SOUTHWEST RESEARCH INSTITUTE®

FALL 2023

TECHNOLOGY TODAY®

COOPERATIVE RESEARCH FOR COST-EFFECTIVE SOLUTIONS

ROS-I Consortium Celebrates First Decade

The ROS-Industrial consortium, a project dedicated to advancing open-source robotics for manufacturing and industry, celebrated its 10th anniversary at its 2023 annual meeting. The consortium has grown from 14 member organizations in 2013 to over 85 organizations, representing a broad range of industries and academic institutions. ROS-Industrial has also expanded to include member consortia in Europe and the Asia-Pacific region, attracting members globally.

ROS-Industrial's repositories of open-source robotics software tools are regularly updated and customized, advancing industrial robotics and enabling robots to perform new and diverse tasks, such as manufacturing aerospace composites (pictured). Members have access to a range of tools and activities, such as technical roadmapping, workforce development and developer meetings. Focused technical projects benefit the consortium and the community while supporting growth of the software repository.

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ON THE COVER

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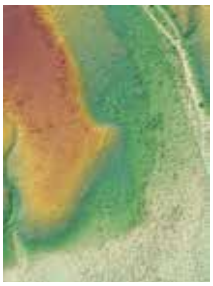

To support the Permian Basin consortium, SwRI uses various techniques to measure the faults, fractures and mechanical layering of rock strata in outcrops to understand how similar characteristics below ground could affect fossil fuel production.

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IN THIS ISSUE

We like to say that innovation is in our DNA at Southwest Research Institute, but we are not just innovative in technology. We also pursue new methodologies to address problems common among our clients. For instance, when a new law passed in 1984 enabling collaboration in the research arena, we were ready to launch our first automotive consortium to help industry effectively apply new technologies to clean up diesel emissions. As an independent nonprofit already working with a broad range of clients, SwRI is in a great position to lead these ventures, addressing industry regulations or similar competitive pressures with precompetitive research.

This issue of Technology Today focuses on consortia SwRI creates and manages to offer cost-effective approaches to solve industry-wide challenges. These consortia and joint industry programs allow competitors to collaborate, pooling financial resources and providing a forum for addressing common goals. Consortia members guide research initiatives and typically have access to research findings and intellectual property.

The first few automotive consortia addressed emissions, fuel efficiency and performance, including the highly successful clean diesel consortium, now entering its ninth phase. As the industry landscape changed, so did the consortia, which now include battery research and evaluating "e-fluids" for electrified powertrains with overarching goals of helping decarbonize the automotive sector.

With the success of the automotive consortia, the concept moved into other research arenas as SwRI helped turn the basic science of geology into a practical tool for oil and gas exploration and production. Petroleum geologists analyze rock outcrops to learn how those same formations behave deep beneath the surface to understand the pathways and barriers to fossil fuel production in various oil fields, including the Permian Basin discussed in this issue.

SwRI also operates consortia to improve aerospace safety, including managing the award-winning NASGRO® software to help users understand and control fractures in aircraft and other critical structures that can crack and fail after repeated loading, such as takeoff, flight and landing.

Featured on the opposite page, ROS-Industrial is another software-driven consortium, which facilitates an open-source, collaborative program to advance robotics for manufacturing and industry.

Over the last 40 years, SwRI consortia have successfully helped members address common pain points — particularly meeting regulatory requirements for safety, health and the environment — while providing a creative, cost-effective way to fulfill our mission to benefit government, industry and humankind.

Sincerely,

Walter D. Downing, P.E..
Executive Vice President/COO

COOPERATIVE RESEARCH FOR COST-EFFECTIVE SOLUTIONS

consortium

noun, single:
con · sor · ti · um [kuhn-sawr-shee-uhm]

noun, plural:
con · sor · ti · a [kuhn-sawr-shee-uh]

An association of companies especially formed for a particular purpose.

In the early 1980s, Southwest Research Institute worked with the diesel engine industry to meet new particulate emissions limits. Lacking expertise in emissions or aftertreatment technologies, manufacturers focused on improving combustion through engine design. Diesel filters, or diesel particulate traps, were developed as a possible "aftertreatment" solution. However, engine manufacturers, government and academia applied the technology with mixed results.

At about the same time, President Ronald Reagan signed the National Cooperative Research Act. Developed to promote innovation, facilitate trade and strengthen the competitiveness of the United States in world markets, the law limited the antitrust liability of joint research and development ventures. Ten days after the law passed in 1984, SwRI initiated its first multiclient cooperative research program, soliciting joint funding to develop precompetitive research into a consortium studying particulate filter regeneration mechanisms. SwRI was particularly well-positioned to run this consortium as an independent, nonprofit organization already serving government and industry in both the engine and emissions research and development space.

Various automotive consortia that followed initially addressed performance, emissions and fuel efficiency. Today, consortia are also evaluating battery technology and lubricants for electrified powertrains as focus shifts to decarbonizing the transportation sector. With that in mind, SwRI is hosting the inaugural Global Decarbonized Mobility Summit (GDMS) Nov. 13–17. The GDMS will assemble industry members from multiple automotive-related consortia and joint industry projects at SwRI's San Antonio headquarters. Throughout the summit, SwRI staff experts will hold sessions on the latest research and development advancements, pathways for lowering emissions through decarbonization, and how the industry can meet the latest technology challenges associated with lowering greenhouse gas emissions.

The Global Decarbonized Mobility Summit will highlight a wide range of innovative research, developments and demonstrations of solutions currently happening. The Institute has a long history of guiding collaborative programs that help clients pool resources and funding, enabling SwRI's next-generation research to reduce or eliminate emissions.

The summit will begin with regular project status meetings for automotive consortia members. On Nov. 14, GDMS will open to non-consortia members from automotive, transportation, manufacturing and other mobility sectors to learn about innovative decarbonization technologies. Programming will include expert-led sessions regarding SwRI internal research on the future of mobility as well as a campus tour.

Global Decarbonized Mobility Summit

Over the last 40 years, SwRI has run 23 consortia and joint industry programs with one focused on clean diesel engines reaching its ninth phase. Other consortia and joint industry programs featured in this focused issue of *Technology Today* include oil and gas exploration and production, aerospace safety software tools and industrial robot software cooperative research as well as the four automotive consortia that follow. Consortia are the best way to leverage limited R&D budgets for high risk/high reward future mobility solutions. And SwRI consortia benefit from a longstanding internally funded research program.

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FOUR AUTOMOTIVE CONSORTIA

Decarbonizing the transportation sector

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SwRI developed single-cylinder research engines to efficiently evaluate new engine concepts.

1 CHEDE
Clean Highly Efficient Decarbonized Engines

In 1991, SwRI launched the industry's longest-running advanced engine research consortium. The successive clean diesel programs have resulted in a long history of cooperative research between SwRI and the diesel engine industry, eventually for light- and medium-duty applications as well. From the start, the program has pursued the world's most efficient powertrain solutions to address existing and potential regulations and industry needs 10-plus years into the future. The latest four-year program continued the tradition, incorporating aggressive new efficiency, performance and emissions goals with a pivot toward hybrid-electric powertrains. Goals include research and demonstration of technologies to meet the world's strictest emissions and fuel economy standards.

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Exhaust emissions of particular concern are greenhouse gases and nitrogen oxides or NOx. NOx has direct harmful effects on human health and indirect effects on the environment and ecosystems. All gasoline and diesel internal combustion engines (ICEs) produce NOx. Reducing the pollutant is usually accomplished by minimizing combustion temperatures to produce less NOx and then using aftertreatment devices to react with it, breaking it down into less harmful constituents. Limiting NOx in diesel engines is particularly challenging. The heavy-duty powertrain emission goals for CHEDE-8 included more stringent goals than the Environmental Protection Agency's anticipated greenhouse gas and NOx rules for model year 2027. CHEDE-8's light-duty emissions goals aim for upcoming European NOx and CO_2 standards. Building on more than 30 years of advanced engine research, the ninth phase of CHEDE will kick off on Nov. 15 with a new name, Clean Highly Efficient Decarbonized Engines (CHEDE-9), that reflects today's goals in sustainable transportation.

CONCENTRATION

The CHEDE-8 Program Advisory Committee, consisting of consortium members, sets the focus on technologies to exceed future fuel economy and emissions regulations using electrified powertrains, particularly off-road and heavy equipment applications offering significant opportunities to integrate high-power-density engines with highly efficient motor and battery systems. The consortia looked for innovative ways to improve ICE efficiency

DETAIL

Brake thermal efficiency (BTE) indicates the fuel efficiency of internal combustion engines. The higher the brake thermal efficiency, the lower the fuel consumption and greenhouse gas emissions.

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SwRI maintains extensive engine development and test facilities to support advanced diesel engine research.

through advanced combustion strategies, smokeless diesel combustion and novel aftertreatment integration methods. The team considered engine fundamental architecture, novel waste heat recovery systems and new operational approaches. To develop cost-effective light-duty diesel solutions, the consortium looked at diesel-hybrid electric powertrains, super-low emission solutions and CO_2-minimized powertrains.

To create a clean hybrid-electric diesel engine powertrain, CHEDE-8 used advanced modeling and simulation technology to investigate innovative combustion systems and powertrain energy management. Additional strategies to improve efficiency while reducing emissions included advanced air and exhaust gas recirculation systems, waste heat recovery and advanced friction reduction methodologies. The team also looked at a systems approach to integrating various aftertreatment solutions to address the more challenging emissions reduction needs of diesel engines.

SwRI has extensive facilities and novel test capabilities to support hybrid electric diesel engine research, including 15L, 13L, 6.8L and 2.8L research engines as well as dedicated single-cylinder research engines. Laboratory facilities include an optical combustion visualization vessel, a high-pressure spray setup and bearing and liner friction test stands. SwRI also has a battery and advanced electronics laboratory as well as transmission and driveline evaluation facilities.

ACCOMPLISHMENTS

Through CHEDE-8, SwRI designed three different hybrid diesel powertrains. The heavy-duty powertrain coupled a 13L engine with a 48-volt motor and electrified accessories. This powertrain would allow heavy-duty long-haul trucks of the future, increasing fuel economy by over 30% through better engine efficiency, optimized oil and coolant flow, and some energy recovery from braking. The medium-duty powertrain shrank the engine size using a high-voltage electrical system. For future vocational vehicles such as dump or garbage trucks, this powertrain could reduce fuel use by 40% and create an efficient plug-in hybrid medium-duty powertrain. Finally, the light-duty powertrain pursued a low-emissions plug-in hybrid concept, coupling a smaller diesel engine with an electrified axle to provide high fuel efficiency for future SUVs and light commercial vehicles.

CHEDE-9

As CHEDE-8 draws to a close, the next phase is starting with 2035 goals to reduce greenhouse gas emissions by 35–50% from 2024 model-year products while reducing tailpipe NOx to below 1 part per million. Transportation power concepts will be differentiated by access to energy and energy storage — power and range — requirements. When long range, high power and long durability are needed, CHEDE-9 will be adapting internal combustion engines to be the net-zero CO_2 powertrain of the future.

CHEDE-9 is looking at the full range of duty cycles of light-, medium- and heavy-duty applications, identifying key strategies for each. For vehicles with low average power and daily range (~100 miles), the consortium is focusing on e-fuels and dual-fuel strategies. For vehicles with medium power and daily range requirements (~300 miles), the team is investigating hydrogen-powered internal combustion engines (H_2-ICE) research. For applications requiring high average power and long daily range (~600+ miles), the consortia will investigate liquid-fueled or H_2-ICE-based powertrains that use CO_2-neutral (or better) fuel sources.

For more information about CHEDE, contact Chris Bitsis Jr. at chris.bitsis@swri.org or 210-522-5509.

2 HEDGE® High-Efficiency Dilute Gasoline Engine

SwRI launched the HEDGE consortium in 2005 with the goal of improving gasoline engine efficiency for light- and heavy-duty vehicle applications. At the time, engineers anticipated that the Environmental Protection Agency's post-2010 emissions goals would limit efficiency and cost advantages diesel engines had over their gasoline counterparts. One of the main impediments to improving gasoline engine efficiency is engine knock, a violent, uncontrolled combustion event characterized

SwRI developed an air handling system for a client to improve fuel consumption and regulate emissions, applying HEDGE-developed technology to a production-level product.

SwRI has extensive facilities to support H_2 engine research, including five engine test cells outfitted with light-duty, medium-duty and heavy-duty hydrogen supercharged engines and fuel cell equipment. As an outgrowth of advanced engine research, SwRI has launched an H_2-ICE consortium to explore engine applications for this carbon-neutral fuel.

DETAIL

Engine knock occurs when fuel burns unevenly in an engine cylinder, causing knocking or a pinging sound, which can ultimately damage engine components.

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by a knocking or pinging sound generated as pressure waves resonate through the engine.

HISTORY

The consortium organizers sought to mitigate knock by reintroducing a portion of the engine's exhaust products back into combustion chamber. They proposed that exhaust gas recirculation (EGR) would reduce knock through a phenomenon called charge dilution. The extra, largely inert exhaust gas molecules displace oxygen in the combustion chamber, effectively slowing the chemical chain reactions that lead to engine knock. They convinced several well-known OEM and supplier companies to cooperatively fund research into this unique new concept, and the High-Efficiency Dilute Gasoline Engine (HEDGE) consortium was born.

SUCCESSION

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This first iteration of the HEDGE consortium successfully demonstrated that combining cooled EGR with advanced spark-ignition technology significantly improved engine fuel efficiency by reducing knock, allowing operation at improved combustion phasing and higher compression ratios. The gasoline engines in the HEDGE consortium achieved fuel consumption rates that were equal to or better than similar diesel engines.

Upon completion of its original four-year schedule, sufficient interest in continuing the research led to the HEDGE II consortium, which kicked off in 2009, continuing its focus on high levels of EGR combined with supporting technologies such as turbocharging, advanced charge motion, high-energy ignition, etc. Every four years a new consortium commences, each building on the learning and success of the previous program, until the present day where the HEDGE-V consortium continues, which includes many members of the original HEDGE-1 group.

ACCOMPLISHMENTS

Over the last 18 years, most major automotive manufacturers and Tier I suppliers have participated in the consortium. Nearly every hybrid-electric car today has an engine inspired by the HEDGE program. Cooled EGR effectively mitigates other forms of destructive abnormal combustion such as Low-Speed Preignition or LSPI. Other notable HEDGE developments include the invention of the patented Dedicated-EGR (D-EGR) concept, which enhances the properties of EGR with partially burned rich combustion products, and the SwRI-patented Dual Coil Offset (DCO) technology, which greatly increases the energy delivered by the sparkplug without the damaging effects of high-energy ignition systems. This long-running program has served to significantly strengthen SwRI's relationship with critical OEM clients and continues to spark (pun intended) new and innovative ideas for single-client projects.

