Mars 2020 Rover Mission Status in 2016

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***Abstract*—Mars 2020, NASA's next Mars rover mission, continues NASA's Mars Exploration Program with a focus on seeking signs of ancient life and helping to prepare for future human explorers. NASA will select a landing site likely to have once been habitable by microbial life and with the geologic record capable of preserving signs of its presence, if it ever existed. The rover will explore the landing site using a powerful set of instruments that support both in situ investigations and the selection of Mars samples to be collected, sealed, and left on the surface of Mars for possible future return.**

INTRODUCTION

Mars 2020, NASA's next Mars rover mission, builds on the legacy of earlier missions in NASA's Mars Exploration Program with a focus on seeking signs of ancient life and helping to prepare for future human explorers. The Mars Exploration Rovers Spirit and Opportunity as well as the later Mars Science Laboratory (MSL) Rover Curiosity had the charge to follow the water. Curiosity has the additional charge to explore the habitability of ancient Mars but is not looking directly for signs of life. See Figure 1 for an overview of recent NASA Mars program missions. To seek signs of ancient life, NASA will select a landing site with a high potential to have once been habitable and to preserve signs of life. The Mars 2020 rover will then explore that site using a powerful set of instruments that support both in situ investigations and the selection of well-documented Mars samples to be collected, sealed, and left on the surface of Mars for possible future return. To help prepare for future human explorers, the Mars 2020 rover carries instruments designed to measure the thermal environment during entry, descent, and landing (EDL), and the weather on Mars as well as an experiment to demonstrate the production of oxygen from carbon dioxide on the surface of Mars.

This paper describes key challenges faced by the Mars 2020 mission. These include development of a Sampling and Caching System, control of contamination in the collected samples, and establishing a mission cadence that allows all mission objectives to be achieved within the primary mission duration.

Note that the Mars 2020 mission collects the Mars samples but does not return them; the sample tubes will be left in documented locations on the surface to be selected during the course of the mission. The Mars Exploration Program is studying future mission concepts and architectures that could seek to return the samples. No commitment has been made to implement those missions.

Fig. 1: *Mars 2020 mission builds on the legacy of NASA's Mars Exploration Program, addressing the highest-priority science and preparing well-selected samples for possible return to Earth.*

MISSION OBJECTIVES

Mars 2020 has four objectives as described in the Program Level Requirements Appendix (PLRA) to the Mars Exploration Program Plan (Reference 1):

A. Characterize the processes that formed and modified the geologic record within a field exploration area on Mars selected for evidence of an astrobiologically-relevant ancient environment and geologic diversity.

B. Perform the following astrobiologically relevant investigations on the geologic materials at the landing site:

1. Determine the habitability of an ancient environment.
2. For ancient environments interpreted to have been habitable, search for materials with high biosignature preservation potential.
3. Search for potential evidence of past life using the observations regarding habitability and preservation as a guide.

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C. Assemble a rigorously documented and returnable cache of samples for possible future return to Earth.

1. Obtain samples that are scientifically selected, for which the field context is documented, that contain the most promising samples identified in Objective B, and that represent the geologic diversity of the field site.
2. Ensure compliance with future needs in the areas of planetary protection and engineering so that the cached samples could be returned in the future if NASA chooses to do so.

D. Contribute to the preparation for human exploration of Mars by making significant progress towards filling at least one major Strategic Knowledge Gap (SKG). The highest priority SKG measurements that are synergistic with Mars 2020 science objectives and compatible with the mission concept are:

1. Demonstration of *In-Situ* Resource Utilization (ISRU) technologies to enable propellant and consumable oxygen production from the Martian atmosphere for future exploration missions.
2. Characterization of atmospheric dust size and morphology to understands its effects on the operation of surface systems and human health.
3. Surface weather measurements to validate global atmospheric models.
4. A set of engineering sensors embedded in the Mars 2020 heat shield and backshell to gather data on the aerothermal conditions, thermal protection system, and aerodynamic performance characteristics of the Mars 2020 entry vehicle during its entry and descent to the surface.

MISSION OVERVIEW

NASA has selected the ATLAS V 541 launch vehicle for Mars 2020. This is the same launch vehicle used by MSL in 2011. The launch period is in July and August 2020. After a seven and a half month cruise, Mars 2020 will arrive at Mars in February 2021.

