SOUTHWEST RESEARCH INSTITUTE®

SPRING 2021

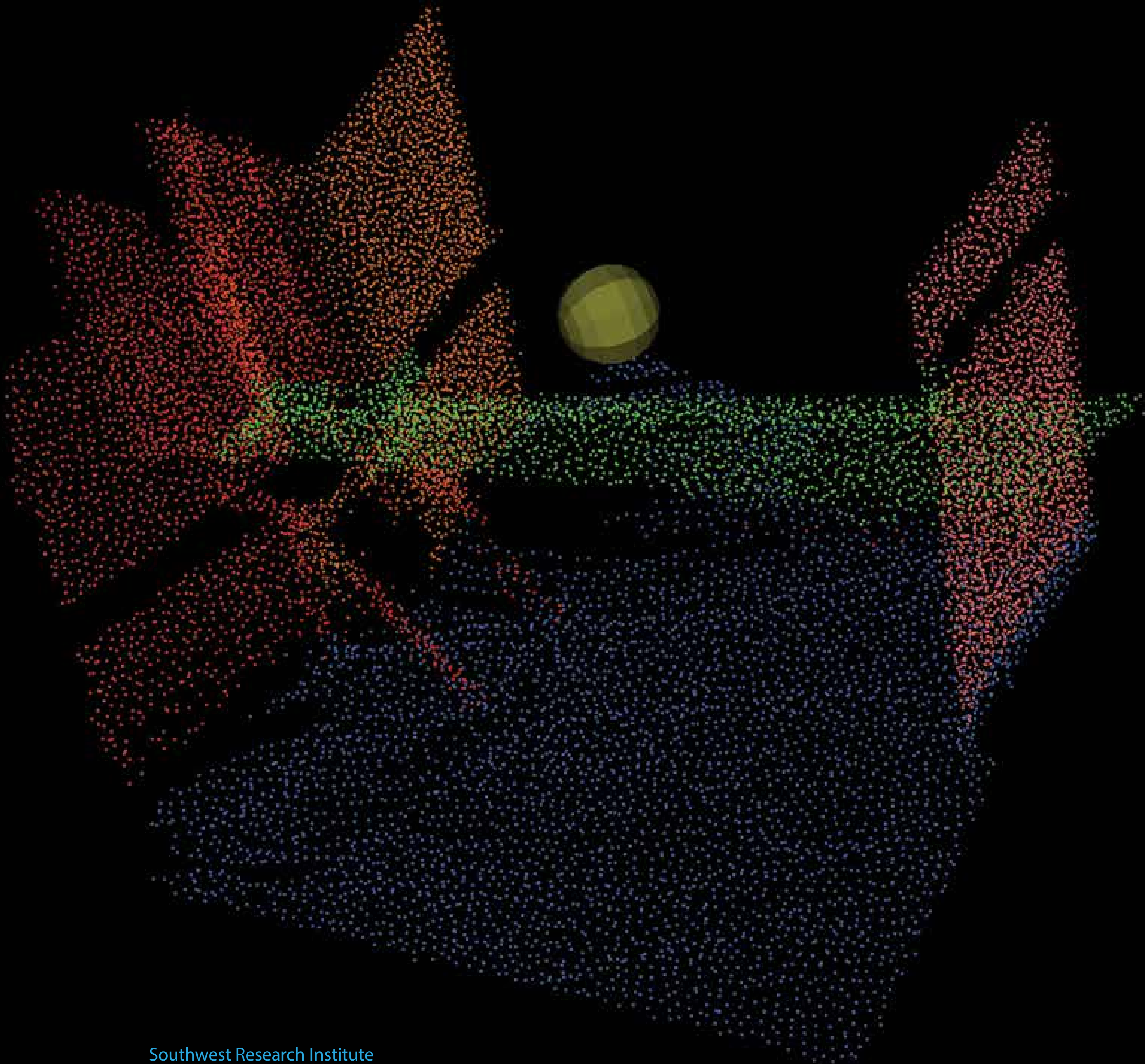
TECHNOLOGY TODAY®

AERIAL ASSESSMENTS

2 AERIAL ASSESSMENTS

10 REVOLUTIONARY ROBOTS

22 FAST-TRACKING FAST CHARGING



Southwest Research Institute engineers are helping adapt small drones to autonomously operate within confined spaces. An advanced perception system developed with internal funding uses computationally efficient techniques to precisely and intuitively identify structures, depicted by these colorful point clouds.

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SPRING 2021 • VOLUME 42, NO. 1

TECHNOLOGY TODAY

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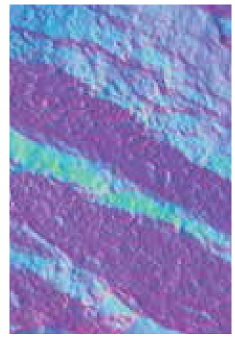

ON THE COVER

SwRI is integrating drone-based data collection with 3D visualization techniques to provide insights into faults and fractures in geologic structures. Outcrop surfaces can be colored according to orientation, highlighting the fault surface geometries and the complexity of small-scale fault networks.

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IN THIS ISSUE

We like to say that SwRI does research ranging from "Deep Sea to Deep Space," and that's a true statement. We also say that our work ranges from imagination to reality. Sometimes we perform *basic* research in fields such as space physics while at other times we conduct *applied* research to design and build submersibles to explore the ocean floor. *Basic* research leads to new ideas; our *applied* research turns ideas into innovative technologies.

This issue of Technology Today offers good insight into innovation as well as applied research. Proceeds from oil and gas production led to the very creation of SwRI. But where "wildcatters" once used intuition to locate hit-or-miss test wells, SwRI has helped turn the basic science of geology into a practical tool for exploration. Petroleum geologists analyze rock outcrops to learn how those same formations behave deep beneath the surface. But how do you study a remote, rugged outcrop? You develop sensitive machine-vision tools — and collect data via a drone!

Meanwhile, an SwRI space scientist used the starfish's bizarre eating habits to develop an innovative robotic sampler that can gather materials from the surface of an asteroid or planet, then turn itself inside-out to store them for a safe return to Earth.

And speaking of robots, at SwRI they come in all sizes, from that miniature machine-vision drone to the world's biggest industrial robot. Read how we help aircraft maintenance facilities quickly and safely remove the paint from jumbo jets.

And finally, as electric vehicles advance with new battery technologies, lengthy charging time remains an obstacle to their widespread acceptance. But fast charging requires high-capacity outlets, and too-fast charging can shorten battery life. We are helping solve the problem by manipulating the charging process to optimize charge time while reducing loss of battery life.

As you can see, the answers to our clients' most vexing problems often rest squarely in our wheelhouse — applied research and innovative solutions.

Sincerely,

Walter D Downing

Walter D. Downing, PE
Executive Vice President/COO

D024765

AERIAL ASSESSMENTS & SUBSURFACE PREDICTIONS

Making quantitative subsurface predictions from aerial outcrop imagery

By Adam J. Cawood, Ph.D., David A. Ferrill, Ph.D., and Kevin J. Smart, Ph.D.

In the early 1900s, finding new reservoirs of water and oil was more an art than a science. “Wildcatters” — including the father of Southwest Research Institute’s founder, Tom Slick Jr. — roamed the country prospecting for oil, drilling exploration wells in unproven oil fields. Once known as “Dry Hole Slick” after a string of bad luck when at least 10 exploratory wells came up dry, Tom Slick Sr. discovered Oklahoma’s giant Cushing oil field in 1912 and then became known as the “King of the Wildcatters.” The initial well produced for the next 35 years. SwRI is now using modern digital techniques to improve the accuracy and efficiency of geological data collection and analysis. These data-driven approaches allow SwRI scientists to make quantitative predictions about the subsurface.

ABOUT THE AUTHORS

From left: Dr. Kevin Smart manages SwRI’s Earth Science Section, offering extensive expertise in computational solid mechanics, structural geology and geomechanics, field mapping and geologic fracture analysis. Dr. David Ferrill is an Institute scientist with international research experience in characterizing reservoirs and aquifers, interpreting tectonic stress and analyzing rock deformation and fracture mechanisms. Dr. Adam Cawood is a structural geologist specializing in the use of close-range remote sensing techniques for structural analysis, particularly using digital photogrammetry to reconstruct outcrops for geological analysis. Cawood is also a founding member and lead curator of eRock (www.e-rock.co.uk), an open-source repository of digital outcrops for teaching, research and science communication.

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SwRI's Dr. Adam Cawood collects UAV imagery of surface rock exposures with precise GPS data to build high-resolution, accurate "digital outcrops" for geological data extraction.

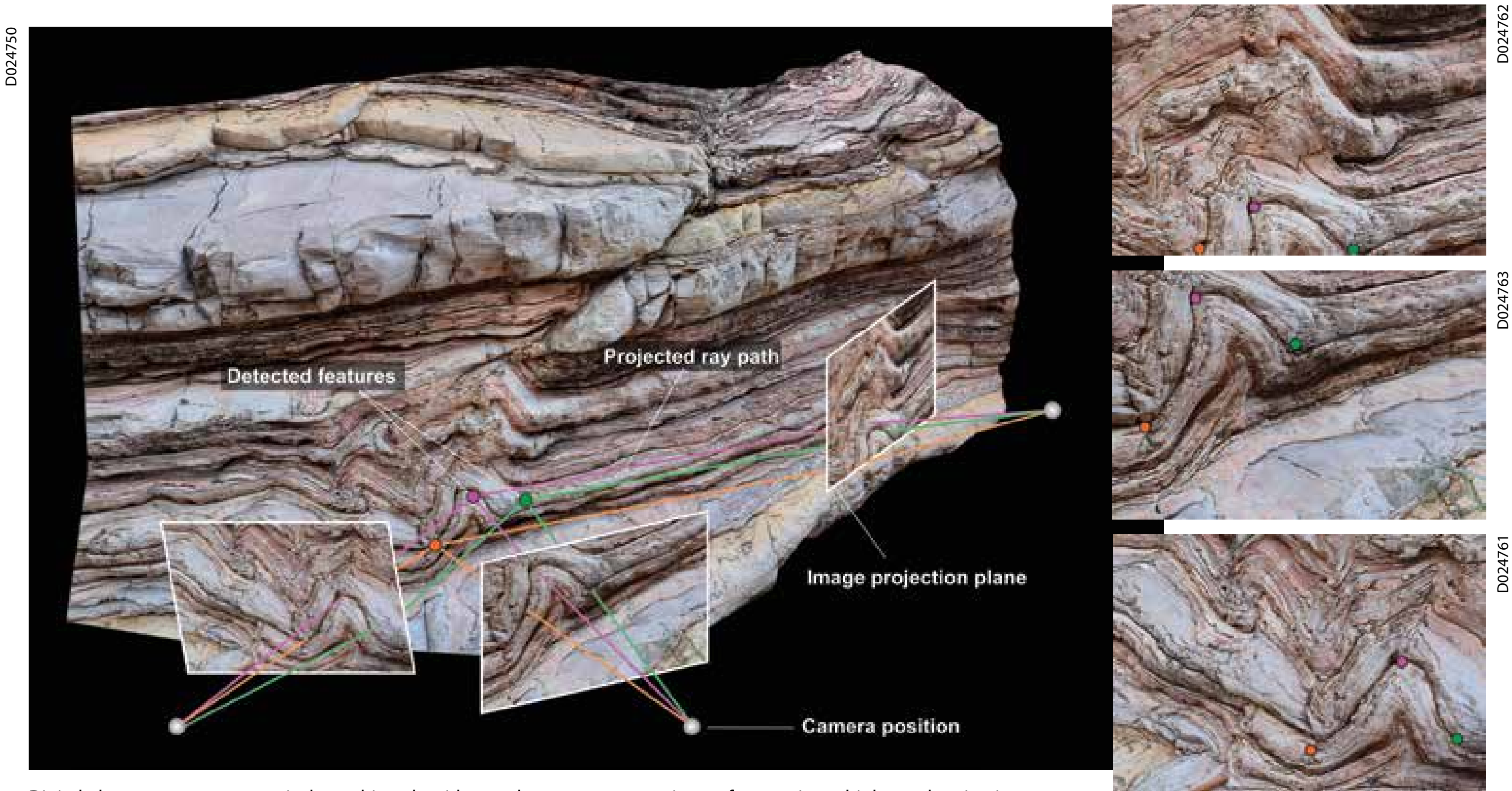
For the past 30 years, SwRI has taken some of the gamble out of resource exploration and development, offering quantitative structural geology and geomechanics services to help clients better understand the complex interplay between subsurface structures, rock properties and fluid flow. Our research, consulting and training services benefit not only oil and gas exploration, but also geothermal exploration, groundwater management and geological storage and disposal of waste materials.

Recently, SwRI began integrating unmanned aerial vehicles (UAVs), or drones, with modern digital photogrammetry and automated feature detection to improve our understanding of subsurface geology. By precisely aligning aerial imagery, structural geologists can use high-resolution 3D reconstructions to extract geological information from surface rock exposures, or outcrops. These data provide detailed information about the geometrical properties of fault and fracture networks, which can be used to predict geological structures in analogous settings underground. This work allows scientists to quantitatively predict how faults and fractures affect subsurface fluid flow and storage. These predictions are important for a range of industries, including geothermal energy, carbon dioxide sequestration, oil and gas extraction, groundwater management, geological storage or disposal of hazardous waste and even planetary exploration.

PHOTOGRAMMETRY: BEGINNINGS

Map makers first used photogrammetry, or the process of using overlapping imagery, to extract 3D measurements, in the 1850s when cartographers used photographs taken from church steeples to map the neighborhoods of Paris. Since then, photogrammetry has been used to generate detailed topographic maps across the Earth's surface and even reconstruct the surface topographies of Mars and Venus.

Over the course of the 150 years between the invention of photogrammetry and the dawn of the 21st century, the process of



Digital photogrammetry uses pixel searching algorithms to locate common points or features in multiple overlapping images.

using photographs to acquire elevation data remained essentially unchanged. The manual identification of common points in overlapping images was used to calculate the elevation of photographed objects. While incremental improvements in photogrammetric equipment and techniques allowed measurements to be collected more efficiently and accurately, manually identifying objects in photographs remained the norm. This labor-intensive process was eventually superseded in the 1960s and 1970s by other distance measuring systems such as Light Detection And Ranging (LiDAR).

