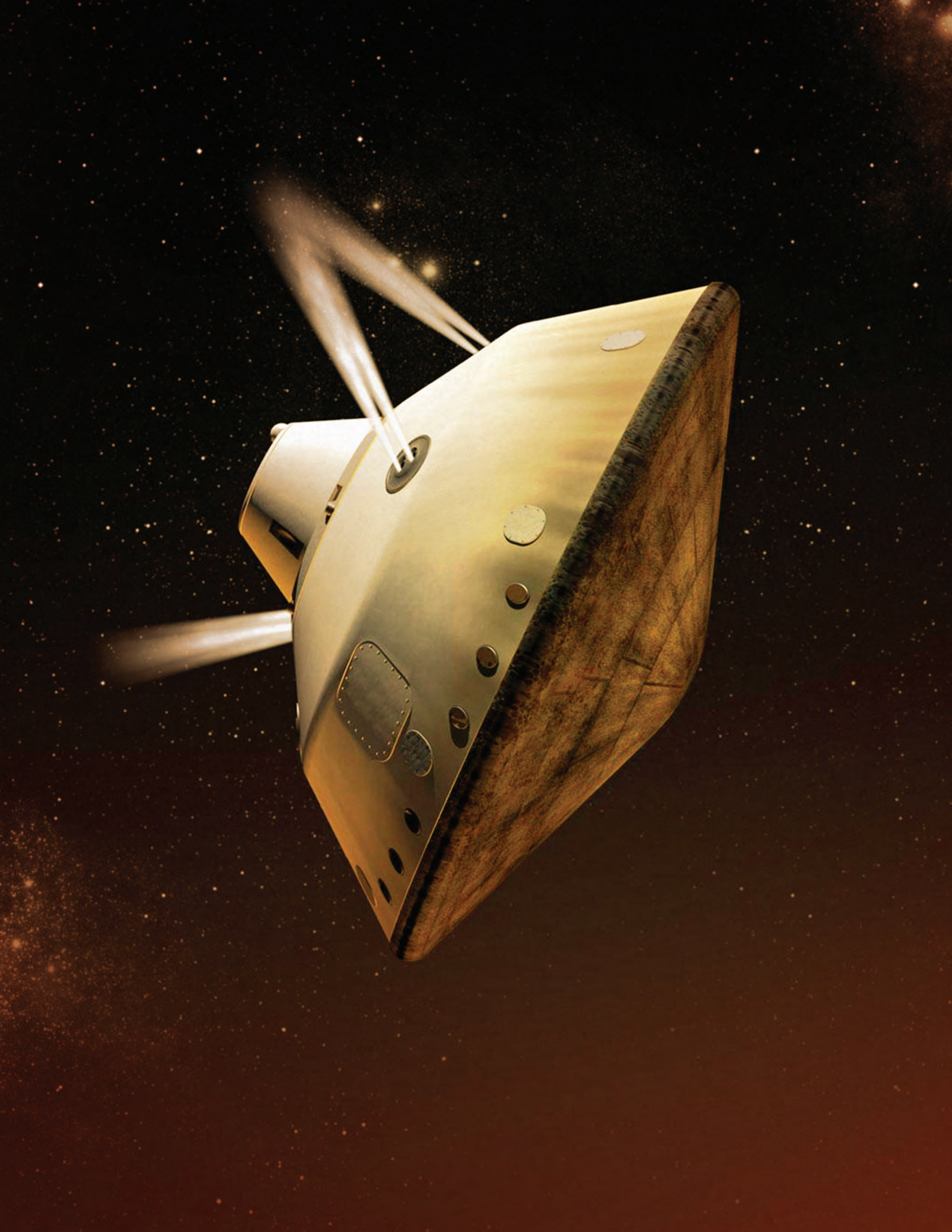
National Aeronautics and Space Administration

CURIOSITY AND NASA'S MISSION TO MARS: A CASE FOR SMALL BUSINESS

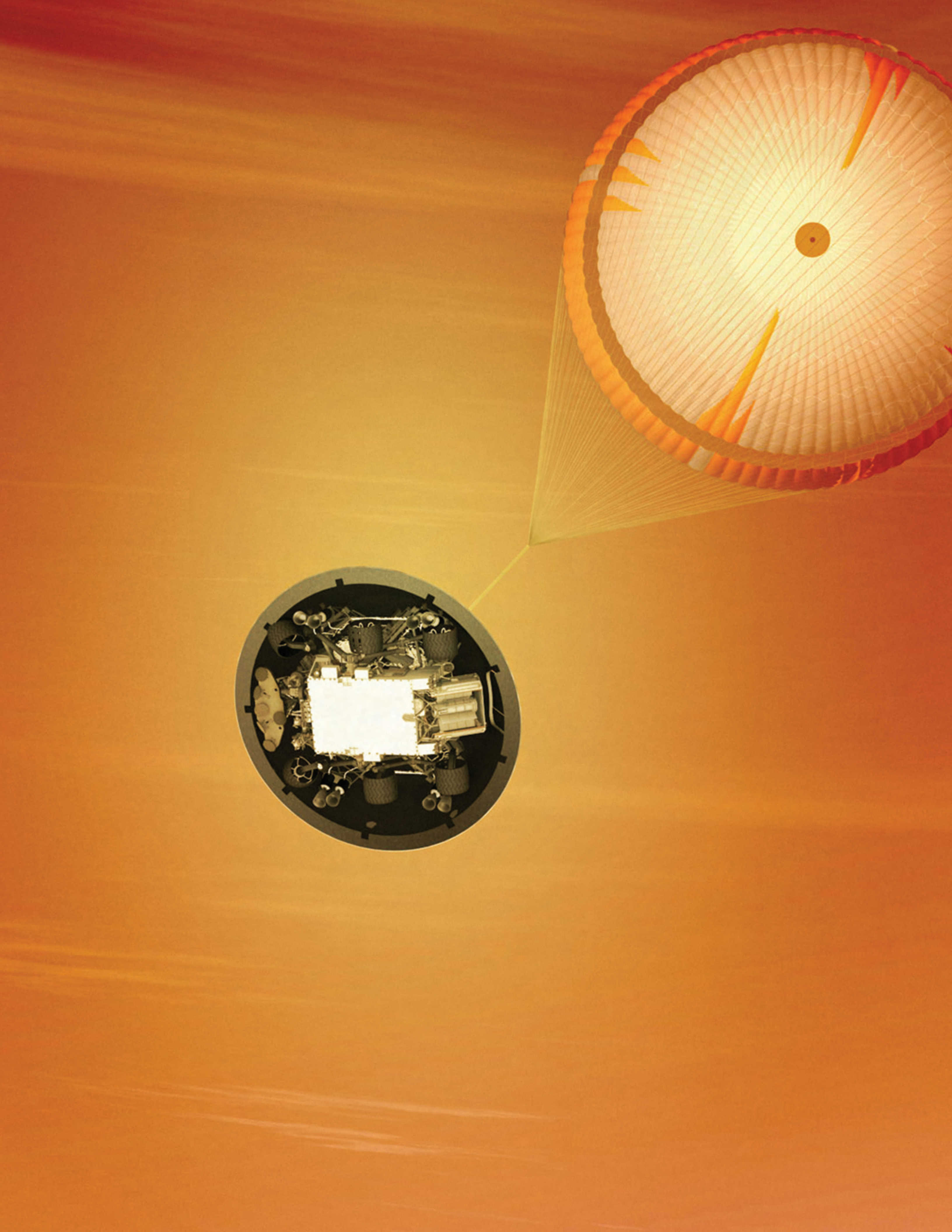
NASA OFFICE OF SMALL BUSINESS PROGRAMS

where small business makes a big difference



WHERE SMALL BUSINESS MAKES A BIG DIFFERENCE

Table of Contents



U.S. Small Business Administration Congratulatory Letter

I want to congratulate everyone involved in the historic landing of NASA's Curiosity rover on Mars. The success of this mission is a testament to American innovation and ingenuity and to our enduring drive to explore new frontiers.

As President Obama said, "The successful landing of Curiosity—the most sophisticated roving laboratory ever to land on another planet—marks an unprecedented feat of technology that will stand as a point of national pride far into the future."

From the amazing people at NASA to the private-sector businesses who helped build the innovative technology and components, this truly was a team effort. In particular, I want to recognize the small businesses that were part of this mission.

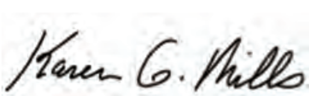
Whether it's the camera system built by Malin Space Science Systems that showed us the first breathtaking images from the landing or Litespeed Bicycles in Tennessee that helped build Curiosity's titanium suspension arms, these small businesses not only are making an impact in markets in the U.S., but, as *Inc.* magazine wrote, they were able to make their mark 154 million miles from Earth.

These businesses embody the entrepreneurial spirit, the drive, and the ability of America's small businesses to build groundbreaking tools and parts that help make even the most sophisticated projects successful. This mission is a shining example of what is possible when America's small businesses are given the chance to do what they do best.

At the SBA, we oversee the nearly $100 billion in Federal contracts that go to America's small businesses each year. It's one of the Federal Government's most important small business programs. All over the country there are small businesses that have the skills, the expertise, and the vision to assist in tackling the most challenging public- and private-sector projects.

As you consider your contracting priorities and the strength of your supply chain, I urge you to look to America's small businesses. As was evident in the recent Mars mission, they get the job done.

Warm regards,



Karen G. Mills
Administrator
U.S. Small Business Administration

From the National Aeronautics and Space Administration Administrator

Small business represents the best of the American spirit of innovation. These entrepreneurs have displayed the drive needed to solve problems and create capabilities that have helped our Nation reach the Moon, launch great observatories, and enable humans to live and work in space, possibly indefinitely. Small businesses and entrepreneurs employ half of America's workers and create two out of every three new jobs. They're an essential part of our economic engine and a critical part of President Obama's vision for NASA.

NASA is focusing again on the big picture of exploration and the crucial research and development that will enable the missions of tomorrow. Those missions will take us farther than we've ever been—ultimately, a human mission to Mars. The successful landing on Mars of the Mars Science Laboratory with the Curiosity rover is an important step toward that goal becoming a reality.

The dedicated and mission-focused work of our small business partners has been essential to Curiosity's ongoing success story, and I'm especially proud of NASA's work with them. Curiosity is the largest rover that has ever been sent to another planet and will provide invaluable data regarding Mars that will benefit the scientific community for years to come. Small businesses helped support the design and fabrication of Curiosity and also took part in many other activities that made the mission possible.

Due to the hard work of everyone in the Agency, NASA exceeded our small business goal for fiscal year 2011. NASA was one of only three of the "big seven" Federal agencies—the ones that together spend approximately 90 percent of small business–eligible dollars—that exceeded its small business goals. Approximately $2.5 billion in prime contracts was awarded directly to small businesses in 2011, and that's up about $75 million from the previous year. Our large prime contractors awarded approximately $2 billion in additional subcontracts to small businesses in fiscal year 2011. This clearly shows how committed we are to the small business community and how important they are to our Nation continuing to remain the leader in space exploration.

Small businesses are critical partners in NASA's work to create that future, and together we're opening the next era of space exploration. I want to thank the small business community for your hard work with the Mars Science Laboratory/Curiosity mission. Your contributions are one of NASA's most valuable assets, and each day you're helping us to create the world's strongest space program.

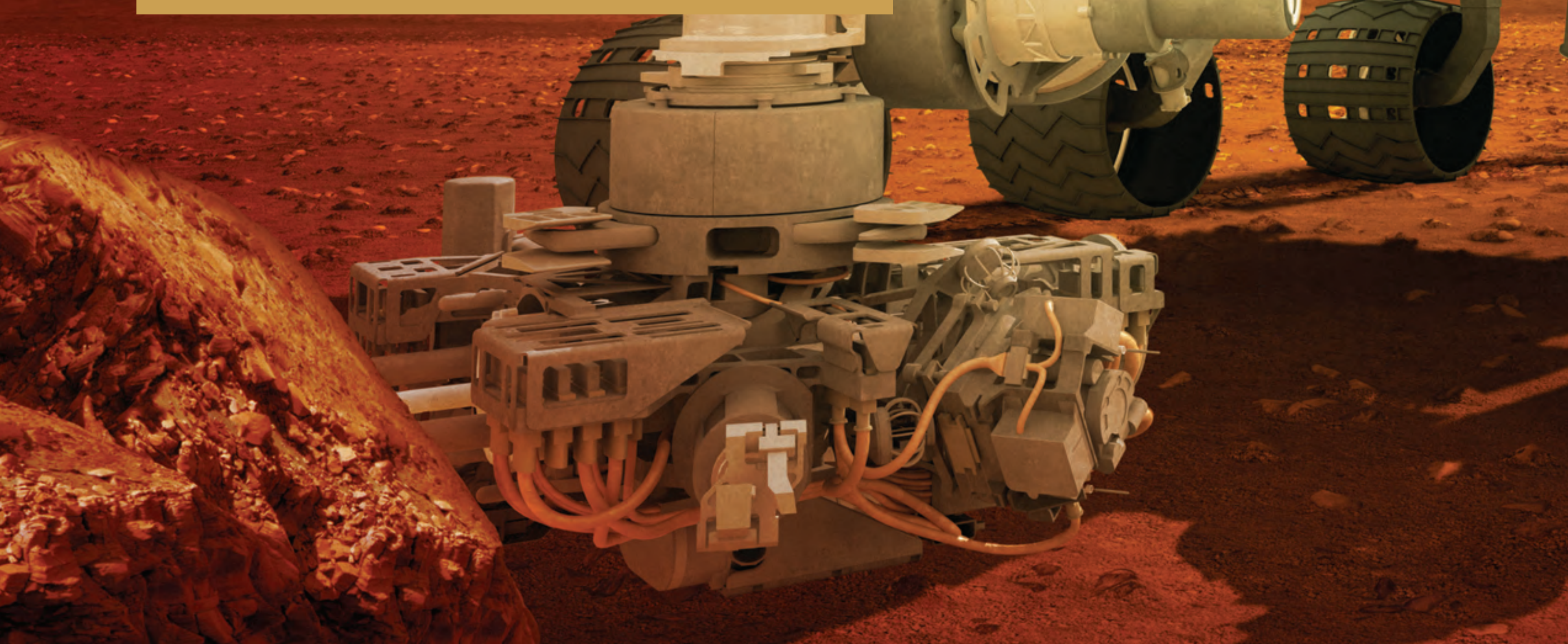
Charles F. Bolden, Jr.
Administrator
NASA

VISION STATEMENT

The vision of the Office of Small Business Programs at NASA Headquarters is to promote and integrate all small businesses into the competitive base of contractors that pioneer the future of space exploration, scientific discovery, and aeronautics research.

MISSION STATEMENT

- To advise the Administrator on all matters related to small business,
- To promote the development and management of NASA programs that assist all categories of small business,
- To develop small businesses in high-tech areas that include technology transfer and commercialization of technology, and
- To provide small businesses with maximum practicable opportunities to participate in NASA prime contracts and subcontracts.



Message to the Nation

I am proud to highlight in this booklet just a few of the numerous companies that played significant roles in the National Aeronautics and Space Administration (NASA) success in landing the Mars Science Laboratory (MSL), aptly named Curiosity. On Sunday, August 5, 2012, 10:30 p.m. Pacific time, when Curiosity landed on Mars, I personally felt the same wave of patriotism and excitement as most of the country.

When I thought of the amazing accomplishment NASA had just completed and all of the diverse, hard work it took to design, fabricate, and launch the largest rover mankind ever deployed to explore our universe, I felt the need to highlight the small businesses involved. As the Associate Administrator of the small business programs at NASA, I personally know that our slogan, "Where Small Business Makes a Big Difference," is not just a saying. NASA's small business program is strongly supported by senior managers, NASA Mission Directorates, and all personnel involved in the acquisition process and in the Mission Support Directorate. I have to especially recognize Administrator Bolden; Mr. William McNally, Assistant Administrator, Office of Procurement; the Center Directors; the Procurement Officers located at each of the Centers; and, especially, all of the Agency's Small Business Specialists for making NASA's small business programs the best in the Federal Government. I also need to recognize the Business Opportunity Office and the engineers and management at the Jet Propulsion Laboratory for ensuring that companies like the ones in this publication have the opportunity to prove that small businesses have the technical skills necessary to complete one of NASA's most complicated missions. I won't repeat all the numbers that are addressed in Administrator Bolden's letter; however, they do support my point.

