uncertainties (QMU) for understanding the accuracy of our models
- Use of Probabilistic Risk Assessment (PRA) to support design studies, end-to-end reliability analysis
- Model validation testing

2.5 Key Trade Studies and Systems Engineering

The systems engineering team has developed and maintained a detailed map of trade studies and are assessing options to achieve the most robust overall architecture factoring the following properties:

- Mission success
- Complexity
- Cost
- Development and operational risk
- Performance
- Implementation

Key metrics being used within the trade space and between the elements are:

- Cost, Mass, Power
- Schedule margin (development and operations) including surface timeline, orbital operations timeline
- Planetary protection metrics (e.g. reduction factors, probabilities)
- PRA results initially used for relative comparisons and identification of driving events
- Performance (e.g. # of samples, landing accuracy, delivered surface mass)
- Performance margins (e.g. launch margin, delta velocity (DV) margin, mass margin)

Among the various trade studies the ones around which the entire architecture pivots are:

- OS design (including number of tubes and shape
- Approach to "Break-the-Chain"
- MAV propulsion technology
- SRL entry, descent and landing approach and any need augmentations
- ERO propulsion approach and related performance

A key part of the systems engineering process that will be used to close the architecture is the use of Model-Based Systems Engineering (MBSE) for the development and control of the overall concept of operations starting from the Mars 2020 cache to returning tubes to the surface of the Earth.
The implementation of this cross-Agency and multi-Center systems engineering effort will be facilitated by the following uses of MBSE:

- Provide a reliable, single source of truth for all teams (parameters, function dictionary, …)
- Manage systems engineering data across organizations
- Build an integrated system model of technical and programmatic information collaboratively with ESA and other NASA centers
- Have a verifiably consistent model
- Enable analysis of integrated systems engineering data (requirements coverage, PRA)
- Enable reuse by avoiding duplication
- Automated generation of reports & engineering documents

The team is proceeding toward closure of a robust MSR campaign architecture in late 2019.

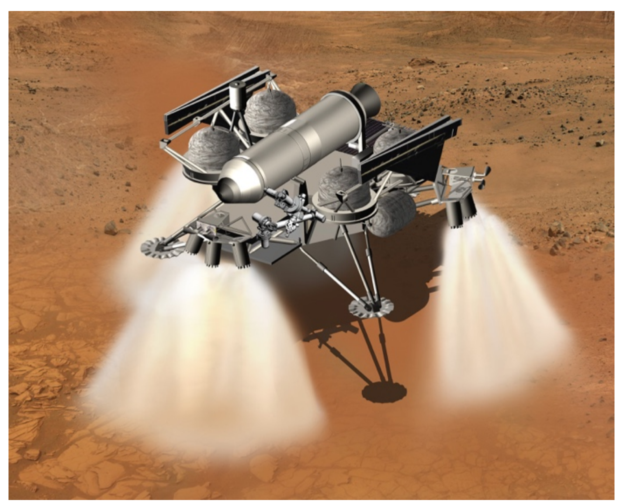

Fig. 3. Propulsive Platform Lander concept

3. Lander Concepts Under Study

The MSR Sample Retrieval Lander (SRL) team has been actively studying two lander concepts: a Propulsive Platform Lander (PPL) and a Sky Crane Delivered Lander (SDL). The SRL must land on Mars, deploy the Sample Fetch Rover (SFR), and maintain the lander and the MAV within safe operating conditions including temperatures while the rover retrieves the M2020 sample tubes. Once the SFR returns with the tubes the following operations will be conducted: transfer tubes to the OS in the MAV Payload Assembly (MPA), using the Sample Transfer Arm (STA); assemble the MPA to the MAV; prepare the MAV for launch (heat to operational temperatures and erect); and execute the MAV launch. The two lander concepts at the time of terminal descent are shown in Figures 3 and 4.