For more information about the current HEDGE-V consortium, contact Ryan Williams at ryan.williams@swri.org or 210-522-5185.

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DETAIL

Direct-injection engines atomize fuel using high pressures to spray fuel directly into the spark plug area to ignite combustion.

SwRI engineers incorporated their DCO and D-EGR engine technologies into a demonstration vehicle to establish the improved fuel economy and reduced exhaust emissions achieved. Both of these technologies were recognized by R&D Magazine as among the 100 most significant technological achievements introduced in 2011 and 2014, respectively.

D026304

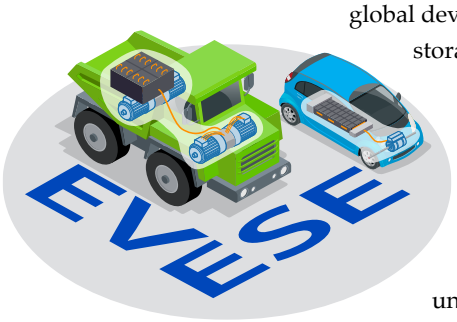
SwRI conducts range and efficiency testing on electric trucks using its all-wheel-drive chassis dynamometer.

D026288

SwRI developed a flow rig to study the impact of direct immersion cooling on battery cell performance and aging.

3 EVESE
Electrified Vehicle and Energy Storage Evaluation

In 2020, SwRI formed the EVESE consortium as a continuation of the Energy Storage System Evaluation and Safety (ESSES-I and ESSES-II) consortium launched in 2011. Initial goals included helping vehicle manufacturers and battery suppliers develop precompetitive, detailed cell-level test data on electrochemical storage systems and performing research to advance testing methodologies to evaluate batteries. Staff members designed the consortium to provide transparency in the automotive battery market to advance global development of energy storage systems.



Electric powertrains offer several operational advantages over traditional powertrains, but they also present several unique challenges, notably a steep sticker price and "range anxiety" — concern that an EV will run out of power before reaching its destination or a suitable charging point.

CONCENTRATION

The mission of SwRI's EVESE consortium is to provide analysis and evaluation of current electrified vehicle technologies and conduct research focused on improving the efficiency, performance, safety and cost to improve adoption of electrified powertrains. To facilitate the transition to electrified vehicles, state agencies are working with the private sector to develop affordable fueling and charging options. In addition, most vehicle manufacturers have made a commitment to selling a majority of electrified vehicles as soon as 2030 to 2040. With these commitments, understanding state-of-the-art technologies for lithium-ion batteries, electric motors and electrified vehicles is crucial.

Initially the ESSES consortium focused on vehicle and component benchmarking, particularly the lithium-ion battery packs dominating the market. Engineers developed test systems to ensure the performance and safety of EV technology, particularly the battery packs. SwRI used internal research funding to understand critical failure modes, developing techniques to simulate and physically test thermal, structural and crash failures, investing a tremendous amount of capital in its battery test laboratory. The facility can simulate multiple environments, altitudes, and shake and vibration scenarios. To address battery safety, engineers have designed tests to evaluate different materials between the cells, evaluating both the structural and energy propagation effects through the pack, as well as how heat propagates between cells.

Structural deformation that could occur in a crash can be simulated at crush test facilities for individual cells and full packs. SwRI ballistics experts evaluate battery response to fire and projectiles impinging the pack and how to mitigate damage in these scenarios. SwRI's anechoic chambers support battery electromagnetic interference and compatibility testing.

ACCOMPLISHMENTS

With benchmarking and safety testing protocols in place, the team turned to more advanced research subjects, including studying different battery designs and chemistries to find the most cost-effective package.

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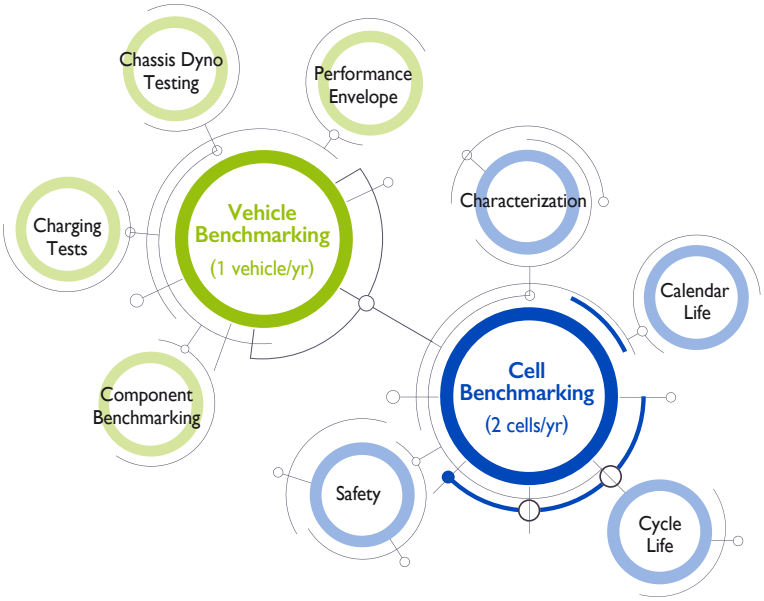
A complementary Grid-Connected Battery Energy Storage Systems consortium was established, and both consortia studied new solutions to limit battery degradation while decreasing battery recharge times. Engineers developed a real-time controller to monitor lithium plating during fast-charging events and adjust 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. The SwRI controller increased the charging by 30% with significantly reduced degradation over manufacturers' recommended fast-charging strategies. The consortia are also investigating lithium plating diagnostics and novel safety technologies, along with new thermal management protocols, particularly during aggressive charging and discharging events. 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.

For more information about EVESE, contact Ian Smith at ian.smith@swri.org or 210-522-2041.



SwRI's EVESE consortium analyzes current electrified vehicle technologies to improve the efficiency, performance, safety and cost of these technologies, including lithium-ion battery and vehicle/component benchmarking.

D026282

4 AFEV
Advanced Fluids for Electrified Vehicles

In 2021, SwRI launched the AFEV consortium to advance the industry's understanding of the unique stressors placed on electric vehicle (EV) and hybrid vehicle fluids. The consortium seeks fluid solutions for next-generation vehicles, advancing and optimizing EV fluids or e-fluids and powertrain design.

CONCENTRATION

As electric vehicles push speeds and power levels higher, understanding the role of lubricants in protecting hardware and delivering desired performance is critical. Initial topic areas for AFEV center around lubricant performance criteria necessary to properly protect and enhance operations of electrified powertrains. In any automotive application, lubricants and hardware must work together. The environment inside electric vehicles is unique when compared to conventional powertrains.

Lubricants and hardware work together to form a complete system, and as hardware evolves, lubricant requirements also change. Electrified vehicle fluids place a stronger importance on heat transfer properties, corrosion resistance, electrical conductivity and performance under high-speed conditions. Various new architectures and designs under development may require a different emphasis on fluid performance.

To improve performance and cost, AFEV will characterize new materials, higher input speeds, larger gear reductions and electrical considerations to help lubricant formulators develop the best fluids and hardware suppliers create advanced designs. Understanding EV fluid performance and developing methods to assess it are critical in determining how fluid formulations will affect the overall system.

Important performance metrics for e-fluids include how well they protect hardware at high speeds relative to traditional automotive applications and optimized heat transfer performance to keep motors operating at peak efficiency. Aeration and compatibility with materials unfamiliar to automotive fluids are also important characteristics. The electrical properties of e-fluids must be understood and balanced for safe, optimized performance. Lubricants also affect overall drivetrain efficiency, important for improving the range of EVs. E-fluid testing is an emerging field of study in the lubrication industry, and the Advanced Fluids for Electrified Vehicles consortium is performing the fundamental research needed to develop tests relevant for electric vehicles.

For more information about the AFEV consortium, contact Peter Morgan at peter.morgan@swri.org or 210-255-3143.

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SwRI's AFEV consortium is combining its expertise in powertrain development with extensive experience characterizing fuels and lubricants to target electric vehicle fluids, or e-fluids.

D026306

SAFETY *in the* SKIES

Fracture Control Using SwRI's NASGRO® Software

By Craig McClung, Ph.D., and Joe Cardinal, P.E.

D026285

Today, travelers board commercial aircraft routinely and confidently, knowing that they are extremely safe despite the inherent risks of air travel. On very rare occasions, a crack can initiate and grow in a critical component after repeated loading, and this can lead to costly failures in aerospace and other industries. Advanced technology helps ensure the integrity of these highly stressed structural components during the design and certification process. Ultimately, this technology may allow space tourism aboard commercial spacecraft with the same confidence.

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ABOUT THE AUTHORS: Dr. Craig McClung is a senior program director in Materials Engineering with nearly 40 years of research and program management experience in fatigue and fracture, focusing on the structural reliability of components. Joe Cardinal is a program director in Structural Engineering with over 40 years of experience performing and managing structural integrity projects in a wide range of applications, including structural, stress, fatigue and fracture mechanics analyses. Both engineers work in SwRI's Mechanical Engineering Division.

D026296

The NASGRO fatigue crack growth and fracture software is a key safety technology helping prevent component failure. Developed jointly by Southwest Research Institute and NASA Johnson Space Center (JSC) since 2001, the NASGRO tool performs the essential calculations necessary to establish confidence in structural performance for flight vehicles and other critical mechanical components around the world.

NASGRO began as the NASA/FLAGRO computer program, developed by NASA and its contractors in the 1980s for fracture control of the Space Shuttle, the world's first fleet of reusable spacecraft. Royce Forman and Dr. V. Shivakumar led the development of these early versions. Following the tragic Aloha Airlines accident in 1988, caused by extensive fatigue cracking of the metal fuselage, NASA began extending the software to address aircraft structures. Initially NASA released the resulting NASGRO Version 3 in 1999 as a free download, but the agency soon recognized that users would need support to realize the benefits. NASA asked SwRI about joining forces to take advantage of the Institute's world-class expertise in fracture mechanics, fatigue and damage tolerance analysis as well as a long-standing relationship with JSC.

In 2000, SwRI and NASA signed a Space Act Agreement, and SwRI took over industrial distribution and support of NASGRO, providing royalty-free software licenses to NASA and its contractors. Through this agreement and subsequent renewals, SwRI and NASA have worked together to develop and implement new NASGRO technology. A small team of fracture mechanics specialists and software engineers at Jacobs Technology in Houston also support NASGRO as contractors for NASA and SwRI.

CONSORTIUM LAUNCH

The worldwide aerospace community immediately recognized and embraced the unique capabilities of NASGRO. In 2001, SwRI organized a NASGRO consortium that included companies in nine countries, joining forces to develop the next generation of the software.

DETAIL

NASGRO's NASMAT database contains 9,000 sets of data for various materials, including more than 3,000 sets of fatigue crack growth data and more than 6,000 fracture toughness data points.


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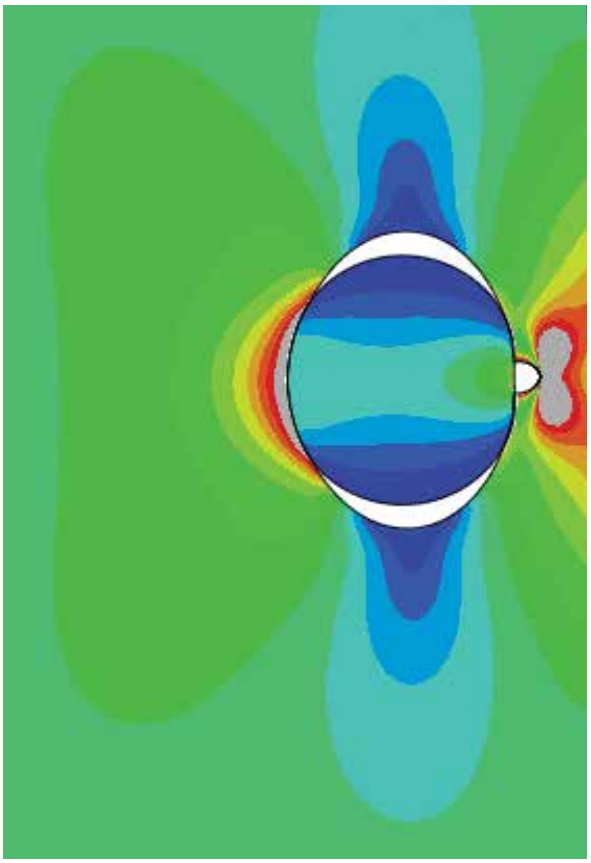
Staff Engineer Jim Feiger studies how a crack in a material sample changes over time, under cyclic loading — important data to inform NASGRO software.

In 2003, NASGRO 4.0 — the first version released by SwRI — received an R&D100 Award, recognizing it as one of the 100 most technologically significant new products of the year. NASA also recognized it with its Software of the Year Award. Despite this auspicious start, SwRI's NASGRO story was just beginning.

The NASGRO industrial consortium drives software advances and updates. Organized in renewable three-year cycles, the consortium has tripled in overall size during the past 20 years. Participants now include 24 companies working in more than 15 countries, designing, building and supporting spacecraft, aircraft, rotorcraft and gas turbine engines for aircraft propulsion or power generation. The unique legal framework governing consortia allows these companies — some of which are direct competitors — to work together collaboratively on precompetitive technology that supports improved safety.

The consortium participants provide expert guidance to the SwRI developers, identifying the future NASGRO enhancements most needed. This arrangement ensures that developers tackle the most important challenges and develop practical solutions for immediate application. Participants receive site licenses or corporate licenses for the resulting NASGRO versions. Companies working on different product applications have some unique needs, of course, and so NASGRO has evolved over time to become a much more powerful tool serving multiple industries.

This strategic collaboration also includes NASA and the European Space Agency (ESA), organizations that not only help identify development priorities but also help fulfill them. ESA has regularly provided in-kind contributions of new technology developed specifically for NASGRO under ESA contracts, and ESA and its contractors receive royalty-free NASGRO licenses for use on ESA projects. NASA applications of NASGRO are not limited to spacecraft. For the past 10 years, NASA has provided supplementary funding to SwRI to develop NASGRO enhancements needed to perform fitness-for-service (FFS) analyses of safety-critical ground-based steel pressure vessels. With these enhancements, NASGRO supports FFS analyses to ASME and API pressure vessel standards and expands applications to industries beyond its initial aerospace focus.