The small businesses that you'll read about in this book are just a few of the examples of the numerous high-tech firms that enable NASA to complete our various missions. Working with our technical personnel and procurement personnel, the Small Business Specialists work very hard to locate and work with small businesses. These companies prove that when they get the opportunities to demonstrate their capabilities, they can get the job done. The Small Business Specialists at the Centers work very hard to ensure that small businesses are discussed in the very early stages of the acquisition process so that they have maximum practicable opportunities for NASA prime contracts and subcontracts.

In closing, I want to thank these companies, and those I failed to mention, for the work they did in making the Curiosity mission such a success by providing their unique technical capabilities to this very important NASA mission. I would also like to thank the other small businesses that support NASA every day in various capacities and that allow us to function on a daily basis. Without this type of support, NASA would not be able to accomplish feats such as the Mars Science Laboratory.

Glenn A. Delgado
Associate Administrator
NASA Office of Small Business Programs

The Metrics: Small Business Achievements at NASA

NASA AGENCY **FISCAL YEAR 2012**

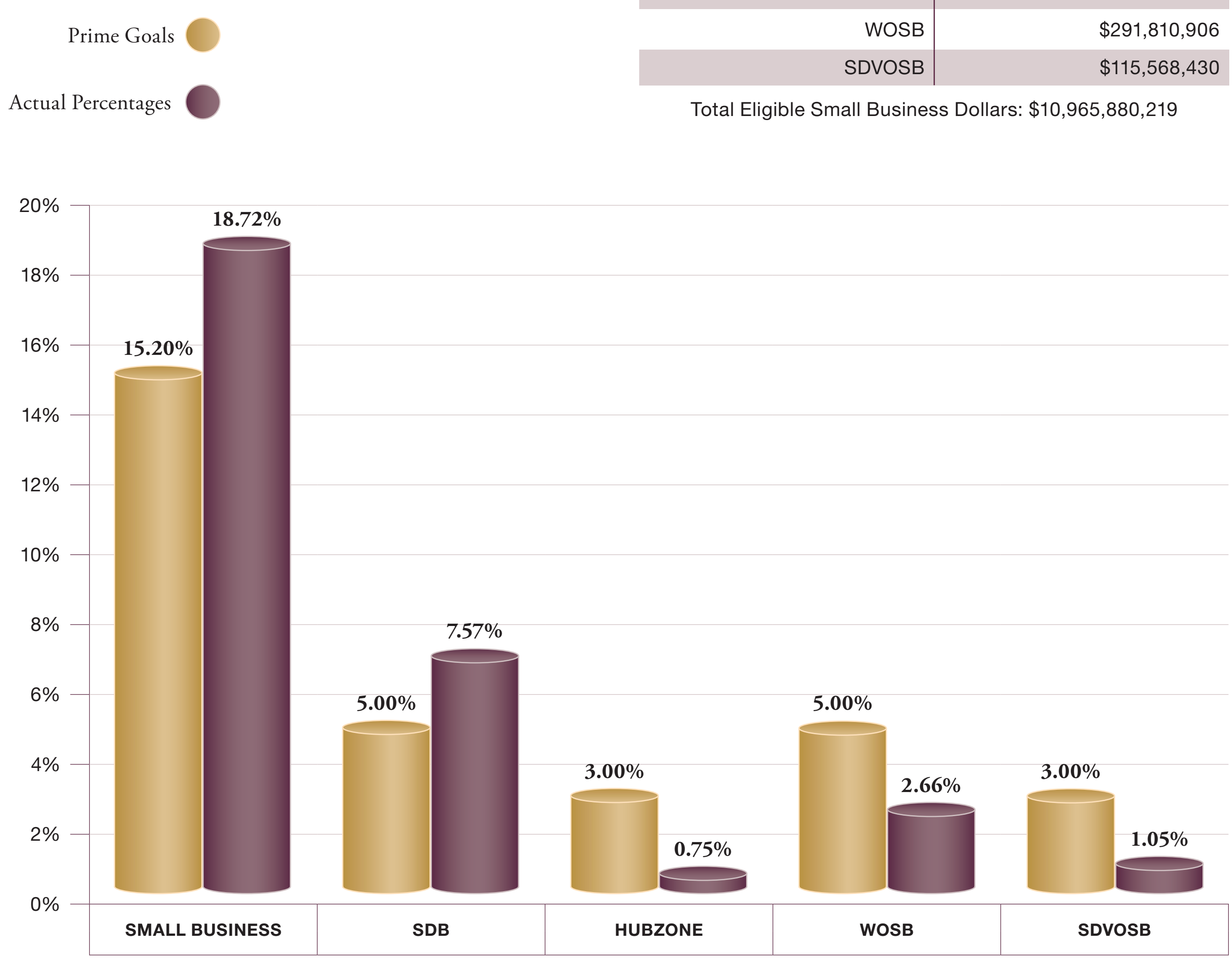
SMALL BUSINESS PRIME METRICS GOALS VS. ACTUAL PERCENTAGES

Data generated August 7, 2012

from the Federal Procurement Data System–Next Generation (FPDS-NG)

CATEGORY	DOLLARS
Small Business	$2,052,385,498
SDB	$830,279,712
8(a)	$386,051,417
HUBZone	$82,319,054
WOSB	$291,810,906
SDVOSB	$115,568,430

Total Eligible Small Business Dollars: $10,965,880,219



NASA AGENCY **FISCAL YEAR 2011**

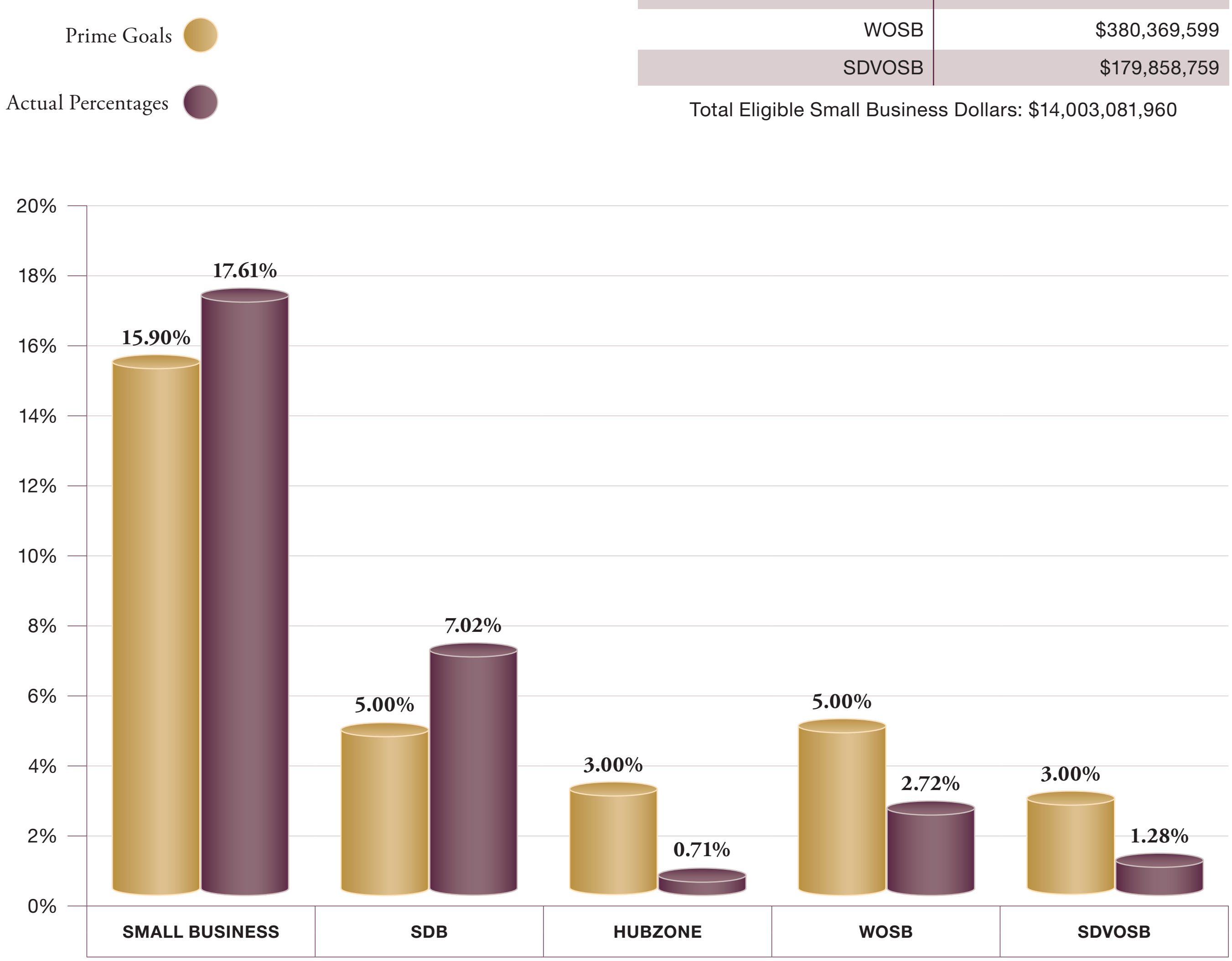
SMALL BUSINESS PRIME METRICS GOALS VS. ACTUAL PERCENTAGES

Data generated August 7, 2012

from the Federal Procurement Data System–Next Generation (FPDS-NG)

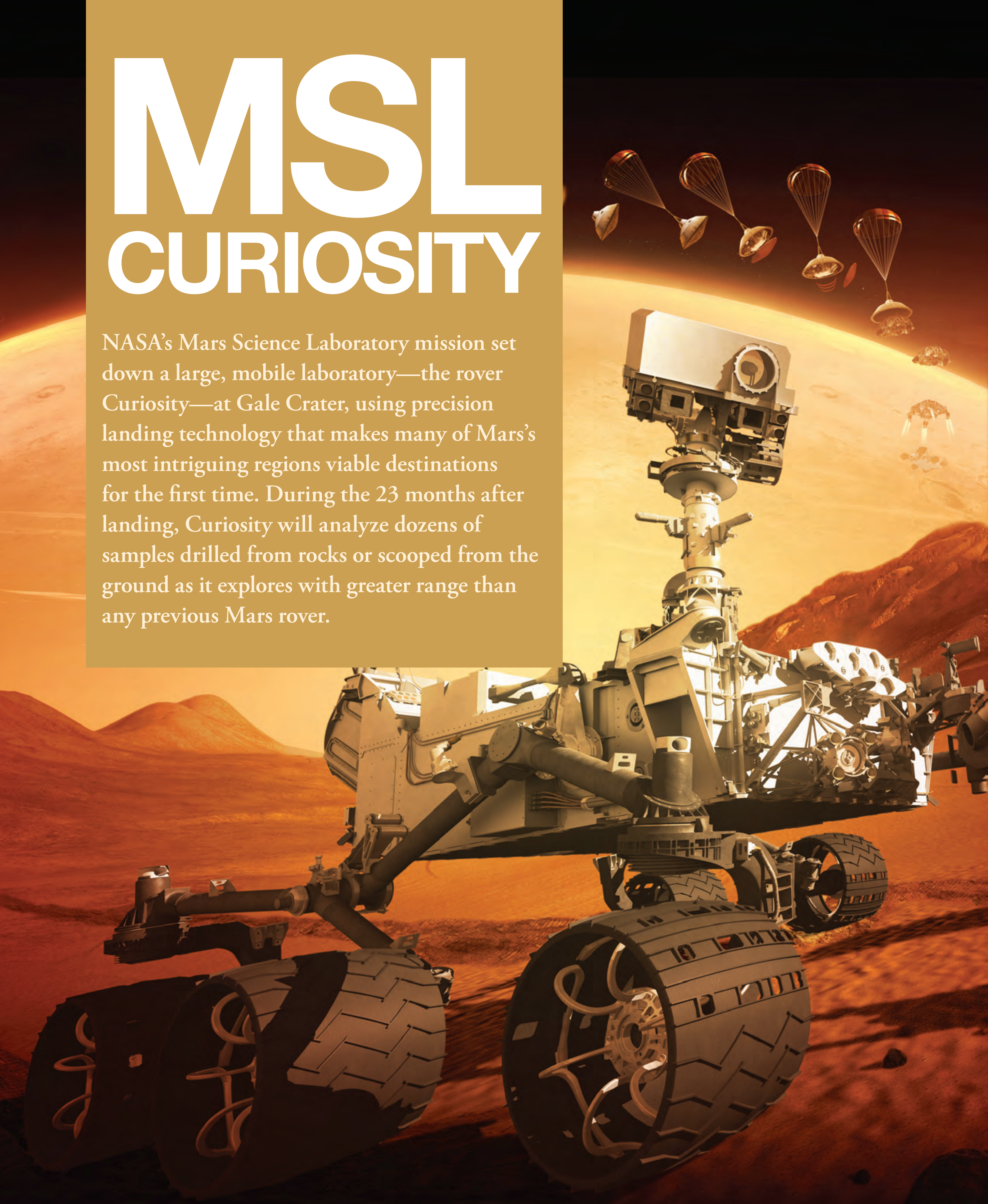
CATEGORY	DOLLARS
Small Business	$2,465,555,529
SDB	$982,722,973
8(a)	$430,422,364
HUBZone	$99,453,587
WOSB	$380,369,599
SDVOSB	$179,858,759

Total Eligible Small Business Dollars: $14,003,081,960



MSL CURIOSITY

NASA's Mars Science Laboratory mission set down a large, mobile laboratory—the rover Curiosity—at Gale Crater, using precision landing technology that makes many of Mars's most intriguing regions viable destinations for the first time. During the 23 months after landing, Curiosity will analyze dozens of samples drilled from rocks or scooped from the ground as it explores with greater range than any previous Mars rover.



About the NASA Mars Science Laboratory and Curiosity

Curiosity carries the most advanced payload of scientific gear ever used on Mars's surface, a payload more than 10 times as massive as those of earlier Mars rovers. Its assignment: Investigate whether conditions have been favorable for microbial life and for preserving clues in the rocks about possible past life.

MISSION OVERVIEW

The Mars Science Laboratory (MSL) spacecraft launched from Cape Canaveral Air Force Station, FL, on November 26, 2011. Mars rover Curiosity landed successfully on the floor of Gale Crater on August 6, 2012, universal time (evening of August 5, Pacific time).

Engineers designed the spacecraft to steer itself during descent through Mars's atmosphere with a series of S-curve maneuvers similar to those used by astronauts piloting NASA Space Shuttles. During the 3 minutes before touchdown, the spacecraft slowed its descent with a parachute, then used retrorockets mounted around the rim of an upper stage. In the final seconds, the upper stage acted as a sky crane, lowering the upright rover on a tether to the surface.

Curiosity is about twice as long (about 3 meters, or 10 feet) and five times as heavy as NASA's twin Mars Exploration Rovers, Spirit and Opportunity, launched in 2003. It inherited many design elements from them, including six-wheel drive, a rocker-bogie suspension system, and cameras mounted on a mast to help the mission's team on Earth select exploration targets and driving routes. Unlike earlier rovers, Curiosity carries equipment to gather samples of rocks and soil, process them, and distribute them to onboard test chambers inside analytical instruments.

NASA's Jet Propulsion Laboratory (JPL) in Pasadena, CA, builder of the MSL, engineered Curiosity to roll over obstacles up to 65 centimeters (25 inches) high and to travel up to about 200 meters (660 feet) per day on Martian terrain.