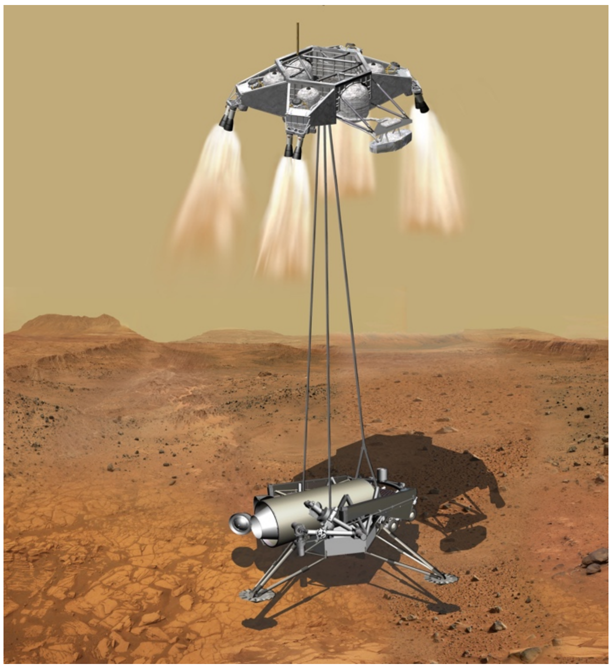

Fig. 4. Skycrane Delivered Lander concept

Most of the Entry, Descent and Landing (EDL) technology is common to both options and is based on Mars Science Laboratory. This includes the aeroshell and the parachute system. However the currently assumed entry is timed at a Mars season of low atmospheric density and will likely require some augmentation of the EDL capability over Mars 2020 to deliver the required mass with appropriate margins.

The key study elements are the same regardless of the option. Accommodation of both a MAV (400 kg allocation) and fetch rover (120 kg allocation) within the lander and inside an aeroshell with margins on both mass and volume is currently being studied. Both solar power and thermal design are being considered for the worst-case environments. The MAV propulsion technology, performance (including mass), and reliability is currently being evaluated for multiple propulsion systems (currently a single stage to orbit hybrid and two stage to orbit solid). Several challenges on with the OS, including tube accommodation and insertion into MAV are being studied. Finally, planetary protection design and implementation strategies are being considered.

The team has come up with initial configurations and structural sizing based on heritage EDL and the accommodation of the MAV and SFR. The SDL concept utilizes heritage Sky Crane EDL from MSL and M2020.

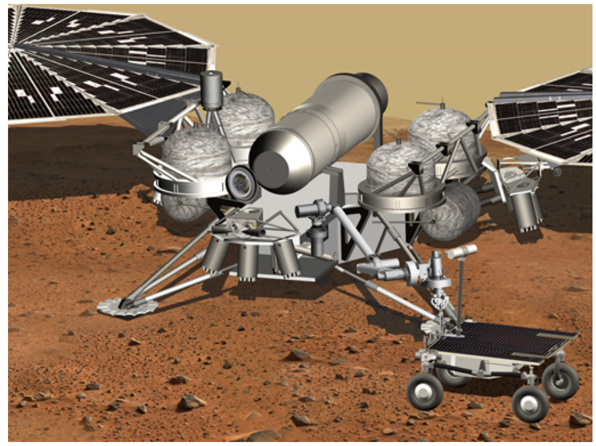

Fig. 5. Propulsive Platform Lander with SFR and STA

The cruise stage is based on the lander mass, the backshell is unchanged, and the descent stage is currently unchanged. Both concepts do, however, utilize a slightly larger, 4.7m spherical heatshield, than what has been used in previous Mars landers. This provides significant additional volume inside the aeroshell that is critical to accommodate the Lander payloads. The PPL concept employs an EDL more similar to Viking or Insight, using the scaled M2020 cruise stage and entry system, but with descent and landing thrusters as part of the platform itself.

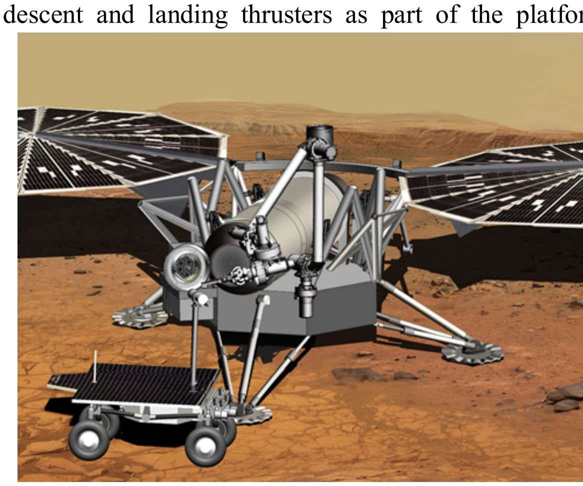

Fig. 6. Skycrane Delivered Lander (SDL) with SFR and STA performing tube transfer

Both concepts currently meet functional constraints and have specific advantages/disadvantages. The SDL concept provides a softer landing with less plume/ground interactions due to the Skycrane technology. The PPL concept provides larger configuration and packaging flexibility/margin (in both volume and mass) but presents the complication of potentially significant plume/ground interactions due to the landing thrusters firing closer to the ground (the thruster utilize a shower head nozzle but the ground pressure and effects are still being studied)

Both concepts are in the early study phase and require much deeper study and design including into areas such as SFR accommodation, MAV accommodation (including launch) and tube transfer.