GOING DIGITAL

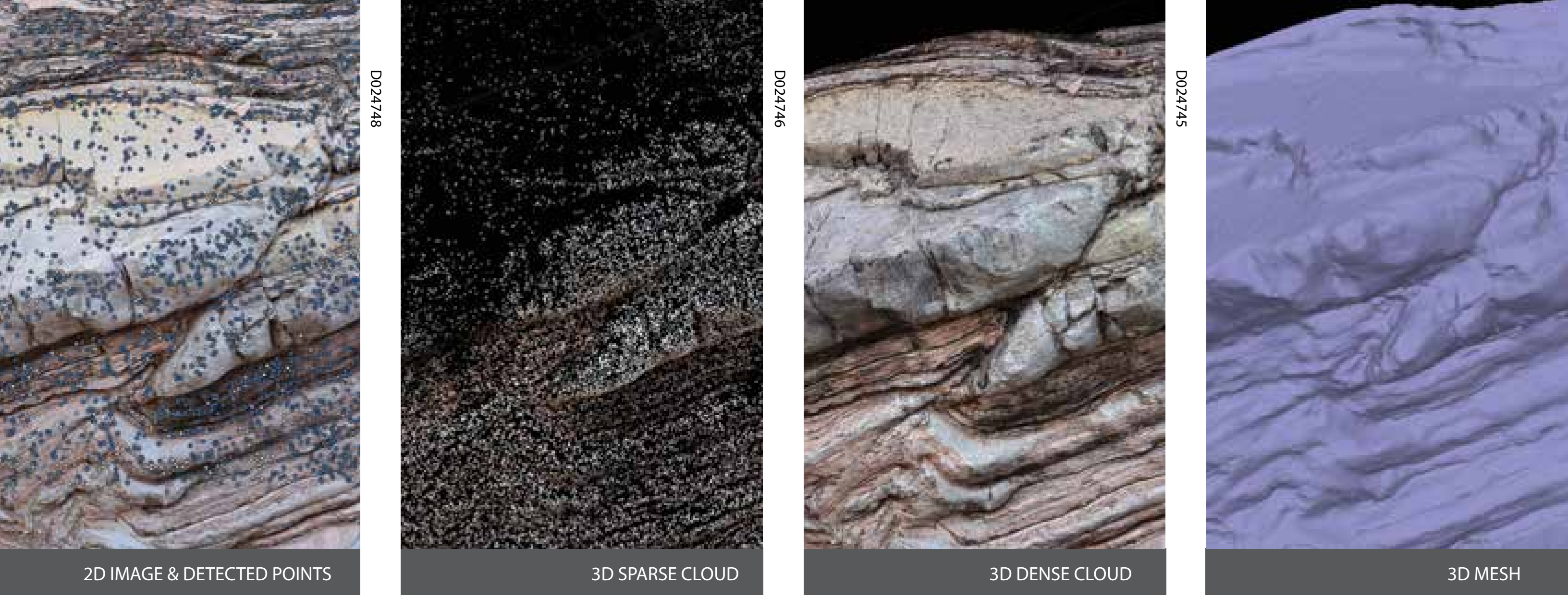
Widespread adoption of digital photography and the associated development of computer vision techniques have revolutionized photogrammetry over the past decade. Automated pixel searching and matching algorithms have replaced manual point picking in traditional photogrammetry, making the process more efficient and more flexible than traditional approaches. Conventional photogrammetry uses pairs of images and relies on precise knowledge of camera positions and lens distortion parameters. In contrast, digital photogrammetry can automatically generate 3D models from hundreds to thousands of digital photographs in unordered image collections without requiring precise geospatial data or prior optical information. Today's modern digital photogrammetry can rapidly reconstruct 3D scenes with minimal user input, has a flexible approach to image alignment and does not rely on specialized knowledge or expensive equipment.

In parallel with advances in digital photogrammetry, the past decade has seen a revolution in commercially available UAV technology. Relatively low-cost drones can be outfitted with high-resolution digital cameras for close-range remote sensing. Because aerial imagery can be collected rapidly, efficiently and at low cost, scientists, engineers and surveyors can digitally reconstruct 3D scenes with unprecedented speed and efficiency.

SwRI geologist Dr. Kevin Smart uses a compass clinometer to measure fault orientations by hand.

DETAIL

Compass clinometers are used to measure the 3D orientation of geological surfaces such as faults, fractures or bedding surfaces.



Features or objects in 2D images are automatically detected and aligned using computer vision algorithms. This process converts 2D images into 3D geometric information that can be used for geological analysis.

Today, UAVs and digital photogrammetry are used in a range of applications, from agriculture and infrastructure monitoring to flood and natural hazard risk management.

DIGITAL GEOLOGY

The study of outcrops is critical to understanding geological processes and helping geoscientists accurately predict subsurface geological features. SwRI structural geologists have been studying fault and fracture networks at outcrops for several decades, determining that the geometric properties of these networks can strongly influence fluid flow pathways and distribution below ground.

Field geologists traditionally measure outcrop faults and fractures using manual techniques and handheld instruments, with tools such as compass clinometers, tape measures and field notebooks. SwRI is improving the efficiency and reliability of geological data collection using digital photogrammetry techniques. With UAV photography and precise GPS measurements, the team can generate high-resolution, accurately scaled and precisely oriented digital outcrops to extract reliable digital measurements. This approach does not negate the need for traditional geological fieldwork but rather expands the field geologist's toolbox. Field measurements and observations remain critical for benchmarking digital data and for providing in-depth knowledge of geological processes.

FROM DIGITAL OUTCROP TO GEOLOGICAL DATA

SwRI's digital outcrop models allow large datasets to be extracted more efficiently, safely and cost-effectively than traditional fieldwork. These 3D reconstructions can contain hundreds of millions of data points, providing a wealth of geological information. Geostatistical predictions typically rely on large datasets, and digital outcrops have the potential to meet this need. Translating these rich datasets into geological understanding or valid predictions in the subsurface, however, remains a challenge.

The current approach to extracting geological measurements from digital outcrops involves time-consuming hand

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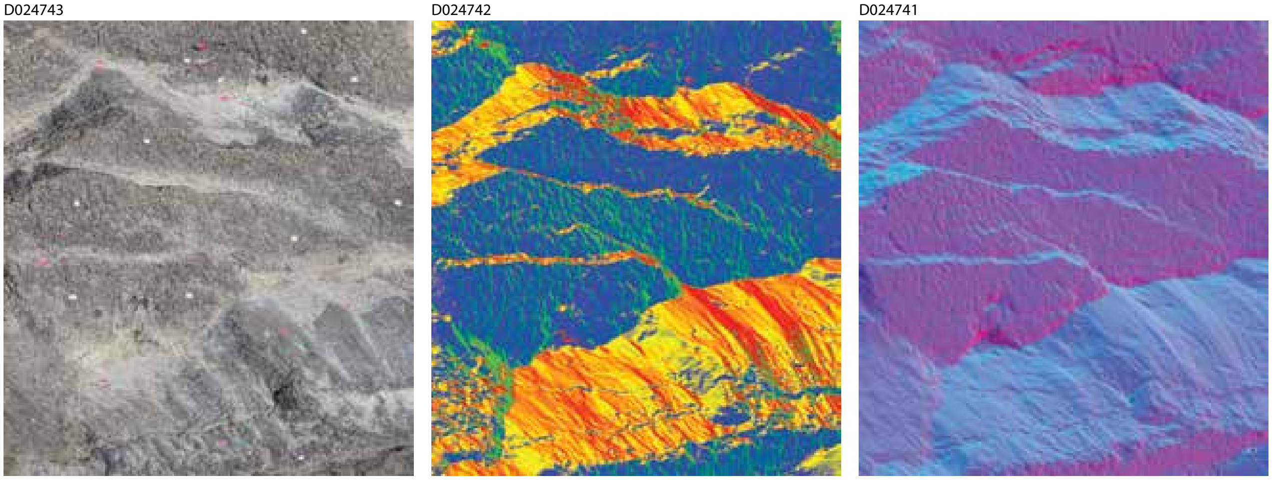
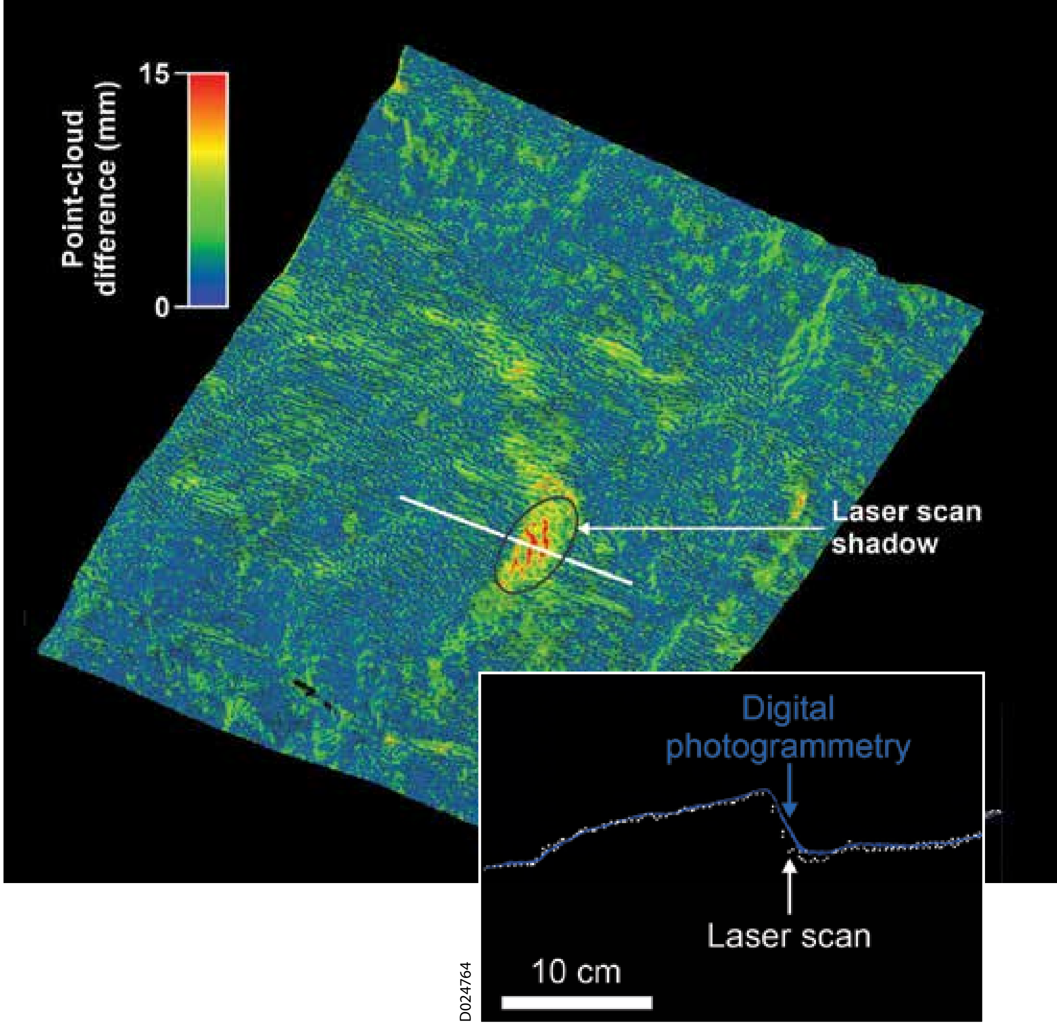


High-resolution 3D data and data visualization techniques provide insights into fault and fracture network properties. Scientists apply false colors based on outcrop surface orientations to highlight fault geometries and the complexity of small-scale fault networks, which appear as warm colors (yellow to red) in middle image and blue in image at right.

D024744

Looking at outcrops in the Canyon Lake Gorge, SwRI geologists tested the accuracy of digital photogrammetry against existing laser scan data. This comparison map shows the differences between laser scan and digital photogrammetry data at a test location and highlights the improved coverage and accuracy provided by aerial imagery and photogrammetric reconstruction.



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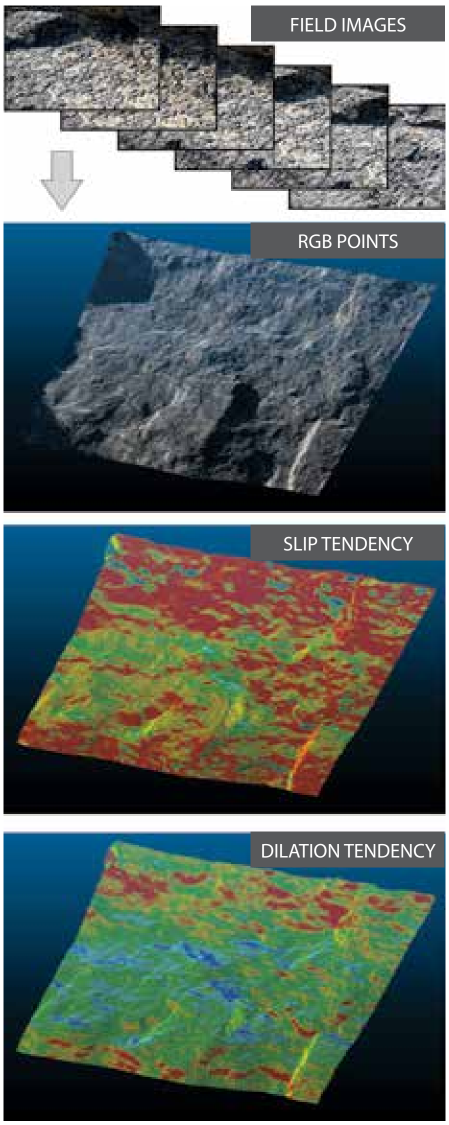

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Outcrop images are used to generate a 3D point cloud and mesh of an exposed fault surface. SwRI analyzed the reconstructed fault surface with its 3DStress® software to understand fault initiation and growth, and the implications for fluid flow along fault surfaces in the subsurface.