The rover's electrical power is supplied by a U.S. Department of Energy radioisotope power generator. The multimission radioisotope thermoelectric generator produces electricity from the heat of plutonium-238's radioactive decay. This long-lived power supply gives the mission an operating lifespan on Mars's surface of a full Mars year (687 Earth days) or more. At launch, the generator provided about 110 watts of electrical power to operate the rover's instruments, robotic arm, wheels, computers, and radio. Warm fluids heated by the generator's excess heat are plumbed throughout the rover to keep electronics and other systems at acceptable operating temperatures.

The mission uses radio relays via Mars orbiters as the principal means of communication between Curiosity and the Deep Space Network of antennas on Earth.

The overarching science goal of the mission is to assess whether the landing area has ever had or still has environmental conditions favorable to microbial life, both its habitability and its preservation. Curiosity landed near the foot of a layered mountain inside Gale Crater. Layers of this mountain contain minerals that form in water and may also preserve organics, the chemical building blocks of life. The portion of the crater floor where Curiosity landed has an alluvial fan likely formed by water-carried sediments. The selection of Gale Crater followed the consideration of more than 30 Martian locations by more than 100 scientists participating in a series of open workshops.

The selection of a landing site of prime scientific interest benefited from the examination of candidate sites with NASA's Mars Reconnaissance Orbiter since 2006, from earlier orbiters' observations, and from a capability of landing within a target area only about 20 kilometers (12 miles) long. That precision, about a fivefold improvement on earlier Mars landings, makes feasible sites that would otherwise be excluded for encompassing nearby unsuitable terrain. The Gale Crater landing site is so close to the crater wall that it would not have been considered safe if the mission had not been using this improved precision.

Advancing the technologies for precision landing of a heavy payload yields research benefits beyond the returns from the MSL itself. Those same capabilities would be important for later missions, both to pick up rocks on Mars and bring them back to Earth and to conduct extensive surface exploration for Martian life.

SCIENCE PAYLOAD

In April 2004, NASA solicited proposals for specific instruments and investigations to be carried by the MSL. The Agency selected eight of the proposals later that year and also reached agreements with Russia and Spain for carrying instruments those nations provided.

A suite of instruments named Sample Analysis at Mars analyzes samples of material collected and delivered by the rover's arm, plus atmospheric samples. It includes a gas chromatograph, a mass spectrometer, and a tunable laser spectrometer with combined capabilities to identify a wide range of organic (carbon-containing) compounds and determine the ratios of different isotopes of key elements. Isotope ratios are clues to understanding the history of Mars's atmosphere and water. The principal investigator is Paul Mahaffy of NASA's Goddard Space Flight Center, Greenbelt, MD.

An x-ray diffraction and fluorescence instrument called CheMin also examines samples gathered by the robotic arm. It is designed to identify and quantify the minerals in rocks and soils and to measure bulk composition. The principal investigator is David Blake of NASA's Ames Research Center, Moffett Field, CA.

Mounted on the arm, the Mars Hand Lens Imager takes extreme close-up pictures of rocks, soil, and, if present, ice, revealing details smaller than the width of a human hair. It can also focus on hard-to-reach objects more than an arm's length away. The principal investigator is Kenneth Edgett of Malin Space Science Systems, San Diego, CA.

Also on the arm, the MSL Alpha Particle X-ray Spectrometer determines the relative abundances of different elements in rocks and soils. Dr. Ralf Gellert of the University of Guelph, ON, Canada, is the principal investigator for this instrument, which was provided by the Canadian Space Agency.

The MSL Mast Camera, mounted at about human eye–height, images the rover's surroundings in high-resolution stereo and color, with the capability to take and store high-definition video sequences. It can also be used for viewing materials collected or treated by the arm. The principal investigator is Michael Malin of Malin Space Science Systems.

An instrument named ChemCam uses laser pulses to vaporize thin layers of material from Martian rocks or soil targets up to 7 meters (23 feet) away. It includes both a spectrometer to identify the types of atoms excited by the beam and a telescope to capture detailed images of the area illuminated by the beam. The laser and telescope sit on the rover's mast and share with the Mast Camera the role of informing researchers' choices about which objects in the area make the best targets for approaching to examine with other instruments. Roger Wiens of Los Alamos National Laboratory, Los Alamos, NM, is the principal investigator.

The rover's Radiation Assessment Detector characterizes the radiation environment at the surface of Mars. This information is necessary for planning human exploration of Mars and is relevant to assessing the planet's ability to harbor life. The principal investigator is Donald Hassler of Southwest Research Institute, Boulder, CO.

In the 2 minutes before landing, the Mars Descent Imager captured color, high-definition video of the landing region to provide geological context for the investigations on the ground and to aid precise determination of the landing site. Pointed toward the ground, it can also be used for surface imaging as the rover explores. Michael Malin is the principal investigator.

Spain's Ministry of Education and Science provided the Rover Environmental Monitoring Station to measure atmospheric pressure, temperature, humidity, winds, and ultraviolet radiation levels. The principal investigator is Javier Gómez-Elvira of the Center for Astrobiology, Madrid, an international partner of the NASA Astrobiology Institute.

Russia's Federal Space Agency provided the Dynamic Albedo of Neutrons instrument to measure subsurface hydrogen up to 1 meter (3 feet) below the surface. Detections of hydrogen may indicate the presence of water in the form of ice or bound-in minerals. Igor Mitrofanov of the Space Research Institute, Moscow, is the principal investigator.

In addition to the science payload, equipment of the rover's engineering infrastructure contributes to scientific observations. Like the Mars Exploration Rovers, Curiosity has a stereo navigation camera on its mast and low-slung, stereo hazard-avoidance cameras. Equipment called the Sample Acquisition/Sample Preparation and Handling System includes tools to remove dust from rock surfaces, scoop up soil, drill into rocks and collect powdered samples from rocks' interiors, sort samples by particle size with sieves, and deliver samples to laboratory instruments.

The Mars Science Laboratory Entry, Descent, and Landing Instrument Suite is a set of engineering sensors designed to aid in the design of future missions by measuring the atmospheric conditions and the performance of the spacecraft during the arrival-day plunge through the atmosphere.

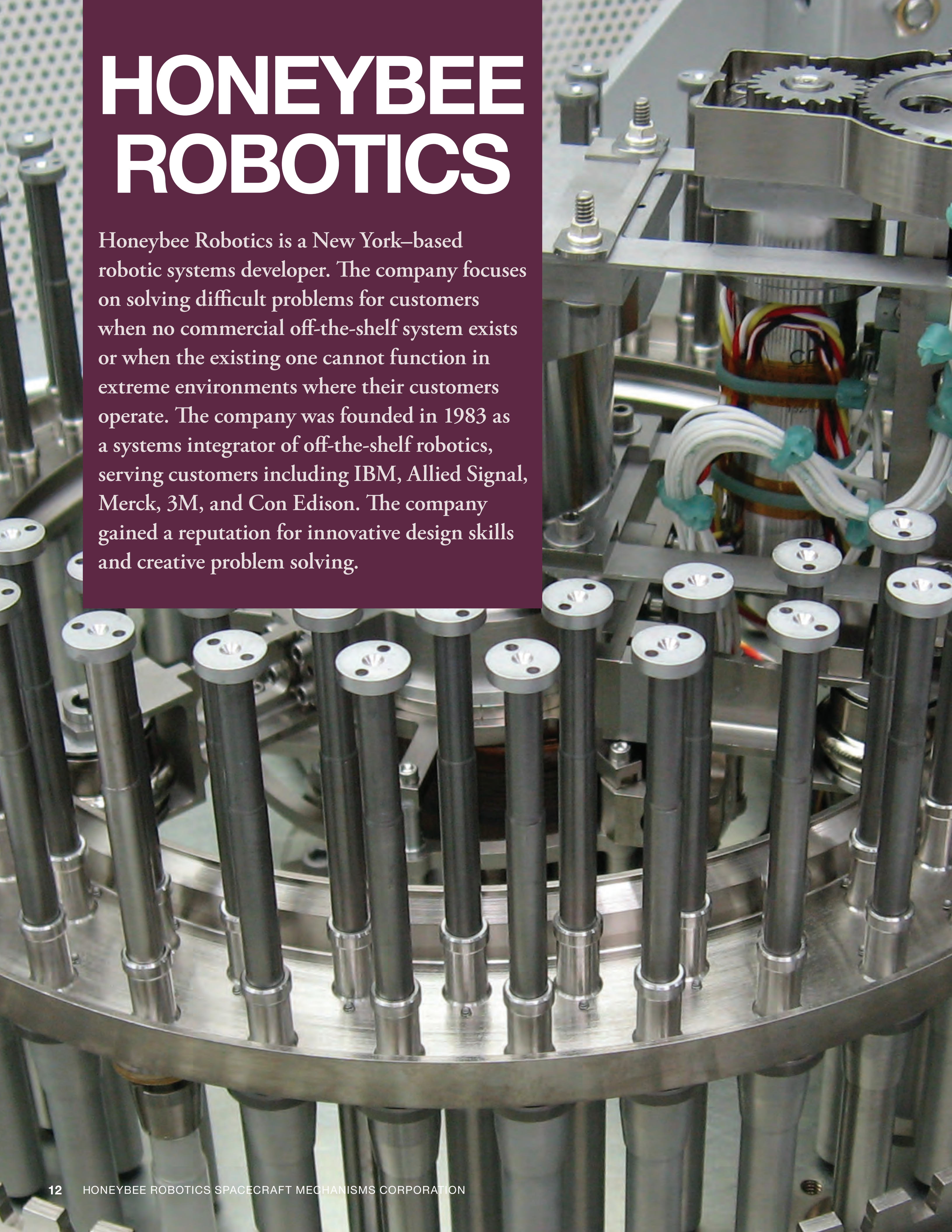
PROGRAM/PROJECT MANAGEMENT

The Mars Science Laboratory is managed for NASA's Science Mission Directorate in Washington, DC, by JPL, a division of the California Institute of Technology in Pasadena. At NASA Headquarters, David Lavery is the Mars Science Laboratory program executive and Michael Meyer is the program scientist. In Pasadena, Peter Theisinger of JPL is the project manager and John Grotzinger of Caltech is the project scientist.

To learn more about the MSL and Curiosity, visit *http://mars.jpl.nasa.gov/msl/*.

HONEYBEE ROBOTICS

Honeybee Robotics is a New York–based robotic systems developer. The company focuses on solving difficult problems for customers when no commercial off-the-shelf system exists or when the existing one cannot function in extreme environments where their customers operate. The company was founded in 1983 as a systems integrator of off-the-shelf robotics, serving customers including IBM, Allied Signal, Merck, 3M, and Con Edison. The company gained a reputation for innovative design skills and creative problem solving.



Honeybee Robotics Spacecraft Mechanisms Corporation

Honeybee received its first National Aeronautics and Space Administration (NASA) contract in 1986 and has subsequently worked on over 300 projects with nearly all the NASA Centers, including supplying hardware for the last three generations of Mars surface missions: the Rock Abrasion Tool (RAT) for the Mars Exploration Rover (MER) mission, the Icy Soil Acquisition Device (ISAD) and Thermal Evolved Gas Analyzer (TEGA) dust cover for the Phoenix Mars mission, and the Sample Manipulation System (SMS) and Dust Removal Tool (DRT) for the Mars Science Laboratory mission.

Today, Honeybee is dedicated to developing technology and products for next-generation advanced robotic and spacecraft systems that must operate in increasingly dynamic, unstructured, and often hostile environments. The company works with NASA, the Department of Defense, academia, and industry. Our products and technologies range from complete systems to subsystems to critical, enabling technologies, and from early-stage feasibility studies through design, production, and validation.

Across its three facilities, Honeybee has approximately 40 employees and revenues of more than $6 million. Its New York headquarters includes a 15,000-square-foot facility with a machine shop and Class-100 clean environment. The company also has offices in Longmont, CO, and Pasadena, CA, which focus on developing flight hardware and geotechnical systems, respectively.

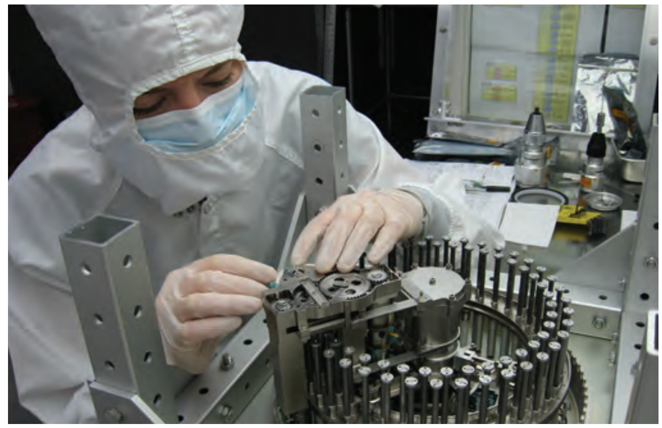
CONTRIBUTIONS TO THE MARS SCIENCE LABORATORY

Honeybee contributed two systems to the Mars Science Laboratory: the Sample Manipulation System and Dust Removal Tool.

THE SAMPLE MANIPULATION SYSTEM

Sample Manipulation System Function

The Sample Analysis at Mars (SAM) instrument is the core science payload of Curiosity, designed to analyze Martian samples with a suite of three instruments: a quadrupole mass spectrometer, a gas chromatograph mass spectrometer, and a tunable laser spectrometer. To physically bring samples



from the SAM solid sample inlet to one of three instruments on board SAM and remove spent samples, Honeybee designed the Sample Manipulation System (SMS) as a "robotic laboratory assistant." SMS leverages sample transfer work originally performed under a Phase 1 Small Business Innovation Research (SBIR) effort.

The SMS is a unique robotic system developed to deliver a high packing density of 74 sample cups in a reliable, fault-tolerant manner while minimizing system mass and control complexity. In developing the SMS, Honeybee placed special focus on reliability, cleanliness, protection of the fragile sample cups, and mechanism test data.

The SMS is responsible for the controlled manipulation of the sample from SAM's sample inlet device to pyrolysis ovens, where samples are pyrolyzed and evolved gases plumbed to the analytical suite. Once inserted into the pyrolysis oven, the SMS applies a predetermined force to create a hermetic seal between the sample cup and the interior of the oven. The sensitivity of SAM's spectrometers requires the SMS to be very clean so as not to contaminate Martian samples and produce false positives or mask sample signatures with known outgassers within the SMS.

Sample Manipulation System Design

The SMS accepts solid samples from the Mars Science Laboratory (MSL) rover via SAM's Solid Sample Inlet Device into any of 74 sample cups and transports the selected sample cup to a pyrolysis oven. Once the SMS inserts the sample cup into the oven, it creates a seal force sufficient to provide a leak rate between the cup and the oven of less than 1E-5 cc He/sec. The SMS must consume less than 6 W continuous and 18 W peak power.

The sample cups are separated into three categories: solid sample quartz cups (60), foil-topped metal cups for wet chemistry experiments (10), and foil-topped metal cups containing calibration samples (4). The SMS must position each cup within 0.71 mm true position at multiple interfaces including the solid sample inlet device, foil puncture stations for the metal cups, and a pyrolysis oven on each row of the SMS Sample Carousel Disk.

Mechanically, SMS is an under-actuated three-Degree-Of-Freedom (DOF) robotic system. Two rotational degrees of freedom are provided by the Center Hub Actuator. A toggle mechanism on the Sample Carousel Disk couples the Sample Carousel Disk to either the Ground Ring or the Rotating Elevator Frame. When the Sample Carousel Disk is coupled to the Rotating Elevator Frame, the Center Hub Actuator positions a given sample cup at an oven, inlet, or puncture station (for metal cups). When the Sample Carousel Disk is coupled to the Ground Ring, the Rotating Elevator Frame rotates independently of the Sample Carousel Disk and positions the Elevator subassembly beneath a given sample cup. At that point, the Elevator actuator (third DOF) can raise and lower the sample cup.

