Introduction

What’s next? Curiosity’s results lead to more questions, and to address them NASA launched another mission in summer, 2020. That mission, called simply “Mars 2020” builds on MSL’s experience to change, enhance, and improve the mission and the rover. The Mars 2020 rover is named “Perseverance”, and it carries a helicopter named “Ingenuity.”

First, Mars 2020 will reuse much of the basic architecture and design work that MSL invented. For example, the TDS (Terminal Descent Sensor) landing radar software that MSL developed from scratch was simply copied, and will be reused exactly as it was.

Second, a different type of landing site was chosen, enabled by enhanced landing technology.

Third, the suite of science instruments is changed up. Some are upgrades of MSL instruments with new technology. Others will not be re-flown, having done their job.

Finally, some new instruments have been designed to answer new questions, expanding our understanding of the Red Planet in brand new ways. And additional experiments aim squarely at preparing for human exploration.

EDL (Entry, Descent, and Landing) Technology

In every Mars landing to date, we could only aim at a large landing area, the “landing ellipse,” pre-selected to be “safe enough,” and not to be unlucky enough to hit one of the few known hazards that any large area holds. Hazards include large boulders, or steep crater slopes. The Mars 2020 EDL design adds two great improvements.

1. The landing ellipse is 50% smaller, with the addition of range trigger technology to finely tune parachute-deployment timing. MSL was constrained to select $25 \times 20$ km landing areas; now, many more (smaller) areas are targetable.

2. TRN (Terrain Relative Navigation: see Fig. 12.1) is the new ability to determine in the last minutes that the spacecraft is heading unluckily toward a known hazard, and to divert to a safe spot. This is exactly what Apollo 11 did, on manual control, to avoid a boulder field.


EDL Cameras  Mars 2020 adds a suite of cameras to photograph, for the first time, the dramatic series of high-speed activities that occur far outside our view. Never before have we witnessed a supersonic parachute opening in the Martian atmosphere, the rover being lowered on a tether from its hovering descent stage to the surface, the tether being cut, or the descent stage flying away after rover touchdown. This will be invaluable to future missions improving on the technology. The images should also comprise a fantastic public engagement tool.

Landing Site Imagine studying Earth from only six locations! And all six in “safe to land” areas—say, the Arabian, Gobi, Saharan, Mojave, Atacama, and Tanami Deserts. The EDL technology improvements described above enabled selecting a more challenging but interesting destination. Jezero crater (see Fig. 12.2) includes an ancient lake-delta system, where a variety of rock types have been mixed together over time.

Thinking While Driving The MSL rover can drive itself for short distances by taking pictures and analyzing them on board to find a safe driving path. The analysis takes a long time, and the rover has to stop moving while it computes its next steps. Mars 2020 adds a “FastTraverse” ability to greatly speed up that processing, meaning that the rover need not pause its driving to continue in safety.

You might be thinking about self-driving cars moving along at highway speeds and wondering what’s the big deal. It’s actually quite impressive when you consider that the rover’s computer is far, far less powerful than a car computer, because we traded off computing power for durability to help it survive and work in the vacuum of outer space on the long trip to Mars. Also, self-driving cars have the benefit of paved roads, painted lines, and GPS (Global Positioning System) satellite signals; they would not survive the unmarked terrain of Mars.
Wheel Redesign  Early in Curiosity’s surface mobility, route planners avoided slippery sand and stayed on solid, rocky ground to keep firm footing and make the best progress. Yet over time, the aluminum wheels accumulated much more damage than expected. And not just a few spots thinning out—large holes became ripped out. Fig. 12.3 shows pictures of the same wheel surfaces taken several weeks apart. Note the gaping holes appearing over time, as though punched out with a juice can opener. That’s not good; it would be difficult to rove without wheels. Nothing in the planning or test campaign predicted this level of wear so soon in the mission. It had not been observed on previous rovers.

So first, the drivers switched to preferring soft sand over hard pointy rocks. Second, the engineers mounted a fierce effort to reproduce the damage with test wheels on Earth, to understand what was causing it. And third, the operations team re-planned the overall route to avoid the kind of ground now known to be hazardous.
In direct response to this harrowing experience by Curiosity, Perseverance will sport thicker, more durable aluminum wheels, with reduced width and a greater diameter (52.5 cm) compared to MSL’s (50 cm) wheels.

**Coring Drill and SCS (Sample Caching System)** Both MSL and Mars 2020 carry drills to get at material from the interior of rocks. MSL’s *percussive impact* drill grinds the rock to powder and gathers it up as it goes, and then delivers that powder to instruments in the rover body for analysis. Afterwards, the powder is dumped out to clear the way for the next sample.
We can learn much more about, and from, the rocks of Mars if we can bring samples home. Laboratories on Earth of course have a greater variety of more powerful instruments than any rover could possibly carry.

