# Riding the Red Planet

## Perseverance traverses Mars to answer questions about the future of space exploration

Matthew Jaster, Senior Editor

*This image shows parts of the robotic arm on NASA's Perseverance rover flexing and turning during its first checkout after landing on Mars. Photo courtesy of NASA/JPL-Caltech.*

Mistakes happen. We can pore over the details 120 times, yet errors can still slip through the cracks. This is how the wrong MLB player appears in a photograph on the cover of a Chicago newspaper or why a public relations department begs political figures to 'stay on script' to avoid viral video clips. Fortunately, we can fix these errors by publishing a new version of an article or retaping a video interview. I thought about this in great length as I watched the Perseverance Mars rover landing back in Feb. 2021.

There are no second chances in a project of this magnitude. At the time, you could see it on the faces of all the NASA employees watching the landing from Mission Control. If you were involved in any technical aspect of the rover mission, there was little to do but watch, observe, breathe, and hope for the best.

The level of uncertainty and panic in that moment was felt far beyond Mission Control. Engineers and manufacturers across the globe were involved in Perseverance's drive system, controls, electronics, robotics, etc. Miraculously, the rover landed without complication. Today, it continues to ride around the red planet collecting data, soil samples and giving Earth new insights on our solar system.

### Making Another Trip to Mars

I sat down with Forest City Gear's Fred Young back in 2012 to discuss his team's work on the Curiosity rover. Back then, he was thrilled the FCG staff was participating in a groundbreaking engineering experience.

"It's exciting, it's challenging and most importantly it's a great learning experience," Young said at the time. "To imply that we had a major role in this project is a considerable leap of faith, but bottom line, the gears had to work and the Jet Propulsion Laboratory (JPL) had to select the best ones to make the trip."

Fast forward to the Mars 2020 Perseverance rover and FCG was tasked with supplying and creating components for nearly every actuator on the vehicle including the drive systems, articulating arms, science drills, and camera focal gear sets. The components were planetary gears, sun gears, single and multi-stage housings, and armature shafts.

*Forest City Gear was tasked with supplying and creating components for nearly every actuator on the vehicle including the drive systems, articulating arms, science drills, and camera focal gear sets. Photo courtesy of FCG.*

"What's most memorable about the project is the realization that you are working on parts that will be going to Mars," said Jared Lyford, director of manufacturing operations at FCG. "As you work through the project, no matter what level, you get wrapped up in the nuances of your responsibility in that moment. Then, at some point you stop and realize, this particular item is going to Mars to do very specific and unique work. This is not a commodity and is very much a one-off. You really appreciate being part of something much larger than your own contribution."

Lyford said that the rover programs leverage as much previous design elements as possible. "This allows for efficiencies to be had in tooling design and production. The customer's requirements tend to become more sophisticated over time, and there are always a few new challenges, by way of part design, to keep things interesting," Lyford added.

He said the most difficult part of the latest rover project was program management. The development of the process plans and associated engineering requirements was very rigorous. Combining that with the project management required to track through process development and into production made it even more demanding.

"The timing required to meet a production end goal is critical as the components need to be delivered in order for the actuator assembly, test, and final build," Lyford said. "The culmination of all of this must align with NASA's launch timing. There is a very specific window for the entire project to be finalized. If that window is missed, I believe it was approximately two years for the next launch window due to Mars' and Earth's alignment."

Lyford has enjoyed following the exploits of Perseverance since the landing. "I recall this being very exciting. You almost hold your breath as you feel so connected to the project and its success. The moment the rover landed on the surface of Mars, the entire company celebrated. The enthusiasm was similar to what you see in Mission Control while watching it live!"

The FCG team understood the challenges they faced during these historical aerospace programs and are consistently working to improve operations to address projects in the future.

"FCG is preparing by remaining current in both technology and training. It's our dedication to human resources and the latest equipment that allows us to perform for customers with 'out of this world' challenges," Lyford said.