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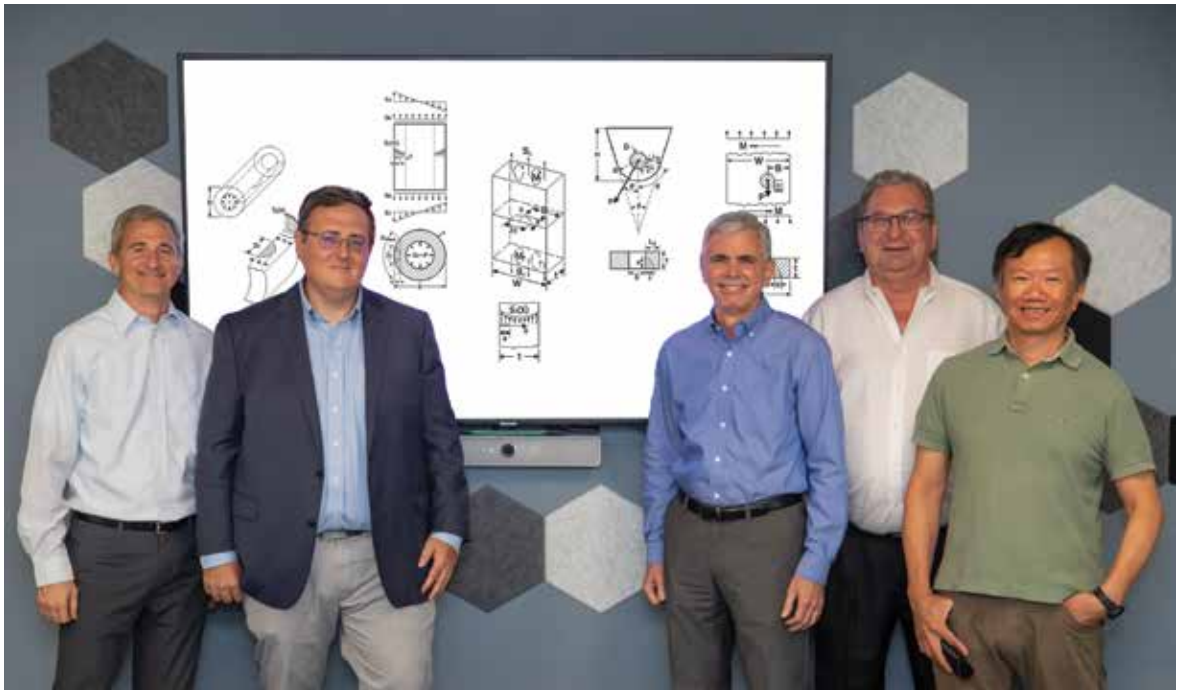
Engineers verify NASGRO solutions for predicting fatigue crack growth and fracture using finite element analyses, which show the stress that created and continues to affect a crack at an aircraft fastener hole.



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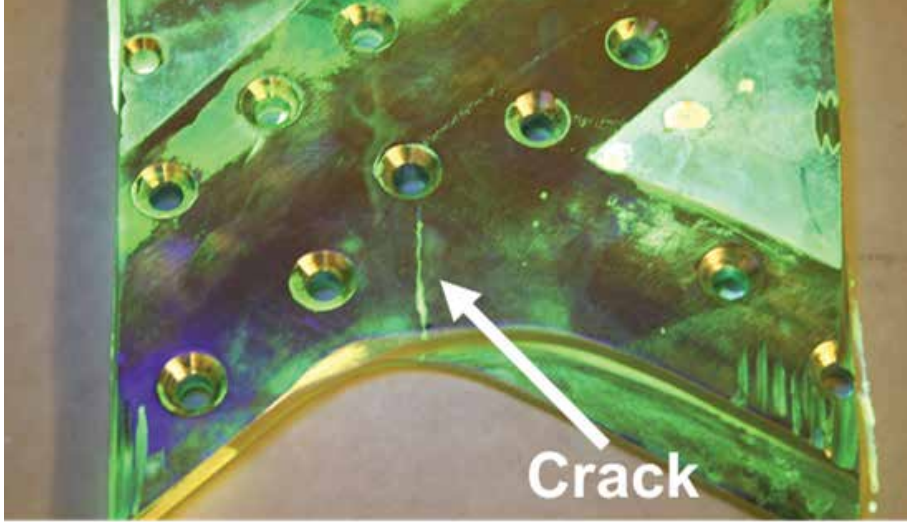
NASGRO has been growing and flourishing at SwRI for more than 20 years. The original NASGRO leaders at SwRI (from right) — Dr. Yi-Der Lee, Joe Cardinal and Dr. Craig McClung have identified and are mentoring the next generation of NASGRO leadership. Dr. James Sobotka specializes in computational fracture mechanics and joined SwRI in 2014 to support NASGRO. Luciano "Lucky" Smith has more than 20 years of practical experience at SwRI performing and leading damage tolerance analyses of aircraft structures.



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NASGRO integrates real-world data to continuously improve modeling.

CRACK GROWTH CALCULATIONS

NASGRO performs mathematical simulations of a fatigue crack growing in a metal component. Crack models calculate the effect of the applied cyclic and residual stresses, as well as the size and shape of the crack, on the driving force for crack growth. Using material properties characterized by standardized experiments, the NASGRO crack growth equation predicts how fast a crack grows and assesses the onset of fracture, establishing the safe service life of a component. These life predictions guide inspection methods and intervals for safe operation of a component.

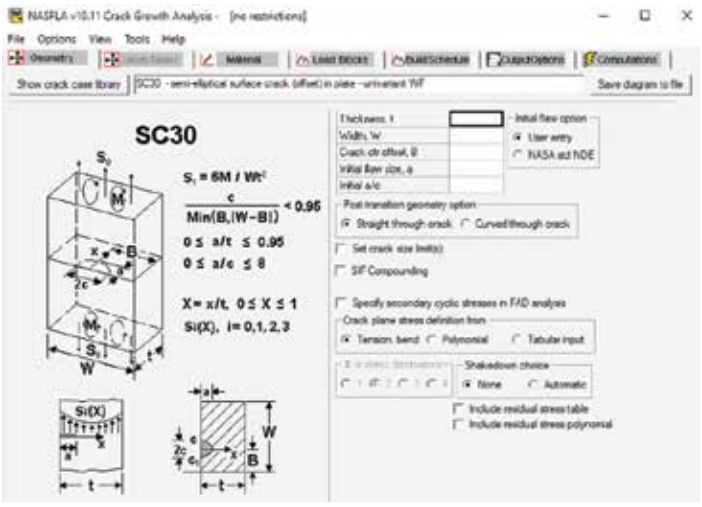
Crack models must be exceptionally fast to facilitate millions of calculations at many potential crack locations in a complex structure. These rapid crack models are based on idealized geometries — for example, a semi-elliptical crack in a rectangular plate — and must accommodate a wide variety of geometric shapes, dimensions and applied stress distributions while still providing highly accurate results when used as surrogates for actual components. The NASGRO team has developed many unique crack models. SwRI's Dr. Yi-Der Lee and Dr. James Sobotka have pioneered computational methods to develop and calibrate advanced crack models for various scenarios, including complex stress gradients acting on the crack plane. These specialized configurations include tapered lugs with oblique contact loads, multiple curved cracks at rows of holes and cracks in pressurized cylinders or spheres. Powerful new computational methods verify the accuracy of new crack models by statistically comparing their results with hundreds or thousands of high-fidelity three-dimensional finite element analyses.

NASGRO v3 included 40 crack models, a number that was state of the art in 1999. The current tool, NASGRO v10.2, includes 115 crack models, far more than any other available fracture assessment software. About half of the original v3 crack models have been revised or replaced/supplemented with corresponding new crack models.

The other distinguishing feature of NASGRO is its large library of material properties for fatigue crack growth and fracture. NASGRO contains properties for more than 500 metals and alloys tested under various conditions, a number that continues to grow as new data and materials are added to its database. The NASMAT module included with NASGRO also contains the original test data used to generate the properties and can calculate properties from new user data.

EMERGING APPLICATIONS

In addition to providing NASGRO licenses to consortium participants, NASA and ESA, SwRI also licenses individual versions of NASGRO to other users in industry and government worldwide.



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NASGRO is a suite of different computer programs for different types of fatigue and fracture mechanics analyses, including the main module NASFLA (shown), which calculates fatigue crack growth lifetimes.

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Since 2006, SwRI has conducted more than 90 NASGRO courses, teaching more than 1,800 users about fatigue crack growth theory as well as basic and advanced NASGRO capabilities.

D026294

NASGRO and SwRI's Dr. Craig McClung and Joe Cardinal were inducted into the Space Technology Hall of Fame this year. These awards recognize life-changing technologies emerging from global space programs, increasing public awareness of the benefits of space exploration.

Over 1,000 single-seat licenses and more than 60 site licenses have been purchased since 2002. About half of these users are outside the United States. Commercial licensing extends NASGRO use to many other companies and universities for a range of applications, including railroad tank cars, ship structures, submersibles, marine structures and more.

In the past few years, NASGRO has seen significant growth in several major emerging markets. For example, NASGRO is the preeminent tool used by the burgeoning commercial space industry. SpaceX, Blue Origin, Sierra Space and United Launch Alliance are all consortium participants, and many other commercial space companies are NASGRO licensees. NASGRO is also attracting substantial attention from the rapidly expanding advanced air mobility industry. Developers of eVTOL (electric vertical take-off and landing) air vehicles as well as electrified conventional aircraft are using NASGRO to design and certify products for safe operation.

NASGRO's exceptional technical capabilities, which include extensive libraries of crack models and material properties, put the tool in a class by itself. NASGRO is a suite of eight complementary programs used to analyze fracture and fatigue crack growth. These integrated modules include user-friendly graphical interfaces that facilitate the calculation of stress intensity factors, critical crack size, fatigue crack growth life and material properties.

Responding to requests from NASGRO users within NASA and the consortium, SwRI developed a 20-hour NASGRO training curriculum in 2006. The curriculum covers basic fatigue crack growth theory as well as basic and advanced NASGRO capabilities. The team taught in-person NASGRO short courses at SwRI at least two times each year through 2019. In this time frame, instructors also taught nearly 40 courses at client sites — industrial users, NASA or ESA — including 14 courses in Europe. When the COVID-19 pandemic hit, the team pivoted to a live virtual delivery method, and the training volume nearly doubled: 22 courses taught in less than three years. To date, SwRI has presented the NASGRO short course 90 times to almost 1,800 students.

In 2023, the Space Foundation inducted NASGRO into the Space Technology Hall of Fame, recognizing its broad and profound impact — the second SwRI technology recognized. Created in 1988, the Hall of Fame recognizes the life-changing technologies emerging from global space programs, increasing public awareness of the benefits of space exploration and encouraging further innovation by recognizing individuals, organizations and companies that adapt technologies originally developed for space to improve the quality of life for all humanity.

SwRI has released 20 production versions of NASGRO since 2001, with version 11.0 under development. It is the most widely used fatigue crack growth and fracture software in the world with many thousands of users. If you have flown on a commercial transport aircraft or rotorcraft in the past 20 years, then it is highly likely that NASGRO made it safer. And if you fly on an air taxi or a commercial spacecraft in the next 20 years, it is almost certain that NASGRO enabled the new technology to take flight.

For more information about NASGRO, go to the NASGRO website (nasgro.swri.org), listen to the "Fracture Control with NASGRO" podcast at https://www.swri.org/podcast/ep55, or contact Craig McClung at craig.mcclung@swri.org or (210) 522-2422 or Joe Cardinal at joseph.cardinal@swri.org or (210) 522-3323.

Since 2013, SwRI has managed another aerospace consortium — the Numerical Propulsion System Simulation or NPSS® — for its members. NPSS is an advanced object-oriented thermodynamic modeling environment used by the aerospace industry to simulate turbomachinery, air-breathing propulsion systems, liquid rocket engines and engine control systems. The flow-network tool also can be applied to model refrigeration cycles, multiphase heat transfer systems, vehicle emission analyses or supercritical carbon dioxide (sCO_2) power cycles.

Originally developed at NASA's Glenn Research Center in 1995, NPSS allows machinery manufacturers to model and integrate critical performance information with infrastructure models. SwRI's NPSS team maintains the software and creates new features. In 2020, the consortium developed NPSS integrated development environment (IDE) to make the software more accessible to new and casual users while easing the process of developing new models and investigating existing models. The consortium also develops and maintains NPSS EMI — for Elements, Models and Interfaces — which enhances the engineering functions within NPSS.

Questions about NPSS? Contact Griffin Beck at griffin.beck@swri.org or (210) 522-2509.

D026278

SwRI geologists create virtual outcrops using drone photogrammetry to map and analyze inaccessible outcrops in the Permian Basin, such as this fractured sandstone bed in the Alta Formation. Photogrammetry is the science of obtaining reliable information about physical objects and the environment by recording, measuring and interpreting photographic images.

DECIPHERING DEFORMATION IN THE PERMIAN BASIN

Permian Basin consortium enters third phase

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

The Permian Basin in West Texas and Southeastern New Mexico is a "super basin," representing one of the most prolific oil and gas-producing regions in the United States. More than 35.6 billion barrels of oil and about 125 trillion cubic feet of natural gas had been produced as of January 2020. The basin is approximately 250 miles wide (east-west) by 300 miles long (north-south) and consists of two primary areas of production — the Midland Basin in the east and the Delaware Basin in the west — separated by the Central Basin Platform.

After a century of oil production focused on conventional oil fields and vertical wells, the last decade has seen a shift in focus to unconventional production with horizontal wells and extensive hydraulic fracturing programs to exploit reservoirs with very low permeability.

ABOUT THE AUTHORS: The authors recently completed a field geology campaign studying outcrops near Marfa, Texas. Dr. David Ferrill (left) is a structural geologist with expertise in diverse tectonic regimes, and international oil and gas exploration and production experience. He has extensive expertise characterizing reservoirs and aquifers, interpreting tectonic stress fields and analyzing mechanical stratigraphy, rock deformation and fracture mechanisms, and serves as principal investigator for the Permian Basin consortium. Dr. Adam Cawood (center) is a structural geologist specializing in close-range remote sensing for quantitative structural analysis. His research focuses on natural deformation processes, with an emphasis on leveraging structural data for improved understanding of the subsurface. Dr. Kevin Smart (right) is a structural geologist with extensive expertise in computational solid mechanics. He is manager of the Earth Science section in the Space Science Division and part of a team conducting an integrated program of structural geology and geomechanics research for the energy industry.