Using a single actuator to position both the Rotating Elevator Frame and the Sample Carousel Disk required more than 360° of rotation of the center hub. A twist capsule transfers power and signals to the elevator actuator and feedback switches on the Rotating Elevator Frame, allowing for 693° of rotation, hard stop to hard stop.

To allow SAM to reuse sample cups in an extended mission scenario, the SMS must deliver up to 1,350 N with an accuracy of ±10 percent of the commanded seal force. A seal is created with the pyrolysis ovens via an annealed copper disk brazed to the sample cup and a titanium knife-edge on the oven. Each successive use of a sample cup requires a larger seal force.

Quality Control on the Sample Manipulation System

Contamination control played a significant role in SMS development. The spectrometers aboard the SAM suite have the capability to detect molecules

in the parts-per-billion range. Thus, the SMS must be extremely clean, be free of particles, and exhibit a very low outgassing rate. The outgassing rate of the SMS was required to be less than 4.2E-14 g/cm^2/sec as measured by a quartz crystal microbalance. This ultimately corresponded to a delta/delta frequency reading on a Thermoelectric Quartz Crystal Microbalance (TQCM) of 1 Hz/hour/hour during bakeout.

The SMS must move the sample from the inlet location and seal it in the pyrolysis oven in 5 minutes or less. This requirement is driven by the extreme contamination sensitivity. A given sample cup, once preconditioned in the pyrolysis oven, must not be exposed to the interior of the SMS for an extended time to prevent contaminating the measurement on the solid sample. Contamination concerns required the SMS to provide a vacuum seal to prevent the contamination of the interior of the SMS during assembly, test, and launch operations.

The SMS must be capable of recovering from an unexpected power loss. Feedback devices and a robust high-level control architecture combined to provide full fault detection and correction capability. By integrating feedback to the output of the mechanism, motor hall counts can be compared to optical switch state transitions to detect faults by a prompt, safe, and recoverable means. Together with the hard stops on the center hub, the SMS is capable of full recovery from an unexpected loss of power that would result in the loss of position information. The SMS may also operate should either the motor hall sensors or the optical switches fail. It is a redundant control scheme.

THE DUST REMOVAL TOOL

The Dust Removal Tool (DRT) is designed to expose the natural surfaces of Martian rocks obscured by layers of dust deposited by aeolian processes. The flight unit DRT was integrated with the Mars Science Laboratory on its end-of-arm tooling in early 2011. The DRT is similar to the dust removal feature of the Rock Abrasion Tool on the Spirit and Opportunity rovers of the MER mission, without the grinding feature.

The DRT is designed to be compact and operate on a low power budget. Contained within a cylinder 154 mm long and 102 mm in diameter, the DRT has a mass of just 925 g. Using a single brushless DC motor, the DRT removes dust from an area 45 mm in diameter. The mechanism features a high-reduction single-stage planetary gearbox and a hinged brush block, both of which incorporate lessons learned from previous Mars missions.

The DRT is designed to interact with unstructured extraterrestrial surface objects and environments. During the dust-removal process, a set of brushes articulate to maintain surface contact as they rotate at high speed. The wide range of rock surface characteristics, along with severe resource constraints, makes the DRT solution a significant contribution for its simplicity and robust design.

OTHER SIGNIFICANT WORK

Government funding, such as the SBIR program, is critical to the success of Honeybee Robotics. The company is an active participant in NASA SBIR work and has participated in dozens of Phase I SBIR awards. A number of NASA research and development (R&D) and flight mission contracts, as well as terrestrial military and commercial spinoffs totaling over $39 million, have followed our initial entrance into this market via the SBIR program.

Most notably, the core of Honeybee's business is in planetary sampling technology, which started with 1996 NASA SBIR Phase I and II awards (contract numbers NAS8-40703 and NAS8-97034, respectively, for "Miniature Planetary Subsurface Sample Acquisition" and "Sample Transfer Systems"). These SBIR projects focused on the design, development, manufacture, and testing of low-mass drill systems in Mars-relevant materials (ice, rocks, and soils) with low tool preloads that acquire, capture, and transfer cuttings to science instruments.

With the support of SBIR and similar Government awards, Honeybee Robotics is now a leading developer of robotic planetary subsurface access and sample acquisition systems. Our most notable successes are the two Rock Abrasion Tools on the Mars Exploration Rovers, which were instrumental in proving that large amounts of water once flowed on Mars, and the Icy Soil Acquisition Device for the Phoenix Mars mission, which was instrumental in proving that ice and the conditions for life have been available on Mars. Most recently, the Sample Manipulation System for the Mars Science Laboratory leverages sample transfer work performed under our original Phase I SBIR effort.

Notably, we are also currently parlaying the experience gained through these efforts for mining and for the military. Honeybee has been funded several million dollars to work on sampling and sensing technologies to develop an automated "Mine of the Future" for a major international mining concern. We have also developed an excavation device for the Navy for the purposes of uncovering roadside explosive devices from a robotic platform.

COMMUNITY OUTREACH AND EDUCATION

Honeybee Robotics is committed to preparing the next generation of engineers and explorers. Our activities include the following:

- Offering student internships to college students and recent graduates to train their skills and expose them to the full project life cycle.
- Sponsoring student research in competitions such as the Lunabotics Competition, which Honeybee has sponsored and participated in for the last 3 years.
- Mentoring student teams and judging student competitions, such as the joint NASA–Worcester Polytechnic Institute Sample Return Robot Challenge.
- Hosting tours and technology demonstrations and delivering classroom presentations on the value of robotics and science, technology, engineering, and mathematics education for students of all ages.
- Providing public outreach, such as our sponsorship and technology demonstrations at the Planetary Society's Planetfest celebration around the landing of the Mars Science Laboratory.

HONEYBEE ROBOTICS
Spacecraft Mechanisms Corporation

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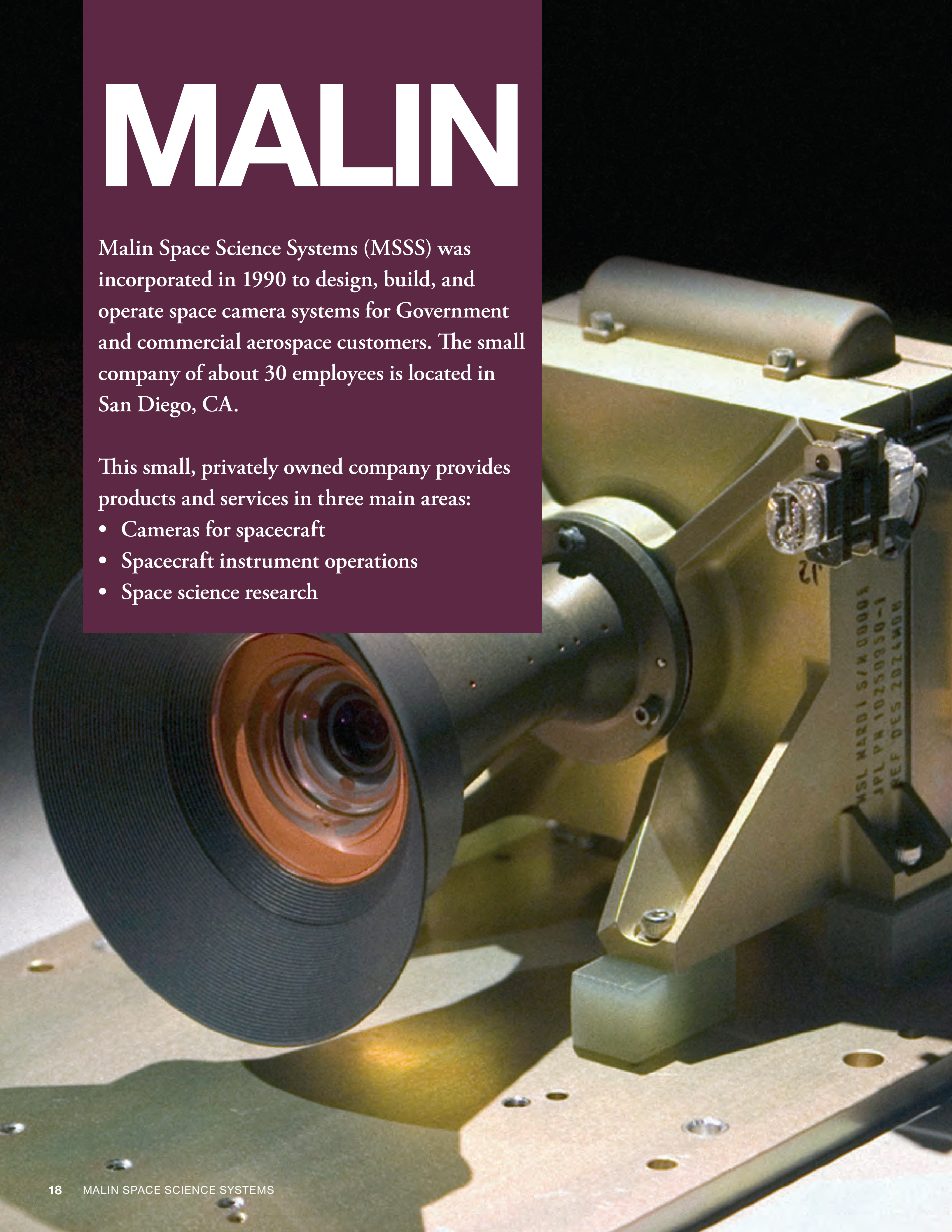
MALIN

Malin Space Science Systems (MSSS) was incorporated in 1990 to design, build, and operate space camera systems for Government and commercial aerospace customers. The small company of about 30 employees is located in San Diego, CA.

This small, privately owned company provides products and services in three main areas:

- Cameras for spacecraft
- Spacecraft instrument operations
- Space science research



Malin Space Science Systems

Three deep space cameras built by MSSS are currently operating in orbit around Mars. Four more are operating on the surface of Mars. Three additional MSSS cameras are imaging the Moon from an orbital altitude of just 50 km. MSSS instruments have operated in deep space for a total of more than 250,000 hours and have returned more than 500,000 images.

CONTRIBUTIONS TO THE MARS SCIENCE LABORATORY

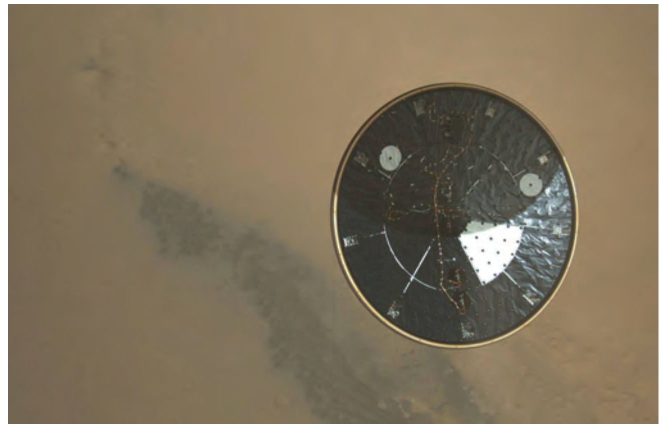
In 2004, MSSS was selected to provide three camera systems (four total cameras) for NASA's MSL rover. The first two of four MSL cameras, the Mars Descent Imager (MARDI) and the Mars Hand Lens Imager (MAHLI), were delivered to the Jet Propulsion Laboratory (JPL) in 2008. The second pair of cameras, fixed focal length Mast Cameras (Mastcams) with a 34-mm and 100-mm focal length, was delivered in March 2010. The MSL rover was launched in late 2011 and landed on Mars in August of 2012.

OTHER SIGNIFICANT WORK

The initial focus of MSSS was on the development of the ground data system for—and operation of—the Mars Observer Camera (MOC) aboard NASA's Mars Observer. After the spacecraft was lost in August 1993, MSSS participated in NASA-sponsored studies aimed at recovering from the loss and was selected to build the spare MOC for NASA's Mars Global Surveyor (MGS).

MGS was launched in 1996, and the MOC was operated by MSSS for 10 years, through calibration and Mars meteorological imaging during the interplanetary cruise phase, the spacecraft orbit insertion aerobraking period, the MGS primary mission, and multiple extended missions.

At the same time that MSSS started work on the MGS MOC in the mid-1990s, the company was developing a very small, modular camera system for future spacecraft flight opportunities. The work culminated with the selection of MSSS to provide cameras for the Mars Surveyor 1998 orbiter and lander, later named Mars Climate Orbiter and Mars Polar Lander. Both of these NASA spacecraft were lost upon arrival at Mars in 1999.

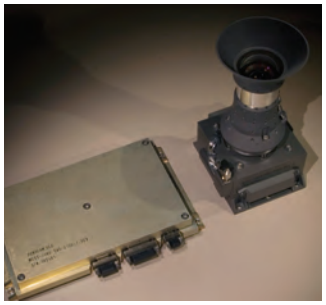


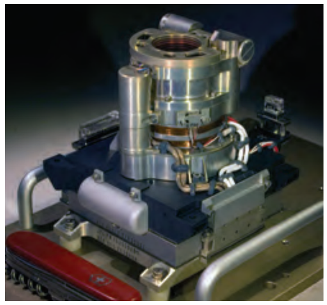
As the Mars Surveyor 1998 cameras were being built, MSSS was selected in 1997 by Arizona State University to provide the Visible Imaging Subsystem (VIS) of the Thermal Emission Imaging System (THEMIS) instrument aboard the Mars Odyssey orbiter and by JPL to provide a descent camera for the Mars Surveyor 2001 lander. The 2001 lander was canceled after the loss of the Mars Polar Lander.

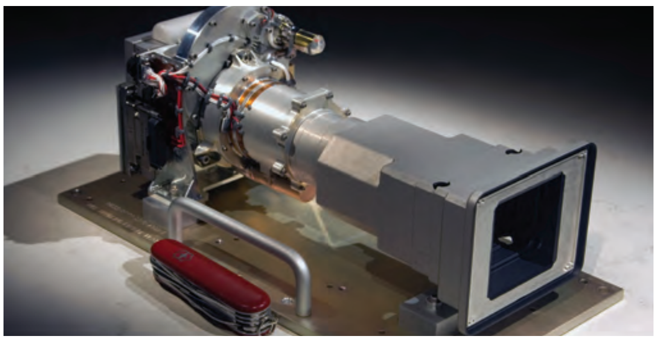
The THEMIS VIS camera, operated by Arizona State University, is still acquiring data and has been doing so from Mars orbit since 2002. The 2001 descent camera flew on the Phoenix Mars mission launched in 2007 but was not permitted by NASA to acquire data during the landing in May 2008, owing to concerns on the spacecraft side of the interface.

In 2003, MSSS developed and delivered a Video Graphics Array (VGA)–format color video camera to fit within the extremely constrained mass, volume, power, and budget requirements of the Planetary Society's Cosmos-1 solar sail mission. This mission suffered a launch vehicle failure and never reached orbit.

MSSS developed the Mars Color Imager (MARCI) and Context Camera (CTX) for NASA's Mars Reconnaissance Orbiter, launched in 2005. MSSS operates these instruments daily; they have been orbiting Mars since March 2006, and each week MSSS posts on its Web site a video of the latest Martian weather observed by MARCI.







In 2004, MSSS was selected to provide three camera systems (four total cameras) for NASA's MSL rover and three cameras for NASA's Lunar Reconnaissance Orbiter (LRO) mission. The LRO Cameras (LROC) were delivered to the NASA Goddard Space Flight Center in 2008. The LRO was launched and began acquiring data from orbit around the Moon in 2009. The LROC system is operated by investigators at Arizona State University.

In 2006, MSSS developed the Engineering and Public Outreach Camera (EPOC) for the LRO mission. This camera was designed with two 3-megapixel color complementary metal–oxide–semiconductor (CMOS) imagers and two sets of optics to separately capture high-definition video of the LRO solar array and high-gain antenna deployments and gimbaling, with views of the Moon and Earth in the background. The LRO project ultimately elected not to fly EPOC, due to schedule constraints with spacecraft accommodations.