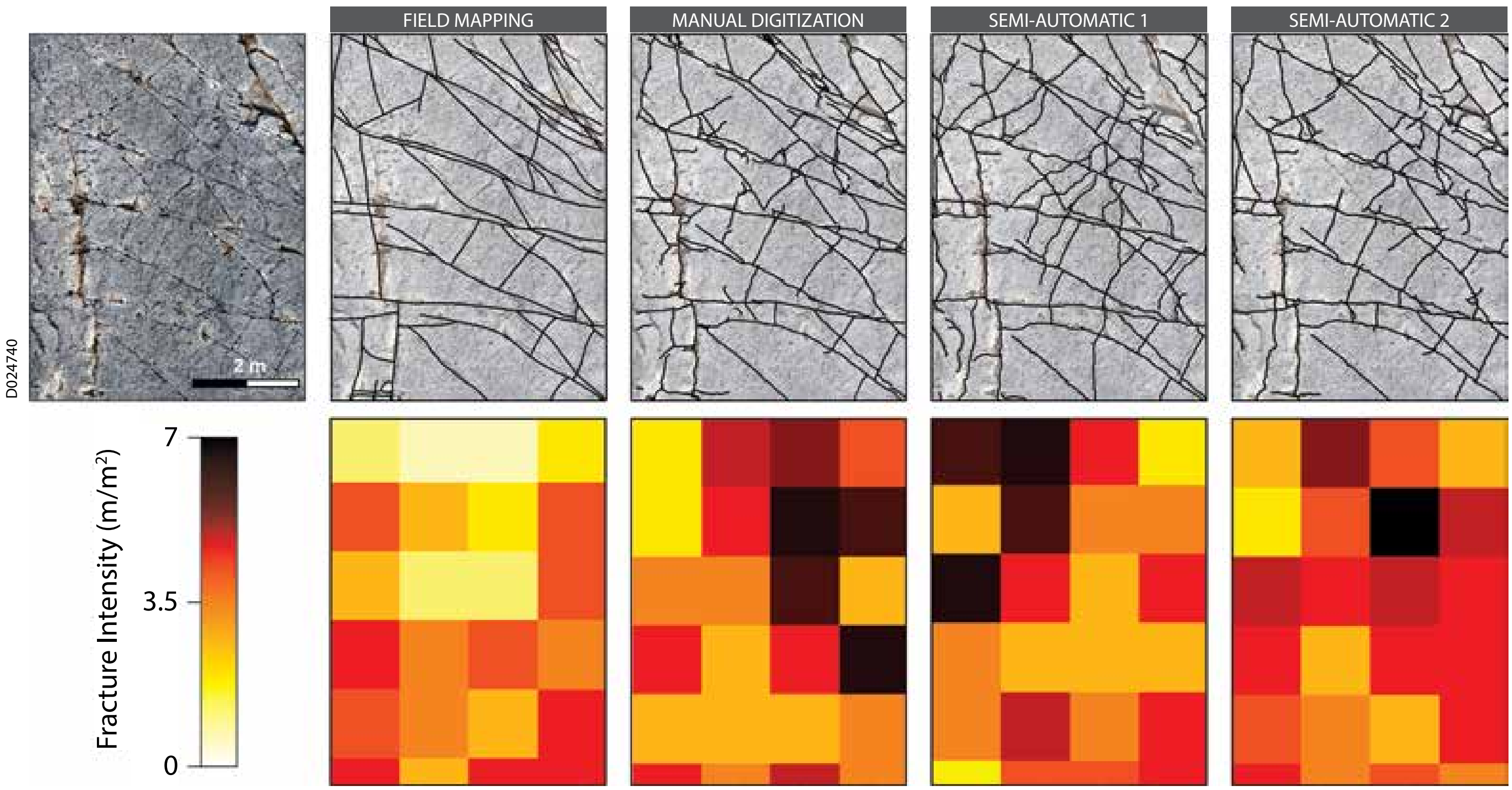
digitizing of geological features, where a geologist traces faults and fractures in a digital 3D environment. While this is generally faster than field-based fault or fracture mapping, it still requires a significant amount of user input. SwRI scientists are using computer vision techniques such as edge detection algorithms and computer-assisted interpretation work-flows to address this challenge. Early results are showing promise and have improved the efficiency of digital data extraction. By developing digital data extraction workflows that are both robust and more efficient than existing approaches, SwRI is fully leveraging recent developments in digital photogrammetry and UAV technology to develop a data-driven approach to geological modeling.

DETAIL

A digital outcrop model is a 3D representation of a geologic outcrop surface, either as a textured polygon mesh or as a 3D point cloud.

DATA-DRIVEN PREDICTIONS

In the traditional approach to using outcrops as analogs for the subsurface, a geologist makes outcrop observations and measurements to infer geological conditions or rock properties underground. While this approach has proved invaluable for conceptual understanding of the subsurface, limitations of traditional fieldwork mean that robust statistical predictions are not always possible. With improved digital sampling abilities — such as sampling at a range of observation scales and at regular intervals — SwRI is now able to apply data-driven approaches to under-standing and predicting subsurface fault and fracture properties. This capability is equally applicable to traditionally accessible outcrops and outcrops that are generally inaccessible due to vertical or overhanging outcrop surfaces or unstable rock. By performing multivariate statistical analysis on compiled geological variables, SwRI scientists aim to improve the understanding



SwRI geologists use field-based fracture maps to investigate the efficiency and accuracy of digital methods. Semi-automatic approaches yield higher detail fracture maps in a fraction of the time taken to map fractures manually.

of how multiple geological factors combine to influence the formation of faults and fractures.

SwRI is developing a suite of quantitative relationships between combined geological properties and the properties of fault and fracture networks. SwRI is combining digital measurements of fault and fracture properties — such as fracture lengths, orientations and abundance — with other geological variables — such as mechanical properties, layer geometry and thickness, and rock type, mineralogy and porosity. Geologists then combine these data with properties that are readily measurable or available from subsurface data such as wellbore information and seismic images to make probabilistic predictions of fault and fracture properties at depth. These results will provide the foundation for understanding and predicting complex fault and fracture properties in a range of geological settings.

DETAIL

Multivariate statistical analysis addresses multiple statistical outcome variables at a time, addressing multiple measurements and their relationships to explore data structures and patterns.

FUTURE DIRECTIONS

Currently, SwRI geologists are focused on both methodological approaches to digital data extraction, and more broadly, on predicting fault and fracture network properties below ground. This work is important because these geological structures play a significant role in how fluid moves through subsurface rock. While current methods for extracting oil and gas from reservoirs rely on understanding the properties of subsurface faults and fractures, these factors will remain important as the world transitions to alternative energy sources such as geothermal resources. Effective extraction of geothermal energy relies on understanding faults and fractures and how those features influence fluid circulation pathways underground.

The growing global population is intensifying pressures on natural resources. The imperative to meet global targets for reducing greenhouse gas emissions means that carbon dioxide sequestration and effective groundwater management will become increasingly important in the future. As with many subsurface applications, understanding and predicting the mechanisms for the flow and retention of fluids in rock formations are critical for managing our aquifers and for safe, effective long-term underground storage of carbon dioxide.

Improved understanding of the subsurface will help ensure that current and future energy needs are met, groundwater resources are managed sustainably and contaminants and waste products can be safely isolated underground. As SwRI digital photogrammetry technology advances, it will improve our understanding of what controls fault and fracture properties and allow geoscientists to make better predictions of subsurface properties. Predicting what lies beneath has the potential to improve operations for a range of critical applications.

Questions about this story? Contact Cawood at adam.cawood@swri.org or 210.522.3958.

Two SwRI experiments recently flew aboard Blue Origin's New Shepard suborbital rocket. The Box of Rocks Experiment II (BORE II) tested new technology for magnetically attaching to and sampling asteroids. The second experiment evaluated a tapered liquid acquisition device (LAD) designed to safely deliver liquid propellant from fuel tanks to a rocket engine.

BORE II continued a 2016 experiment studying the behavior of meteorite-like materials inside a container at low gravity. BORE II used materials that mimic meteorites more accurately to test the novel Clockwork Starfish sampling device.

Taking inspiration from the aquatic echinoderm, which turns part of itself inside out to engulf its prey, Clockwork Starfish is a tetrahedron with magnetized sides that can fit in the palm of your hand. Magnetic materials on the surface of most asteroids allow the Clockwork Starfish to passively gather samples from any asteroid it is dropped on. The "starfish" then stores the samples for transport by turning itself entirely inside out.

"While current asteroid sample return missions visit single asteroids and collect samples from one or two locations on their surface, a future mission carrying dozens of micro-sampler landers like these could return samples from various locations on numerous asteroids," said SwRI's Dr. Alex Parker, who led the development of the Clockwork Starfish device. "This would be a game changer for understanding the origin and history of the solar system."

"This could offer a simple but robust alternative to other means of sampling small bodies, like drilling," said SwRI's Dr. Dan Durda, the experiment's principal investigator. "Instead, it could be as easy as bringing a magnet along."

SwRI also evaluated how effectively a tapered LAD eliminates potentially dangerous vapor bubbles in fuel from being transferred to the rocket engine.

Engineers at SwRI and NASA's Glenn Research Center created the tapered LAD to address problems that could arise with longer spaceflights beyond Earth orbit. A long spaceflight could require large amounts of fuel to be stored at low temperatures and then transferred to the rocket engine, but current LADs have straight channels that are vulnerable to internal vapor bubbles.

These vapor bubbles can hinder liquid propellant from transferring to other tanks or damage rocket engines during ignition. SwRI's Kevin Supak, Dr. Amy McCleney and Steve Green evaluated a LAD with a tapered channel that passively removes the bubbles through surface tension. A smaller version of LAD was tested on New Shepard in December 2019. The recent experiment tested several larger-scale versions that include design modifications to more accurately capture bubble movement physics that would occur in actual cryogenic tanks.

"We hope that the tapered LAD concept can offer a low-cost efficient solution for cryogenic fluid management for long-duration spaceflight," Supak said. "Historically, technology used to manage bubbles in cryogenic tanks has been costly to design and deploy."

SwRI plans an additional experiment aboard New Shepard in the future to investigate other geometries for the LAD design.

SwRI EXPERIMENTS FLY ABOARD SUBORBITAL ROCKET

SwRI has designed a new technology to magnetically attach to asteroids and sample their surfaces. Scientists tested two Clockwork Starfish devices in low gravity aboard Blue Origin's New Shepard rocket.

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Dr. Amy McCleney was part of the team evaluating a liquid acquisition device (LAD) designed to safely deliver liquid propellant from fuel tanks to rocket engines. LADs with tapered channels designed to passively remove vapor bubbles in fuel through surface tension were recently tested on New Shepard.

LASER-FOCUSED ON REVOLUTIONARY ROBOTS

BY PAUL EVANS

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One hundred years ago, Czech playwright Karel Čapek coined the word robot, and since then, engineers have been chasing fiction in the pursuit of robotic solutions in a variety of applications. The word robot evokes a wide range of ideas, from the fictional droids in the "Stars Wars" universe to the mechanical arms widely used in manufacturing plants and the disc-shaped autonomous vacuums sweeping our homes.

Engineers at Southwest Research Institute are ushering in a new wave of mobile robots without boundaries, closing the gap between science fiction and the real world. Today's robot concepts are limitless and represent a range of shapes and sizes from small crawling bots to the largest automated systems in the world. Robots are ideal for performing dull, dirty, dangerous and delicate tasks or for improving process quality, repeatability and throughput. At SwRI, what drives a robot concept is the job it needs to accomplish. Today's commercially available off-the-shelf robots can effectively meet the requirements of many applications. When no readily available robot matches a project's demands, SwRI's multidisciplinary team of roboticists creatively goes to work, conceptualizing ideas and translating them into reality.

DETAIL

A roboticist conceptualizes, designs, builds, programs and experiments with robots.

BRIDGING THE GAP

It was this exact gap, where available robot solutions did not meet the process and requirements necessary, that launched SwRI on a journey to build the largest mobile robot system in the world, to deliver one of the most powerful laser coating removal solutions to the aerospace industry. SwRI's ability to create this ingenious giant is

For more than 30 years, SwRI has developed large robotic systems for aerospace applications such as a robotic depaint system designed to maintain the U.S. Air Force's fleet of F-15 fighter jets.

rooted in our successful history of working in the automated airplane depaint industry. Our staff has been creating and installing large-scale depaint systems for the military since the early 1990s, servicing fighter aircraft such as the F-15 Eagle and the F-16 Falcon.

All aircraft must undergo periodic paint stripping, inspection and repainting multiple times over the course of their service lives. Paint must be removed for weight savings and to allow engineers to inspect the aircraft structure for any signs of corrosion or damage. Without automation, the depaint process is labor-intensive and uses potentially harmful chemicals, producing large volumes of hazardous waste. Previous generations of SwRI's automated depaint systems removed workers from harm's way and used less hazardous plastic media to blast off coatings. However, these systems were impractical for larger airframes.

Using internal research, SwRI demonstrated a new high-precision laser that selectively removes the paint, topcoat and primer from aircraft. This technology can be applied to other structures such as bridges, vehicles and ships.

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In 2009, while building a pair of robots for next-generation fighter aircraft, SwRI began to contemplate what large-scale robots of the future would look like and how they would operate. Our team envisioned a future where robots could move between hangars, instead of being fixed in place and dedicated to one facility. We envisioned a future where the depaint process was precise, fast and clean.

These creative thoughts led to two key game-changing internal research programs that catapulted SwRI into the world of large-scale laser-wielding mobile robots.

DETAIL

As a nonprofit research and development organization, SwRI uses part of its net income to invest in tomorrow's innovations, allowing staff members to explore innovative and unproven concepts without contractual restrictions and expectations. In 2020, SwRI initiated 114 new projects, investing more than $10 million in internal research.

INVENTION INVESTMENT

Using SwRI's internal research and development (IR&D) program in 2010, we developed and demonstrated laser ablation to strip coatings from military planes. Once the team demonstrated selective coating removal — stripping paint layer by layer — at promising production rates, SwRI began pursuing new opportunities in robotic laser coating removal. A fiber laser process was ideal for routing the laser beam to the end of the robot arm to remove a range of coatings. To meet commercial aviation needs, engineers then investigated a range of coatings and explored using carbon dioxide lasers for some commercial aircraft paints.

At the same time, another IR&D project explored how to revolutionize robotic workspaces with its Mobile Robotic ROving Accurate Manipulator (MR ROAM). We integrated a robot arm onto a mobile base, to take the robot to the job instead of bringing the job to the robot. This successful research project led to a commercial automated warehousing application.

DETAIL

Lasers use a medium, such as a ruby crystal, loaded with electrons that repeatedly amplify and concentrate light until it emerges in a powerful beam. A fiber laser uses fiber-optic cables as the amplifying medium to efficiently pipe concentrated light beams wherever they are needed.

SYNERGY

In addition to our internal research portfolio, another critical factor in SwRI's ability to create the largest robots in the world is the expertise of our staff and our state-of-the-art facilities. Our multidisciplinary staff has years of experience in process development and fabrication techniques in a range of technical fields, all critical for advanced robotics development and integration. Additionally, SwRI's unique facilities include a heavy article test building offering the cranes, high bay and advanced tools and machinery needed to build the largest and heaviest systems. Once we demonstrated the laser coating removal and mobile manipulator expertise, SwRI applied this to the development needs of a commercial client. SwRI's task was to develop a laser coating removal robot that would remove paint from the largest aircraft in the fleet while remaining adaptable and scalable, to remove coatings from the smallest aircraft as well. In collaboration with XYREC Inc., with SwRI providing research and development services, the Laser Coating Removal (LCR) robot was born.

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Engineers developed a small-scale mobile manipulator system to demonstrate using an off-the-shelf industrial manipulator, mobile platform and metrology system. The system was adapted for picking up and sorting items in a warehouse application.