D026276

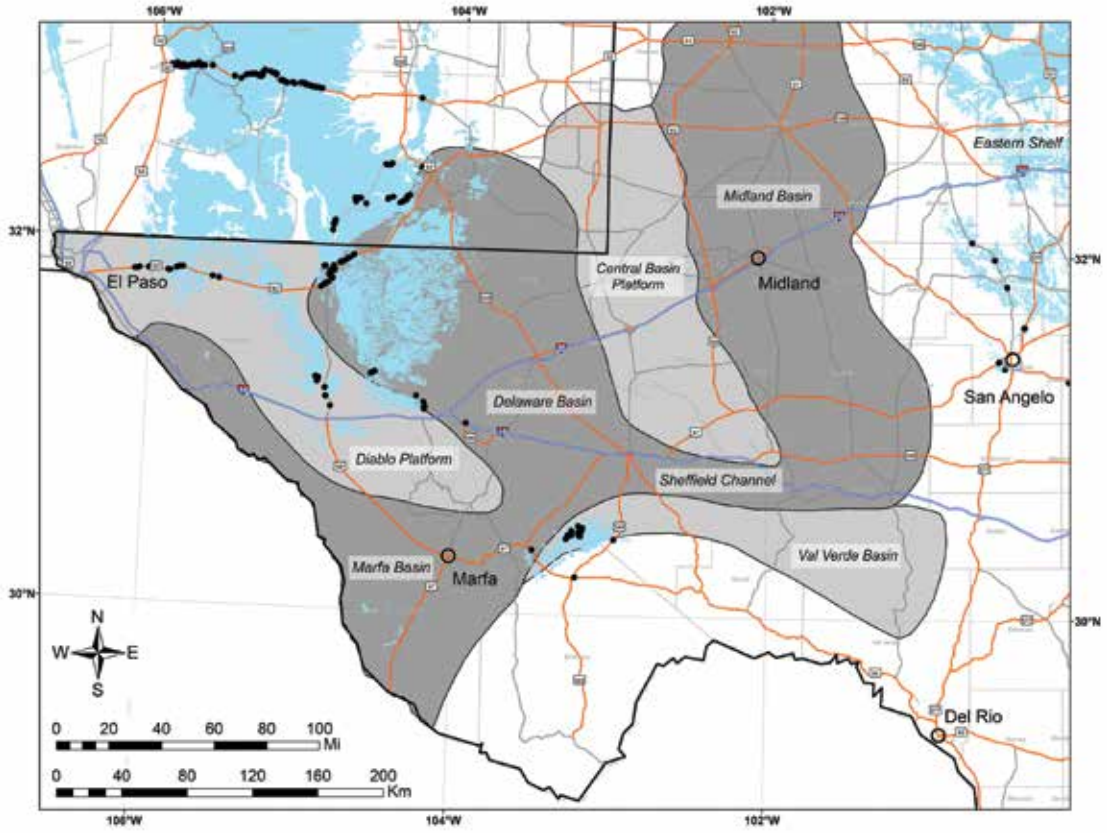
DETAIL

Unconventional oil and gas reservoirs, or plays, are accumulations where oil and gas are tightly bound to the rock.

Unconventional production techniques reversed a production downturn, allowing the basin to exceed its previous peak in the early 1970s. In 2021, the Permian Basin accounted for more than 41% of total U.S. crude oil production and more than 15% of total U.S. natural gas production. As of 2019, the Energy Information Administration estimated remaining proven reserves in the Permian Basin exceed 12.1 billion barrels of oil and 49.9 trillion cubic feet (Tcf) of natural gas, making it one of the largest hydrocarbon-producing basins in the United States and the world.

The relatively flat surface topography across most of the Permian Basin belies the complexity of its subsurface geology. The layers of rock record a long geologic history, including four major geologic events caused by the shifting of the Earth's tectonic plates. During approximately 323 million years of tectonism, the Permian Basin developed and accumulated sediment including the lower Permian Wolfcamp shale. This organic-rich oil and gas source rock extends across the subsurface of the Permian Basin and represents the most prolific tight oil and shale gas-bearing formation in the region. This unconventional reservoir and layers below were deposited around the uplifts of the Ancestral Rockies and Ouachita deformation, geologic events that occurred when the continents now represented by North America, South America and Africa collided around 300 million years ago. The rock deformed due to stress from continental tectonic events, as layers folded and shifted, changing shape and size. The deformation caused regionally variable fault and fracture networks throughout the rock layers.

The earlier Ouachita and Ancestral Rockies tectonic events influenced basin depth and the thickness and sediment makeup of the strata deposited during these mountain-building events. Younger tectonic events occurring after these sedimentary layers were buried and solidified included the Laramide orogeny that formed the modern Rocky Mountains and the subsequent deformation associated with formation of the Basin and Range Province. Both of these tectonic episodes had variable and widespread impact on faulting and fracturing of rock layers across the Permian Basin region.



This regional map of West Texas and southeast New Mexico shows the location of Midland Basin, Delaware Basin and Marfa Basin within the overall Permian Basin complex. Outcrops of Permian strata are shown in light blue, and black dots indicate locations of some of the outcrops investigated by SwRI's Permian Basin consortium.

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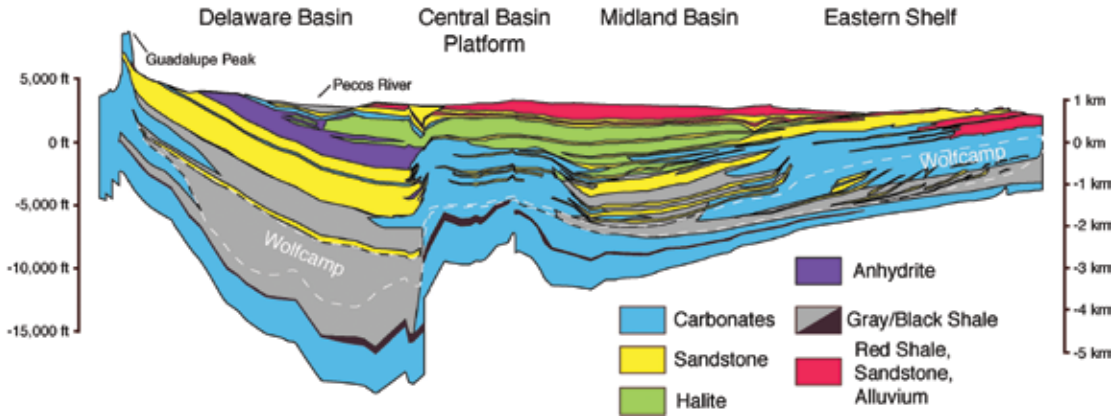

This figure illustrates the layers of rock present in the Permian Basin, particularly the Wolfcamp shale deposits.

DETAIL

Geologic strata are layers of rock, each with distinguishing properties or attributes, chronicling the history of the Earth.

Natural deformation features such as fractures and faults in the Permian reservoirs and associated strata from all of these overlapping tectonic events have wide-ranging yet poorly understood impacts on oil and gas exploration and production. Hydraulic fracturing is considered essential to economic success in unconventional reservoirs made up of layers of fine-grained rock with low permeability. Natural fractures can also be extremely important for providing pathways to deliver hydrocarbons to the well for effective production. Other considerations include understanding how pre-existing faults can move (slip) — due to wastewater injection, hydraulic fracturing and/or production — and produce earthquakes.

PHASE 1

SwRI launched the Permian Basin consortium in 2017 to help the oil and gas industry better understand and predict faulting, fracturing and folding and how they relate to mechanical stratigraphy, which represents rock mechanical properties, layer thicknesses and interface behavior between rock layers. From 2017 to 2019, Phase 1 explored natural surface outcrops, as well as road cut and quarry exposures, to understand how mechanical stratigraphy and tectonic setting influence natural fracturing and related deformation. These investigations included fieldwork at approximately 400 outcrop locations in and around the Permian Basin, characterizing faults and fractures as well as sampling and analyzing mineral-filled fractures (veins) for fluid inclusions. The team used fluid inclusion analyses and stable isotope geochemistry of vein materials to determine geologic conditions such as depth, temperature, pressure and water source at the time of vein formation. The team also analyzed core samples from the basin and correlated subsurface mechanical stratigraphic and vein analyses of core samples collected in the region.

DETAIL

The Laramide orogeny refers to a series of mountain-building events affecting western North America in the Late Cretaceous and Paleogene periods.

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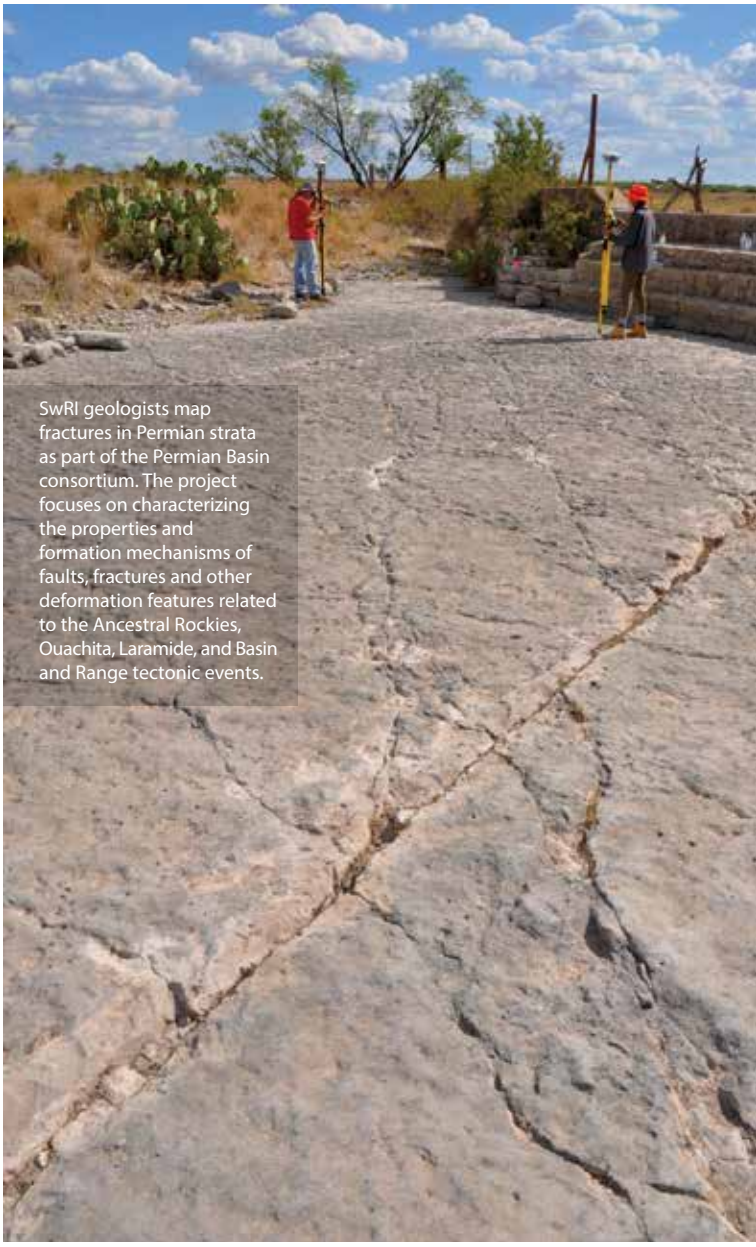


SwRI geologists map fractures in Permian strata as part of the Permian Basin consortium. The project focuses on characterizing the properties and formation mechanisms of faults, fractures and other deformation features related to the Ancestral Rockies, Ouachita, Laramide, and Basin and Range tectonic events.

DETAIL

The Wolfcamp shale was deposited in the Permian region around 280–295 million years ago.

D026299

In the Permian Basin, sandstone beds develop complicated, dense and interconnected fracture networks, whereas Wolfcamp shales may be relatively unfractured or develop independent fracture networks, resulting in limited fracture connectivity across the different layers of rock.

D026309

Small-displacement faults represent the largest fractures, forming the backbone of the fracture-controlled permeability network.

DETAIL

Calcite veins are common in rocks as the products of fluid movement and mineral deposition along fractures. These structures constrain the geochronology of basin deformation, fracture and fault system evolution, and fluid movement including oil and gas migration through the fault and fracture network.

PHASE 2

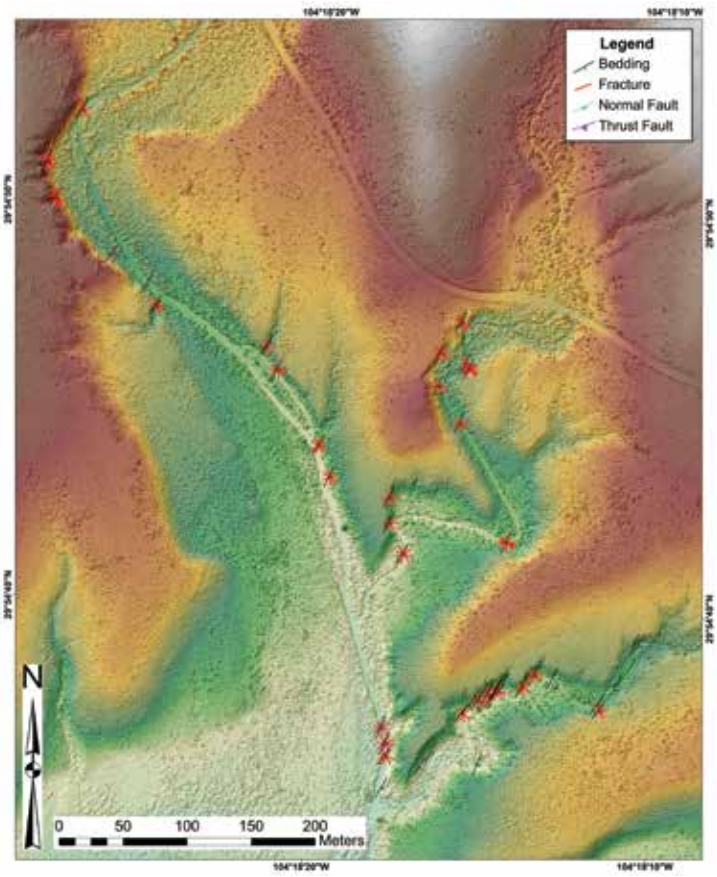
From 2019 to 2022, the consortium built on Phase I results, including aggregation and analysis of subsurface fracture data from dozens of Permian Basin wells contributed by consortium members. Mineralogic analyses of outcrop samples augmented mechanical stratigraphy datasets for outcrop fracture studies. Phase 2 refined estimates of the conditions associated with faulting and fracturing through detailed fracture analyses of outcrops in and around the Delaware and Midland Basins and performing additional vein sampling and fluid inclusion analyses of calcite veins.