MSSS also developed Junocam, a color camera system for education and public outreach use on board Juno, a NASA spacecraft launched toward Jupiter in August 2011. Juno will reach the giant planet in 2016.

MSSS is currently developing the ECAM modular, off-the-shelf space camera platform for spacecraft engineering, space surveillance, and situational awareness applications for NASA, intelligence/defense, and commercial aerospace customers. This platform builds on flight heritage designs from the Camera Monitoring Assembly, the MSL cameras, and the LROC flight programs.

Malin Space Science Systems

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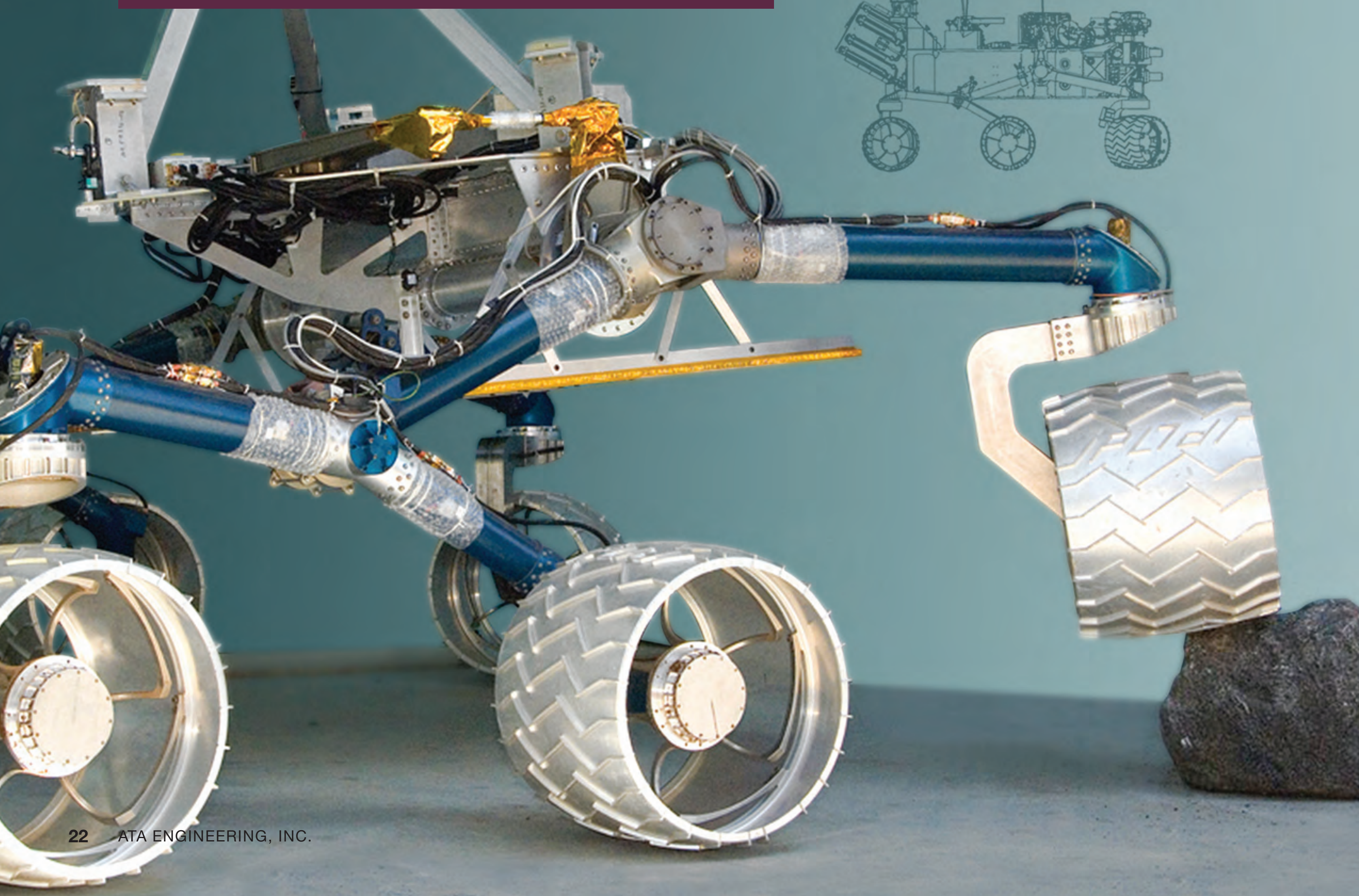
Michael C. Malin
President and Chief Scientist

ATA

ATA Engineering, Inc., is a provider of analysis- and test-driven design solutions for mechanical and aerospace systems. ATA is an employee-owned small business where each and every member of our staff contributes to and shares in the success of our company. No one person, from our newest employee to our president, owns more than 4 percent of the company. Many significant decisions are made by consensus—including hiring, the location of our facilities, and the acquisition of computers and software tools.



ATA Engineering, Inc.

CONTRIBUTIONS TO THE MARS SCIENCE LABORATORY

The successful landing of the Curiosity rover in the early morning hours of August 6, 2012, was a significant milestone in the history of planetary exploration for NASA and JPL. It demonstrated that JPL and its contractor teams could overcome the many technical hurdles required to take the largest, most complex, most capable roving robotic geologist ever designed and safely launch, land, and operate it on the planet Mars.

With shared values and approaches, and a shared passion for space exploration, ATA has found its work with JPL to be rewarding and exciting. We feel fortunate to have become a trusted partner supporting JPL's ambitious endeavors in space.

OVERVIEW OF ATA INVOLVEMENT WITH THE CURIOSITY ROVER

Working as an extension of and complement to the JPL team, ATA assisted in many phases of the development of the Curiosity rover, shown in figure 1. More than 16 ATA staff members simultaneously supported JPL during periods of this project. ATA's support of MSL included a significant focus on the analysis and testing of entry, descent, and landing (EDL), with emphasis on understanding the loads in the rover's mobility system at and immediately before touchdown and how these loads were influenced by changing conditions. ATA also assisted with the development and analysis of the rover wheels, actuators, and thermal control systems. The rover chassis and chassis-mounted components were further analyzed by ATA, including a suite of remote sensing instruments called the ChemCam Body Unit and a sample standard for verifying organic cleanliness called the Organic Check Material. Additionally, the multifaceted sample acquisition and handling system—whose job is to extract, process, and deliver Martian soil and rock samples to the rover's instrumentation—was the subject of much ATA involvement, with emphasis placed on the performance of the robotic arm, turret, and drill. The remote sensing mast (RSM), a device on top of the rover capable of photographing and analyzing the surrounding environment, was another point of focused ATA involvement. Expanded details regarding these diverse areas of involvement are provided below.

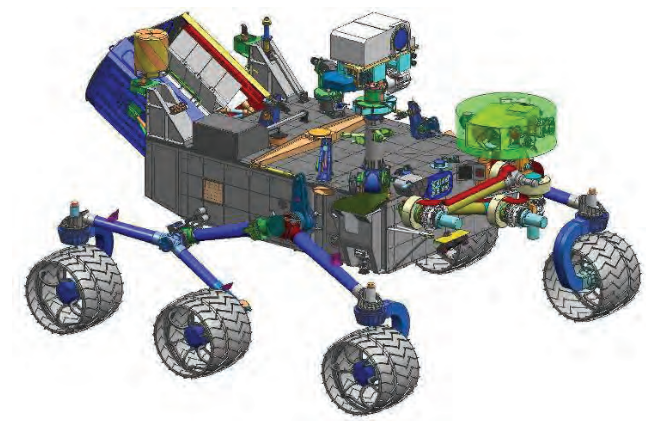


Figure 1. Computer rendition of Curiosity.

DESIGNING, CONSTRUCTING, AND TESTING THE ROVER TEST CHASSIS

The mobility system for Curiosity, which includes the wheels, legs, and joints that allow the rover to move around the planet, is a sophisticated system that demanded creative and rigorous design and testing. Harsh operating conditions were part of the testing that explored, for example, severe impacts against large rocks during landing at less-than-ideal sites in extreme crosswinds. Such conditions necessitated a robust test chassis onto which the mobility legs could be mounted for impact testing in a specially built touchdown facility (figure 2). This test chassis needed to have provisions for different weights and center-of-gravity locations because of the difficulty of duplicating the Martian environment here on Earth; gravity on

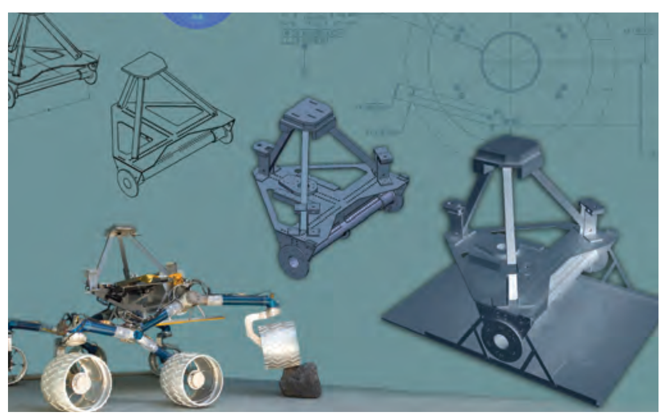


Figure 2. Depiction of Curiosity test chassis design performed by ATA.

Figure 3. Test rover shown in touchdown facility on (a) sand-covered incline and (b) simulated rock field.

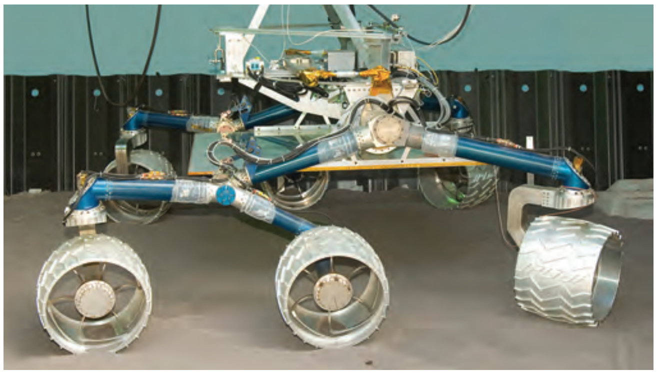


Figure 3a.

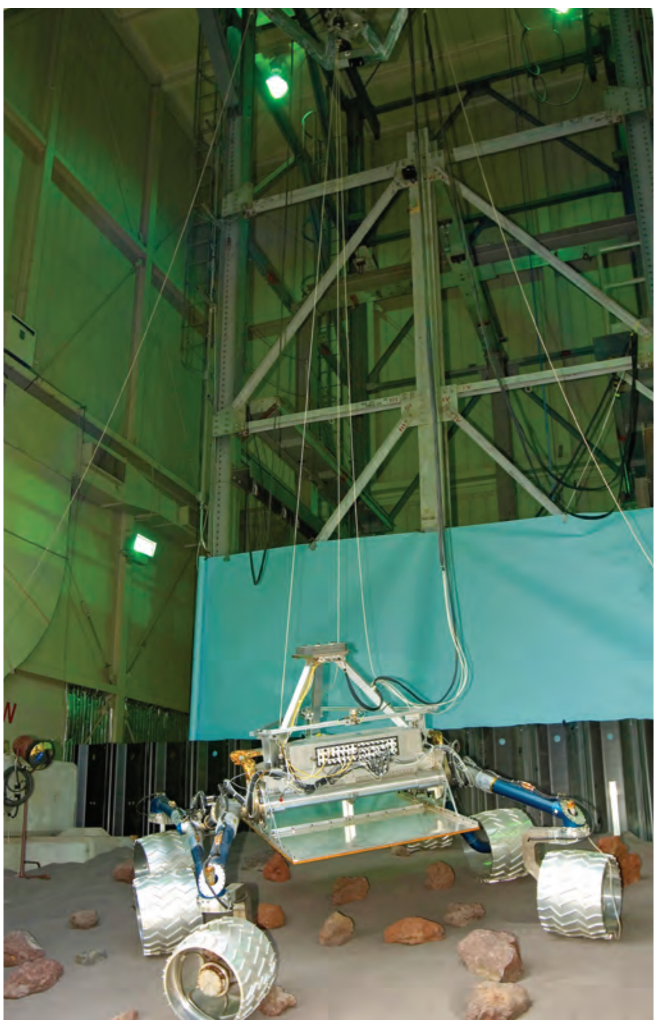


Figure 3b.

Mars is ⅜ that of Earth, so the loads the rover sees in the two locations are quite different. ATA designed a test chassis using readily available materials and manufacturing techniques. This low-cost, rapid-development approach provided a test platform that met both the challenging schedule of the test program and the rigors of the extreme service environment. The end product survived its jarring treatment without any hint of structural damage.

MODELING AND TESTING ROVER ENTRY, DESCENT, AND LANDING

A significant focus of ATA's support of MSL was the analysis and testing done for the EDL sequence, which came to be known as the "7 Minutes of Terror" during the final phase of the August 6 landing. This support spanned over 5 years and was multifaceted, including at the outset test support for the rover shown in figure 3. ATA created a computer model of the test rover and compared the simulation results with those observed first-hand from testing. This comparison allowed us to understand the strengths and limitations of the computer model and apply this understanding to improving the computer model used to represent the Mars-bound rover. ATA performed thousands of computer simulations of the rover landing on Mars under all types of conditions. For example, different rover touchdown velocities, twisting rates, and ground slopes were computationally studied, as depicted in figure 4(a). ATA created custom computer code that enabled these studies to be done in a rapid and automated fashion. Figure 4(b) shows a frame from one such touchdown computer simulation, in which the loads imparted to the rover chassis by the overhead bridles are indicated. Rock impact was also an important part of this large computational study, as represented in the visualization in figure 4(c).

An important part of this work was developing an intuitive understanding of how the rover responded to specific touchdown conditions. For example, a rover landing on downward-sloping ground undergoes chassis rotation and changing bridle loads.

During descent, the mobility system transitions from the stowed configuration to a fully deployed, ready-for-touchdown state. ATA helped JPL apply their data from tests performed on this subsystem to the corresponding

Figure 4. Computer simulations of rover touchdown were performed (a) under many different simulated conditions, making ample use of (b) visualization tools showing rover touchdown loads and (c) rock strike representations.

Figure 4a.

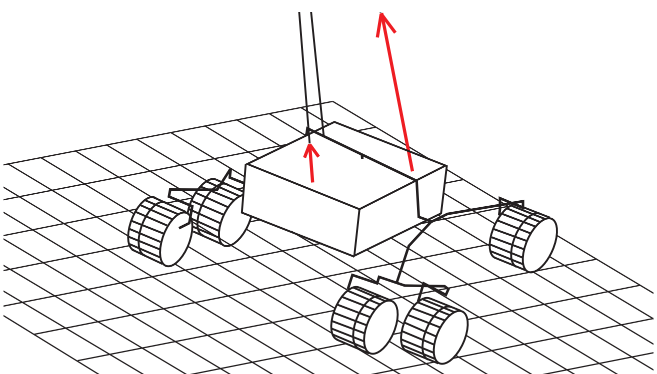


Figure 4b.

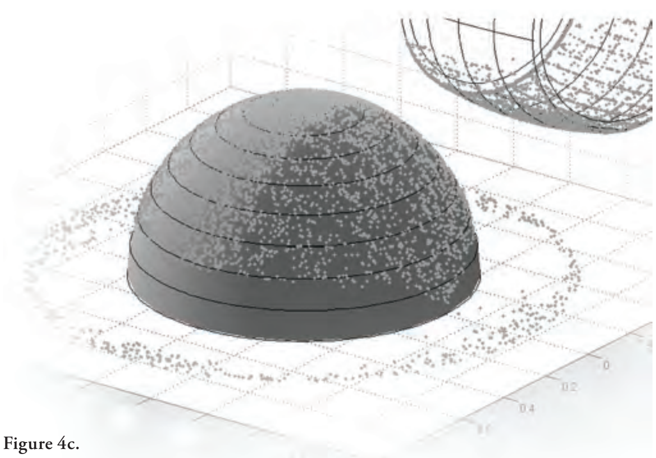


Figure 4c.

computer-based simulation model to ensure the model's accuracy. During this work, ATA found that one of the critical mobility joints was represented with significantly higher stiffness than was actually the case and helped recommend a resolution.