4. Orbiting Sample (OS) Container Concept and Sample Transfer Arm

The OS must hold desired number of sample tubes as cached by Mars 2020. The final number of tubes and the shape of the OS (e.g. spherical or cylindrical) to be returned is still being traded, but currently ranges from 20 to 30. The maximum assumed mass is 12 kg and diameter is 280 mm. Tubes would be inserted into the OS by the Sample Transfer Arm on the lander. Transferring from a tube "tray" on the SFR directly into the OS in the MAV. (See Figures 7 and 8). After the samples have been inserted, the OS then must be assembled and finally launched to orbit by MAV. The tubes need to be secured and maintained through environmental conditions through Mars launch, Earth return and Earth landing. Constraints placed on the management of the sample tubes by science include maintaining the temperature to less than +30 ºC and magnetic field below ½ mT (at the sample). Additionally, the OS must accommodate rendezvous and tracking by visual wavelength cameras on the orbiter and have sufficient albedo (assumed >0.7) to be detected in Mars orbit.

The details of the rendezvous and capture process and introduction to the processing of the OS for return to Earth are discussed in [4].

Fig. 7. Spherical OS concept in assembled configuration

Fig. 8. Sample tubes installed in a conceptual OS.

5. Mars Ascent Vehicle Concept

Numerous propulsion options have been evaluated in the past for the MAV. Most recently these included: single stage monopropellant, liquids and hybrids as well as two stage solids. [3] In 2016, the hybrid option was selected for technology development to mature the novel propellant combination that resulted in both the lowest Gross Lift Off Mass (GLOM) of the study as well as low temperature storage capability.

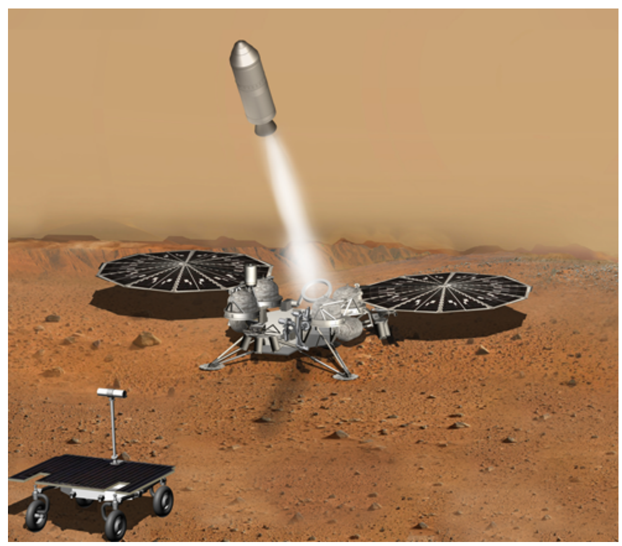

Fig. 9. Propulsive Platform Lander with MAV launch

The concepts for the MAV are currently being developed by a team at JPL and Marshall Space Flight Center (MSFC). The MAV would be responsible for launching the OS from the surface of Mars to a >350 km altitude, 25 degree inclination orbit. Dispersions are currently desired to be maintained below 1 degree; however, this may become more flexible with the decision return opportunity. The drivers for the MAV are the mass (400 kg) and geometry (3 m long by 0.57 m diameter) in order to fit within the lander described in the previous section.

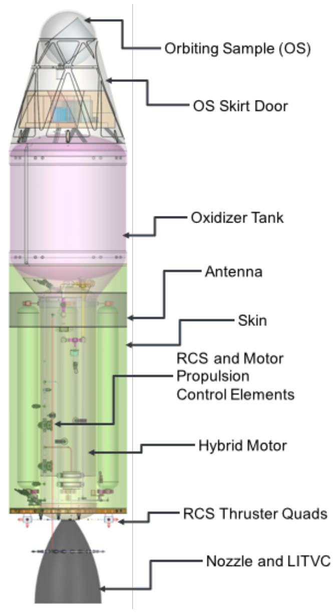

Fig. 10. Hybrid MAV Concept

Currently, two contractors are working together with JPL and MSFC to demonstrate performance of a single stage to orbit hybrid propulsion system using a wax-based fuel and Mixed Oxides of Nitrogen (MON) oxidizer capable of being stored in the variable and low temperature conditions on Mars. The hybrid MAV concept is shown in Figure 10. Moderately high performance, long duration burns (90s) and autonomous restarts and Liquid Injection Thrust Vector Control (LITVC) have been demonstrated at approximate full scale with the more easily procured MON-3 oxidizer. However, vaporization of the oxidizer has proven to be challenging and additional energy has been used to achieve stable combustion to date. Testing with the desired oxidizer will be carried out in the next year to determine its feasibility for flight.