Results from the first two consortium phases showed how deformation styles vary depending on regional tectonic context and local structural position. Our studies provided detailed insights into how mechanical stratigraphy influences fault and fracture properties at bed and formation scales, controlling the dimensions (particularly height), abundances, orientations and geometries of faults and fractures. The work has documented how weak beds — rock layers of sufficiently lower strength than adjacent layers — terminate fractures and faults. Understanding these influences not only improves natural fracture prediction in the subsurface, but the research results also provide analogs for newly formed or reactivated subsurface fractures associated with hydraulic fracturing. Fluid inclusion studies from outcrop samples provide important evidence that fractures now observable in outcrops at the surface formed at depths up to several miles, on par with current depths of horizontal well drilling and hydraulic fracturing in the basin, implying that similar fractures are likely at reservoir depths. Many of the sampled veins contain liquid hydrocarbon inclusions. Ultraviolet fluorescence analyses indicate a range of oil types, recording progressive fluid trapping over time as oil migrated through the rocks.

PHASE 3

SwRI just launched the third phase of the Permian Basin consortium, which will run through 2026. Phase 3 leverages work completed in Phases 1 and 2 with particular focus on developing quantitative relationships for subsurface deformation prediction. Planned research includes surface and subsurface investigations to characterize the mechanical stratigraphy and natural deformation that influence stimulation and production in the Permian Basin. Planned tasks involve an increased emphasis on quantitative outcrop-based structure and mechanical stratigraphy data collection. Goals include developing causal relationships for interpreting deformation based on layer age, rock type, mechanical stratigraphy, tectonics and structural constraints, culminating in a predictive workflow.

An exciting project expansion in Phase 3 involves new field investigations of a series of outcrops around the Chinati Mountains southwest of Marfa, Texas. In particular, the 5,600-foot-thick



D026286

Digital photogrammetry generates detailed digital topographic maps for mapping and locating detailed structural measurements of faults, fractures and bedding in outcrops.

D026298

Geologists study cross-cutting sets of fractures such as the ones shown here to understand regional stress changes during the tectonic evolution of the basin.

DETAIL

In geology, fabric describes the orientation or alignment of minerals, grains or structures in a rock associated with deformation or metamorphism, which reveals important information about its tectonic history, stress regime, strain rate and fluid flow.

Wolfcampian age shale and sandstone deposited in basin and slope settings within the Marfa Basin provide excellent outcrop analogs for productive reservoirs in the Delaware and Midland Basins.

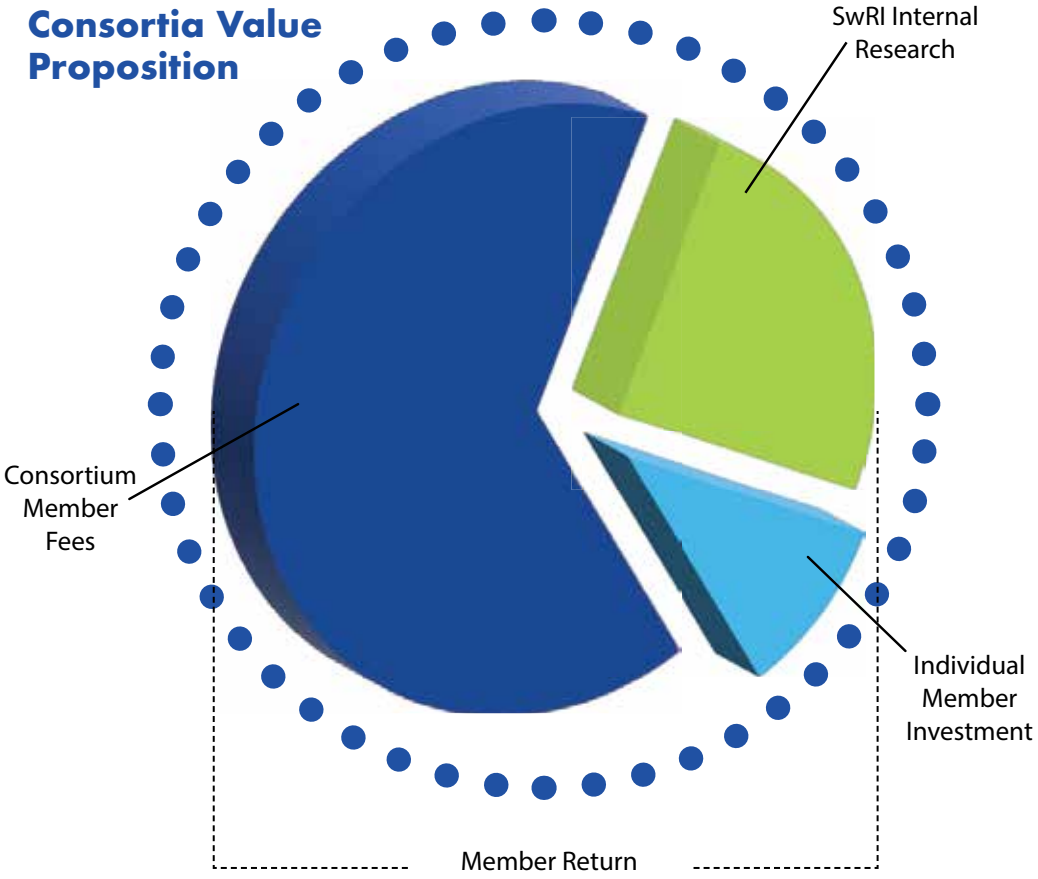
SwRI geologists used internal funding to collect outcrop data, securing access to private ranches critical to the success of this project. Results of this research campaign provide the foundation for additional follow-on work planned for Phase 3 of the Permian Basin consortium. Outcrops reveal much larger volumes of rock than what can be studied by well or core samples. This "outcrop scale" observation is particularly important to understanding the distribution of deformation "fabrics," including fracture network and mechanical layering at the scale of a hydraulic fracture treatment ("frac stage"), and fills a missing data gap in understanding of the subsurface.

Phase 3 will continue to study the structures, faults and fractures in reservoirs and associated strata to support planning, production and development-related activities in the hydrocarbon-producing formations of the Permian Basin. Resulting integrated datasets and predictive workflows will support subsurface fracture prediction and geomechanical analyses as well as provide material to train consortium members' staff to identify the key attributes that affect stimulation and production in the region. Phase 3 kicked off with a meeting and field trip to the Marfa Basin in fall 2023. New members are welcome.

Questions about this story or joining the consortium? Contact David Ferrill at david.ferrill@swri.org or 210-522-6082.

TURBOCHARGING R&D

For nearly 40 years, SwRI has developed and managed collaborative programs that enable clients to pool their research and development dollars for precompetitive research through consortia and joint industry programs (JIPs). Members gain more benefit together than typically possible through individual research and can apply advances to their products and services. SwRI also supports consortia with internally funded research. Current consortium topics range from automotive to aerospace, oil and gas, robotics, batteries and energy storage system applications.



NGL

NEXT GENERATION LIQUEFACTION

- 2016–present
- 2 phases
- 2 clients, 4 research entities, 3 independent consultants
- 2 journal articles published, 17 conference papers
- 9 oil & gas industry sponsors

EAGLE FORD JIP

- 2012–2017
- 2 phases
- 10 oil & gas sponsors
- 19 articles published

PERMIAN BASIN CONSORTIUM

- 2017–present
- 3 phases
- 9 oil & gas industry sponsors

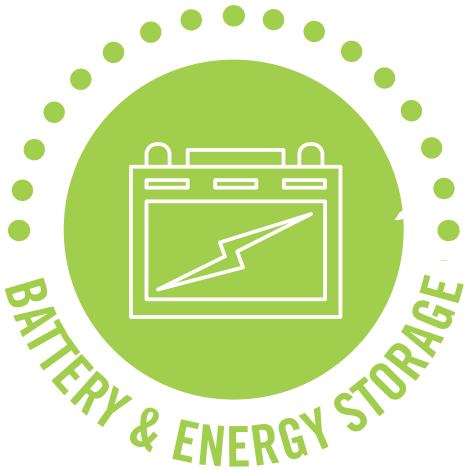
SMART CALC

SOUR MEASUREMENTS IN AUTOCLAVE FOR RELIABLE THERMODYNAMIC CALCULATIONS

- 2023
- Currently in phase 1 of 2
- 4 members

NASGRO
- 2001–present
- 8 three-year cycles
- 24 participants
- 10 versions released

NPSS
NUMERICAL PROPULSION SYSTEM SIMULATION
- 2013–present
- 12 members
- 3 software development areas
- 12 papers



BESS
BATTERY ENERGY STORAGE SYSTEM FOR ELECTRIC GRID JIP
- 2021–2023
- 5 members
- 1 patent application
- 3 papers

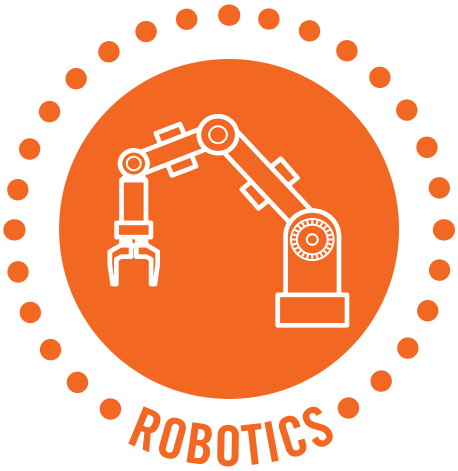
EVESE
ELECTRIFIED VEHICLE AND ENERGY STORAGE EVALUATION
- 2020–present
- 14 members total, 10 current
- 3 papers

AC2AT
ADVANCED COMBUSTION CATALYST & AFTERTREATMENT TECHNOLOGIES
- 2014–2022
- 2 phases
- 12 members in AC2AT, 5 members in AC2AT-II
- 2 articles published

HEDGE
HIGH-EFFICIENCY DILUTE GASOLINE ENGINE
- 2005–present
- 5 phases
- 24 members
- 45+ patents/pending
- 90+ papers

CHEDE
CLEAN HYBRID ELECTRIC DIESEL ENGINE
- 1991–present
- 9 phases
- 40 members total, 24 current
- 34+ patents
- 65 papers

AFEV
ADVANCED FLUIDS FOR ELECTRIFIED VEHICLES
- 2020–present
- 26 members
- 5 research tasks



ROS-INDUSTRIAL
- 2013–present
- 92 members
- 8 tools

swri.org/consortia

NOVEL DIRECTION-FINDING TECHNOLOGY WINS R&D 100 AWARD

R&D World Magazine has recognized SwRI's Wideband Conformal Continuous-Slot Antenna Array as one of the 100 most significant innovations for 2023. Since 1971, SwRI has received 52 R&D 100 awards.

This state-of-the-art technology provides naval ships with high-performance, high-frequency radio frequency direction-finding (DF) and signal acquisition while conforming around shipboard mast structures. Modern-day DF systems determine the direction of enemy combatants, provide situational awareness and serve to locate emergency transponders for search-and-rescue operations.

"The operating frequency and bandwidth of modern radio frequency, or RF, communications signals are trending increasingly higher, outpacing the performance of modern direction-finding antennas," said SwRI Staff Engineer Patrick Siemsen, who led the project. "Current DF antennas must maintain precise electromagnetic spacing between array antenna elements to prevent grating lobes or ripples in the beam-formed antenna patterns, which can cause performance issues."

Traditional shipboard high-frequency DF antennas are typically mounted at the top of a mast due to inter-antenna element spacing requirements or situated on a yardarm off the side of the mast, a location that can cause structural blockages, reduced sensitivity and degraded performance.

The Wideband Conformal Continuous-Slot Antenna Array, released as part of SwRI's AS-750 family of advanced antenna arrays, overcomes the performance issues commonly encountered at higher frequencies. The array was designed using electromagnetic modeling software and takes inspiration from an unorthodox concept for a wideband antenna array originally conceived by electronics engineer Harold Wheeler in 1948, which until now was largely theoretical.

"Our AS-750 antenna arrays use a series of continuous slot antennas with closely spaced antenna feeds around the perimeter array," Siemsen said. "The close spacing is possible through symmetrical, dual-ring microstrip corporate feed networks. We can conform the antenna array around the support mast without losing processing performance, and the design allows higher-priority navigational and threat-warning systems to be mounted above it."

The SwRI Wideband Conformal Continuous-Slot Antenna Array enables existing and future naval platforms to support the need for communications intelligence systems to perform the previously unachievable high-performance signals processing of increasingly sophisticated ultra-high and super-high frequency signals. The antenna array is only seven inches high and requires a fraction of the space required by comparable arrays without sacrificing the durability necessary for the demands of a naval shipboard environment.

Though designed for naval shipboard signals intelligence applications, the AS-750 antenna arrays are suitable for other uses and installations where similar mounting restrictions apply or when low-profile packaging is desired. The SwRI team is investigating other applications for the antenna arrays, including airborne and land-based uses.

"Southwest Research Institute strives to uncover innovative solutions to complex problems," said SwRI President and CEO Adam L. Hamilton, P.E. "I am very proud of the work SwRI does and pleased to know this technology, which will provide significant support to naval operations, has been recognized as one of the most important innovations of the year by the R&D 100 Awards and their esteemed judges."

SwRI's state-of-the-art Wideband Conformal Continuous-Slot Antenna Array, jutting out from near the base of this mast, provides naval ships with high-performance, high-frequency radio frequency direction-finding and signals acquisition while conforming around shipboard mast structures.

D025611_8510

NASA Funds DIMPLE Lunar Lander/Rover

NASA has selected SwRI to lead a $50 million lunar lander/rover instrument suite, Dating an Irregular Mare Patch with a Lunar Explorer, or DIMPLE, designed to understand if the Moon has been volcanically active in the geologically recent past. DIMPLE, which was developed by SwRI, will use cameras and radioisotope-based dating to determine the age and composition of an anomalously young-looking patch of lunar basalt named Ina.

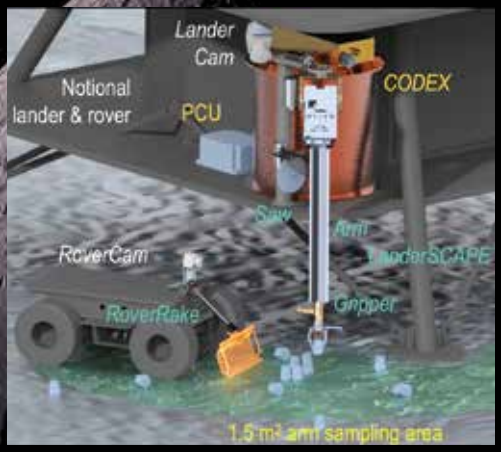
DIMPLE will date the rocks at Ina directly using the first-ever purpose-built radioisotope rock dating instrument for use in space, called CODEX (Chemistry Organic and Dating Experiment). Ina is an enigmatic formation of unusually smooth mounds surrounded by rough troughs, all inside the central crater of a large volcano. Ina looks much younger than other places on the Moon because it has very few impact craters. Impact craters build up on the lunar surface over time, so older surfaces generally have more impact craters compared to younger surfaces.