One of the most complex subsystems tests for MSL was the Skycrane Full Motion Drop Test. Here the rover and descent stage were coupled together and hung from an overhead crane. The descent stage–rover separation bolts were fired to release the rover, which was then lowered on the three electromagnetically braked bridles (part of the Bridle Umbilical Device, or BUD), with the mobility system deployment occurring during the rover's descent. ATA used the computer model to simulate this test and to recommend adjustments to the mobility release timing to avoid overloading the BUD.

Finally, of relevance to landing and traverse, the rover wheels were also a point of ATA focus, where technical support was provided to expand the capacity of the wheel model used by JPL and streamline its implementation (figure 5).

Figure 5a.

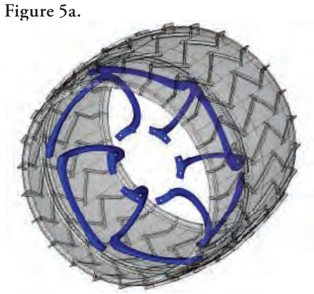


Figure 5b.

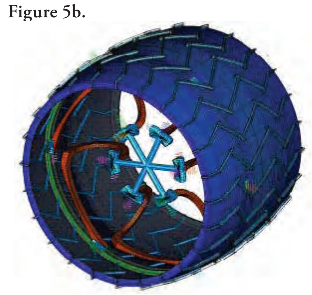


Figure 5. Rover wheel analysis showing (a) the original engineering graphical representation and (b) the computer simulation model.

DEVELOPMENT OF REMOTE SENSING MAST

ATA provided analysis support for JPL's RSM design team. The RSM is a large, heavy structure that is mounted to the top deck of the rover chassis, allowing Curiosity to photograph and analyze its environment. During the trip to Mars, the RSM sat in a stowed, face-down position on the top deck. In this position, carefully designed restraints prevented the RSM from experiencing excessive motion during launch and landing but also had to allow for some motion due to expansion and contraction as the rover experienced very large temperature swings between launch day in Florida, the trip through space, and the Martian surface. ATA developed virtual models of the RSM to analyze these different conditions and ensure mission success. The very large temperature swings on Mars itself could also distort the alignment of the cameras in the RSM. Because these cameras act as stereo pairs, any misalignment would result in incorrect depth calculations, making it difficult to drive the rover safely and efficiently. ATA used the computer models to consider alternate materials, bolted connections, and structural designs to effectively cancel out these thermal deformations and maintain precise alignment despite the extremes of the Martian climate.

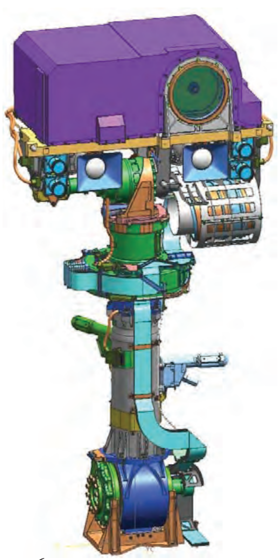


Figure 6a.

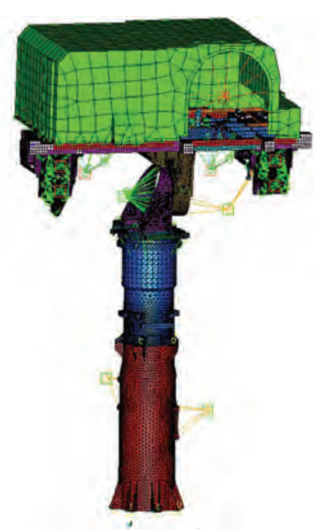


Figure 6b.

Figure 6. Remote sensing mast as (a) represented in graphical engineering software and (b) shown in its physics model embodiment.

CONCLUSION

From helping ensure rover health during launch, interplanetary flight, and landing to ensuring performance in traversing and analyzing the Red Planet, ATA was fortunate to support JPL in a broad range of multidisciplinary engineering tasks. The professional and personal satisfaction derived from participating in such a technically rich project in support of a mission of historic magnitude was keenly appreciated by the engineers at ATA. It was in this spirit that two ATA engineers traveled to Kennedy Space Center to watch the launch of Curiosity. One engineer even brought his 9-year-old daughter, who filmed the launch and later gave a presentation on Curiosity to her fifth-grade class.

On the night of Curiosity's landing, the feeling of pride was palpable at ATA headquarters as the conference room packed with ATA staff and families erupted in cheers following word of the successful rover touchdown.

RECOGNITION

As a small, close-knit organization, ATA approaches problems using integrated teams. We share JPL's multidisciplinary approach to developing new and comprehensive solutions to a range of problems that do not fall readily into single categories. With over 33 labor-years of support to JPL missions over the past 8 years, ATA Engineering is proud to have played a significant role in the mechanical and thermal design and testing of Curiosity. As a result of our performance in supporting JPL, ATA was JPL's small services business nominee for NASA's George M. Low award for 2009 through 2012. We were also selected by JPL as their 2010 Small Business Subcontractor of the Year and received the Thomas H. May Legacy of Excellence Award for outstanding subcontract performance. More than 50 ATA engineers (over half of ATA's staff) have worked on JPL programs over the years, collaborating to share expertise and develop engineering techniques that are now routinely used by JPL staff.

ATA Engineering, Inc.
2010 Small Business Subcontractor of the Year
NASA Jet Propulsion Laboratory

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Columbus Technologies and Services, Inc.

OVERVIEW

Columbus Technologies and Services, Inc., an 8(a) Small Business Administration (SBA) certified Small Disadvantaged Business, was founded in 2001 by Ajay Handa. Columbus is headquartered in El Segundo, CA, with locations throughout the country. Columbus is dedicated to customer satisfaction and providing high-quality support in the areas of information technology, software, science, engineering, and professional services to a diverse group of clients from the aerospace, commercial, and Federal sectors. Columbus is International Organization for Standardization (ISO) 9001 and Capability Maturity Model Integration (CMMI) Level 2 certified. We directly support several Government agencies and academic institutions including NASA; the Department of Defense (DOD); Health and Human Services (HHS); the Army National Guard; the University of California, Los Angeles; Brown University; and the California Institute of Technology. We also maintain strong business relationships with large and small businesses throughout the United States.

Our expertise in managing and providing human and technical resources and solutions helps our customers solve their most pressing technical, strategic, and operational challenges, ensuring the overall success of their programs. At Columbus, we take pride in providing innovative and customized technology-based solutions to fulfill the needs of our customers and exceed their expectations. We have a history of successful, high-quality contract performance and have been recognized with over 150 awards and recognitions for our efforts. At Columbus, "a passion to provide excellence" represents our commitment to the success of each of our customers.

Columbus is a premier information technology (IT), software engineering, systems engineering, and scientific solutions company addressing critical research and technology issues for NASA, the Federal Aviation Administration (FAA), HHS, DOD, and commercial customers. Columbus staff scientists, engineers, and IT professionals support NASA's mission-critical systems including engineering, implementation and operation of both software and hardware systems, mission planning and logistics, instrument design, and science data analysis. Columbus was recently awarded the $250 million Software Engineering Support contract for the Applied Engineering and Technology Directorate (AETD) at NASA's Goddard Space Flight Center. Software engineering is increasingly critical to the success of NASA's exploration vision. Columbus employees work closely with AETD's Software Engineering Division staff to design and implement state-of-the-art software and IT solutions for flight and ground systems in the development and test labs, simulation facilities, and integration centers. Columbus opened its Greenbelt, MD, office to support Goddard and its Atlantic City, NJ, office to support FAA Hughes Technical Center.

Columbus engineers and technicians performed work similar to that shown in this image, including designing, building, assembling, and testing multiple MSL components.

CONTRIBUTIONS TO THE MARS SCIENCE LABORATORY

Columbus has provided to the MSL project a wide variety of design, build, assembly, and test support functions for mechanical and electrical systems, as well as engineering, development, and deployment of flight and ground software and computing environments.

At JPL, Columbus provided hardware structural analysis support, finite element modeling/analysis, mechanical design/engineering, prototype flight hardware fabrication, propulsion subsystem design, hardware testing and quality assurance, Field-Programmable Gate Array (FPGA)/digital electronics design and development, flight hardware/software test bed infrastructure support, engineering technician support, spacecraft propulsion fabrication and assembly, and ground data system computing infrastructure design and administration. Some specific examples include the following:

- Used conventional hand analyses and finite element analysis in performing structural analysis, finite element modeling, and detailed stress analysis. Aerospace standard practices were applied in the computation of structural margins of safety. Performed structural analysis.
- Developed prototype and flight hardware and assembled and supported the testing of mechanical devices. Columbus flight technician specialists worked with JPL employees in the assembly and disassembly of mock-ups, prototypes, and flight spacecraft.
- Performed space flight hardware quality assurance engineering. Inspected various types of electrical or mechanical hardware to ensure that they matched plans. Provided prints and furnished specification documents. Generated appropriate inspection documentation reflecting the acceptance or rejection of the hardware. Interfaced with project managers, project element managers, task managers, and mission assurance managers to assist in the development of appropriate quality assurance engineering requirements. Assisted in the generation of workforce/cost plans, quality assurance procedures, and instructions. Interfaced with technical organizations in developing and qualifying new materials and fabrication processes. Developed appropriate verification plans and acceptance/rejection criteria for new processes.
- Participated in the MSL Power Analog Module design team that developed the simulation test bench, simulation test cases, and test vectors for FPGAs used on the MSL Guidance Interface and Drivers and Load Control Card modules.
- Performed fabrication, assembly, testing, and gas sampling operations on R&D and flight components and systems for MSL.
- Worked closely with other team members during the integration and test phases for the flight cold encoders. Provided expert technical support during the assembly of cold encoders prior to environmental testing and during the disassembly subsequent to such testing.
- Supported flight and nonflight projects during their development life cycle and mission operations. Supported senior IT engineers in the architecture of the infrastructure for flight hardware and software test beds. Accountable for ensuring that project/user systems installation and configuration schedule requirements are met. Wrote and modified Shell and Perl scripts to address the needs of IT engineers and users. Installed,

managed, and troubleshot UNIX, VxWorks, Solaris, Java, and Linux systems. Supported the execution of Jumpstart and Kickstart. Added, modified, and deleted user accounts. Maintained network services.

- Provided technical support for the Ground Support Equipment (GSE) Hardware and Software Group responsible for the design, build, test, and delivery of GSE hardware. Provided support to the MSL GSE team that developed that Electrical Ground Support Equipment (EGSE) and reported to the MSL hardware lead. Performed hand soldering of printed circuit board components, fabrication of custom cables, assembly of electronic chassis, and mounting of electronic components and cables in electronic cabinets.

At Goddard Space Flight Center, Columbus provides support to the Sample Analysis at Mars (SAM) instrument postdelivery flight software. Columbus provides postdelivery and Phase-E flight software support:

- SAM flight software support for Phase E operations includes the development of additional operational scripts for science operations on Mars, updates and maintenance to the existing flight software, support for the SAM test bed completion at Goddard, and processing support to facilitate science analysis of downlinked flight data.
- SAM flight software support for Phase D postdelivery operations included support for testing at JPL before integration onto the rover and instrument checkout after integration, as well as launch site test support.

CAPABILITIES

Columbus Technologies and Services offers a wide range of information technology, engineering, and professional services.

INFORMATION TECHNOLOGY

- **Software/hardware—**Design, engineer, develop, integrate and test, operate, and maintain
- **Databases/application tools—**Design, install, configure, and administer
- **Configuration management—**Documentation, maintenance, release, and control
- **Computers/networks/data centers—**Design, administer, operate, and maintain
- **IT security—**Data and system integrity of mission-critical systems

ENGINEERING SERVICES

- **Multiple engineering and technical disciplines—**Systems, manufacturing, electrical engineering services, tooling and technical support services, reliability, maintainability, human factors, calibration, hardware fabrication, assembly, cabling and maintenance, and radio frequency microwave
- **Aerospace and defense—**Exploration; systems integration; satellite operations and communications; radar and air defense systems; command, control, intelligence, surveillance, and reconnaissance; intelligence analysis; and logistical support

PROFESSIONAL SERVICES

- **Project/program management—**Routine and complex systems
- **Science—**Space science and health science design, research, and experimentation
- **Engineering—**Mechanical, electrical and systems—on site and in the field
- **Logistics—**Coordination of the deployment of military personnel and equipment
- **Business operations and administration—**Accounting, contracts, and office operations
- **Continuous process improvement—**Improvement of efficiency and reduction of costs

RECOGNITION

Columbus receives recognition from our customers and the media for our performance and achievements in many areas. Below are some of our awards from customers and features from publications:

- ***Federal Times* magazine—Ranked #16 in Federal Government Top Systems Engineering Contractors—**Columbus was listed in the November 14, 2011, *Federal Times* print edition as one of the top contractors providing systems engineering services to the U.S. Federal Government. The top 100 contractors were listed according to Federal spending in fiscal year 2011. Columbus provides systems engineering services for customers such as Goddard Space Flight Center, JPL, the Navy, and the Air Force.

- ***Washington Technology* magazine—Ranked #20 in 2011 Top 8(a) Prime Contractors—**The rankings are based on the Federal Procurement Data System–Next Generation and use data collected from the 2010 Government fiscal year.
- **Ernst & Young—2011 Entrepreneur of the Year—**Ajay Handa, Columbus CEO, received this Greater Los Angeles Award in the services category. According to Ernst & Young LLP, the award recognizes outstanding entrepreneurs who demonstrate excellence and extraordinary success in such areas as innovation, financial performance, and personal commitment to their businesses and communities. Ajay was selected by an independent panel of judges, and the award was presented at a gala event at the Beverly Hilton Hotel on June 21, 2011.
- **2011 SBA 100—**Columbus was featured in the SBA 100, a list of 100 businesses that have created at least 100 jobs since receiving SBA assistance.
- **Thomas H. May Legacy of Excellence Award—**Columbus received this award at NASA and JPL's 22nd annual High-Tech Small Business Conference on Tuesday, March 2, 2010. The Thomas H. May Legacy of Excellence Award is presented annually by JPL to a small business for excellence in subcontracting performance. This is a Center-level recognition that was presented to honorees during the 2009 NASA Small Business Symposium and Awards Ceremony. The award was established in memory of Thomas H. May in honor of his lifelong dedication to small business utilization.
- **2009 Small Business Industry Award Winner in the Small Business Subcontractor of the Year category for JPL—**The NASA Small Business Industry Awards recognize the outstanding small business prime contractor, small business subcontractor, and large business prime contractor that best support NASA in achieving its mission. Small Business Industry Awards are made in three categories: (1) Small Business Prime Contractor of the Year, (2) Small Business Subcontractor of the Year, and (3) Large Business Prime Contractor of the Year.

Selection criteria for the Small Business Subcontractor of the Year categories are as follows: (1) performs well as subcontractor on NASA contracts; (2) provides value-added and outstanding support—on schedule and within cost—to the prime contractor and innovative solutions to problems or issues that arise in the execution of the contract; and (3) works cooperatively with NASA and prime contractor personnel.