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SwRI demonstrates the A5 Robotic System, a mobile platform designed for adaptability and flexibility for a range of aircraft manufacturing and maintenance activities, including surface processing.

SwRI developed the largest mobile robot system that positions the most powerful carbon dioxide laser on any surface of an aircraft to quickly, cost-effectively and cleanly remove coatings.

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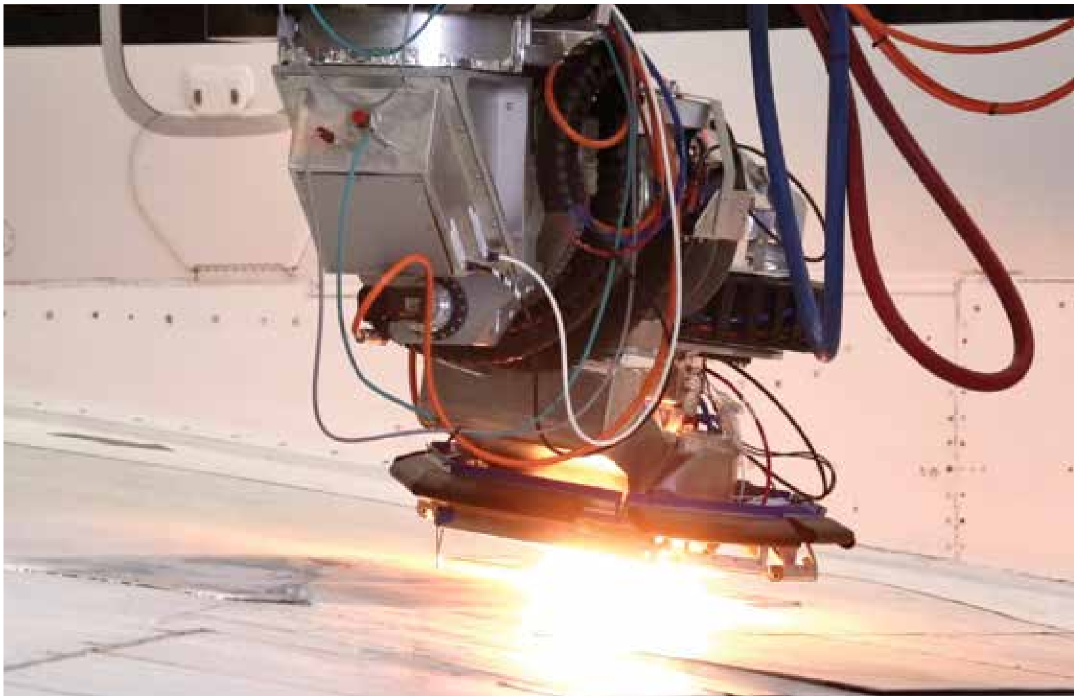

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The LCR system precisely and efficiently removes coatings from full aircraft for maintenance operations. The LCR system is the only known solution for high-speed removal of the full range of aircraft coatings, including all colors and clear coatings, over a broad range of defense and commercial aircraft — from fighter-sized jets to cargo-sized airframes. One LCR can work independently or can team with another, providing additional flexibility and portability to optimize facility usage.

CUSTOM FLEXIBILITY

The LCR system uses the largest commercially available carbon dioxide laser deployed via the largest mobile manipulator. It includes intelligent process monitoring and control to precisely conduct the coating removal process, which can remove a single layer or multiple layers all the way down to the substrate. The LCR system is unique. No other depaint system can remove aircraft coatings from a broad range of substrates as quickly or in such an environmentally friendly fashion.

Key to the LCR is coupling the laser removal process with a robotic system uniquely designed to deliver the laser beam via the robotic end effector. The system's laser process is controlled by a proprietary closed-loop, computer-vision-based software and includes an innovative "scanner" that

DETAIL

An end effector is the device attached to a robotic arm that performs a task. The nature of the device depends on the robot application and can include grippers or tools.

sweeps the laser over the surface of the aircraft. Intelligent process monitoring and control delivers the laser beam to precisely and safely remove coatings layer by layer.

The LCR's 20-kilowatt laser combusts and evaporates all paint colors, and the resulting paint effluent is immediately vacuumed from the surface and passed through a filtration system. The system's built-in, closed-loop, color recognition and control system accurately strips metal and composite surfaces, making selective removal possible. The laser is deployed on a 7-degrees-of-freedom robotic arm mounted on a 3-degrees-of-freedom mobile platform. "Degrees of freedom" refers to the positioning capability of the system and includes moving on the x, y and z axes as well as rotational movements such as roll, pitch and yaw. This level of manipulation requires sophisticated software to control the robot's geometric path around the aircraft, following the three-dimensional contour of the airframe in an optimal trajectory. The autonomous mobile platform moves automatically to position the robot manipulator near the aircraft.

The system is available in four sizes. The smallest targets small aircraft such as fighter jets and helicopters, and the largest strips commercial passenger and cargo aircraft with the most passenger capacity and heaviest weight limits. The computer-controlled system is monitored by an operator from a supervisory room. The system is designed to execute the laser removal process to meet the recommendations of the SAE MA4872A standard for thermal stripping.

SLASHING PROCESS TIME

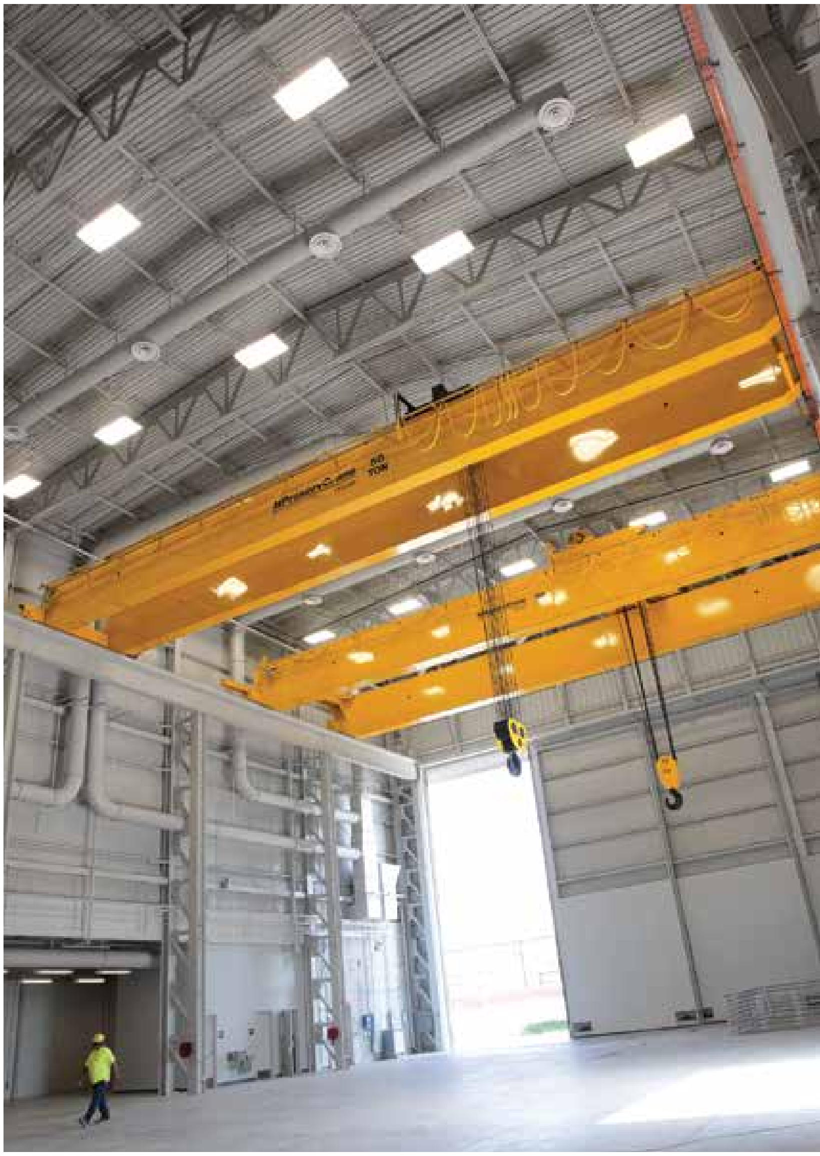
The LCR system may shorten processing time by up to 45%, drastically reducing cost per aircraft and minimizing support facility usage.

Over the course of the R&D effort, 115 SwRI employees played a role in LCR development. Additionally, client leadership and a host of their suppliers supported a range of equally important efforts focused on design, manufacturing and compatibility with a broad range of quality standards and industry regulations.

R&D World magazine recognized the LCR system as one of the 100 most significant innovations of 2020. The R&D 100 Awards are known as the "Oscars of Innovation."

The innovation truly blends key technologies and processes. Independently, they are interesting; collectively they create a revolutionary game-changer in mobile robotics for lasering paint from a full range of aerospace surfaces, from components to small fighter jets to the largest commercial and cargo aircraft.

Questions about this article? Contact Evans at paul.evans@swri.org or call 210.522.2994.



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SwRI's 20,283-square-foot Heavy Article Test facility is designed to fabricate and test large, heavy components. The building is 56 feet tall and features two bridge cranes, 100-ton and 50-ton. A 20- by 20- by 20-foot floor pit allows below-ground access to test articles and sliding hangar-style doors on either end of the building allow open access to the facility.

ABOUT THE AUTHOR:
Paul Evans is director of SwRI's Manufacturing and Robotics Technologies Department, which has a broad program in developing and deploying advanced manufacturing and robotics technologies. The department founded ROS-Industrial, an open-source extension of the Robot Operating System (ROS), and hosts the South Central regional office of the Texas Manufacturing Assistance Center (TMAC).

D022511_9595

MISSION JUNO: EXTENDED & EXPANDED
BY THE NUMBERS

PRIMARY MISSION

Investigate Jupiter's origins, interior, atmosphere and magnetosphere

LAUNCH: August 5, 2011 **ARRIVAL:** July 2016

PRIMARY MISSION ENDS: July 2021

34 Science Orbits

SPACECRAFT

1ST Spacecraft Equipped with a Radiation Vault

400 POUND Titanium Electronics Vault

29 Science Sensors on **11** Instruments

3 Solar Panels Spanning **66 FEET**

IMAGES COURTESY NASA/JPL/DLR/JPL-CALTECH D024769

"Since its first orbit in 2016, Juno has delivered one revelation after another about the inner workings of this massive gas giant. With the extended mission, we will answer fundamental questions that arose during Juno's prime mission while reaching beyond the planet to explore Jupiter's ring system and largest satellites."
—SwRI's Scott Bolton, Juno principal investigator

"The Juno team will start tackling a breadth of science historically required of flagships. This represents an efficient and innovative advance for NASA's solar system exploration strategy."
— Lori Glaze, Planetary Science Division Director, NASA HQ

EXTENDED MISSION

Investigation of Jupiter's northern hemisphere and polar cyclones, dilute core, magnetic features being sheared by Jupiter's zonal jets; flybys of Io, Europa and Ganymede; observation of the distant boundaries of the magnetosphere; and the first exploration of Jupiter's rings

MISSION STARTS: August 2021 **MISSION ENDS**: September 2025

42 Additional Orbits

6 Flybys over the Great Blue Spot, a Magnetic Enigma

1ST Detailed Exploration of Jupiter's Faint Rings

19 Atmospheric Occultations

MOON FLYBYS

3 EUROPA FLYBYS

1ST Mapping of Europa's Ice Shell Thickness

1ST Search for Io's Global Magma Ocean

1ST Measurement of Space Weathering on an Icy Moon

2 GANYMEDE FLYBYS

CYGNSS Satellite Mission Extended

NASA has extended the Cyclone Global Navigation Satellite System (CYGNSS) mission through at least 2023 and possibly through 2026. The constellation of microsatellites designed, built and operated by SwRI with the University of Michigan has made history over the past four-plus years, penetrating thick clouds and heavy rains to accurately assess wind speeds and better understand hurricane intensification.

The NASA senior review panel rated the mission extension proposal as excellent, based on the current health of the constellation of instruments, particularly considering the low-cost nature of the sensors. They also found that the operations team has been agile in dealing with unexpected GPS signal variability, using state-of-the-art engineering automation to handle instrument anomalies.

The microsatellites — each roughly the size of a carry-on suitcase — make frequent measurements of ocean surface winds to monitor the location, intensity, size and development of tropical cyclones. Flying in formation, the spacecraft cover an orbital swath that passes over most of the Earth's hurricane-producing zone, up to 35 degrees north and south of the Equator.

"Launched in late 2016, the spacecraft have provided round-the-clock surface wind speed measurements to help improve intensity forecasting of tropical cyclones," said SwRI's William Wells, CYGNSS operations phase systems engineer. "We continue to develop new versions of algorithms that improve the data, in addition to exploring novel applications, such as soil moisture monitoring and ionospheric modeling."

This science is critical because, over the past few decades, forecasters have improved hurricane path predictions significantly, but the ability to predict the intensity of storms has lagged. Flying aircraft through storms to collect data is difficult and dangerous, and prior space-based technology was incapable of seeing though the heavy precipitation common in hurricanes. GPS signals, however, penetrate intense rain, and the CYGNSS microsatellites use these signals, reflected off the ocean surface, to calculate wind speeds

"Moving forward, we continue adapting the mission for new investigations related to tropical cyclones, oceanography and land science applications, among many others," said SwRI's Jillian Redfern, CYGNSS project manager and mission operations manager. "For instance, CYGNSS has detected and mapped flood inundation under dense forest canopies and monitored flooding in and around Houston and Havana after landfalls by Hurricanes Maria and Irma, respectively."

"The CYGNSS project team is delighted to receive approval for a three-year mission extension and is very appreciative of NASA for its continuing support," said Dr. Chris Ruf, the CYGNSS principal investigator from the University of Michigan. "The science investigations to date using ocean surface wind measurements to study tropical meteorology in general, and tropical cyclone processes and forecasting in particular, can continue to progress and improve our understanding of the physical processes involved and our ability to predict them. I'm sure I speak for all the members of the science and operations teams when I say we are very excited about what the next three years will bring."

In addition to building the eight microsatellites in the CYGNSS constellation, SwRI runs the mission operations center from our Boulder, Colorado, location. The constellation uses GPS signals that penetrate thick clouds and heavy rains to accurately assess wind speeds and better understand hurricane intensification.