Upon arrival at Mars, Mars 2020 uses MSL's EDL system augmented with two new capabilities. The "Range Trigger" capability allows the system to trigger parachute deployment based on range and not just altitude. This reduces the size of the landing ellipse. The "Terrain Relative Navigation" capability makes use of a hazard map stored on the flight processor. If images taken during descent indicate a high probability of landing on one of those hazards, a small divert maneuver in a selected direction will be commanded to avoid the hazard. This allows the mission to select a landing site closer to the intended science regions of interest.

The rover systems are qualified for a 1.5 Mars year lifetime and designed to support 20 kilometers of traverse distance. The mission is designed to collect at least twenty ~15 gram samples of rock, regolith, or witness samples during the prime mission while also achieving the other mission objectives. The rover hardware is designed to reliably acquire a total of at least 37 samples allowing additional sampling and caching to continue after the prime mission. Each sample will be collected and hermetically sealed within an individual sample tube.

Figure 2 shows an image of the MSL launch and artist's conceptions for Mars 2020's cruise, EDL, and surface mission phases.

Fig. 2: *Mars 2020 launch (as represented by MSL), Cruise, and Entry Descent and Landing (EDL) approach follows the MSL approach with a few changes. The surface mission concept significantly leverages MSL's Curiosity but is unique to Mars 2020.*

ROVER CONCEPT

The Mars 2020 rover design has high heritage from the Curiosity rover design. The avionics, power, guidance, navigation and control (GN&C), telecommunications, thermal, and mobility subsystems use the Curiosity designs with few changes. See Figure 3.

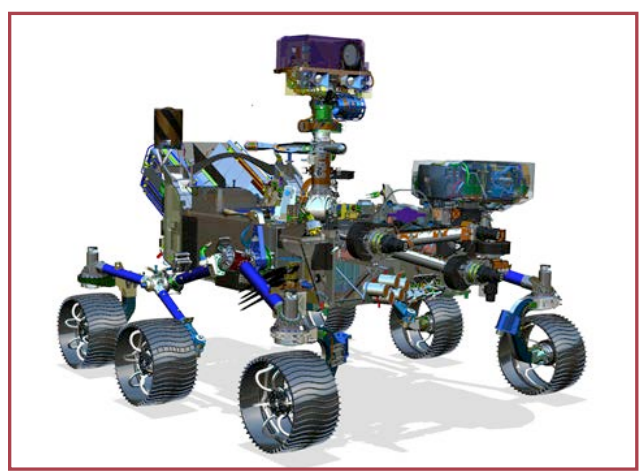

Fig. 3: *Mars 2020 Rover*

The science and technology instrument suite is new for Mars 2020. It is larger than and significantly different from Curiosity's science instrument suite. The Sampling and Caching (SCS) system is entirely new. It will use a coring drill to collect Mars samples directly into sample tubes, seal and store the tubes, and eventually place them

on the surface of Mars. Both the instruments and the SCS are described below.

The large robotic arm on the front of the rover differs from Curiosity's for two primary reasons. First, it needs to precisely pick up and drop off drill bits loaded with sample tubes and second, it must accommodate a larger turret at the end of the robot arm. This turret houses the coring drill and two science instruments. Manipulating the drill bits and sample tubes within the SCS requires motors beyond those needed for Curiosity. The motor controller electronics has been modified from the Curiosity design to accommodate these modified and added motors.

Achieving 20 cached samples during the prime mission will require significant enhancements to the surface flight software. The mobility software is being modified to allow greater autonomy to permit greater average traverse distances per mars day (sol). A simple planner has been added to the flight software to enable more efficient and autonomous use of resources such as energy and operating time during the warmer part of the sol and energy based on local measurements rather than conservative predictions of resources.

The Curiosity wheels experienced damage when driving over sharp rocks, so the Mars 2020 wheels have been redesigned to be more robust.

The combination of the larger instrument suite, new SCS system, and modified wheels leads to a heavier rover. Since the rover lands directly on its wheels, some of the mobility components have been modified to support this larger mass at touchdown.

PAYLOAD

The selected payload is shown in Figure 4.