Mars 2020 includes a coring drill, which is hollow, sculpting out cylinders of rock to place in sample tubes for a still later potential mission to retrieve and bring to Earth. It will be extremely important, and tricky, to keep these few dozen samples pristine, so that they represent Mars and not contamination from Earth picked up along the way.

The Mars 2020 SCS is a complex set of robotic components to accept those possibly broken rock cylinders from the coring drill, seal them inside rugged tubes, and store the tubes inside the rover. Over many months, individual samples will be collected at differing sites as the rover explores Jezero crater. Eventually one or more depot locations will be chosen where the samples will be disgorged and left on the surface, so a later mission could pick them up from one place without repeating the lengthy exploration.

**Mars 2020 Science Instrument Changes**

Many of the instruments on the Perseverance rover have changed due to operational experience, new specific goals and advances in technology (see Fig. 12.4).

![Mars 2020 Rover](image)

**Fig. 12.4** Mars 2020 Science Instruments. (Image courtesy NASA)
Mars Environmental Dynamics Analyzer (MEDA) MSL’s REMS (Rover Environmental Monitoring Station) instrument passes its legacy, via the Insight Mission’s TWINS (Temperature and Wind for InSight) package, on to Mars 2020’s MEDA. MEDA is a set of sensors that measure temperature, wind speed and direction, pressure, relative humidity, radiation, and dust size and shape.

One of MSL’s lessons learned is how much dust and debris are kicked up in the final seconds of landing. The REMS wind sensor, we believe, was damaged at touchdown by that grit-storm and its results have been degraded ever since. MEDA’s design is therefore modified based on our better understanding of the landing environment.

MastCam-Z Mars 2020 adds a zoom lens to the MSL Mastcam, and otherwise uses this excellent camera design as-is. The zoom lens allows us to gather higher resolution pictures around a site without time-consuming driving in all directions.

SuperCam MSL’s ChemCam (Chemistry and Camera instrument) vaporizes tiny samples of rocks, analyzing the resulting plasma blast to determine what elements were in the sample. A black-and-white camera provides context for the sample used. Mars 2020 upgrades the black-and-white camera to color, and additional lasers and spectrometers allow analysis not just of elements, but of minerals and molecules.

PIXL (Planetary Instrument for X-ray Lithochemistry) MSL’s CheMin performs X-ray spectroscopy on ground-up samples of rock powder. That is, the drill bores into a rock, and delivers the dust to CheMin, which is mounted inside the rover body.

On Mars 2020, PIXL is mounted at the end of the very long arm, analyzing minerals by scanning across a rock, thus gaining knowledge not only of what is there, but where different minerals are relative to each other.

SHERLOC (Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals) and WATSON (Wide Angle Topographic Sensor for Operations and Engineering) MSL’s MAHLI (Mars Hand Lens Imager) self-focusing color camera, with white-light and ultraviolet light sources, examines fine detail on surface rocks. Mars 2020 adds to that spectrometers and a laser to gather a wider breadth of information. Also, SHERLOC carries small pieces of spacesuit material to examine over time, gathering data on how they hold up in the harsh Martian environment—valuable things to know for future astronauts!

New Science Instruments

(New!) RIMFAX (Radar Imager for Mars’ Subsurface Experiment) You can’t judge a book by its cover, and you can’t understand a planet by just its surface. Ground-penetrating radar is a way to look beneath the surface and see how multiple layers of material, whether rock, sand, ice, or water, etc. lie on top of each other. NASA’s Mars Reconnaissance Orbiter flies the SHARAD (Shallow Radar) instrument to see such changes over very large areas.
As Perseverance roves across the surface, its RIMFAX will peer down through the ground beneath it. RIMFAX can detect ice, water or salty brines of more than 30 feet (10 meters) beneath the surface of Mars.

(New!) MOXIE (Mars Oxygen In-Situ Resource Utilization Experiment) Humans are fond of breathing, and to do that you need O₂ (oxygen molecules). Sadly, Mars has less than a fraction of a percent as much O₂ in its atmosphere than Earth has. This has not been a problem so far, as all missions to Mars have been with robots.

Future missions landing astronauts on Mars may fill the need by breaking apart CO₂ (carbon-dioxide) molecules from the Martian air into plain C (carbon) and the needed O₂. Perseverance’s MOXIE will be the first demonstration of this life-preserving technology on another planet. We need to know how much O₂ we can generate, and how much that varies depending on the air temperature, pressure, and how clear or dusty the incoming air is. MOXIE will characterize how well the process works over day/night cycles, over seasons, and during dust-storms.

Because there are no humans on board this mission to use the O₂ generated, MOXIE will simply vent it back outside. Those future missions will need to build on MOXIE’s experience to figure out how much O₂ they can make, and how fast, at what energy cost. They will also need to work out how to store it.