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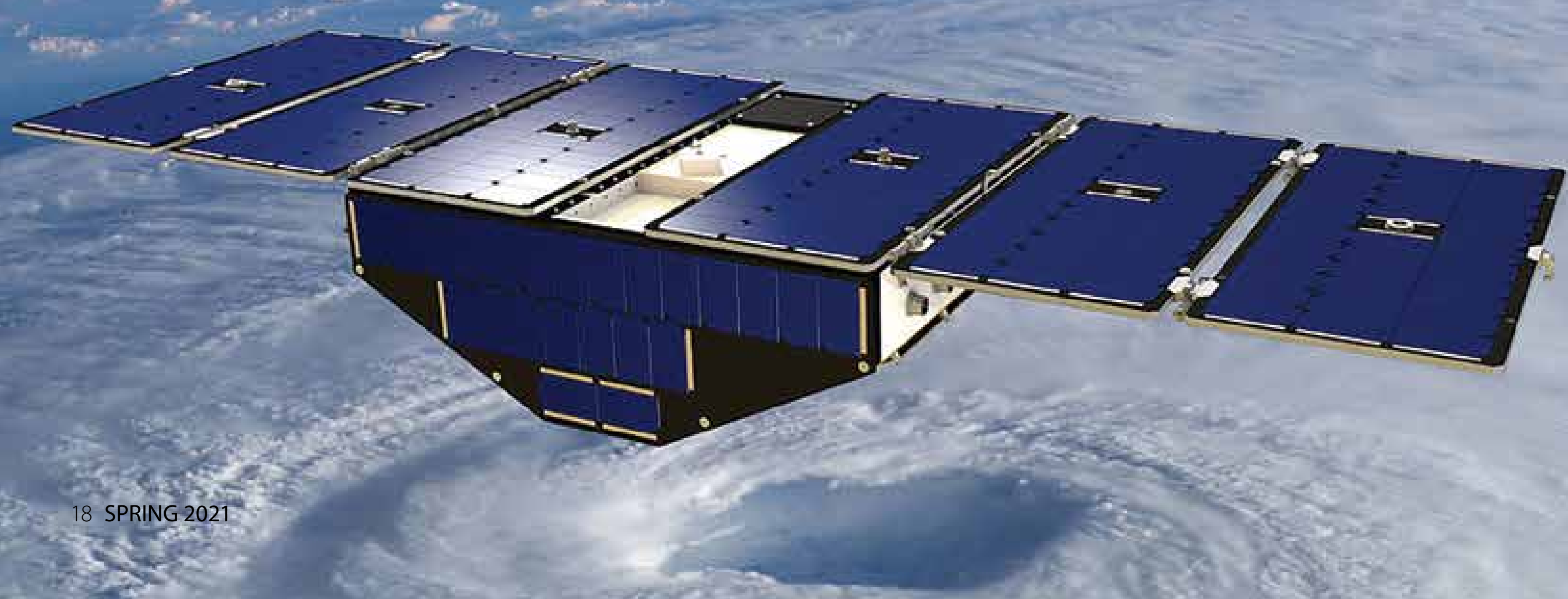

IMAGES COURTESY NOAA/NASA/UNIVERSITY OF MICHIGAN D022855 D024768

EVALUATING AI-ASSISTED DESIGN IN AIR TAXIS

SwRI has received a four-year Defense Advanced Research Project Agency (DARPA) contract to develop air taxi technology while evaluating the capabilities of artificial intelligence-augmented design systems. The project is part of DARPA's Symbiotic Design for Cyber Physical Systems program.

Air taxis are short-range electric aircraft designed to carry a small number of passengers relatively short distances. Many companies are currently developing different air taxi designs.

"Air taxis are an exciting idea that also present unique engineering challenges," said Austin Whittington, the project principal investigator. "In many ways, it's the perfect concept to test an AI's design capabilities."

Designing an air taxi presents several engineering challenges and a wide range of design options. Larger versions include quadrotor layouts, which use four spinning rotors to lift the aircraft. Others use many distributed propellers for vertical take-off and landing while relying on traditional lifting surfaces (wings) for the majority of the flight profile.

Engineers led by Dr. James Walker, director of SwRI's Engineering Dynamics Department, will create air taxi components that an AI computer design system will use to design the completed vehicle.

"What's exciting about the air taxi is that advances in controls, batteries and electric motors have completely opened up the design space," Walker said. "There are lots of potentially viable designs to be explored."

SwRI will analyze the AI's air taxi designs and evaluate its design capabilities, judging AI-augmented designs based on whether they meet specific criteria. These standards include that a system be no larger than two cars parked beside each other, with a useful range of at least 20 to 30 miles and capable of carrying at least two people. The specific requirements will be developed as part of the program.

"There's less room for human error with AI-driven design," Whittington said. "Plus, AI systems are capable of thinking far outside the box and come up with concepts that people never would have."

For instance, in 2004, NASA announced that its Evolutionary software, an AI program, had designed a powerful, compact antenna for use on a collection of small satellites set to be launched into orbit around the Earth. The AI software had observed millions of potential designs before delivering an unusually shaped antenna that met all of the requirements.

Whittington's team will also collaborate with Vanderbilt University researchers on modeling the air taxi's cyber-physical systems (CPS), computer systems that link sensing, control and computation between user and machine. They are increasingly common in automobiles and can be found on nearly every commercial and military aircraft.

SwRI Enhances Automotive Catalyst Testing

Engineers integrated a mass spectrometer with existing SwRI technology to expand capabilities to evaluate engine emissions control technologies. These aftertreatment systems, which treat exhaust and reduce harmful pollutants escaping into the environment, require stringent testing. Incorporating a mass spectrometer enables a broader range of aftertreatment performance evaluations in real time.

Mass spectrometers identify molecules by analyzing their mass-to-charge ratio, detecting chemicals invisible to other instruments. SwRI's Universal Synthetic Gas Reactor (USGR®) tests catalysts with a Fourier Transform Infrared (FTIR) spectrometer, which uses IR radiation to identify and quantify molecules present in a gas sample. Different chemical structures absorb light at specific wavelengths, producing unique spectral fingerprints.

"Integrating a mass spectrometer with the USGR system overcomes limitations of the FTIR spectrometer, which cannot monitor chemicals that are infrared inactive," said Dr. Grant Seuser, a post-doctoral researcher in SwRI's Powertrain Engineering Division, who led the project. "The mass spectrometer can detect a broader range of exhaust components, allowing a more complete picture of aftertreatment system performance."

The FTIR monitors pollutants, while the mass spectrometer detects hydrogen, oxygen and dinitrogen formation, providing data to build comprehensive scientific models of the catalyst. The merger of the technologies enables testing of three-way catalysts in real time.

The successful integration of a mass spectrometer with the USGR system widens the scope of testing possibilities beyond aftertreatment systems. Other uses include measuring engine emissions directly, battery testing, environmental and chemical processes monitoring, and much more. SwRI offers the specialized evaluation and development services to a range of clients, including engine, vehicle and catalyst manufacturers.

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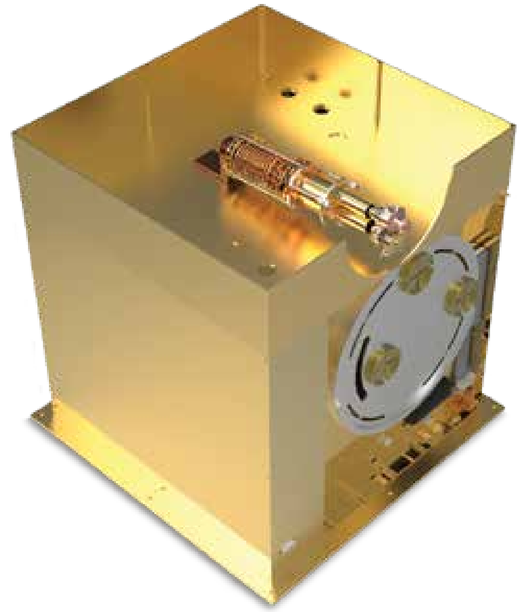


D024757

CODEX ADDS DATING APP

SwRI scientists have expanded the capabilities of the prototype spaceflight instrument Chemistry Organic and Dating Experiment (CODEX), designed for field-based dating of extraterrestrial materials. CODEX now uses two different dating approaches based on rubidium-strontium and lead-lead geochronology methods.

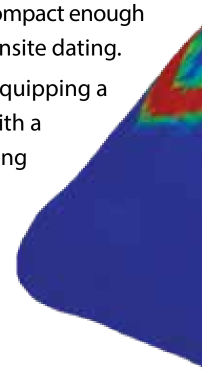
"The central aim of CODEX is to better understand some of the outstanding questions of solar system chronology, such as the duration of the late heavy bombardment or how long Mars was potentially habitable," said SwRI's F. Scott Anderson, who is leading the development of the instrument.

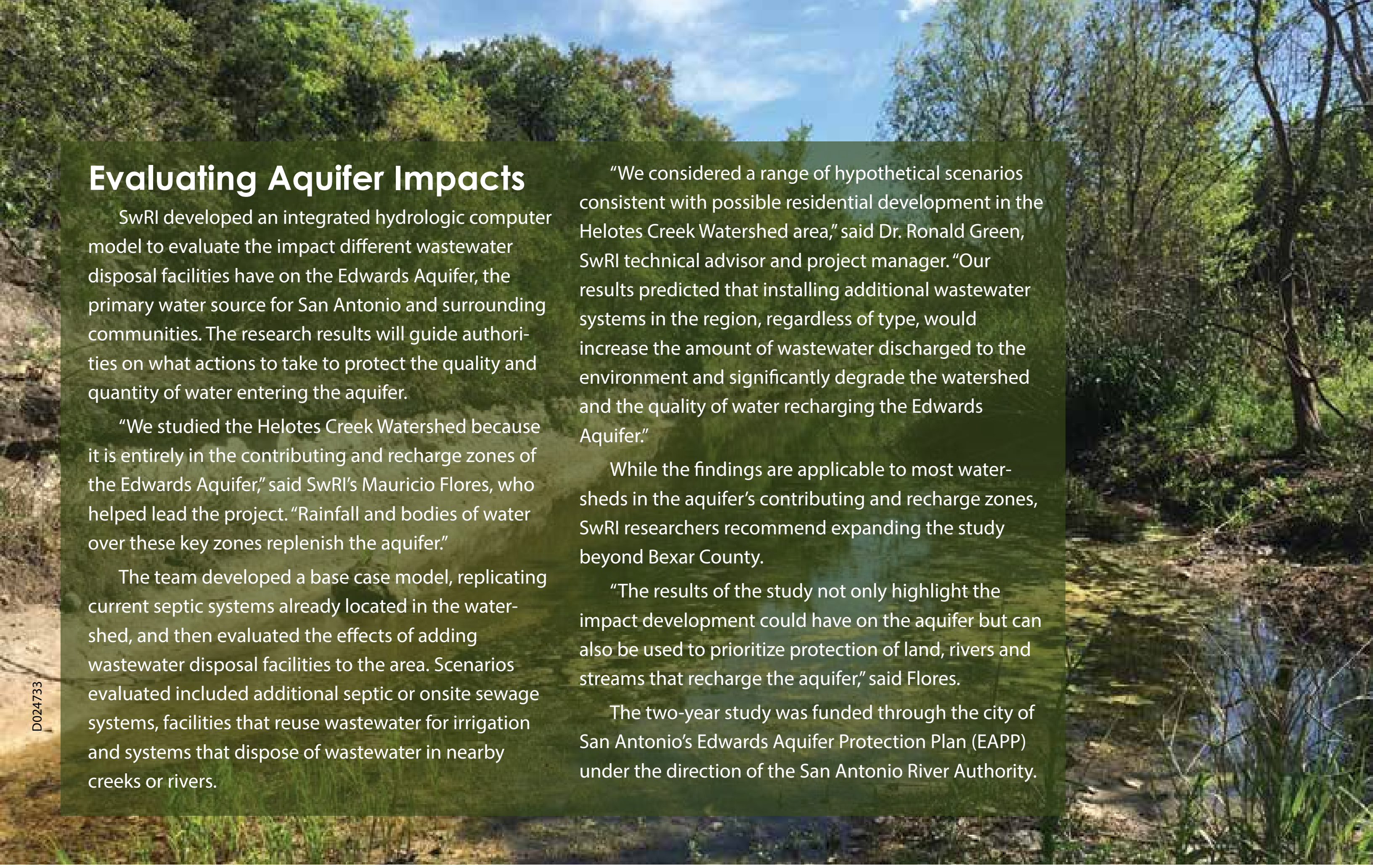
Scientists estimate the ages of inner solar system objects by counting impact craters, with the assumption that objects with more craters have existed for longer periods of time. These estimates are partially calibrated by the ages of moon rocks obtained by astronauts in the 1960s. However, in areas not explored by astronauts, age estimates could be wrong by hundreds of millions to billions of years. Thus, dating more samples is critical to our understanding of the age of the solar system.

Earlier versions of CODEX exploited the natural radioactive decay of rubidium into strontium to measure how much time had elapsed since a rock sample formed. In addition to that method, CODEX now measures lead isotopes produced by the natural decay of uranium in a sample to obtain an independent estimate of its age.

Scientists are interested in dating hundreds of potential sites on the Moon and Mars, but sample return missions are expensive and time-consuming. For this reason, CODEX is designed to be compact enough to be incorporated into a spacecraft to conduct onsite dating.

"This experiment raises the prospect of equipping a future lander mission to the Moon or Mars with a single dating instrument capable of exploiting two complementary isotopic systems," Anderson said. "This combination would permit consistency checks and afford us a more nuanced understanding of planetary history."





D024733

Evaluating Aquifer Impacts

SwRI developed an integrated hydrologic computer model to evaluate the impact different wastewater disposal facilities have on the Edwards Aquifer, the primary water source for San Antonio and surrounding communities. The research results will guide authorities on what actions to take to protect the quality and quantity of water entering the aquifer.

"We studied the Helotes Creek Watershed because it is entirely in the contributing and recharge zones of the Edwards Aquifer," said SwRI's Mauricio Flores, who helped lead the project. "Rainfall and bodies of water over these key zones replenish the aquifer."

The team developed a base case model, replicating current septic systems already located in the watershed, and then evaluated the effects of adding wastewater disposal facilities to the area. Scenarios evaluated included additional septic or onsite sewage systems, facilities that reuse wastewater for irrigation and systems that dispose of wastewater in nearby creeks or rivers.

"We considered a range of hypothetical scenarios consistent with possible residential development in the Helotes Creek Watershed area," said Dr. Ronald Green, SwRI technical advisor and project manager. "Our results predicted that installing additional wastewater systems in the region, regardless of type, would increase the amount of wastewater discharged to the environment and significantly degrade the watershed and the quality of water recharging the Edwards Aquifer."

While the findings are applicable to most watersheds in the aquifer's contributing and recharge zones, SwRI researchers recommend expanding the study beyond Bexar County.