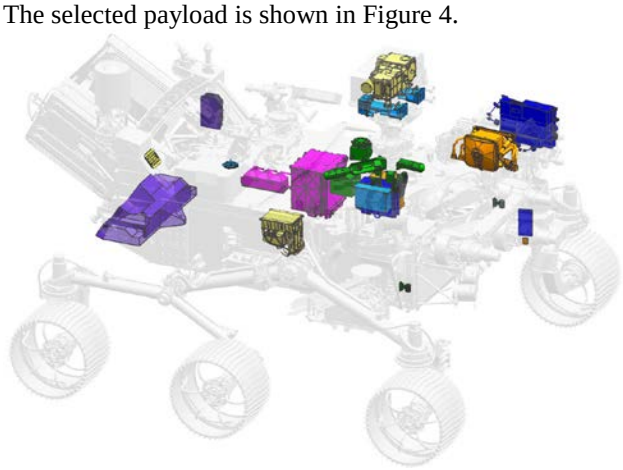

Fig. 4: *Mars 2020 payload locations on the rover*

The following color-coded key identifies each instrument:

Instrument Key
Mastcam-Z Stereo Imager
MEDA Mars Environmental Measurement
MOXIE In-Situ Oxygen Production
PIXL Microfocus X-ray Fuorescence Spectrometer
RIMFAX Ground Penetrating Radar
SHERLOC Fluorescence and Raman Spectrometer and Visible Context Imaging
SuperCam Laser-Induced Breakdown Spectroscopy and Raman Spectroscopy

The payload includes:

- Mastcam-Z, a mast-mounted advanced camera system with panoramic and stereoscopic imaging capability with the ability to zoom. The instrument also will contribute to the determination of mineralogy of the Martian surface and assist with rover operations. The principal investigator is James Bell, Arizona State University in Phoenix.

- SuperCam, a mast-mounted remote sensing instrument that can provide imaging, chemical composition analysis, and mineralogy of rocks and regolith at a distance of a few to a few tens of meters from the rover. SuperCam will also be able to detect the presence of organic compounds in rocks and regolith. The principal investigator is Roger Wiens, Los Alamos National Laboratory, Los Alamos, New Mexico. This instrument also has a significant contribution from the Centre National d'Etudes Spatiales,Institut de Recherche en Astrophysique et Plane'tologie (CNES/IRAP) France.

- Planetary Instrument for X-ray Lithochemistry (PIXL), an X-ray fluorescence spectrometer that will also contain a high-resolution imager to determine the elemental composition of Martian surface materials. PIXL is an arm-mounted proximity instrument that maps elemental composition in an area of about 1 cm^2. The principal investigator is Abigail Allwood, NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California.

- Scanning Habitable Environments with Raman &

Luminescence for Organics and Chemicals (SHERLOC), an arm-mounted spectrometer that will provide high-resolution imaging and uses an ultraviolet (UV) laser to determine fine-scale mineralogy and detect organic compounds in a ~1 cm^2 of rock surface. SHERLOC will be the first UV Raman spectrometer to fly to the surface of Mars and will provide complementary measurements with other instruments in the payload. The principal investigator is Luther Beegle, JPL.

Following the Project SRR / MDR (October 2014), NASA Headquarters augmented the capability of the SHERLOC investigation by including a Wide Angle Topographic Sensor for Operations and eNgineering (WATSON) that: a) augments turret fine-scale imaging capability by adding MSL MAHLI heritage optics to the SHERLOC instrument, and b) provides contextual science and engineering data to the operations teams

- The Mars Oxygen ISRU Experiment (MOXIE), an exploration technology investigation that will produce oxygen from Martian atmospheric carbon dioxide. The principal investigator is Michael Hecht, Massachusetts Institute of Technology, Cambridge, Massachusetts.

- Mars Environmental Dynamics Analyzer (MEDA), a set of sensors that will provide measurements of temperature, wind speed and direction, pressure, relative humidity and dust size and shape. The principal investigator is Jose Rodriguez-Manfredi, Centro de Astrobiologia, Instituto Nacional de Tecnica Aeroespacial, Spain.

- The Radar Imager for Mars' Subsurface Exploration (RIMFAX), a ground-penetrating radar that will characterize the geologic structure of the subsurface. The principal investigator is Svein-Erik Hamran, Forsvarets Forskning Institute, Norway.

LANDING SITE

Eight landing sites for Mars 2020 are currently under consideration, see Figure 5. The selected site must provide clear opportunities to safely and efficiently explore and sample geologically diverse regions with high potential to preserve signs of **ancient** life and planetary evolution.