"This challenges our understanding of lunar geochemical evolution, since a geologically recent eruption requires unexpectedly long-lived heat sources in the lunar interior," said SwRI Institute Scientist Dr. F. Scott Anderson, principal investigator of DIMPLE. "If Ina really is as young as it appears, that means that the Moon has been volcanically active much more recently than scientists have thought. Or, if we find that Ina is as old as typical lunar rocks, that indicates that the material properties of certain rocks can fool us, if we are not careful, as we try to understand the ages of planetary surfaces throughout the solar system."

If rock formations like Ina do not give rise to impact craters, or do not preserve them over the eons, then some current ideas about solar system history could be wrong. The CODEX instrument exploits the natural radioactive decay of rubidium into strontium as a measure of how much time has elapsed since a rock sample formed. The SwRI-led team has been developing CODEX for two decades.

"Dating is a challenging process. Traditional techniques are not easily adapted to spaceflight, requiring a sizable laboratory and several months to determine a date," Anderson said. "By contrast, the entire DIMPLE payload is going to weigh less than 50 kilograms and needs to run autonomously on the Moon. In our lab, we have shown that CODEX can accurately date rock samples like those we expect to find at Ina with a precision of better than ±375 million years, which is more than sufficient to situate the origin of Ina in the billions-of-years-long history of the Moon."

DIMPLE is part of NASA's Payloads and Research Investigations on the Surface of the Moon (PRISM), which will be delivered to Ina through the Commercial Lunar Payload Services (CLPS) initiative. The DIMPLE team includes The Aerospace Corporation, the University of Bern, Colgate University and Lockheed Martin.



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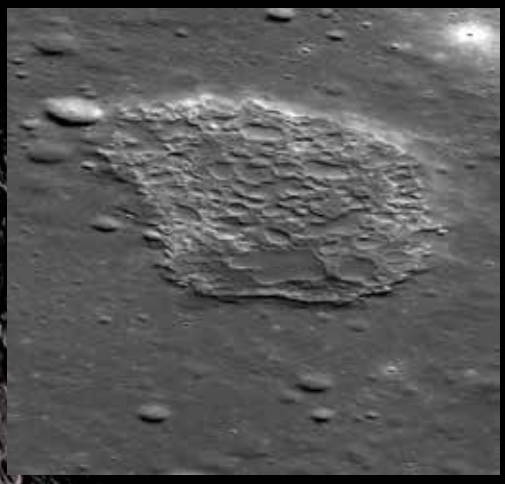
A camera, sample collection arm and the CODEX instrument will remain on the DIMPLE lander, while a rover equipped with a camera and rake will scoop and transport samples back to the lander instruments for detailed study.



D026313

The DIMPLE lunar lander/rover instrument suite will use a camera and radioisotope-based dating to determine the age and composition of this mysteriously young-looking patch of basalt known as Ina, shown here in a Lunar Reconnaissance Orbiter image.

IMAGES COURTESY LOCKHEED MARTIN/SwRI/UNIVERSITY OF BERN/THE AEROSPACE CORPORATION/ NASA/GSFC/ARIZONA STATE UNIVERSITY

D026307

ENABLE-ING ENHANCED PERFORMANCE, REDUCED INJURY RISK

SwRI recently launched its new Engine for Automatic Biomechanical Evaluation (ENABLE™) markerless biomechanics system.

ENABLE is a user-friendly, markerless-motion-capture system that leverages artificial intelligence, computer vision algorithms and biomechanical modeling. The key advantage of ENABLE is it efficiently captures motion without requiring physical body markers to be attached to a human subject.

"Following years of internal research and applied client projects, SwRI has made ENABLE commercially available for biomechanical analysis in sports, medicine, research and other human performance applications," said Institute Engineer Dr. Dan Nicolella. "We are excited about all the potential applications from sports to military medicine."

Historically, sports scientists have relied on the tedious process of attaching physical markers to a human subject at precise locations on the body to capture kinematics data with special infrared cameras. ENABLE circumvents physical markers by leveraging novel computer vision algorithms that process standard video. An SwRI-developed neural network identifies and tracks over 80 virtual points on the human body including the locations of wrists, elbows, knees, ankles and other joint positions.

ENABLE combines novel artificial intelligence algorithms with OpenSim biomechanical modeling to analyze the properties of human physical motion, or kinematics, from standard video. Sometimes known as the geometry of motion, kinematics enables the mathematical quantification of walking, running and other precise physical movements. SwRI used internal funding to develop ENABLE into a portable, user-friendly system that can, for instance, help improve pitchers' accuracy and alter their mechanics to reduce injury.

"With so many open questions about the underlying mechanisms driving pitching injury and actions that can prevent injury, we wanted to design an optimal control framework to investigate the cause-effect relationship between pitching mechanics and injury risk," said Research Engineer Ty Templin. "We ran optimization scenarios to make subtle changes to the pitchers' motions and mechanics to minimize shoulder torque, which was our metric for injury. We then maximized the hand velocity, which was our metric for performance."

SwRI's markerless biomechanics system is unique in its forward dynamics optimization capability, which allows users to examine scenarios that incorporate hypothetical changes to the subject's movements. For example, researchers found that a straightened stride leg more efficiently transfers energy into the pitch.

"We trained ENABLE to see those locations in views from multiple cameras. ENABLE robustly computes the 3D location of each virtual point on the body to accurately map the subject's motion," said Omar Medjaouri, an SwRI senior research engineer who specializes in computer vision. "Combining computer vision and biomechanics, ENABLE creates a personalized biomechanical model of each subject and uses this model to constrain the resulting movement to the physical reality of the human body to output kinematics that are highly accurate."

Templin, Nicolella and their colleagues plan to investigate the various benefits the system can offer, including studying the movements of basketball players.

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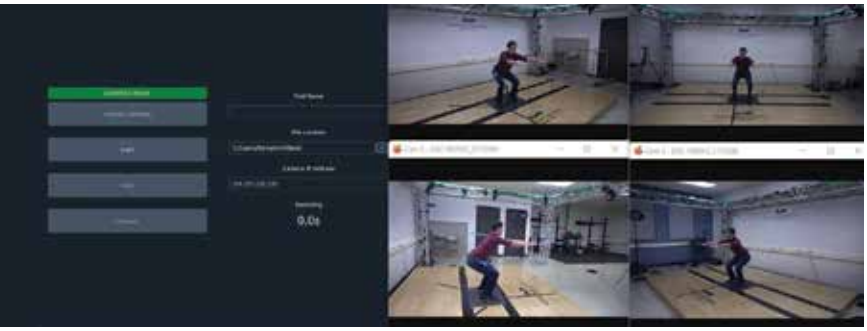

The SwRI-developed Engine for Automatic Biomechanical Evaluation (ENABLE™) markerless biomechanics software has an optional graphic user interface (GUI). Images at left are raw data of athlete performance. Images on right depict kinematics from video inputs.

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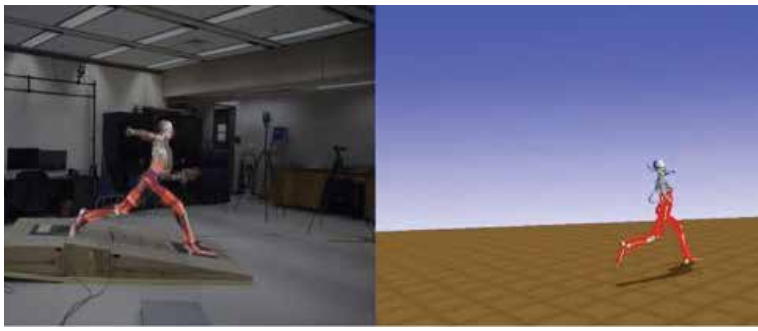


This portable, user-friendly system incorporates the ENABLE™ analysis tool to improve pitchers' accuracy and alter their mechanics to reduce injury risk.

Ancient, High-Energy Impacts Likely Fueled Venus Volcanism

An SwRI-led team has modeled the early impact history of Venus to explain how Earth's sister planet has maintained a youthful surface despite lacking plate tectonics. The team compared the early collision histories of the two bodies and determined that Venus likely experienced higher-speed, higher-energy impacts creating a superheated core that promoted extended volcanism and resurfaced the planet.

"One of the mysteries of the inner solar system is that, despite their similar size and bulk density, Earth and Venus operate in strikingly distinct ways, particularly affecting the processes that move materials through a planet," said Dr. Simone Marchi, lead author of a new paper about these findings in Nature Astronomy.

The Earth's shifting plates continuously reshape its surface as chunks of the crust collide to form mountain ranges and, in places, promote volcanism. Venus has more volcanos than any other planet in the solar system but has only one continuous plate for its surface. More than 80,000 volcanos — 60 times more than Earth — have played a major role in renewing the planet's surface through floods of lava, which may continue to this day. Previous simulations struggled to create scenarios to support this level of volcanism.

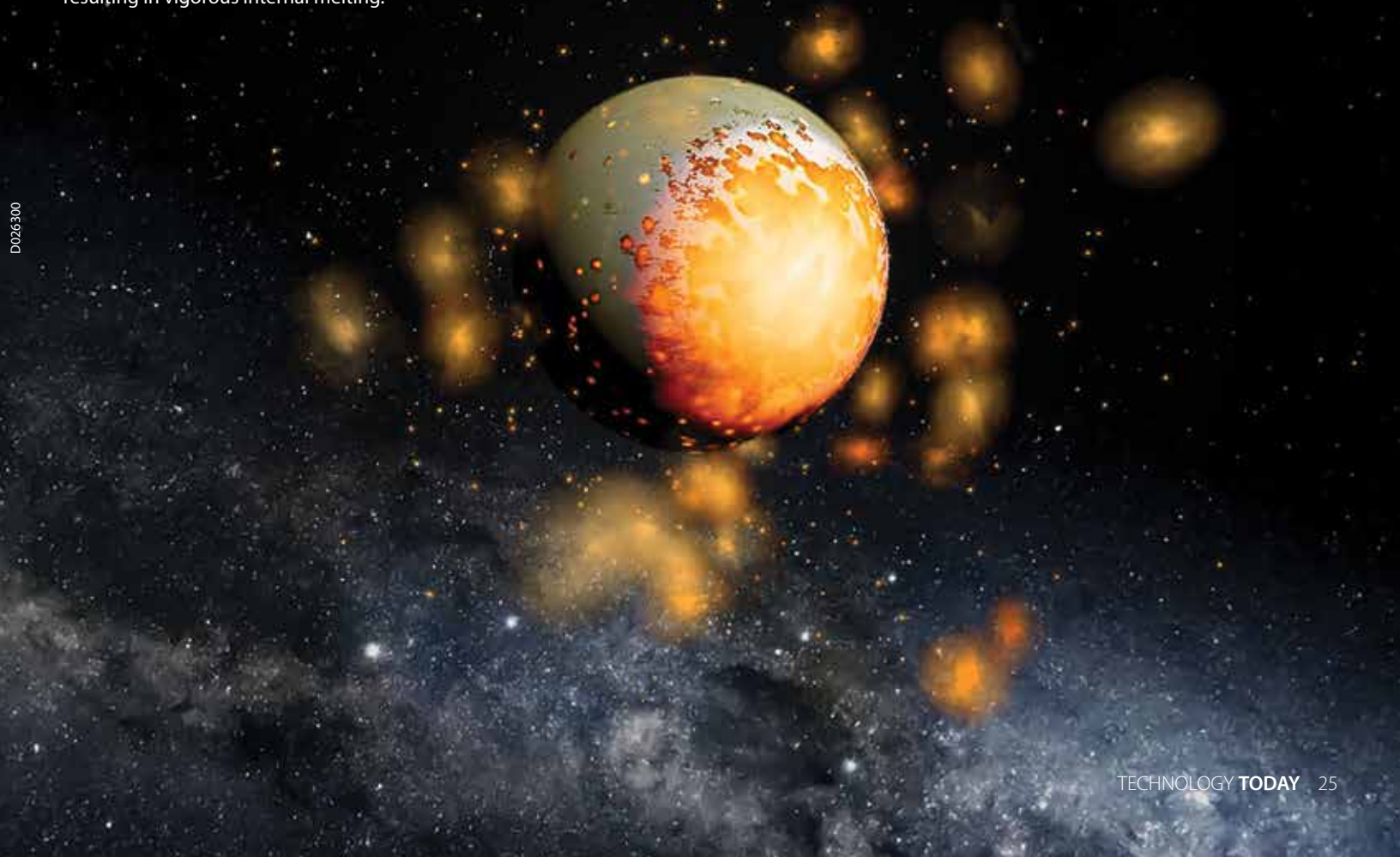
"Our latest models show that long-lived volcanism driven by early, energetic collisions on Venus offer a compelling explanation for its young surface age," said Professor Jun Korenaga, a co-author from Yale University. "This massive volcanic activity is fueled by a superheated core, resulting in vigorous internal melting."

Earth and Venus formed in the same neighborhood of the solar system as solid materials collided with each other and gradually combined to form the two rocky planets. The slight differences in the planets' distances from the Sun changed their impact histories, particularly the number and outcome of these events. These differences arise because Venus is closer to the Sun and moves faster around it, energizing impact conditions. In addition, the tail of collisional growth is typically dominated by impactors originating from beyond Earth's orbit that require higher orbital eccentricities to collide with Venus rather than Earth, resulting in more powerful impacts.

"Higher impact velocities melt more silicate, melting as much as 82% of Venus' mantle," said Dr. Raluca Rufu, a Sagan Fellow and SwRI co-author. "This produces a mixed mantle of molten materials redistributed globally and a superheated core."

If impacts on Venus had significantly higher velocity than on Earth, a few large impacts could have had drastically different outcomes, with important implications for the subsequent geophysical evolution. The multidisciplinary team combined expertise in large-scale collision modeling and geodynamic processes to assess the consequences of those collisions for the long-term evolution of Venus.

And the timing of this new explanation is serendipitous. In 2021, NASA committed to two new Venus missions, VERITAS and DAVINCI, while the European Space Agency is planning another called EnVision.