**forestcitygear.com**

## High Level Engineering Expertise

Robin Phillips, head of maxon SpaceLab, discussed the company's role with Perseverance and the unique helicopter, Ingenuity. Motors and gearboxes were provided by maxon for the project including seven motors and one gearbox inside the rover, two motors on the science arm and one motor utilized for helicopter deployment. Ingenuity needed six maxon DC motors to control the movement of the vehicle.

"Our customer (JPL/NASA) pushed us to develop the highest technology actuators we are capable of," Phillips said. "When you take on a project like this you know you will always have some issue you didn't think of at the beginning—the known unknowns—solving these issues as they arise is a key part of the project management work (as examples, this can be a design that doesn't assemble as we had expected, or a part that turns out to be harder to manufacture than we expected, or some failure that occurs in testing)."

The organizational aspects of running projects like this within a company set up for mass production is also a challenge.

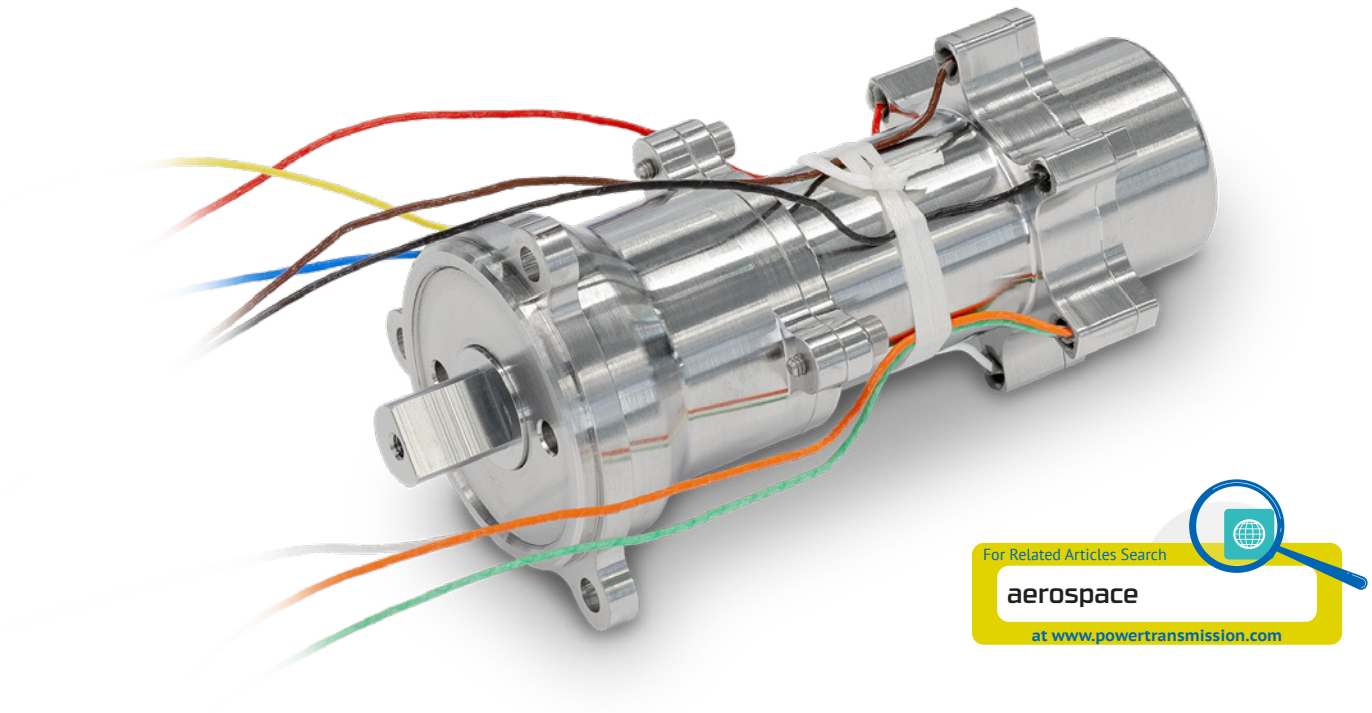
"This needs a different skill set from the assembly staff. It causes projects like the Mars rovers that need special production runs and a high level of engineering input to be viewed as disruptive for the main work of the company," Phillips added. "Our solution has been to copy the well-known Lockheed 'Skunk Works' organizational structure where a small team is broken out from the main company and can work independently whilst still tapping into the knowledge and resources of the main company. This is our SpaceLab."