"The results of the study not only highlight the impact development could have on the aquifer but can also be used to prioritize protection of land, rivers and streams that recharge the aquifer," said Flores.

The two-year study was funded through the city of San Antonio's Edwards Aquifer Protection Plan (EAPP) under the direction of the San Antonio River Authority.

NEW PROTECTIVE COMPUTATIONAL MODELS

SwRI is creating computer models to accurately assess how materials and structures behave under impacts, blasts and shocks. The U.S. Department of Defense project will involve sophisticated state-of-the-art material tests on protective structures commonly used on military bases and at embassies as well as other vulnerable structures in foreign countries.

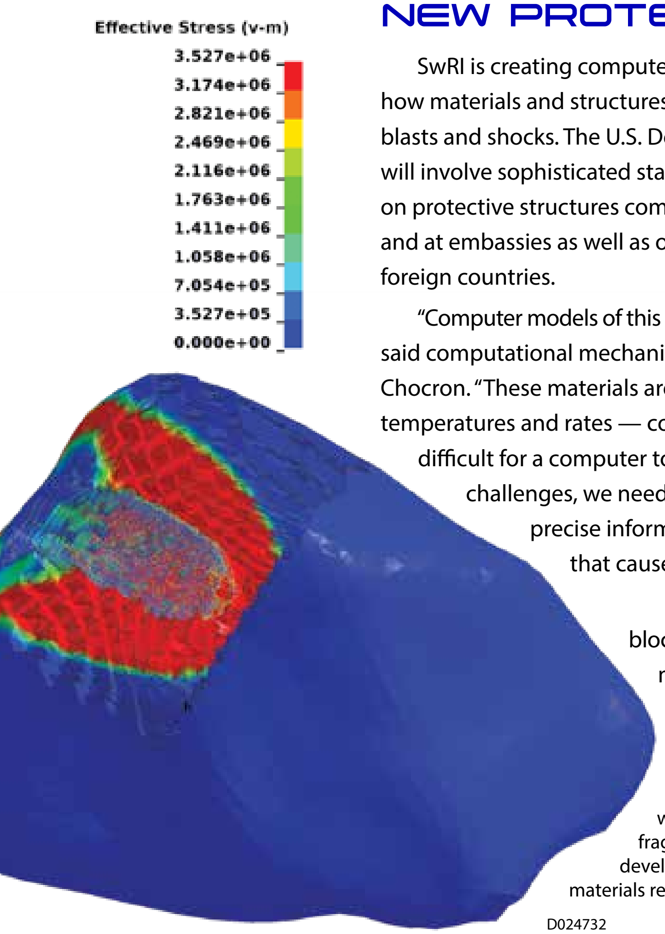
"Computer models of this kind can be very challenging," said computational mechanics Manager Dr. Sidney Chocron. "These materials are taken to extreme pressures, temperatures and rates — conditions that are quite difficult for a computer to simulate. To meet these challenges, we need to feed the computers precise information about the conditions that cause a material to crack or fail."

Chocron is taking a "building-block" approach to create the most accurate computer models. He started by testing small specimens at different temperatures and pressures and will progress to small-scale shock and blast experiments. He will gradually build up to full-scale blast experiments, comparing computer models throughout the process to ensure accuracy.

For the ballistic tests, Chocron is utilizing SwRI's specialized facilities, including its two-stage light gas gun system and the SwRI-developed split-Hopkinson pressure bar.

"The question we're striving to answer is whether a building or bridge will withstand a terrorist attack or any kind of significant ballistic event," Chocron said. "Computer models are often utilized for their predictive accuracy. Experiments can be expensive, but if you're building a valuable structure that might be attacked, you want to be certain it won't fail."

The project will support weapons effects research programs at the U.S. Army Engineer Research and Development Center and other potential DOD agencies.



This computational model of a rock impacted at 2 kilometers per second shows how stress waves propagate from the point of impact, fragmenting the material. SwRI researchers are developing new computer models to predict how materials react to impacts, blasts and shocks.

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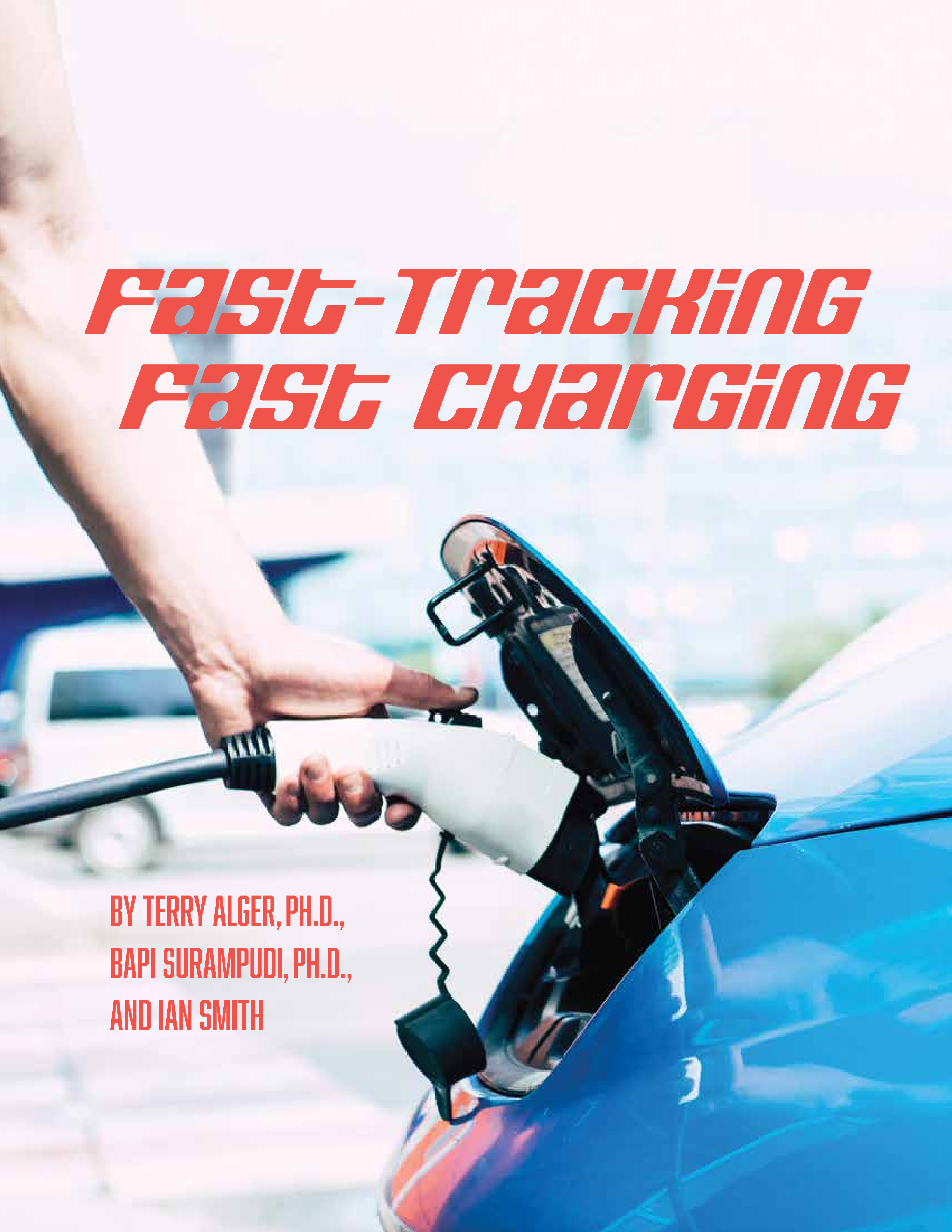
Fast-Tracking Fast Charging



BY TERRY ALGER, PH.D.,
BAPI SURAMPUDI, PH.D.,
AND IAN SMITH

CONCERNS over climate change and urban air quality have led regulators and governments to strongly encourage the use of electric-powered vehicles. The governor of California, for example, issued an executive order in September setting new statewide goals to prioritize clean transportation solutions that include having 100% of in-state sales of new passenger cars and trucks be zero-emission vehicles (ZEVs) by 2035. The order also aims, where feasible, to have 100% of medium- and heavy-duty vehicles be zero-emission by 2045 and for off-road vehicles and equipment to transition to 100% zero-emission by 2035. The governor charged the California Air Resources Board (CARB) and other state agencies to develop regulations or take other steps to achieve these goals. To facilitate the transition, state agencies are working with the private sector to develop affordable fueling and charging options. California is the largest automotive market in the U.S., and 14 other states and the District of Columbia follow its lead concerning emissions rules.

More recently, General Motors made a commitment to zero-emission vehicles by 2035, a move that will influence heavy-duty (HD) truck manufacturers and suppliers. Daimler Trucks, Volvo Cars, Ford Motor Company and Volkswagen AD have also signed on to making California's goals a reality. The U.S. Environmental Protection Agency and other federal entities will face pressure to take similar measures, particularly as the rapid acceleration of the battery electric vehicle (BEV) market slowed in 2019.

The California order does not mandate the use of BEVs — fuel cells running on hydrogen are also an option — nor does it prohibit the import or resale of gasoline-powered vehicles. The end result, however, will almost surely be a significant increase in the number of BEVs on the roads. With this order, California joins 15 countries that have committed to accelerating the adoption of BEVs by banning or restricting the sale of internal combustion engines.

Electric powertrains offer several operational advantages over traditional powertrains, but they also present several unique challenges, notably a steep sticker price and what's known as range anxiety — concern that an EV will run out of power before reaching its destination or a suitable charging point. Southwest Research Institute has been involved with vehicle electrification research and development since 1990 in light-duty, heavy-duty, on-road and off-road markets. We have the experience and technical expertise to assist our customers in addressing their needs for electric powertrains, including testing, research, modeling and analytical services. We also offer abuse, performance and durability evaluations on battery cells, modules and packs and other EV components — expertise that is even more critical as the BEV market expands.

DETAIL

According to the McKinsey Electric Vehicle Index, worldwide electric vehicle (EV) sales rose 65% from 2017 to 2018. But the number of units sold in 2019 rose by just 9% and declined by 25% during the first quarter of 2020.

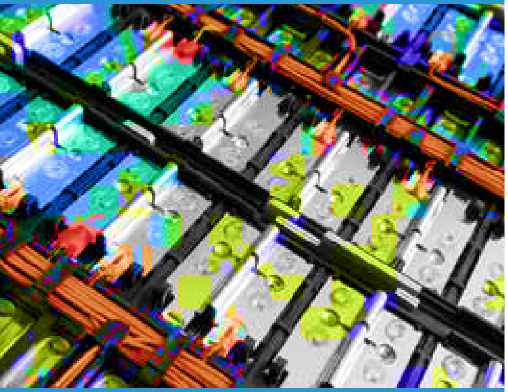
D024682

ABOUT THE AUTHORS: From right, Dr. Terry Alger is the director of SwRI's Automotive Propulsion Systems Department, a Fellow of the Society of Automotive Engineers and a consultant to the Army Science Board. His work at SwRI focuses on improving engine efficiency and emissions through in-cylinder combustion processes, advanced engine technologies and vehicle electrification. Dr. Bapi Surampudi specializes in energy storage system and powertrain research. He has developed control systems for diesel engines, transmissions, electric-hybrid powertrains, electric vehicles and automated vehicles. Ian Smith manages SwRI's Electrified Powertrain Section and the Electrified Vehicle and Energy Storage Evaluation (EVESE) Consortium. This multiclient program focuses on EV benchmarking and testing to understand performance, efficiency and powertrain control strategies.

EV BATTERIES

Today's BEVs are powered by lithium-ion battery packs, multiple cells with housing, electrical connections and, increasingly, control electronics. The battery packs charge and discharge through electrochemistry. In a battery cell, lithium ions move one way as the battery charges, absorbing power, and move in the opposite direction when the battery discharges, when it's supplying power.

During charging, lithium ions flow from a positive cathode, usually a cobalt-oxide material, to a carbon-based negative anode through an electrolyte fluid. Electrons also flow from the positive electrode to the negative electrode but take a longer path around an outer "circuit." The electrons and ions combine at the negative electrode and deposit lithium there. When no more ions will flow, the battery is fully charged.



Lithium-ion battery packs are the energy storage solution of choice for electromobility.

During use, the ions flow back through the electrolyte from the anode to the cathode and electrons flow through the outer circuit, creating an electric current to power the vehicle. When the ions and electrons combine at the positive electrode, lithium is deposited there. When all the ions have moved back, the battery must be recharged.

ADVANTAGES

BEV performance is often superior to conventional vehicles. The torque characteristics of electric motors can provide superior acceleration compared to internal combustion engines, and BEVs are not a mobile source of pollution. While these vehicles are not truly emissions-free — the electricity that runs them has to come from somewhere and renewable sources are not plentiful enough to power the U.S. transportation market — their use in cities would exchange tailpipe pollution in congested urban areas for powerplant emissions located in less populous regions, where it may be less harmful. Finally, for typical urban families, BEVs may be more energy-efficient than conventional vehicles, even factoring in the production and transmission of the electric energy that powers the car. Given these seeming advantages over conventional vehicles, why has the market penetration rate of BEVs been so slow and even recently stalled?

CHALLENGES

Electric vehicles still have significant challenges to overcome. First, and most importantly, is their cost. Lithium-ion batteries are considered the energy storage solution of the future, particularly for electromobility. They store large amounts of energy but are comparatively light and compact. While lithium is the 25th most common element, making up 0.002% of the Earth's crust, commercially viable concentrations are relatively rare. The other battery cathode materials — cobalt, manganese and nickel — are also expensive commodities. While increased manufacturing volumes and improved battery chemistries are bringing costs down, most BEVs are still significantly more expensive than comparable internal combustion engine cars. A considerable amount of research and development from commercial organizations and the U.S. government is aimed at decreasing the rare materials BEVs require. The goal is to reduce the cost of a battery pack, in terms of dollars per kilowatt (kW) hours, to the cost of an internal combustion engine by 2025.

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Above: Senior Research Engineer Kevin Jones uses a mobile data acquisition system to collect battery performance data for an electric vehicle.
Right: Senior Technician Mike Taylor instruments an EV battery module to collect the data needed to develop new solutions to limit battery degradation while decreasing battery recharge times.

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Then there are the range restrictions associated with the limited energy density of a battery compared to a liquid fuel, combined with the time it takes to charge it versus filling a tank with gas. A combination of improved battery chemistries, better thermal management systems, more effective battery management systems and safer large battery packs has increased the range for many BEVs. However, the relatively long time it takes to charge the vehicle, combined with the potential erosion of battery life if it is repeatedly charged too quickly, means that improving fast charging battery packs can go a long way to making BEVs a more attractive option for consumers.