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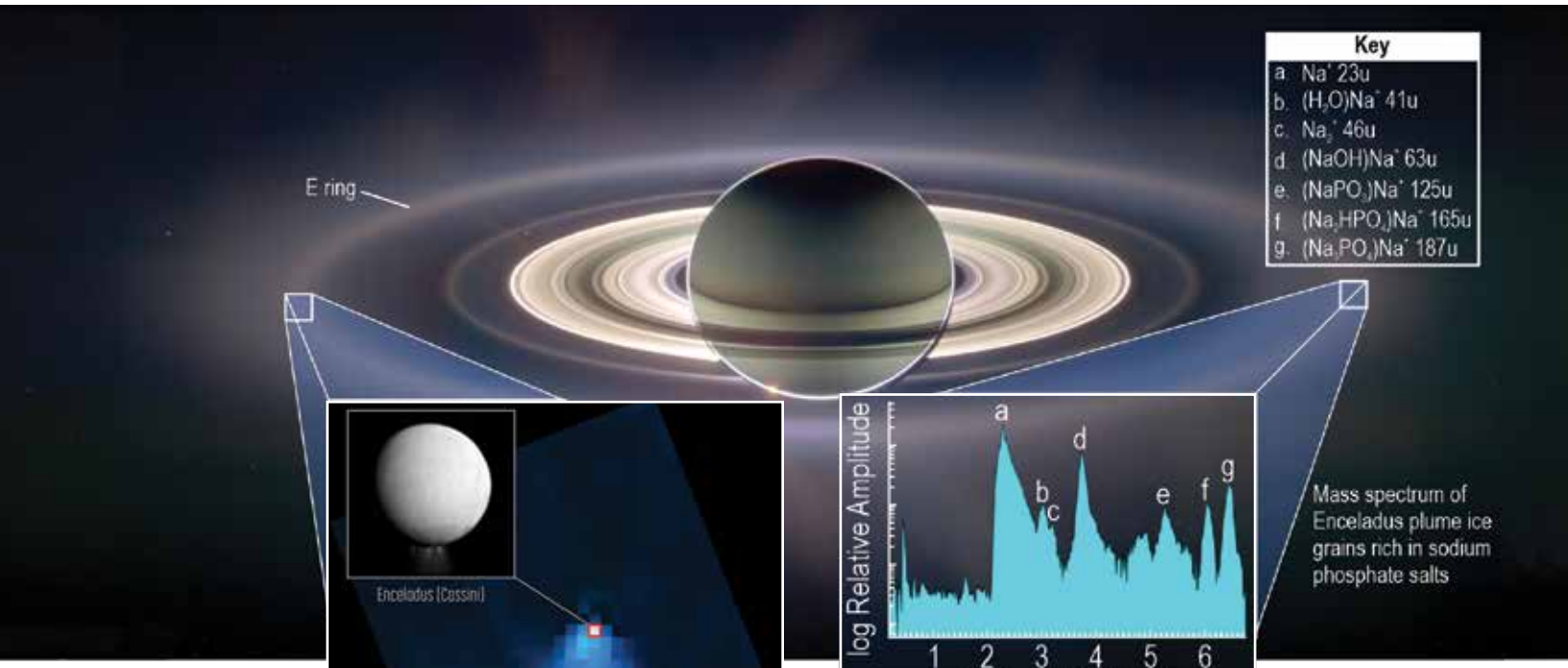


New JWST findings show the plume of water escaping from Enceladus extends 6,000 miles or more than 40 times the moon's size and feeds Saturn's E ring.

D026314

D026298

Scientists found phosphorus, a key building block for life, in ice grains sourced by plume eruptions from the subsurface ocean of Saturn's small moon, Enceladus.

IMAGES COURTESY NASA/ESA/CSA/ALYSSA PAGAN (STSCI)/GERONIMO VILLANUEVA (NASA-GSFC)/SwRI/FREIE UNIVERSITÄT BERLIN

EXCITING ENCELADUS SCIENCE

The search for extraterrestrial life in our solar system just got more exciting with new findings about the environment around Enceladus. A team of scientists including SwRI's Dr. Christopher Glein has discovered new evidence that the subsurface ocean of Saturn's moon Enceladus contains a key building block for life. The team directly detected phosphorus in the form of phosphates originating from the moon's ice-covered global ocean using data from NASA's Cassini mission.

In addition, two SwRI scientists were part of a James Webb Space Telescope (JWST) team that observed a towering plume of water vapor more than 6,000 miles long — roughly the distance from the U.S. to Japan — spewing from the surface of Enceladus. In light of this NASA JWST Cycle 1 discovery, Glein also received a Cycle 2 allocation to study the plume as well as key chemical compounds on the surface, to better understand the potential habitability of this ocean world.

During its 13-year reconnaissance of the Saturn system, the Cassini spacecraft discovered that Enceladus has a subsurface ocean of liquid water, and Cassini analyzed samples as plumes of ice grains and water vapor erupted into space from cracks in the moon's icy surface.

"In 2020 (published in 2022), we used geochemical modeling to predict that phosphorus should be abundant in Enceladus' ocean," said Glein, a leading expert in astro-oceanography. He is a co-author of a paper in the journal Nature describing this research. "Now, we have found abundant phosphorus in plume ice samples spraying out of the subsurface ocean."

The Webb project revealed a new story about Enceladus and how it feeds the water supply for the entire system of Saturn and its rings. As Enceladus whips around the gas giant in just 33 hours, the moon spews water, leaving a halo, almost like a donut, in its wake. The plume is not only huge, but the water spreads across Saturn's dense E ring. JWST data indicate that roughly 30 percent of the water stays in the moon's wake, while the other 70 percent escapes to supply the rest of the Saturnian system.

"The Webb observations, for the first time, are visually illustrating how the moon's water vapor plumes are playing a role in the formation of the torus," said SwRI's Dr. Silvia Protopapa, an expert in the compositional analysis of icy bodies in the solar system who was also on the Cycle 1 team. Spurred by the incredible findings from Webb's first fleeting glimpse of Enceladus, Glein is leading the same team that will observe Enceladus again with JWST in the next year.

The new observations will provide the best remote opportunity to search for habitability indicators on the surface, by boosting the signal-to-noise ratio by up to a factor of 10 compared with Cycle 1. Understanding the time variability of outgassing is also important to plan for future planetary science missions that target Enceladus' plume, such as the proposed search-for-life mission, Orbilander.

MEASURING HYDROGEN/NATURAL GAS BLENDS

D026291

Southwest Research Institute is expanding its flow meter research to address the impact of introducing hydrogen and natural gas blends into the residential and commercial energy mix. Working with NYSEARCH, a nonprofit research and development organization for the gas industry, SwRI will measure the energy content of blended gas to assess the accuracy of current flow meter technology for monitoring usage in homes.

Natural gas is widely used to power appliances and heat homes. In the next decade, some gas companies plan to blend hydrogen gas with natural gas to curb carbon emissions. Because the density of the resulting blends would be significantly different than natural gas, flow meters calibrated to measure the flow of natural gas may have some error when measuring blended gases.

Accurately measuring energy usage with flow meter technology depends on three things. First, SwRI must determine the energy content of blended gas. Second, the team must verify that flow meters accurately read volumetric flow rates. Third, they will measure the density of the blended gas to calculate the mass flow rate.

The team is characterizing the accuracy of three flow meter technologies in a blended gas environment and experimentally gathering density data for hydrogen and natural gas blends for residential applications. SwRI researchers are also investigating the same gas properties for renewable natural gas blends, such as those from landfills and dairy farms.

"We need to address many questions about blended gas and how it affects equipment," said Angel Wileman, manager of SwRI's Thermofluids Section. "When it comes down to it, it will affect people's pocketbooks. Flow meters determine how much gas a distribution company delivers to a consumer, so ensuring that consumers are charged accurately is vital as we move toward using blended gas."

TELESCOPE CAMPAIGN OBSERVES JUPITER'S VOLCANIC MOON IO

D026312

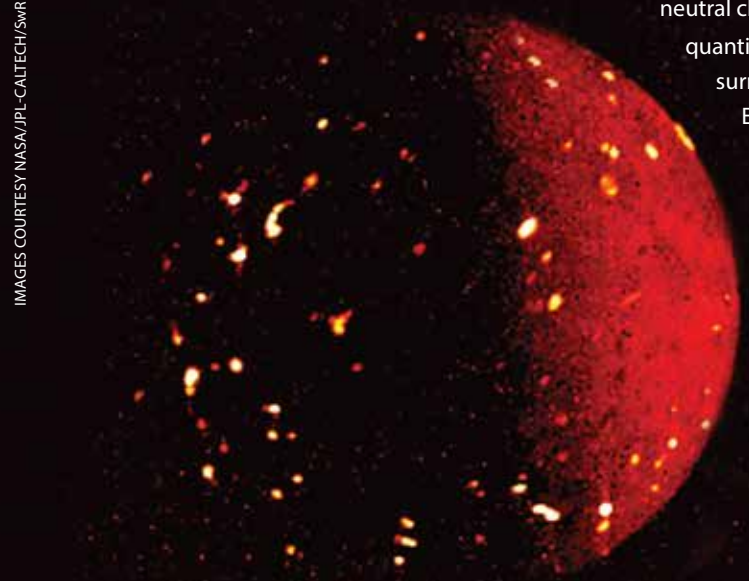
IMAGES COURTESY NASA/JPL-CALTECH/SwRI/ASI/INAF/JIRAM / JOHN SPENCER

The Space Telescope Science Institute recently awarded SwRI a project to use the Hubble and James Webb telescopes to remotely study Io, the most volcanically active body in the solar system. The study will complement the upcoming flybys of the Jupiter moon by NASA's Juno spacecraft, providing insights into Io's contributions to the plasma environment around Jupiter.

"The timing of this project is critical. Over the next year, Juno will buzz past Io several times, offering rare opportunities to combine in situ and remote observations of this complex system," said SwRI's Dr. Kurt Retherford, principal investigator of the campaign, which is using 4.7% of available time for Hubble observations this cycle supplemented with 4.8 hours of Webb observing time. "We hope to gain new insights into Io's dramatic volcanism, plasma-moon interactions and the neutral gas and plasma populations that propagate through Jupiter's vast magnetosphere and trigger intense Jovian auroral emissions."

Io's escaping atmosphere is the dominant source of material in the Jovian magnetosphere, a vast bubble of charged particles swirling around the gas giant. However, the connection between the volcanos, surface volatiles, atmosphere and magnetospheric plasma interaction to Io's extended neutral clouds, the Io Plasma Torus (IPT) and Jupiter's ionosphere remains difficult to quantify and understand. The IPT is a donut-shaped cloud of ions and electrons surrounding Jupiter, created when atmospheric gases escaping from Io are ionized. Electrons collide with the ions, which absorb energy from the collisions and release it as ultraviolet light, which can be detected by telescopes.

"The couplings between time-variable processes are central to understanding the Jupiter system holistically," said Dr. Fran Bagenal, the project's co-principal investigator from the University of Colorado at Boulder. "For example, how much sulfur is transported from Io to Europa's surface? How do auroral features on Io compare with auroras on Earth — the northern lights — and Jupiter?"



SwRI is leading a study to understand how Io, the most volcanic body in our solar system, contributes to Jupiter's plasmasphere. Juno's JIRAM instrument images Io's hot spots, data that will be complemented by Hubble and Webb telescope datasets.

TECHBYTES

Smart Vehicles Improve Overall Traffic Flow

An SwRI project funded by the U.S. Department of Energy (DOE) has demonstrated an average of 15% energy savings when vehicles outfitted with connected and automated vehicle (CAV) systems are introduced into traffic on public roadways. CAVs use wireless smart technology to communicate with other CAVs and traffic infrastructure. SwRI received a $3.2 million award from the DOE's Energy Efficient Mobility Systems (EEMS) initiative to study the energy implications of smart vehicles and intelligent infrastructure solutions within the broader traffic context.

The project used real-life traffic data, specialized testing equipment and computer modeling to quantify the benefits of incorporating SwRI's eco-driving framework into different types of vehicles, studying how those vehicles affected traffic flow.

"We wanted to find the right technology approach that would yield a minimum of 15% in energy savings without negatively impacting traffic flow and trip time," said Stas Gankov, an assistant manager in SwRI's Powertrain Engineering Division. "The average savings are extended to both connected and non-connected vehicles."

The Institute has spent many years developing cutting-edge CAV technologies to help passenger vehicles operate more efficiently while reducing energy consumption and carbon emissions. The SwRI-developed predictive eco-driving algorithm uses information from neighboring vehicles to minimize accelerations. SwRI's power-split optimization application uses knowledge of routes and speeds to optimize battery and engine operations to meet power demands more efficiently.

"We discovered that as eco-driving-enabled vehicles drove more efficiently, using less fuel and less energy, the other vehicles around them adapt and consume less energy, too," said Gankov. "As we introduce more CAVs into the traffic mix, we see an improvement in roadway efficiency. Under the right conditions, this can lead to a reduction in energy consumption of greater than 15% without negatively impacting trip time and traffic flow. Traffic remains largely uninterrupted and flows in a more optimized manner."

D026293

An SwRI-DOE project demonstrated overall energy savings of 15% when vehicles outfitted with connected and automated vehicle systems are introduced into traffic.

D026287

ADVANCED USAF ELECTRONIC WARFARE TECH

The U.S. Air Force awarded Southwest Research Institute a $4.8 million contract to further develop an adaptable, "continuously staring," next-generation electronic warfare system capable of detecting advanced enemy radar signals. Using cutting-edge algorithms in a congested signal test environment, the system demonstrated more than 99% probability of intercepting signals with no false detections in a USAF-verified simulated enemy radar environment.

"Eliminating false detections is crucial, as they force the pilot and plane to divert scarce resources to defeat an 'enemy' that's not there," said SwRI's Jarrett Holcomb, who is part of the technology development team. "As we strive for the fastest detection rate possible, our algorithms provide unmatched accuracy."

Staring, rather than scanning, allows more rapid detection of adversarial pulses, enabling faster response and greater protection for U.S. military aircraft. The cost-efficient, digital ultra-wideband receiver (UWR) technology provides near-instant detection of signals across a wider swath of the electromagnetic spectrum, expanding capabilities to jam enemy radar.

"The U.S. must stay ahead of potential combatants' advanced and emerging radars, while operating radio-frequency environments congested with a range of signals, from military radars to cell phone, TV and radio signals," said SwRI's Finley Hicks, who leads the development team. "SwRI's powerful UWR technology is a long-term defense and intelligence solution, overcoming enemy radar systems, even as they increase bandwidth, agility and adaptability."