When maxon started doing these projects nearly 30 years ago, JPL would tell the company what to change in the designs and monitored every production step.

"Then about 15 years ago when we started working with the European Space Agency (ESA) for ExoMars we decided to try and learn all the necessary processes on how to design and build space standard actuators ourselves. This was a painful process where we had to learn by making mistakes," Phillips said. "Now I think we know what we are doing at a basic level, but each new project then brings new challenges at the detail level. Using these new technologies (design features, material, manufacturing processes) that we already know will work in such applications and environments, allows us to increase our reliability and focus on more complex products/projects."

While the pressure and technical challenges can be harrowing, Phillips and the maxon team learned to embrace the unknown.

"Since we spend so much of our life at work, I am very much of the opinion we need to enjoy our time at work! In the case of the Mars 2020 mission (Perseverance and Ingenuity) it was working with the JPL team, who are the world's best spacecraft mechanism engineers, that I enjoyed





*Motors and gearboxes were provided by maxon for the project including seven motors and one gearbox inside the rover, two motors on the science arm and one motor utilized for helicopter deployment. Photo courtesy of maxon.*

the most. They are a great bunch of people with whom we got on with very well both at a professional and a personal level. They spent a total of several months in Switzerland over three years and we spent a lot of time with them both in and out of maxon."

The EDL sequence (Entry, Descent and Landing) is not called the "7 minutes of terror" for nothing. The sky crane design that puts the rover down on the surface of Mars is a technological tour-de-force but has so many steps that can go wrong that you can't help but be incredibly nervous until you see the signal that says the rover has made it down in one piece. "It's a rollercoaster ride where you breathe a sigh of relief as every key step occurs, only to immediately transition back to nervous anticipation for the next step," Phillips said.

As to the products delivered, knowing that Perseverance's critical sample handling system has now worked for over a year on Mars is the greatest satisfaction, according to Phillips. "It means all the work we put in over those years has paid off. In the case of our Ingenuity motors, as is the case for the entire helicopter, they have exceeded our wildest expectations of how well they would work and how long they would last," he added.

The maxon SpaceLab will continue to participate in exciting space science and exploration missions such as the Mars Sample Return program and the upcoming Artemis manned lunar mission. The company will also become the "go to" actuator supplier for the "new space" commercial satellite industry.

For the commercial opportunities, Phillips noted that the revolution in access to space caused by SpaceX and its competitors finding ways to reuse their launches and hence lower the cost of access to space by an order of magnitude is opening new markets.

"We are positioning ourselves as an actuator supplier for this new and growing market by creating a catalog of standardized space-rated motors, gearboxes, and encoders. These are being qualified against representative specifications by us and will then be available as stock items that can be purchased at much lower prices than custom designs and with much shorter lead times. We believe this will fulfill the needs of this new industry where numerous startups are trying to disrupt what has become a very conservative market."

**maxonworld.com**

## A Little Motion Control on Mars

Cobham Advanced Electronic Solutions (CAES) actuators drive the Perseverance rover wheels and provide steering motion, move the high-gain antenna, and perform remote sensing mast deployment. CAES actuators and radiation hardened (RadHard) microelectronics are currently working to understand Mars' atmosphere and geology, in addition to seeking signs of ancient microbial life.

They are also featured in the instrument pack designed by Malin Space Science Systems. The Perseverance rover's electronics and payloads are based on the CAES UT699 LEON microprocessor, which handles the computing functions for the motor controls as well as the UT54LVDS217 LVDS Serializer, UT54LVDS218 Deserializer and a variety of memory devices.