Columbus Technologies and Services, Inc.
2009 Small Business Subcontractor of the Year
NASA Jet Propulsion Laboratory

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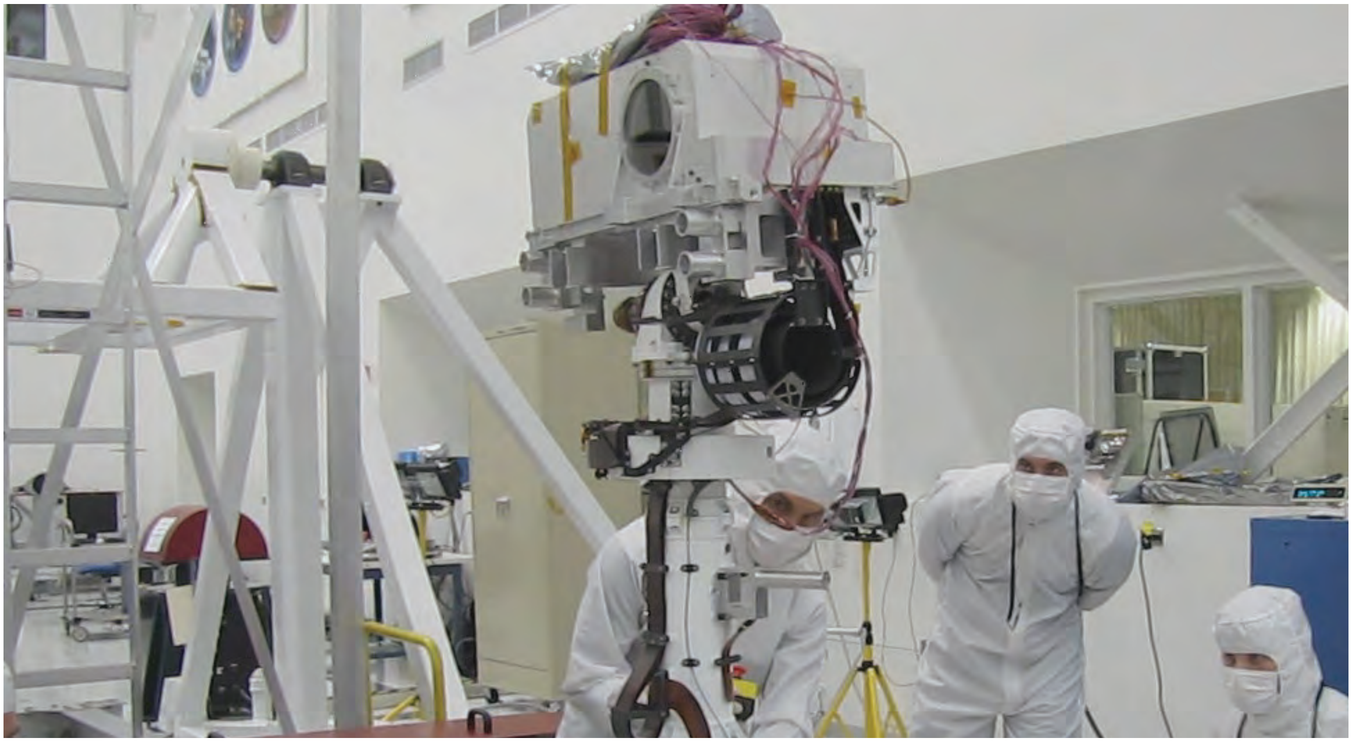
Santa Barbara Applied Research, Inc.



OVERVIEW

Santa Barbara Applied Research, Inc. (SBAR), was incorporated in the state of California in 1980. The company specializes in providing full-spectrum engineering and related technical services to NASA, JPL, and DOD. The corporate headquarters is in Ventura, CA, with satellite offices in Pasadena, CA; Colorado Springs, CO; and Pittsburgh, PA.

In March of 2005, SBAR was awarded a 9-year, multimillion-dollar Temporary Support Effort Personnel (TSEP) contract by JPL. SBAR was to provide a full range of R&D support to JPL and NASA. SBAR was awarded one of three contracts. The original cadre of personnel was approximately 300, and SBAR has the largest workforce of the contractor support personnel. The mission is to support a wide range of management, technical, and professional requirements for a variety of missions, projects, and organizations at JPL. Under this contract, we supplied a highly specialized staff of scientists, engineers, information technology specialists, and technicians who provided support to JPL for the Mars Science Laboratory. SBAR performed over 20 specific projects in research, design and development, project oversight, production support, fabrication, assembly, and mission support for the MSL.

CONTRIBUTIONS TO THE MARS SCIENCE LABORATORY

Some of the major efforts supported by SBAR included the design, development, and test of MSL subsystems; software quality assurance; and MSL fabrication and assembly. These functional areas are addressed below.

MSL DESIGN, DEVELOPMENT, AND TEST SUPPORT

SBAR's engineers provided the Spacecraft Structures and Dynamics Group with structural analyses using finite element analysis, modeling, detailed stress analysis, dynamic analysis, and testing of the MSL.

SBAR mechanical and electronic design engineers participated on design teams in a collaborative environment to design, develop, and test spacecraft flight hardware and support equipment for MSL spacecraft flight projects.

Mechanical designers supported the design of the spacecraft vehicle, mechanical systems, and instruments. They generated and maintained 3D computer-aided design (CAD) models and detailed drawings and supported the MSL during fabrication to ensure manufacturability.

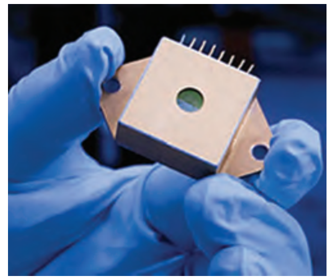
Specific components of the design, development, and test effort included the following:

- Rover structural subsystem.
- Rover mobility subsystem, components, assemblies, and interface drawings.
- Descent stage subsystem and Descent Pyro Relay Assembly (DPRA).
- Drill coring actuator/mechanism percussion movement for core samples.
- Sky crane electromechanical packaging and MSL docking mechanism.
- Backshell Interface Plate (BIP) and Thermal Protection System (TPS).
- Power and Analog Module and the integration and test of power-related electronics boards into MSL assemblies.
- Tunable Laser Spectrometer (TLS).

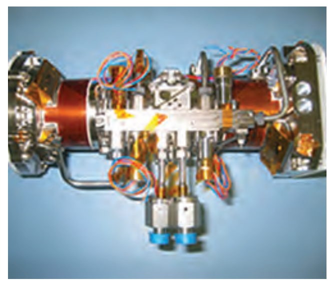
TLS EFFORT OVERVIEW

Many molecular gases have absorption bands in the wavelength region where semiconductor lasers can operate, as shown in the figure. The tunable semiconductor lasers produce a very specific wavelength of light tuned to a fundamental or overtone harmonic frequency of the target gas molecule in the near-infrared band. The light causes the molecule to vibrate and therefore absorb energy. Once adjusted to the specific frequency of the molecule, the laser is minutely tuned to different wavelengths on either side of the original wavelength. The light energy being absorbed at the target gas-absorption frequency is compared to the light energy at the surrounding frequencies, resulting in an extremely precise measurement. New data are integrated every second, making the system quick to respond to variations in the target gas.

SBAR personnel supported the design of the TLS in one of three instruments (the other two are the Quadrupole Mass Spectrometer [QMS] and the Gas Chromatograph [GC]) that make up the Sample Analysis at Mars (SAM) analytical chemistry lab on the Mars mission. TLS has



A hermetically sealed, space-qualified 3.27-micron IC laser for the Mars Science Laboratory TLS instrument.



The optics assembly for the tunable laser spectrometer (TLS) instrument for the Mars Science Laboratory.

unprecedented capability for measuring methane, water, and carbon dioxide abundances, both in the Martian atmosphere and evolved from heated soil samples. In addition, TLS will measure the 13C/12C isotope ratios in both CH_4 and CO_2, as well as the 16O/17O/18O isotope ratios in CO_2.

Using an interband cascade and a tunable diode laser, the TLS has the capability to determine atmospheric methane abundance to 2 percent accuracy and to a lower limit of 1 part per trillion with SAM preconcentration. The instrument and recent test data results will be described in context with the need for understanding Martian atmospheric and geophysical processes.

In this technique, trace molecules in Earth's atmosphere or the atmosphere surrounding another planet may be precisely identified and studied by measuring their infrared absorption spectrum. Such measurements can reveal a wealth of information about the atmosphere: its composition, chemistry, evolution, and winds. However, the availability of tunable infrared lasers with the characteristics needed for a particular measurement or mission are often very limited. Due to the strategic importance of the tunable lasers for spectroscopy, a development activity was formed in the early 1990s.

MSL SOFTWARE QUALITY ASSURANCE

SBAR provided software quality assurance support to flight, instrumentation, and ground data systems for the MSL. We performed software quality assurance product and process evaluations, conducted risk assessments, and provided insight/oversight monitoring of contractors developing software for JPL. In addition, we provided analysis, recommendations, and reports on the status of the software development tasks to the project office. When appropriate, we recommended problem and risk-mitigation solutions to the project office. SBAR software engineers also assisted in the research of new software technology and tools that will benefit future JPL projects.

MSL FABRICATION AND ASSEMBLY

SBAR provided fabrication support of assemblies and components for MSL mission hardware. Our staff assembled and wired printed circuit boards, chassis, and cable assemblies. We performed mechanical assembly and system integration tests.

The assembly required hand soldering; chassis wiring; and the application of adhesives, coatings, and potting materials. When required, support was provided at various customers' labs, the Space Flight Facility, and the environmental test areas.

SBAR provided assistance in the planning and procurement of material to support the fabrication and assembly process.

RECOGNITION

On November 18, 2008, SBAR received the 2008 NASA Small Business Industry Award—a Center-level award—as JPL's Small Business Subcontractor of the Year at an awards ceremony held in Washington, DC. In addition to this Center-level award, SBAR was honored as the Agency-level Small Business Subcontractor of the Year.

Furthermore, SBAR was the first recipient of the Thomas H. May Legacy of Excellence Award presented annually to recognize excellence in subcontract performance. This is a Center-level award presented to a small business honoree during the annual JPL High-Tech Small Business Conference. The award was established in memory of Thomas H. May, a former JPL employee, to honor his lifelong dedication to small business utilization.

Santa Barbara Applied Research, Inc.
2008 Agency-Level Small Business Subcontractor of the Year
NASA Jet Propulsion Laboratory

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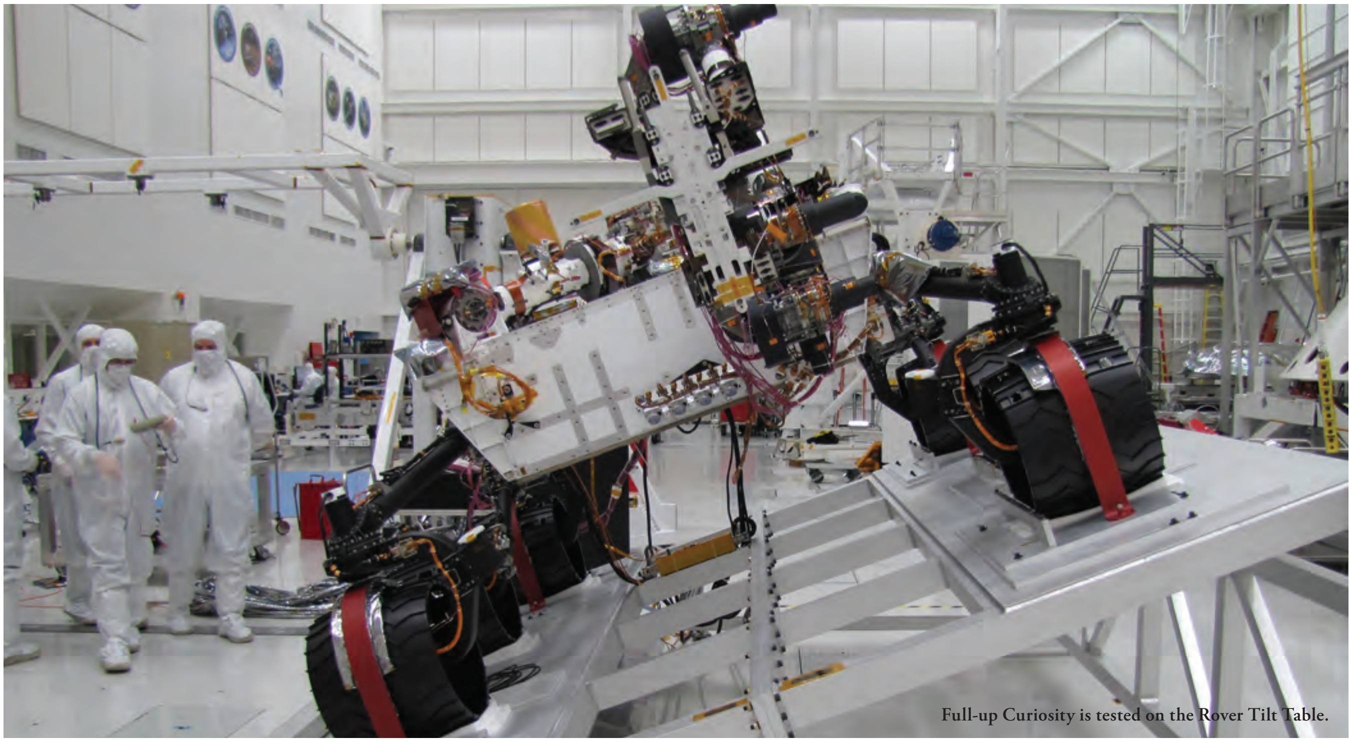
The Terraza Design Group, Inc.



Full-up Curiosity is tested on the Rover Tilt Table.

OVERVIEW

By now, the simulation of the MSL landing has been seen by millions of astonished viewers all over the world. But a few short years ago, long before that flawless landing was achieved, many of us were forced to reevaluate what we ourselves initially considered possible. Many of us had to wrestle with our pragmatic selves and focus on the parts of the mission for which we were responsible. Many more contributors to the MSL mission were not connected directly to the landing effort but instead were consigned to ensuring that all of the hundreds of thousands of incremental steps leading up to that amazing sequence and beyond were accomplished with equal dedication and scrupulous attention to detail. It has been the Terraza Design Group's privilege to have been one of those contributors.

The Terraza Design Group has been performing mechanical engineering and hardware development for some of the world's largest aerospace companies for nearly 20 years. The design of nonflight satellite ground support equipment and tooling is the backbone of our company. We forged our niche with proven dependability and technical acumen, but cost savings were a crucial component to our success. With experience comes proficiency, and after 20 years and thousands of tools and fixtures in our portfolio, we are confident that we can support any client. We are a performance-based, rapid-response solution for large aerospace firms such as the Boeing Company, Rockwell Collins, and NASA's Jet Propulsion Laboratory. In the past, small businesses were allowed to participate in the success of a large company only peripherally, with products not integral to their customer's technical achievements. This is changing, and the Terraza Design Group has been fortunate to have helped forge an alternate path.

CONTRIBUTIONS TO THE MARS SCIENCE LABORATORY

Our introduction to the MSL effort began relatively late in the development of the rover. Terraza was requested to support the system-level assembly and testing of the maturing vehicle. Our tasks were to design the support equipment that provided technicians with access to subsystem components prior to integration and to test the apparatus for the completed rover. In all, we designed and built 12 tools used in course of Curiosity's maturation.

Figure 1. The Entry Vehicle Workstand supports technicians working on the MSL Cruise Stage.

Figure 2. A JPL technician works within the MSL Cruise Stage.

Some, like the Entry Vehicle Workstand (figure 1), were large, multistructure assemblies that were designed to span the Cruise Stage and provide access from above while technicians worked inside (figure 2). A complicating factor in the design was that the Workstand had to be designed so that it assembled like a clamshell around the Cruise Stage so as not to require additional setup time for the flight article.

Other designs were smaller, but no less important. The Robotic Arm Pre-Load Test Apparatus was a very detailed test fixture designed to test the dexterity of the Robotic Arm to ensure that it functioned properly. This tool was a modular assembly that consisted of frame components that were configurable in various positions and heights. It included a mounted load module that was positioned in various locations and angles.