(New!) “Ingenuity”, the Mars Helicopter Scout The first heavier-than-air vehicle to fly on Mars! Quoting the NASA website, “The Mars Helicopter is considered a high-risk, high-reward technology demonstration. If the small craft encounters difficulties, the science-gathering of the Mars 2020 mission won’t be impacted. If the helicopter does take flight as designed, future Mars missions could enlist second-generation helicopters to add an aerial dimension to their explorations.”

Summary

The MSL and its rover, Curiosity have been and remain a fantastic mission—a technological marvel, and a scientific bonanza. She has taught us much about Mars, and by comparison, about our own world. The Mars 2020 rover, helicopter, and its new Entry, Descent, and Landing capability seek to be a worthy successor; capitalizing on rather than repeating what MSL has accomplished. Where similar observations of a new location make sense, the instruments have been improved. Where MSL observations prompted new questions, new types of instruments have been created.

Despite all the advancements, the instruments we can miniaturize and make work on a distant planet cannot compare to what can be accomplished with larger, more power-hungry instruments here at home. For example, while MSL and Mars 2020 each can tell us something about a rock’s elements and molecules, neither can tell us what isotopes of potassium are present in what ratios. On Earth, we could do an isotope analysis, measuring not only what elements are present but how many neutrons (sub-atomic particles) they have, and that serves as a reliable clock for how long the rock material has been decaying since it was formed. Also, on Earth we do much finer microscopic analyses of interior grain structures from extremely thinly sliced rock samples, which helps us understand the conditions (wet vs. dry, under how much pressure, etc.) under which they were formed.

Mars 2020 will prepare a diverse cache for a planned future sample-return mission to bring to Earth, forging the next link in a chain of exploration.
Coronavirus and Remote Work

What does it mean to “work remotely?”

From the moment a Mars rover launches from Earth, your workplace is already as remote as it gets! But being remote from your team is something else again. The hundreds of MSL scientists working together while physically distanced from each other succeed through coordination with a much smaller group based at JPL. That small team is usually all in a single room, coordinating and distilling multiple conversations into a single set of commands for the rover. On March 20, 2020, in response to the Coronavirus outbreak, for the first time none of the team was present at JPL. They say it’s taken some getting used to. Each day’s planning takes longer than before to get the job done. This first all-remote activity drilled a rock sample at the “Edinburgh” location on sol 2713.

Once again, Curiosity has led the way that Perseverance is to follow. Yet the challenges are different. The shift to teleworking came just four months before Perseverance’s July launch—a high-pressure time in the best of circumstances. The planets have to be aligned—literally—for launch: we get a three-week window every 26 months. To make that deadline takes a lot of hands-on work, both with the flight hardware at the launch site in Florida, and with the test-model copies at JPL in California.

Spacecraft components (launch vehicle, cruise stage, descent stage, and rover) were still arriving at the KSC (Kennedy Space Center) launch site as the team converted over to 90% teleworking. The well-named Perseverance mission became the highest priority within NASA, without compromising personnel safety. Those performing mission-essential on-site work were already well-trained and accustomed to wearing masks and other gear to protect the hardware; they updated the procedures to protect each other from virus and kept on working. As of this writing, the spacecraft has launched and is on target to land on February 18, 2021.

How would the Mars 2020 launch have been affected if the pandemic had hit a year earlier, when there was still flight hardware being assembled and tested at JPL? Impossible to say. But the team would have wanted to persevere.

I would like to thank the NASA outreach folks, the Planetary Society, and Wikipedia for making all of the great information above publicly available. The material in this chapter is drawn from the following public websites:

- https://mars.nasa.gov/
- https://science.nasa.gov/technology/technology-stories/Computing-Advances-Enable-New-Rover-Red-Planet
- https://www.nasa.gov/press-release/nasa-announces-landing-site-for-mars-2020-rover
- https://www.nasa.gov/feature/jpl/a-neil-armstrong-for-mars-landing-the-mars-2020-rover
- https://pds.nasa.gov/ds-view/pds/viewProfile.jsp?dsid=MSL-M-REMS-4-ENVRDR-V1.0
- https://mepag.jpl.nasa.gov/reports/iMOST_Final_Report_180814.pdf
- https://nasapeople.nasa.gov/coronavirus/
- https://www.planetary.org/blogs/emily-lakdawalla/2014/08190630-curiosity-wheel-damage.html
- https://en.wikipedia.org/wiki/Mars_2020

In addition, there is material from “Heavyweight Quality, Agile Methods” by DJ Byrne, the keynote presentation for the Agility in Flight Mini-Workshop, 2019 IEEE International Conference on Space Mission Challenges for Information Technology, Pasadena, California.