Space is one of the key passions for the CAES engineering team. The company worked previously on the NASA Mars Curiosity mission where CAES actuators and radiation

hardened integrated circuits completed a 350-million-mile journey and three years of daily tasks while withstanding the challenges of the grueling Martian atmosphere, including -120°C temperatures and a volatile dust environment.

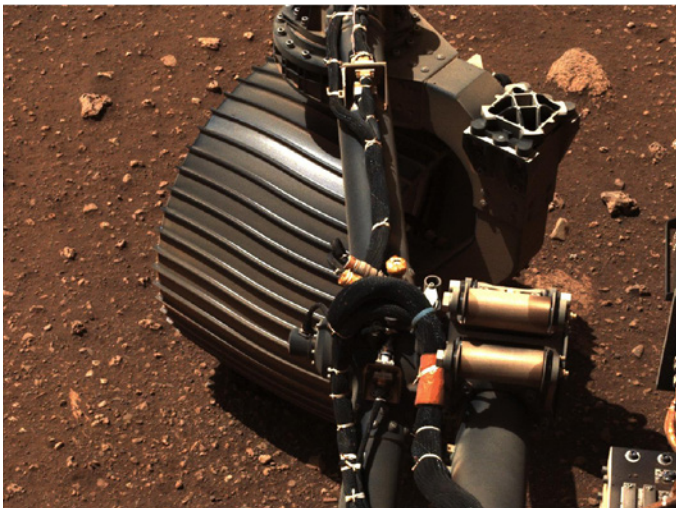
"CAES is honored to serve on the Perseverance Mission and explore Mars once again," said Mike Kahn, president and CEO, CAES. "Our components on the rover are designed specifically for the extreme environmental conditions ahead. We are excited to watch the mission unfold and to continue pioneering electronics that cultivate the future of space exploration."

caes.com

## Research, Research, Research

While we've discussed some of the technology found in previous missions to Mars in *PTE* (powertransmission.com/search?q=mars) here is some data on what the latest rover is carrying:

- Mastcam-Z is an advanced camera system with panoramic and stereoscopic imaging capability with the ability to zoom.
- SuperCam is an instrument that can provide imaging, chemical composition analysis, and mineralogy at a distance.
- Planetary Instrument for X-ray Lithochemistry (PIXL) is an X-ray fluorescence spectrometer and high-resolution imager, which maps the fine-scale elemental composition of Martian surface materials.
- Scanning Habitable Environments with Raman & Luminescence for Organics and Chemicals (SHERLOC) is a spectrometer providing fine-scale imaging and uses an ultraviolet (UV) laser to map mineralogy and organic compounds.
- The Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) is a technology demonstration producing oxygen from Martian atmospheric carbon dioxide.



*NASA's Perseverance rover wiggles one of its wheels in this image obtained by the rover's left Navigation Camera. Photo courtesy of NASA/JPL-Caltech.*

- Mars Environmental Dynamics Analyzer (MEDA) is a set of sensors providing measurements of temperature, wind speed and direction, pressure, relative humidity, and dust size and shape.
- The Radar Imager for Mars' Subsurface Experiment (RIMFAX) is a ground-penetrating radar providing centimeter-scale resolution of the geologic structure of the subsurface.

In a few years, NASA and the JPL will conduct the next rover mission. Someone, somewhere on a shopfloor will be watching with great anticipation, hoping the gears, motors, actuators, and controls exceed expectations. Mistake-free engineering; just another day at the high stakes, industrial office.

Interested in following the exploits of Perseverance as it navigates Mars? Check out the *Mission Rover* update blog at *mars.nasa.gov/mars2020/mission/status/* to learn the latest exploration news and research.

PTE


*Members of NASA's Perseverance rover team react in mission control after receiving confirmation the spacecraft successfully touched down on Mars, Thursday, Feb. 18, 2021, at NASA's Jet Propulsion Laboratory in Pasadena, California. Photo courtesy of NASA/Bill Ingalls.*