The Terraza Design Group, Inc.
2011 Small Business Prime Contractor of the Year
NASA Jet Propulsion Laboratory

Once Curiosity was fully assembled, it underwent a battery of tests to evaluate its mobility. We designed fixtures that had to be able to support the weight of the vehicle while remaining easy to set up and take down. The Rover Ramps could be assembled in up to four configurations, thus testing the ability of the rover to climb obstacles. The Rover Tilt Table tested the fully assembled robotic arm's ability to function while the vehicle was at a dramatic incline. Finally, as one of the final test sequences to be accomplished prior to launch, the rover was tested in the vacuum chamber supported on a test stand designed by Terraza.

The Terraza design team celebrated wildly with the rest of the world when the impressive step of landing on Mars was completed. Those gnawing concerns we once harbored now vanished, leaving us secure in the knowledge that, again, the seemingly impossible had been achieved. Ultimately, as the mission continues to unfold, more and more astounding things about our universe will be revealed.

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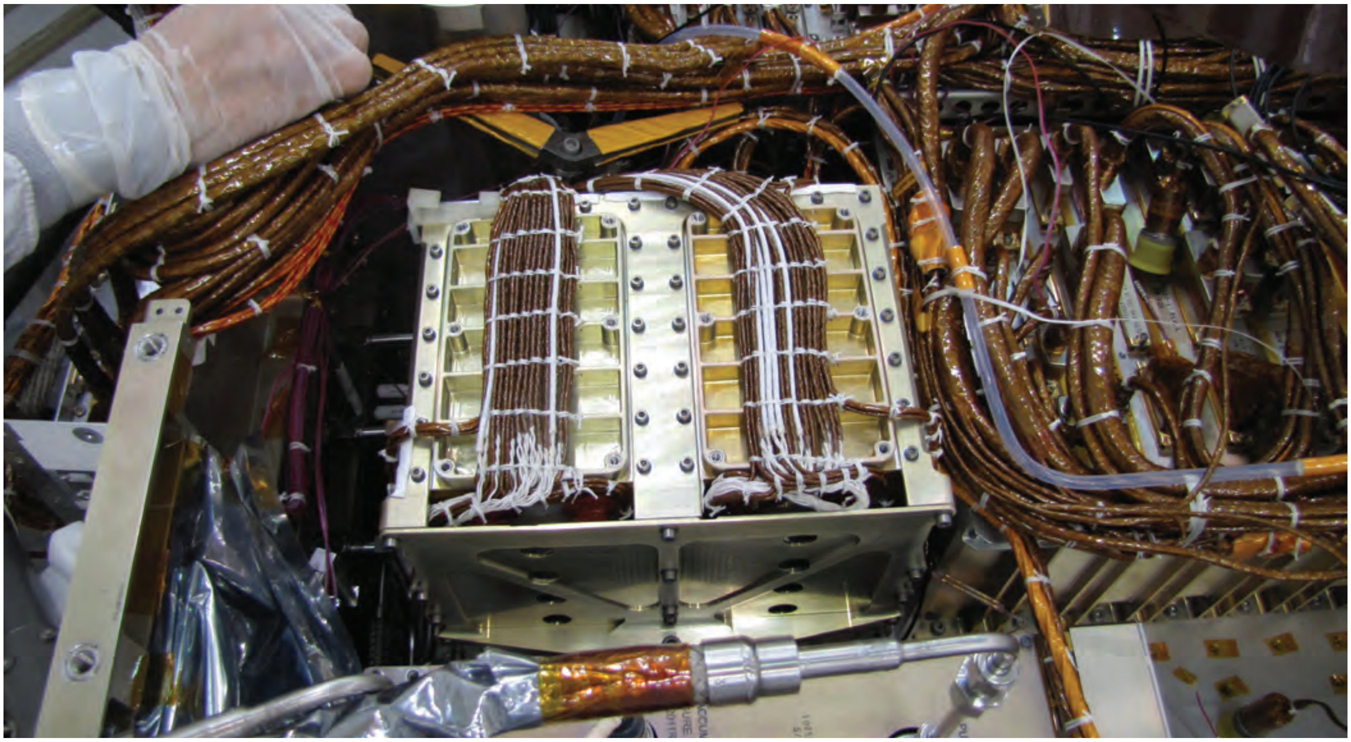


OVERVIEW

Yardney was founded by Michel Yardney in 1944. Its full corporate name then was Yardney Electric Corporation, and it was located in New York City. Yardney was among the first companies in the world to successfully produce and commercialize rechargeable silver-zinc and silver-cadmium batteries. In 1969, the company was acquired by Whittaker Corporation.

In 1970, Yardney's corporate offices and operations were moved to a single 260,000-ft^2 facility located in Pawcatuck, CT. During the 1970s and 1980s, the company expanded its product line to include magnesium–silver chloride batteries, zinc-air batteries, nickel-zinc batteries, nickel-hydrogen batteries, and lithium–thionyl chloride batteries.

In 1990, when the company was acquired from Whittaker by Ener-tek International, the corporate name was changed to Yardney Technical Products (YTP). Ener-tek is a technology-based holding company that holds over 200 patents encompassing many aspects of battery technology. Ener-tek is also AS9100 compliant and is a veteran-owned small business.

In 1995, Lithion was incorporated as an Ener-tek subsidiary to commercialize rechargeable lithium-ion technology. The subsidiary was established to commercialize lithium-ion battery technology developed through YTP's research activities conducted since 1992.

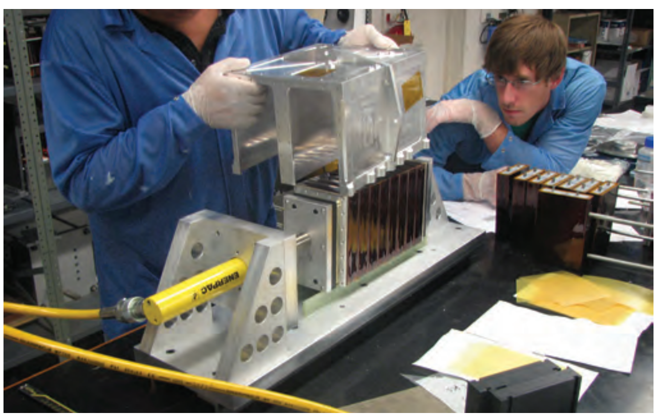
Under contracts with NASA, DOD, and other Government agencies and their prime contractors, Yardney has designed, developed, and delivered high-energy-density batteries for the Mars Exploration Rover missions; the Minuteman and Trident D-5 Strategic Ballistic Missiles; the B-2 Bomber and Global Hawk aircraft; and a long list of satellites, launchers, and specialized unpiloted vehicles.

For over 68 years, Yardney has manufactured batteries for demanding space and military applications. In fact, Yardney has closely supported the U.S. space program since the days of Gemini and Apollo. In 1964, early spacesuit designs required the use of a Portable Life Support System (PLSS) that used the same silver-zinc designs that have since been incorporated for use into today's Evolved Expendable Launch Vehicles (Atlas V/Delta IV) and are still being flown today. Silver-zinc cells were also used for auxiliary power on the Apollo Lunar Module under a contract with Grumman Aircraft Engineering Corporation. Both Eagle-Picher Company and Yardney were suppliers for these programs.

CONTRIBUTIONS TO THE MARS SCIENCE LABORATORY

On August 6, the MSL successfully completed its 9-month journey from Florida to Mars. As with the previous Mars rovers, the mission-critical batteries were manufactured by Yardney Technical Products, Inc., of Pawcatuck, CT, a veteran-owned small business. For this mission, Yardney once again teamed with JPL in Pasadena, CA.

To power the rover and instruments, the Yardney advanced lithium-ion batteries are working with a radioisotope power system that generates electricity from the heat of radioactive decay. This system offers more flexibility than the previous rovers had by removing the reliance on solar panels and the Sun for recharging the batteries. There are two 28-V, 43-Ah batteries



on board. While the main power source is rated for 110 W, the batteries can deliver a peak power of 10 kW. However, the design limit of the power system is closer to 3 kW as a result of limitations in the wiring harness and other components. The batteries will provide the complete power needs of the main computer and all instruments on board, with the radioisotope thermoelectric generator being used to recharge the batteries to full voltage.

Curiosity is over five times as heavy as either of the previous rovers, with more than 10 times the payload of scientific instruments. The mission is expected to operate for at least 1 Martian year (686 Earth days) and is part of the Mars Exploration Program. In addition to the rover batteries, Yardney also manufactured 10 silver-zinc batteries for the Atlas V booster providing the initial lift into space. These batteries are used for stage separation, avionics, and flight termination. "We look forward to watching this mission over the next year and hope for the same stellar success we experienced with the two previous rovers, Spirit and Opportunity," stated Yardney President and COO Vincent A. Yevoli, Jr.

OTHER SIGNIFICANT WORK

In the 1970s, as the space program moved into the development of the Space Transportation System vehicle, commonly known as the Space Shuttle, Yardney was once again an active participant in supplying Extravehicular Mobility Unit batteries for crew life support. The batteries provided hundreds of hours of power for several historical spacewalks. Yardney silver-zinc and nickel-hydrogen batteries were also used on the many Space Shuttle deployment missions as primary payload power, including numerous satellites and interplanetary probes. Various experiments on board the International Space Station used Yardney batteries over the years, with 100 percent mission success.

In the late 1990s, lithium-ion batteries were commercialized for the first time by Sony, and others quickly followed. In this family of rechargeable battery types, lithium ions move from the negative electrode to the positive electrode when discharging and back when charging. The significant improvement in cycle life, energy density, and power density rapidly gained the interest of the space community, as well as battery manufacturers such as Yardney. In 1988, Yardney had acquired the rights to GTE Power Systems, producing lithium–thionyl chloride cells and also beginning an investment into rechargeable lithium-ion technology. Interest in lithium-ion as a commercial battery was growing at a rapid pace, although the applications at this point were primarily for portable power (cameras/phones and eventually laptop computers) and limited to cylindrical 2-Ah capacities. A program to develop a large, space-qualified lithium-ion cell was underway with the support and funding of both DOD and NASA. Initial Government funding came via an SBIR grant focused on the development of higher-capacity and -voltage systems necessary for planetary exploration, as well as future Air Force aerospace applications.

In 1999, through close cooperation with JPL scientists and their patented cold-weather electrolyte formulation, Yardney set its sights on a large-capacity, true-prismatic cell design capable of withstanding the rigors of space flight for 9 months and providing primary power for a NASA mission to Mars known as Mars Surveyor 2001 Lander. Although the program was canceled in 2000, the batteries were fully qualified for space flight and became the benchmark of performance for future Mars missions. With a qualified space cell to offer, Yardney was selected as the battery supplier for the Mars Exploration Rover program, this time to power two rovers versus the previous lander design. Spirit and Opportunity were born—and scheduled for a 90-day mission profile on the planet. That mission was successfully executed with the two rovers landing on Mars in January 2004. While Spirit eventually ceased to function, the good health and status of Opportunity continue today, exceeding its performance requirement by over 8 years. No plans for the battery to see a single Martian winter were anticipated, and it has surpassed all customer expectations.

The Yardney/Lithion cell design has been selected for use on several subsequent programs, and we have worked closely with Johnson Space Center, Marshall Space Flight Center, Goddard Space Flight Center, Ames Research Center, and Dryden Flight Research Center in addition to our close relationship with JPL. We have custom-designed batteries for extraordinary applications performing groundbreaking missions, with contracts being awarded by major prime contractors such as Lockheed Martin and Boeing as well as directly from the NASA Centers. The NASA X-37 Advanced Technology Flight Demonstrator, under contract to Boeing in 1999 and jointly managed by the Air Force and Marshall Space Flight Center, exemplifies the confidence and strong relationships entrusted to the Yardney design team. This battery application employed a 150-V/43-Ah battery to power the reentry of this uncrewed orbital spaceplane, something that had never been done in the history of space flight.

While the company is applauding the initial success of the Mars Science Laboratory battery, another team at Yardney is hard at work developing the main power supply for the NASA Orion Multi-Purpose Crew Vehicle under contract to Lockheed Martin Space Systems Division. This advanced battery goes full circle back to the initial 30-Ah cell case design of the Mars Surveyor Lander, later successfully employed on Mars under the Phoenix Mars mission in 2008. The battery consists of next-generation chemistry successfully developed under another SBIR program with the Navy, and it includes an advanced battery-management system for full voltage monitoring and cell-balancing functionality.

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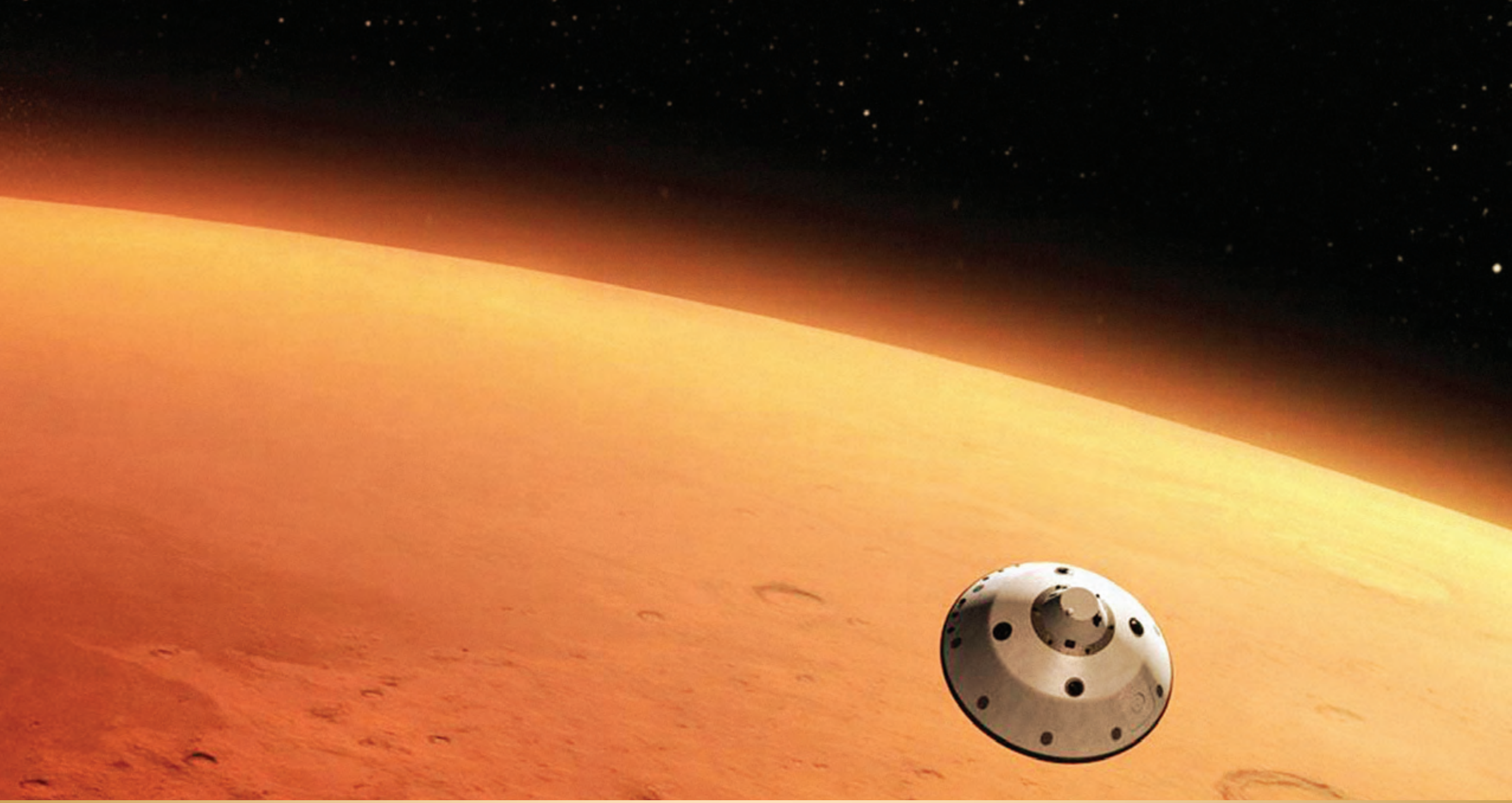

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