DETAIL

Three basic units in electricity are voltage, current (measured in amps) and resistance. Current is equal to the voltage divided by the resistance. To help understand how this works, consider a comparison to plumbing, where voltage corresponds to water pressure, current is comparable to flow rate and resistance is akin to pipe size. When using a tank of pressurized water connected to a hose to water a garden, increasing the tank pressure causes more water to flow from the hose. In an electrical system, increasing the voltage makes more current flow. Increasing the diameter of a hose also increases flow, which corresponds to decreasing resistance in an electrical system to increase current flow.

FAST CHARGING PHENOMENA

A battery's charge rate is often referred to as the "C rate," which measures the battery charge / discharge rates relative to its capacity, where C is the rate it takes to fully charge, or discharge, a battery in one hour. For example, a 2C rated battery will go from 0% state-of-charge (SOC) to 100% SOC in 30 minutes. To achieve an equivalent charge time to that of refueling a fossil-fueled vehicle, a battery must be charged at 12C or higher to match the five minutes it typically takes to fill a standard automotive gas tank. While this is the optimal scenario, most current efforts are targeting a 10–15-minute recharge time, or a 4–6C rate. However, achieving high C rates presents a series of unique challenges to both the battery and the infrastructure needed to support it.

Fast charging battery packs will require a considerable infrastructure investment. For instance, charging a Chevrolet Bolt battery pack in 12 minutes would require 330 kilowatts of electric power or 66 kWh of energy. This would require an average current of 94 amperes (amps), which presents some safety and other concerns. Consider, most homes in the U.S. are wired with a combination of 15-amp and 20-amp, 120-volt circuits with some high-current lines such as 220-volt dryer or electric stove lines. Even the highest current lines only handle 30–50 amps. Today's fastest charging battery stations are located in places such as shopping malls that have the power infrastructure to handle it. As BEVs become more prevalent, public and private sector entities are working diligently to ensure that more stations providing quick recharging are available and that this inherently more dangerous high-voltage power can be delivered safely to electric vehicles.

The greatest challenge with quickly charging BEVs is the damage that fast charging does to the battery itself. Using current technologies, repeatedly fast charging a battery pack significantly degrades the performance and life of the

Technician Arcadio Maldonado prepares lithium-ion battery cells for thermal cycling. Thermal management plays an important role in battery charge and discharge events.

DETAIL

In 2011, SwRI launched the Energy Storage System Evaluation and Safety (EssEs) multiclient consortium to help the EV industry develop precompetitive, detailed cell-level test data on electrochemical storage systems and to advance the methodologies to evaluate batteries. In 2020, SwRI began a new phase of the consortium, renamed the Electrified Vehicle and Energy Storage Evaluation (EVESE) consortium, to better reflect the focus on electric mobility.

battery. Charging a battery is a very exothermic or heat-releasing event, which increases the overall temperature of the battery pack. Charging or discharging a battery at elevated temperatures not only degrades its performance but also has the potential to decrease its lifespan and, in some extreme circumstances, can lead to catastrophic failures.

Another significant issue with fast charging a battery is lithium plating, an irreversible phenomenon caused when metallic lithium coats the surface of the anode, or negative electrode, during charging. Lithium plating occurs when the anode's ability to absorb lithium ions is less than the lithium ion transfer rate, which is very high during a fast charging event. When ions cannot be absorbed, they coat the surface of the electrode, reducing the number of lithium ions available for power transfer and forming dendrites, spike-shaped deposits that degrade battery performance. Eventually, if the dendrites get large enough, lithium plating leads to internal short circuits and battery failure. Preventing lithium plating is a key step to enabling regular fast charging critical to widespread consumer acceptance of BEVs.

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Staff Technician Mario Guillen installs a lithium-ion battery cell in a calorimeter to evaluate the thermal stability limit for battery cells and calculate heat release during failure.

NEED FOR SPEED

The team at SwRI's Energy Storage Technology Center (ESTC) has been developing solutions for fast charging batteries for over a decade. Initial efforts focused on understanding the performance and durability of different battery chemistries under a variety of conditions — charging/discharging rates, ambient temperatures, and so on. For the past decade, SwRI has operated a consortium that evaluates the unique chemistries and designs of batteries to understand the physical mechanisms that cause battery performance to degrade. This information allows the team to develop and tune battery models, enabling us to accurately predict battery performance under a variety of conditions with a limited test data set. More importantly, the know-how and understanding the team has built through this testing has allowed SwRI to propose new solutions to limit battery degradation while decreasing battery recharge times.

One new solution is a real-time controller that monitors lithium plating during fast-charging events and adjusts the charge current accordingly. The goal is to charge the battery at the optimal limit of its ability to intercalate or absorb the lithium ions into the anode, but no faster. This rate is changeable and inconsistent, varying with the state-of-charge of the battery and environmental conditions, so the controller must continually adjust the charging rate in real time. As part of an internally funded project, the ESTC team used a controller on a set of batteries from a

Assistant Manager Mickey Argo oversees SwRI's Energy Storage Technology Center testing facilities, including manufacturing, characterization, life and abuse tests on lithium-ion cells and battery packs.

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Top: Research Engineer Shuvodeep Bhattacharjya models lithium-ion batteries to capture how voltages would change under different currents at different states of charge.
Above: Senior Research Technologist Barrett Mangold instruments a lithium-ion battery module inside a test rig used to evaluate immersive coolants. Immersive cooling significantly improves heat transfer, allowing battery packs to be charged and discharged at higher rates while avoiding negative heat-related effects.

modern EV. Compared to the manufacturer's recommended fast-charging strategy, the SwRI controller resulted in a charge profile that is 30% faster with significantly reduced degradation.

COOL SOLUTIONS

In addition to developing a thorough understanding of the role that battery chemistry plays in the response to environmental conditions and charging/discharging profiles, the ESTC team has studied battery thermal management. This research focuses on maintaining a constant temperature during battery charge and discharge events and developing and applying innovative coolants to improve battery performance and safety.

SwRI's energy storage consortium benchmarked several of the latest BEVs to understand how their thermal management systems function during aggressive charging and discharging events to identify deficiencies and potential improvements. For instance, the team developed a pulsed charging/cooling strategy that exploits the unique nature of the battery chemistry to charge aggressively when cells are in an endothermic or heat-absorbing charge region and then less aggressively when cells are in an exothermic charge region. Charging faster when a battery is absorbing heat than when it is giving off heat reduces the temperature increases usually associated with fast charging. This strategy reduces charge time and battery degradation after multiple fast-charging events.

Typically, BEV thermal management systems use indirect cooling systems, transferring the heat generated through conduction by setting the battery on a cooling plate. This strategy separates the electrically conductive coolant from the battery cells. The technique is superior to air cooling but can significantly increase the size, weight and complexity of the battery pack.

New immersive cooling techniques using liquids that conduct heat but not electricity in direct contact with the battery can improve thermal management. These systems conduct 50 to 100 times more heat than conventional indirect cooling solutions. With this significantly improved heat transfer, battery packs can be charged and discharged at higher C rates while avoiding negative heat-related effects. Moreover, this technology improves safety. When battery cells fail, they undergo extreme exothermic reactions that, if left unchecked, can propagate to other cells and destroy the entire battery pack. An immersed coolant system mitigates thermal propagation, reducing the likelihood of a total battery pack failure.

The next logical step for SwRI's ESTC team is to couple the real-time lithium plating controller with an advanced, immersed coolant thermal management system to push the limits of fast charging without sacrificing battery safety, life or performance. By developing these innovative solutions to the problem of fast charging, SwRI is helping to smooth the path for the adoption of BEVs worldwide.

Questions about this article? Contact Smith at ian.smith@swri.org or call 210.522.2041.

IMAGE COURTESY OF MAXAR/ASU/P.RUBIN/NASA/JPL-CALTECH

D024767

SwRI Studies Massive Metallic Asteroid

An SwRI scientist published new findings about the asteroid 16 Psyche, including the first ultraviolet observations, painting a clearer view of the asteroid than was previously possible.

At about 140 miles in diameter, Psyche is one of the most massive objects in the main asteroid belt orbiting between Mars and Jupiter. Previous observations indicate that Psyche is a dense, largely metallic object thought to be the leftover core of a planet that failed in formation.

"We've seen meteorites that are mostly metal, but Psyche could be unique in that it might be an asteroid that is totally made of iron and nickel," said Dr. Tracy Becker, lead author of the paper published in The Planetary Science Journal. "Earth has a metal core, a mantle and crust. It's possible that as a Psyche protoplanet was forming, it was struck by other objects in our solar system and lost its mantle and crust."

Becker's study comes as NASA prepares to launch the Psyche spacecraft in 2022 to learn more about planetary cores. Metal asteroids are relatively rare in the solar system, and scientists believe Psyche could offer a unique opportunity to see inside a planet.

"We were able to identify for the first time on any asteroid what we think are iron oxide ultraviolet absorption bands," Becker said. "This is an indication that oxidation is happening on the asteroid, which could be space weathering, a result of the solar wind hitting the surface."

The asteroid's surface could be mostly iron, but she noted that the presence of even a small amount of iron could dominate UV observations.

"What makes Psyche and the other asteroids so interesting is that they're considered to be the building blocks of the solar system," Becker said. "To understand what really makes up a planet and to potentially see the inside of a planet is fascinating."

Using AI to Train Military Medical Personnel

SwRI is developing a machine vision tool to help the U.S. Department of Defense assess the biomechanical movements of military medical personnel during training exercises.

The simulation-based training system will compare medical trainee performance to that of experts whose physical motions, or kinematics, have been prerecorded and analyzed in 3D with artificial intelligence.

"Military medical training relies on subjective human evaluations where feedback may vary among trainers," said Dr. Dan Nicolella, who leads the Institute's Human Performance Initiative with Kase Saylor. "SwRI's research will help both instructors and trainees objectively observe how well they are performing a specific task, providing both a quantitative score, based on expert task performance, and task-specific feedback to improve performance."

The $1.25 million project, funded through the Medical Technology Enterprise Consortium (MTEC), is part of a larger DOD effort to improve patient safety and quality of care using more capable medical simulation technologies.

SwRI is adapting its markerless motion capture technology (BIOCAP) used to assess the biomechanics of athletes and for clinical applications. SwRI's mocap technology leverages computer vision algorithms to circumvent the tedious process of attaching physical markers to a human subject to capture 3D motion data. Standard cameras capture video of human subjects, and custom machine learning algorithms quantify individual biomechanical performance for research, clinical and sports science applications.

SwRI uses machine learning to train the automated assessment system using data collected as top professionals complete specific medical tasks. The project will assess the detailed performance of trainees when they suture wounds and provide other combat and hospital care requiring precise hand movements or physical orientations.

"We will develop advanced machine learning algorithms used in 3D markerless motion capture video analysis to improve military healthcare training," Nicolella added.

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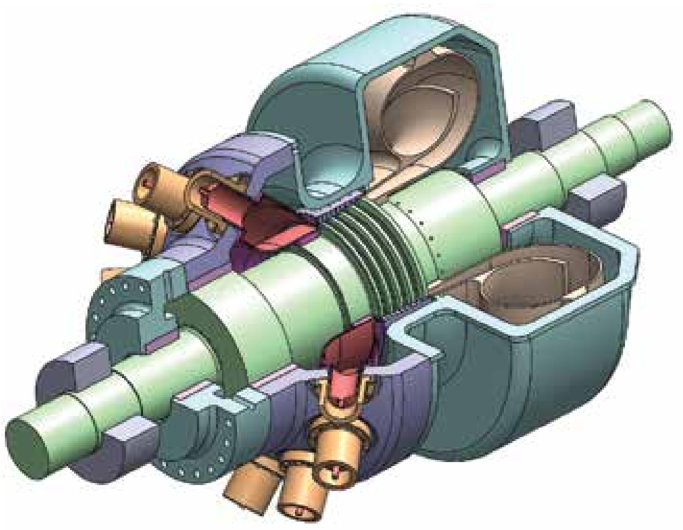


D024729

DESIGNING sCO_2 OXY-FUEL TURBINE

With funding from the U.S. Department of Energy and other organizations, an SwRI-led team is designing a 300 MWe supercritical carbon dioxide (sCO_2), oxy-fuel turbine for use in a direct-fired sCO_2 power plant. The turbine, which can use coal syngas or natural gas as a fuel source, minimizes harmful emissions released to the environment.

"This project leverages the sCO_2 power cycle and incorporates a direct-fired combustor like a traditional gas turbine but at much higher pressures and in a pure CO_2 environment," said Institute Engineer Dr. Jeff Moore, the project leader. "A power plant built with this technology can burn both coal and natural gas at state-of-the-art efficiency with truly zero emissions. The technology offers near 100% carbon capture, while producing no oxides of nitrogen or sulfur emissions typical of traditional coal-fired power plants."

Coal syngas is created by partially combusting coal to create a gaseous stream of carbon monoxide and hydrogen. The process separates sulfur, mercury and other pollutants instead of releasing them into the atmosphere. That stream fuels the turbine and, when burned with pure oxygen, produces only water and near-pure CO_2, which can be captured and sequestered for other uses.

"Our goal is to design the turbine for the coal plant of the future," said Stefan Cich, who is also leading the effort. "As more renewable energy is added to the energy mix, we need to develop smaller, efficient power plants that can come online quickly and meet energy demands when renewable sources are not available, while still reducing overall emissions."

SwRI will be collaborating with General Electric Global Research Center, Air Liquide, 8 Rivers Capital LLC, Electric Power Research Institute Inc., Purdue University and the University of Central Florida on this "Coal FIRST" project.

HACKING EV CHARGING

As part of an automotive cybersecurity research initiative, SwRI engineers simulated a malicious attack to interfere with the charging process of an electric vehicle (EV).

The SwRI team reverse-engineered the signals and circuits on an EV and a J1772 charger, the most common interface for managing EV charging in North America. The researchers successfully disrupted vehicle charging with a spoofing device developed in a laboratory using low-cost hardware and software.

"This initiative was designed to identify potential threats in common charging hardware as we prepare for widespread adoption of electric vehicles in the coming decade," said Austin Dodson, the research computer scientist who led the project. As automotive consumer and manufacturing trends move toward widespread vehicle electrification, market share of EVs is expected to grow to 30% by 2030, according to the International Energy Agency. The cybersecurity of charging technology and infrastructure will become increasingly important as demand for EVs grows.

SwRI performed three manipulations: limiting the rate of charging, blocking battery charging and overcharging. An SwRI-developed "man-in-the-middle" (MITM) device spoofed signals between charger and vehicle. Researchers also drained the battery and generated signals to simulate J1772 charging rates.