6. Sample Fetch Rover Concept

The European Space Agency (ESA) has initiated in June 2018 parallel industrial studies for the Sample Fetch Rover (SFR) as a possible contribution to the Mars Sample Return Campaign. The overarching goals of these studies are to demonstrate technical and programmatic feasibility of an ESA rover (plus potentially egress system). The job of the SFR is to acquire Mars material sample tubes, cached by the NASA Mars 2020 mission, from the surface of Mars, and deliver them to the SRL.

The two competitive parallel studies are managed by Thales Alenia Space Italy and Airbus Defence and Space UK, respectively, and aim at completing phase A/B1 before May 2020. A specific breadboard development will take place with Airbus in order to demonstrate in a field trial the end-to-end operational concept, i.e. the capability to traverse autonomously, pick up the sample tubes and transport them back to the SRL.

Both studies are strongly relying on the ExoMars 2020 mission heritage. In particular, the ExoMars rover based on a triple bogie, six wheel approach will provide a solid starting point in terms of locomotion system, thermal control and energy management system, autonomous navigation as well as overall industrial, operational and scientific expertise.

The SFR studies will also rely on a technology development program, initiated several years ago: the Mars Robotic Exploration Program (MREP) led in particular to relevant capabilities in terms of Guidance Navigation and Control (Visual Odometry, mapping, etc.), miniaturised avionics, as well as low temperature mechanisms and batteries. Additional ESA-led generic technology developments will also be factored; this particularly applies to the domain of microprocessors (Leon 4) and FPGAs (BRAVE).

By mid-November 2018, both contractors will provide their concept for the rover and the egress system. Mass (120 kg NTE for the rover, 25 kg NTE for the egress system) as well as accommodation and volume constraints on SRL are some of the main constraints applied to the system. It is important to note that NASA/JPL and ESA have been working together to define such constraints while keeping the trade-offs open at SRL and also obviously at MSR campaign level. Due to being in a competitive process, the NASA concept for SFR is shown in Figure 11.

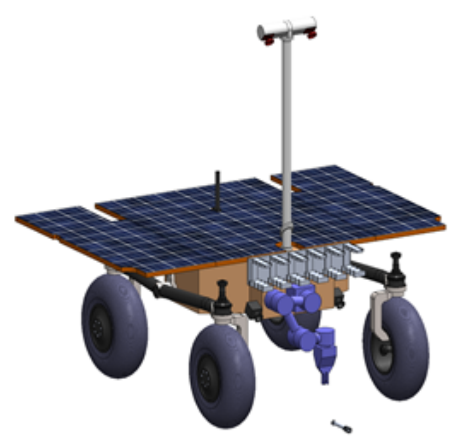

Fig. 11. NASA Concept for Fetch Rover

As mentioned above, ExoMars heritage is a strong starting point as it provides a robust development approach. However, alternatives are also traded-off, e.g. the locomotion systems choice (4 wheels versus 6 wheels, rigid, semi rigid versus compliant wheels, etc.) is being addressed as it can provide interesting advantages, in particular given the volume constraints. The navigation and vision-based fetching are key capabilities for the mission, and will very likely demand higher degrees of autonomy than implemented on any current or past rovers, in particular in view of the plan to rely only on the Earth Return Orbiter (ERO) for UHF relay. Existing orbiter assets (MAVEN, MRO or TGO) may still be available for the SFR surface mission but the approach is to rely on ERO..

Overall, energy availability is the main limitation and on-board efficiency (including operations) will be key to managing the up to 15km (map distance) traverse and sample tube fetching within the 150 sols available for the SFR surface mission.

The possibility of using Mars 2020 as fetch rover was studied. The option was found to be feasible; however, the most robust mission approach was determined to maintain both the fetch rover and Mars 2020.

7. Summary

The MSR campaign architecture trade space is well understood, with reference options defined where appropriate and options are being evaluated to achieve robust campaign architecture closure. The major technical elements are at an appropriately detailed level of definition for this phase of a pre-project effort. Technology development is proceeding per plan. The international and NASA cross-agency team is proceeding toward closure of a robust MSR campaign architecture in late 2019.

Acknowledgements

The information presented about a potential Mars Sample Return campaign is pre-decisional and is provided for planning and discussion purposes only. Some of the research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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