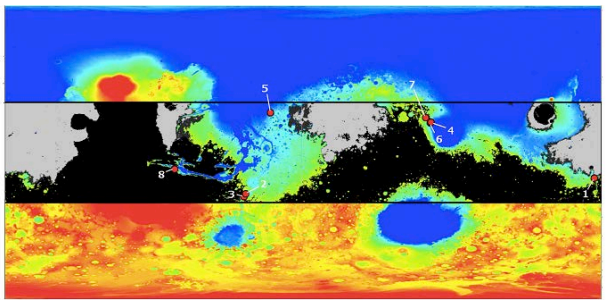

Fig. 5: *Candidate Mars 2020 Landing Sites (need to enlarge figure or otherwise improve visibility of numbers)*

With no mission objective or capability to investigate **extant** life, "special regions" are not under consideration for exploration.

The candidate landing sites (in alphabetical order) are:

- Columbia Hills
- Eberswalde
- Holden
- Jezero
- Mawrth
- NE Syrtis
- Nili Fossae
- SW Melas

The third Mars 2020 landing site workshop will be held Feb. 8-10, 2017, in Pasadena, CA. This and other workshops in the coming years will continue to investigate and rank potential sites contributing to the selection of the ultimate site, probably in 2018.

Detailed information on the candidate landing sites is available at *marsnext.jpl.nasa.gov/*.

KEY CHALLENGES

The key Mars 2020 mission challenges are the development of the new SCS, control of contamination in the collected samples, and achieving all mission objectives within the primary mission duration. Each of these challenges will each be discussed in turn.

SAMPLING AND CACHING SYSTEM

The SCS is shown in Figures 6 and 7. There are four elements of the SCS:

1. An Adaptive Caching Assembly (ACA) that stores sealing plugs and empty and filled sample tubes. The ACA has a station to take images of the tubes at several stages in the caching process, a volume assessment station, a sealing station and a drop-off station. Empty tubes are delivered to the bit carousel and filled tubes are retrieved from the bit carousel.
2. A bit carousel that stores coring and abrasion bits and can rotate any bit into either a position where it can be accessed from the ACA or a position where it can

be accessed by the robotic arm

3. A turret that includes a coring drill, and the PIXL and SHERLOC instruments that require close proximity to Mars surfaces under investigation.
4. A robotic arm used to orient and place the turret close to or on the Mars surface to allow coring drill, PIXL, or SHERLOC observations and to orient and place the coring drill chuck at the opening to the bit carousel to access and change out drill bits