When overcharging, the vehicle's battery management system detected a power level that was too high and automatically disconnected from charging. To limit charging, the MITM device requested the smallest charge allowed (6 amps) to dramatically reduce the charging rate. To block battery charging, a proximity detection signal barred charging and displayed the warning: "Not Able to Charge."

"Discovering vulnerabilities in the charging process demonstrates opportunities for testing standards for electric vehicles and charging infrastructure," said Victor Murray, manager of SwRI's cyber-physical systems section.

D024305_0375

SwRI ADAPTS ANCIENT PROTECTIVE COATINGS

SwRI scientists have developed a new microencapsulation technique based on an ancient method used to seal the wood used in shipping vessels. It took nearly a decade to develop this natural non-hazardous, non-gelatin-based, formaldehyde-free, emulsion-based encapsulation system.

“Drying oils have been used for centuries to treat wood and in paints or coatings,” Staff Scientist Dr. Jamie Oxley said. “Part of the goal for encapsulation is to protect the core. If drying oils work well on a macroscale, on a ship, why not at microscales for microcapsules?”

The Institute has been involved in encapsulation research for more than 70 years, often using common emulsion-based gelatin, formaldehyde or hazardous precursors to create the outer shells and protect product ingredients. The drying oil encapsulation process focuses on the materials used to make the outer shell or matrix. Initial experiments were successful enough to pursue internal research funding to develop a technique that meets client desires for a new, less hazardous encapsulating material.

“Drying oils are a narrow class of natural oils that autoxidize when exposed to air,” Oxley said. “We repurposed this thousand-year-old drying oil chemistry to use as a natural material for the microencapsulation of a variety of active ingredients, including fragrances, phase change materials and pesticides.”

Mixed Metabolic Menu Possible at Saturn Moon

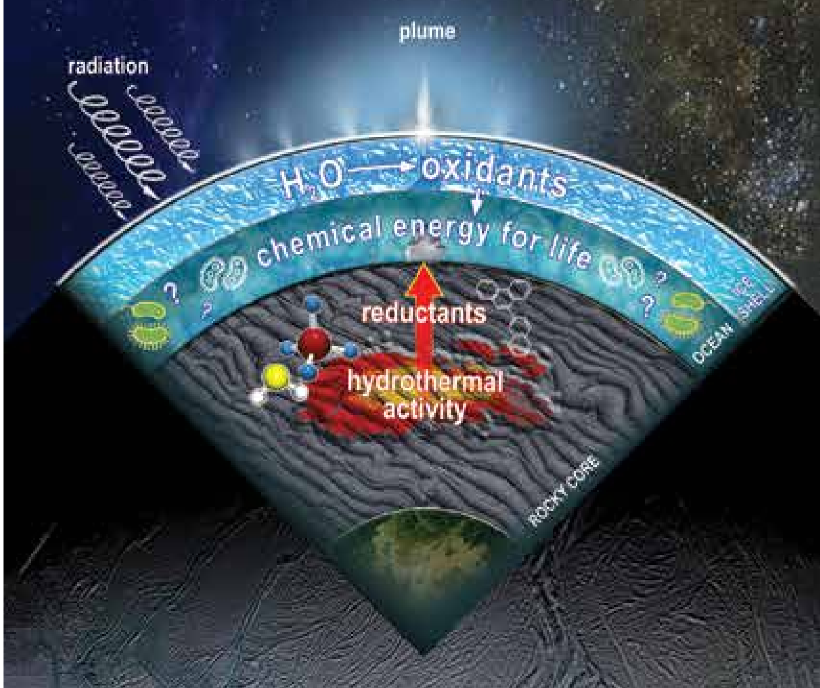
Using data from NASA’s Cassini spacecraft, SwRI scientists modeled chemical processes in the subsurface ocean of Saturn’s moon Enceladus. The studies indicate the possibility that a varied metabolic menu could support a potentially diverse microbial community in the liquid water ocean beneath the moon’s icy facade.

Prior to its deorbit and subsequent destruction in Saturn’s atmosphere in 2017, Cassini sampled the plume of ice grains and water vapor erupting from cracks on the icy surface of Enceladus, discovering molecular hydrogen (H_2), a potential food source for microbes. A new paper published in the planetary science journal Icarus explores other potential energy sources.

“The detection of molecular hydrogen in the plume indicated that there is free energy available in the ocean of Enceladus,” said lead author Christine Ray, who works part time at SwRI as she pursues a doctorate in physics from the University of Texas at San Antonio. “On Earth, aerobic, or oxygen-breathing, creatures consume energy in organic matter such as glucose and oxygen to create carbon dioxide and water. Anaerobic microbes can metabolize hydrogen to create methane. All life can be distilled to similar chemical reactions associated with a disequilibrium between oxidant and reductant compounds.”

These processes are vital to many basic functions of life, including photosynthesis and respiration. For example, hydrogen is a source of chemical energy supporting anaerobic microbes that live in the Earth’s oceans near hydrothermal vents. Perhaps other metabolic pathways could also provide sources of energy in Enceladus’ ocean.

“We compared our free energy estimates to ecosystems on Earth and determined that, overall, our values for both aerobic and anaerobic metabolisms meet or exceed minimum requirements,” Ray said. “These results indicate that oxidant production and oxidation chemistry could contribute to supporting possible life and a metabolically diverse microbial community on Enceladus.”



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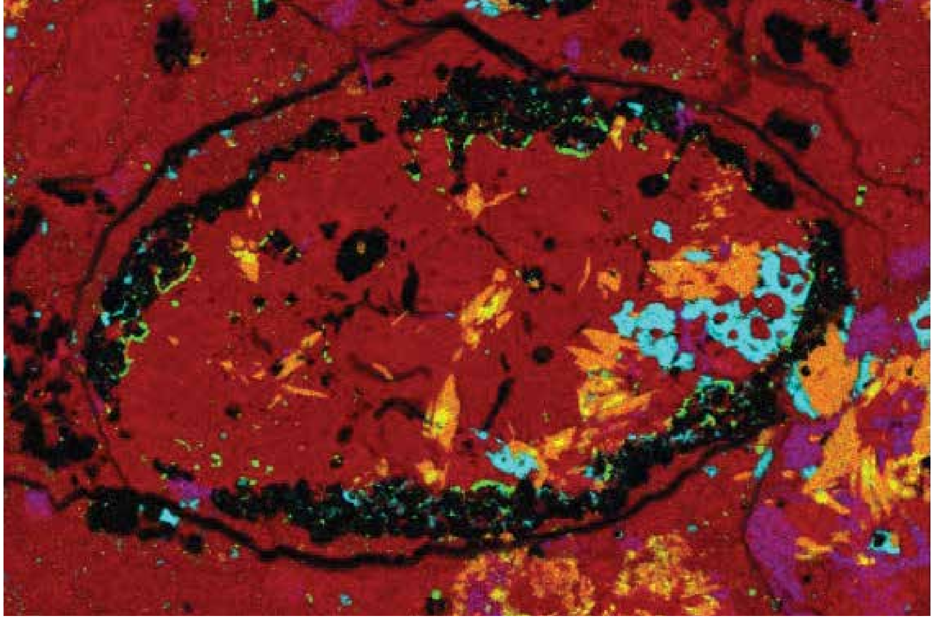

This false-color micrograph of the meteorite sample shows the unexpected amphibole crystals (identified in orange) and points to a large, previously unknown asteroid parent body.

EVIDENCE FOR A PREVIOUSLY UNKNOWN ASTEROID

Most meteorites, rocks that fall to Earth from space, are pieces of asteroids. An SwRI-led team of scientists has identified a potentially new meteorite "parent" asteroid, roughly the size of Ceres, the largest object in the main asteroid belt. Studying a small shard of the meteorite Almahata Sitta (AhS), scientists found minerals formed in the presence of water under intermediate temperatures and pressures, providing evidence for a previously unknown parent body.

"Carbonaceous chondrite (CC) meteorites record the geological activity during the earliest stages of the solar system and provide insight into their parent bodies' histories," said Institute Scientist Dr. Vicky Hamilton, first author of a paper published in Nature Astronomy outlining this research. "Some of these meteorites are dominated by minerals providing evidence for exposure to water at low temperatures and pressures. The composition of other meteorites points to heating in the absence of water. Evidence for metamorphism in the presence of water at intermediate conditions has been virtually absent, until now."

Asteroids — and the meteors and meteorites that sometimes come from them — are leftovers from the formation of our solar system 4.6 billion years ago. In 2008, scientists spectrally characterized a 9-ton, 13-foot diameter asteroid prior to its entry into Earth's atmosphere. They tracked the asteroid trajectory as it exploded into some 600 meteorites over Sudan, allowing the recovery of 23 pounds of samples.

"We were allocated a 50-milligram sample of AhS to study," Hamilton said. "Spectral analysis identified a range of hydrated minerals, in particular amphibole, which points to intermediate temperatures and pressures and a prolonged period of aqueous alteration on a parent asteroid at least 400, and up to 1,100, miles in diameter."

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SUPPORT FOR MILITARY MOBILITY

The U.S. Army government-owned, contractor-operated facility SwRI has hosted for more than 63 years was recently renamed the U.S. Army Ground Vehicle Systems Center Fuels and Lubricants Research Facility. The lab provides advanced vehicle fluids research, development and engineering for the U.S. Army and other government agencies.

SwRI recently enhanced facility capabilities with a new enclosure for testing military battlefield fuel bladders, large collapsible containers that can be airlifted to a forward site, filled from large fuel trucks and then used to supply fuel for tactical vehicles. The fuel bladder test facility is equipped with a concrete floor and a surrounding containment structure. SwRI microbiologists are collaborating with fuels and lubricants specialists, evaluating the effectiveness of biocides in enhancing the stability of stored military fuels.

WEBINARS, WORKSHOPS and TRAINING COURSES HOSTED by SwRI:

Blade Aeromechanic Analysis webinar, April 21, 2021. Free training.

Pulsations & Vibrations Training short course, April 27, 2021. Virtual training course.

ISO 9001 Internal Auditor course, April 28, 2021. Virtual training course.

Hydraulic Fracturing with Foams webinar, April 28, 2021. Free training.

Introduction to Propulsion Simulation Using NPSS course, May 4, 2021. Virtual training course.

Acoustic Induced Vibrations webinar, May 5, 2021. Free training.

Industrial Gas Turbine Combustion webinar, May 12, 2021. Free training.

Materials Science for Mechanical Designers webinar, May 19, 2021. Free training.

An Introduction to Lateral Rotordynamics webinar, May 26, 2021. Free training.

Flow Induced Vibrations (FIV): Reducing the Impact on Piping Systems webinar, June 2, 2021. Free training.

Fundamentals of Centrifugal Compressor Performance Testing webinar, June 9, 2021. Free training.

Compressor Skid Design and Foundation Considerations webinar, June 16, 2021. Free training.

CONFERENCES/MEETINGS:

AIChE Virtual Spring Meeting & GCPS — Virtual. April 18, 2021.

NACE Corrosion Conference & Expo — Virtual. April 19, 2021, Booth No. 2633.

Refinery of the Future — Virtual. May 5, 2021.

22nd Microencapsulation Industrial Convention — Virtual. June 10, 2021.

American Association of Petroleum Geologists. Denver, May 23, 2021.

National Space & Missile Materials Symposium. Rockville, MD, June 21, 2021, Booth No. 12.

Turbine Engine Technology Symposium. Dayton, OH, June 28, 2021, Booth No. 608.

35th Annual Small Satellite Conference — Virtual. August 7, 2021.

D023266

The U.S. Army has awarded Dr. Terry Alger, director of SwRI's Automotive Propulsion Systems Deparment, the Meritorious Civilian Service Medal, the third highest award the Army gives to civilians. The medal recognizes Alger's contributions to the Army Science Board and its recommendations for next-generation battlefield tanks.

D019029_0703

Senior Manager Paul Barrera received a Patriotic Employer Award on behalf of the Office of the Secretary of Defense for Employer Support of the Guard and Reserve. Barrera was nominated by Safety Engineer Melissa Macintyre, who has served as a reservist in the Texas Army National Guard and currently serves in the U.S. Air Force Reserves.

D024664

Manager Don Grosch received NASA's Exceptional Public Achievement Medal for his contributions to the SpaceX Demo-mission. The award recognized his leadership role in conducting ballistics testing to ensure the safety of the rocket, particularly the integrity of the parachute straps for the crew capsule.

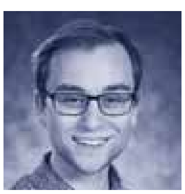
D022028

Dr. Alan Stern, planetary scientist and associate vice president of SwRI's Space Science and Engineering Division, is the first scientist chosen to conduct NASA-funded science experiments aboard a commercial spacecraft. Stern will fly aboard the Virgin Galactic spacecraft called "SpaceShipTwo" on an as-yet unscheduled suborbital mission.

D023118

Research Engineer William Glover (Warner Robins, Georgia) received the Outstanding Young Crow Award from the Association of Old Crows (AOC), recognizing significant contributions and advances in the modernization of Electronic Warfare (EW) systems.

D023104

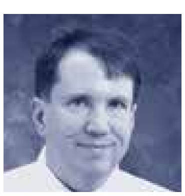


Research Engineer Jarrett Holcomb (Warner Robins) received the AOC Test and Evaluation Award for significant advances in technology and/or procedures in EW testing.

D018524

Vice President Nils Smith received the AOC 2020 Stanley B. Hall Executive Management Award. This award recognizes outstanding leadership in Electronic Warfare/Electromagnetic Spectrum programs.

D016345



Staff Engineer Michael Quinn (Warner Robins) received the 2020 AOC Joseph W. Kearney Pioneer Award from the Association of Old Crows. The award recognizes pioneering activities in or longevity in the EW field.

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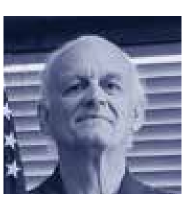

The late Richard Romano (lead research technologist, Warner Robins) received the AOC Specialist 4 James Davis Maintenance Award recognizing his outstanding support for military operations.

SPRING 2021 • VOLUME 42, NO. 1

TECHNOLOGY **TODAY**

Executive Director of Communications
Tim Martin, Ph.D.

Editor
Deb Schmid

Assistant Editor
Rob Leibold

Contributors
Joanna Carver
Robert Crowe
Lisa Peña
Maria Stothoff
Tracey Whelan

Design
Jessica Vidal

Photography
Ian McKinney

Circulation
Stephanie Paredes

Address correspondence to the Editor,
Communications Department,
Southwest Research Institute,
P.O. Drawer 28510, San Antonio, Texas 78228-0510,
or e-mail **dschmid@swri.org**.
To be placed on the mailing list or to make address changes,
call 210.522.2257 or visit **update.swri.org**.

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