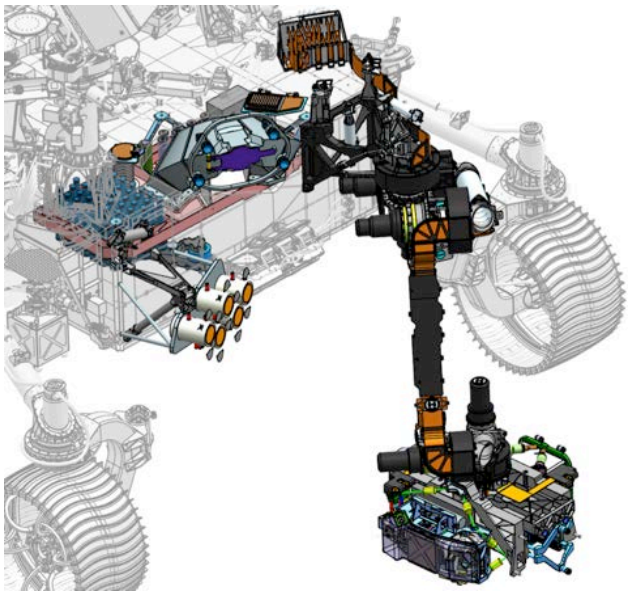

Fig. 6: *Sampling and Caching System on Rover*

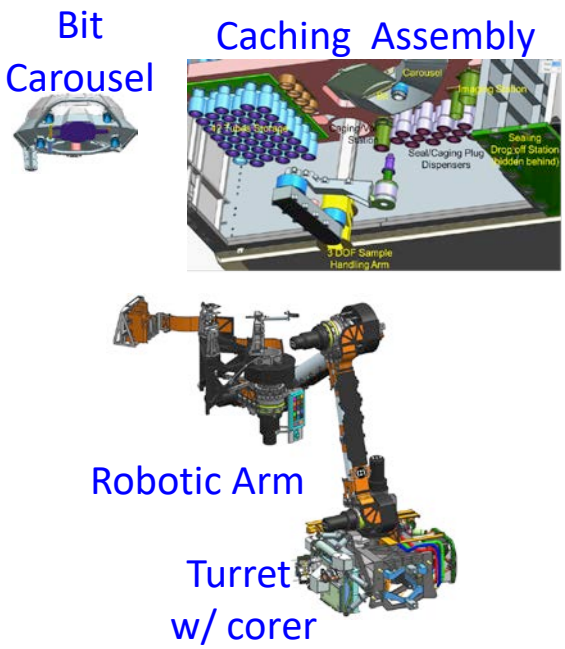

Fig. 6: Elements of the *Sampling and Caching System*

RETURNED SAMPLE CONTAMINATION CONTROL

Although Mars 2020 is not charged with bringing the cached samples back to Earth or studying the returned samples, the project is charged with assuring that any Earth-sourced contaminants that make the round trip from Earth to Mars and back inside the sample tube meet very tight constraints.

These constraints include:

- Assuring a very low probability that any viable (living) Earth organisms are in the sample tubes when they return to Earth
- Limiting the molecular organic contamination in the returned samples. Of special interest are molecules such as amino acids, DNA, glycerol, and naphthalene, although the total organic carbon from these and all other molecules is also constrained.
- Limiting the amount of inorganic contamination that makes the round trip. Separate requirements have been set on the allowable amount of lead, tungsten, cobalt, manganese and about 30 other elements.

EFFICIENT SURFACE OPERATIONS

Curiosity met all its mission objectives during its prime mission, but collected less than one third the number of samples that Mars 2020 is expected to collect during its prime mission. In order to facilitate a higher cadence of sample acquisition, Mars 2020 has made the following changes to design and operations:

Tactical Timeline

On MSL, the operations timeline allows the operations team 11 hours from the time that the telemetry is received from the rover until the time that new commands (informed by that telemetry) need to be ready to be sent up to the rover. On Mars 2020, a target of five hours has been set for this same telemetry-to-command turn-around. This will require improvements in flight software autonomy (so fewer decisions need to be made on the ground) as well as changes to ground software tools and ground system procedures.

Driving Efficiency

On Curiosity, one processor (shared with other functions) performs the computations required for driving. In addition, imaging and planning tasks were performed when the rover was stationary. For Mars 2020, a dedicated processor is available for drive planning computations and imaging and planning tasks are scheduled in parallel with driving. Both of these changes give substantial improvement in the amount of ground that can be covered in one sol.

On Board Autonomy

A simple planner has been incorporated into the surface software design to allow more decisions to be made on the rover. The simple planner has the following

capabilities: real-time (onboard) resource estimation, execution of temperature-triggered wakeups, planning and execution of opportunistic or extendable activities, and pausing activities when a conflict arises (e.g. communications pass) with the option to resume later.

Instrument Pointing

With MSL, images are analyzed on the ground and then commands are sent to the rover to nudge the pointing direction slightly to the desired point on the ground. This is called "closing the loop through the ground," and it requires a significant amount of time. On Mars 2020 closed-loop on-board pointing will be implemented, allowing precision pointing and download of the desired instrument data in a much shorter time.

Prime Mission Duration

Curiosity's prime mission was one Mars year. Mars 2020 is qualifying its hardware for a mission duration of 1.5 Mars years and is currently holding 0.25 Mars years as Project Management reserve, designing operations to achieve all mission objectives in 1.25 Mars years.

FUTURE PATH

The Mars 2020 project has taken advantage of the high heritage of the mission to procure or build some hardware components in the past couple of years. The Project is now in Phase C, with detailed design underway through the scheduled February 2017 Project Critical Design Review (CDR).

Instrument delivery is scheduled for calendar year 2018, followed by instrument integration and test, leading to flight system shipment to Florida in February 2020 and launch from the Cape Canaveral Air Force Station in July or August of 2020. Interplanetary cruise ends in February 2021, targeted at one of the eight candidate sites. As described above, the mission plan is designed to achieve all mission objectives within the prime mission duration.

ACKNOWLEDGEMENTS

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. John McNamee, Matt Wallace, Ken Williford, Mike Wilson, Soren Madsen, and Al Chen of JPL have all made significant contributions to developing the mission description captured in this paper.

The figures in this paper are the work product of the Mars Program office and Mars 2020 managers, engineers, and scientists in preparation for Mars 2020 Project PDR and the NASA Agency Program Management Council key decision point C in 2016.

REFERENCES

[1] Appendix B-11 to the Mars Exploration Program Plan, Program-Level Requirements for the Mars 2020 (M2020) Project, April 27, 2016.