The UWR system follows the Sensor Open System Architecture (SOSA™) Technical Standard to easily integrate into legacy and newly developed Open Architecture Weapon systems. Technology aligned to SOSA allows quick and efficient system component updates to support new capabilities without having to replace or redesign the entire system.

Compared to competing systems, the UWR technology improves on size, weight, power and cost (SWaP-C) requirements, delivering an efficient design with fewer components, lower maintenance expenses and a smaller logistical footprint for deployed units.

SwRI DEMONSTRATES SPACE SOFTWARE MICROPATCH

Southwest Research Institute developed an algorithm to remotely update and repair spacecraft software, slashing time and telemetry bandwidth required over conventional techniques.

The tool not only improves the overall efficiency of satellite software transmissions but also can recover data from failed over-the-air updates and malicious cyberattacks. It works by identifying missing bytes and other errors before deploying a custom "micropatch" to the damaged or missing software.

"Instead of updating an entire file or operating system, which is typically required with over-the-air satellite software updates, our tool can find and patch smaller errors," said Henry Haswell, a research engineer in SwRI's Intelligent Systems Division.

The researchers successfully deployed and tested the tool on the International Space Station (ISS), working with Axiom Space Inc. and Amazon Web Services (AWS). SwRI uploaded and evaluated the micropatch technology on an Axiom Space-operated computer on the ISS. AWS supplied the Snowcone computer to the ISS as part of the Ax-1 mission.

"This real-world demonstration proved the advantages of using this powerful technology," said Diego Alducin, an SwRI computer scientist.

Updating satellite software through sluggish telemetry networks with limited bandwidth and intermittent contacts can interrupt updates and corrupt files in the process. When that occurs, the current standard is to resend the entire file over the network. However, that typically requires waiting for a window when a satellite is aligned with a ground station. This window can be as short as eight minutes and might only occur once every few days.

Prior to ISS testing, SwRI lab-tested five algorithms, simulating several corruption modes. The lab research identified a double breakpoint search (DBS) algorithm as the most promising solution for Earth-to-space deployment. A DBS patch addresses a variety of complex file errors such as insertion, modification and deletion, while legacy systems can only fix simple issues.

D026025_0506

From right, Dr. Jörg-Micha Jahn, MAPS lead investigator, looks on as Benjamin Rodriguez and James Noll prepare the instrument for delivery and integration into NASA's Lunar Vertex lander. MAPS will gather sensitive, high-resolution insights about the Moon's surface, offering more than four times the resolution of orbital instruments, while weighing just 11 pounds (five kilograms) and drawing less than 6 watts of power.

SwRI Delivers MAPS for Moon Mission

SwRI has delivered a plasma spectrometer for integration into a lunar lander as part of NASA's Lunar Vertex investigation, scheduled to commence next year. The target site is the Reiner Gamma region on the Moon's nearside, a mysterious area known to have a local magnetic field.

The SwRI-developed Magnetic Anomaly Plasma Spectrometer (MAPS) will study the interaction of the solar wind with surface materials on the Moon, aiming to understand the origin of the sinuous patterns of bright and dark soil, known as lunar swirls, that correspond with anomalous regions of magnetic rocks.

"MAPS is the latest generation of the spectrometer that originally flew on ESA's Rosetta mission to comet 67P/Churyumov-Gerasimenko," said SwRI's Dr. Jörg-Micha Jahn, MAPS lead investigator. "We will investigate how the influx of the solar wind interacts with the localized magnetic fields and how it could affect features on the lunar surface. The spectrometer will help us determine if charged particles delivered by the solar wind even make it to the surface of the Moon within a magnetic anomaly."

Unlike Earth, the Moon does not have a global magnetic field that protects it from the supersonic solar wind. As these streams of energetic particles hit the lunar surface, magnetic patches bend the trajectories of the solar particles, acting like an umbrella.

"The beautiful patterns of bright and dark materials in the magnetic regions could reveal the effects of magnetism on surface weathering," Jahn said. "Nearby regions not protected by magnetic fields serve as controls. Lunar Vertex could help us quantify space weathering and the relative roles of solar wind exposure versus the effects from cosmic dust hitting the surface. Scientists could then apply this to understand the history and evolution of airless bodies across the solar system."

JUICE-UVS successfully completed its initial commissioning en route to Jupiter. This segment of JUICE-UVS data shows a swath of the southern sky, revealing many UV-bright stars in the Milky Way near the southern constellation Carina on the left. The cloud-like structure on the right is a nearby galaxy called the Large Magellanic Cloud.

JUICE-UVS Collects First Dataset

The SwRI-led Ultraviolet Spectrograph (UVS) aboard ESA's Jupiter Icy Moons Explorer (JUICE) spacecraft has successfully completed its initial commissioning. The UVS instrument is one of three instrument projects comprising NASA's contribution to the JUICE mission. The mission's science goals focus on Jupiter and its system, making multiple flybys of the planet's large, ocean-bearing satellites with a particular emphasis on investigating Ganymede as a potentially habitable planetary body.

"Our team of SwRI scientists traveled to Darmstadt, Germany, to put JUICE-UVS through its paces," said Dr. Randy Gladstone, JUICE-UVS principal investigator. "In June, we opened the UVS aperture door to collect UV light from space for the first time. Soon after, we observed a swath of the Milky Way to verify the instrument was performing well."

SwRI has provided ultraviolet spectrographs for other spacecraft, including ESA's Rosetta comet orbiter, as well as NASA's New Horizons mission to Pluto, Lunar Reconnaissance Orbiter mission in orbit around the Moon and Juno mission to Jupiter.

Weighing just over 40 pounds and drawing only 7.5 watts of power, UVS is smaller than a microwave oven, yet this powerful instrument will determine the relative concentrations of various elements and molecules in the atmospheres of Jupiter's moons once in the Jovian system. A similar instrument, Europa-UVS, will launch in 2024 aboard NASA's Europa Clipper, which will take a more direct route to arrive at the Jupiter system 15 months before JUICE and focus on studying the potential habitability of Europa.

"Having two UVS instruments making measurements in the Jupiter system at roughly the same time will offer exciting complementary science possibilities," said Dr. Kurt Retherford, principal investigator of Europa-UVS and deputy PI for JUICE-UVS.

D026290

NEW SOFTWARE TO HELP DECARBONIZE THE RAIL INDUSTRY

SwRI is helping the freight rail industry assess potential pathways to decarbonization with new open-source modeling and simulation software known as ALTRIOS. ALTRIOS, the Advanced Locomotive Technology and Rail Infrastructure Optimization System, can simulate operational, environmental, infrastructure and financial impacts associated with the adoption of alternative locomotive powertrain technologies.

ALTRIOS supports several simulation modes to assist rail industry stakeholders in their development of optimal technology roadmaps for implementing greenhouse gas emissions (GHG) reduction technologies within their own networks. The largest freight railroads in North America aim to reduce GHG emissions by 40% within the next decade.

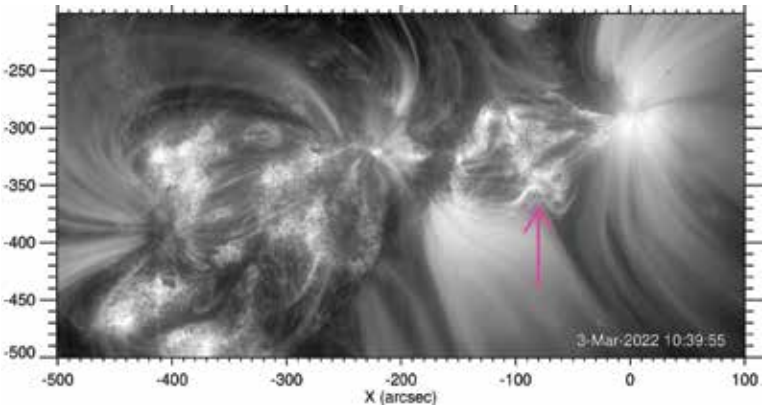
ALTRIOS combines locomotive and energy storage technology modeling with a robust suite of train dispatch, train scheduling, and routing tools. These tools enable users to execute realistic, physics-based simulations of individual trains and supporting rail infrastructure to evaluate the effectiveness of different decarbonization technologies — including hydrogen, biofuels and batteries, among many others — across the U.S. over the course of decades.

"The Class-I North American railroads have already committed to reducing their GHG emissions by setting science-based carbon reduction targets," said Garrett Anderson, a principal engineer in SwRI's Powertrain Engineering Division. "Railroads are using fuel efficiency, renewable fuels and alternate propulsion approaches to achieve the goal. ALTRIOS can cost-effectively assess locomotive decarbonization approaches using computer modeling to help them choose the right technologies for their needs."

ALTRIOS was funded by the U.S. Department of Energy's Advanced Research Projects Agency–Energy (ARPA–E) as part of the LOCOMOTIVES (Lowering CO_2: Models to Optimize Train Infrastructure, Vehicles and Energy Storage) program. It received funding of $1.5 million. SwRI helped develop the software with the National Renewable Energy Laboratory (NREL), The University of Texas at Austin, the University of Illinois Urbana-Champaign RailTec and BNSF Railway.

ALTRIOS is publicly available for download under an open-source license and is compatible with Windows, macOS and Linux.

SwRI's Locomotive Technology Center provided extensive locomotive and railway datasets, simulation and modeling work, and locomotive battery testing expertise to support the ALTRIOS project.



D026292

IMAGE COURTESY UCAR/ZHANG, ET.AL./ NASA/ESA

Using data from ESA's Solar Orbiter, SwRI scientists observed the first high-resolution close-up views of the source of energetic particle jets expelled from the Sun.

OBSERVING SOURCES OF SOLAR ENERGETIC PARTICLE JETS

SwRI scientists observed the first close-ups of a source of energetic particles expelled from the Sun, viewing them from just half an astronomical unit (AU), or about 46.5 million miles away. ESA's Solar Orbiter, a Sun-observing satellite launched in 2020, provided high-resolution images of the solar event.

"In 2022, the Solar Orbiter detected six recurrent energetic ion injections. Particles emanated along the jets, a signature of magnetic reconnection involving field lines open to interplanetary space," said SwRI's Dr. Radoslav Bucik, the lead author of a recent study published in Astronomy & Astrophysics in 2023. "The Solar Orbiter frequently detects this type of activity, but this period showed very unusual elemental compositions."

In one ion injection, the intensity of the rare isotope helium-3 exceeded the amount of hydrogen, the Sun's most abundant element, and the levels of iron were similar to those of isotope helium-4, its second most abundant element. An injection from the same source just two days later measured nearly negligible amounts of helium-3.

"Our analysis shows that the elemental and spectral variations in recurrent injections are associated with the shape of the jet, the size of the jet source and the distribution of the underlying photospheric field that evolved over time," Bucik said. "We believe that understanding the variability in recurrent events from a single source sheds light on the acceleration mechanism in solar flares."

The Solar Orbiter observations are unique as the propagation effects that can affect abundances could be minimal near the Sun. Furthermore, the distance of just 0.5 AU has given the scientific team a remarkably detailed view of solar events.

"When we are closer, we have a considerably better spatial resolution and can see the internal structures associated with acceleration processes as injections evolve," Bucik said. "These observations could ultimately help predict future solar energetic particle events, which can damage satellites and equipment and potentially harm astronauts."

Giant Swirling Waves at Jupiter's Magnetic Boundary

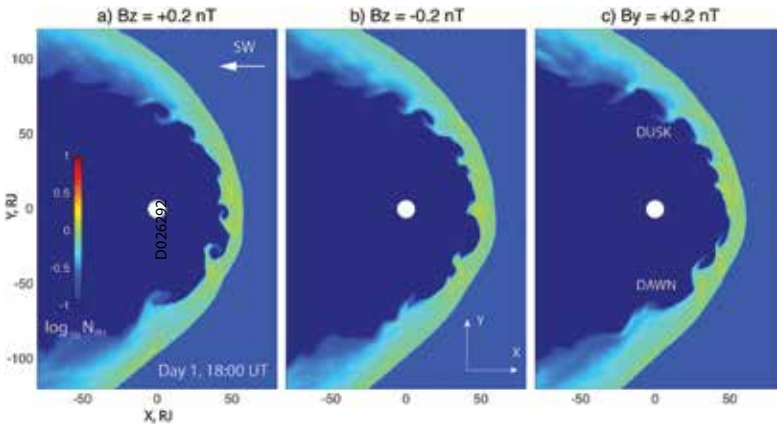
A team led by SwRI and The University of Texas at San Antonio (UTSA) has found that NASA's Juno spacecraft orbiting Jupiter frequently encounters giant swirling waves at the boundary between the solar wind and Jupiter's magnetosphere. The waves are an important process for transferring energy and mass from the solar wind, a stream of charged particles emitted by the Sun, to planetary space environments.

Jake Montgomery, a doctoral student in the joint space physics program between UTSA and SwRI, noted that these phenomena occur when a large difference in velocity forms across the boundary between two regions in space. This can create a swirling wave, or vortex, at the interface that separates a planet's magnetic field and the solar wind, known as the magnetopause. These Kelvin-Helmholtz waves are not visible to the naked eye but can be detected through instrument observations of plasma and magnetic fields in space. Plasma — a fundamental state of matter made up of charged particles, ions and electrons — is ubiquitous across the universe.

"Kelvin-Helmholtz instabilities are a fundamental physical process that occurs when solar and stellar winds interact with planetary magnetic fields across our solar system and throughout the universe," Montgomery said. "Juno observed these waves during many of its orbits, providing conclusive evidence that Kelvin-Helmholtz instabilities play an active role in the interaction between the solar wind and Jupiter."

Montgomery is the lead author of a study published in Geophysical Research Letters that uses data from multiple Juno instruments, including its magnetometer and the SwRI-built Jovian Auroral Distributions Experiment (JADE).

"Juno's extensive time near Jupiter's magnetopause has enabled detailed observations of phenomena such as Kelvin-Helmholtz instabilities in this region," said Dr. Robert Ebert, a staff scientist at SwRI who also serves as an adjoint professor at UTSA.



An SwRI-led team identified intermittent evidence of Kelvin-Helmholtz instabilities, giant swirling waves, at the boundary between Jupiter's magnetosphere and the solar wind that fills interplanetary space, modeled here by University Corporation for Atmospheric Research scientists in a 2017 GRL paper.

D026289

UPCOMING

WEBINARS, WORKSHOPS and TRAINING COURSES HOSTED by SwRI:

Global Decarbonized Mobility Summit (GDMS), Nov. 13–17, 2023.

Supercritical Carbon Dioxide Power Cycles, Nov. 15, 2023.

Life-Cycle Analysis for Transportation Symposium, Nov. 16, 2023.

Geothermal Energy Machinery and Systems (GEMS) Workshop, Nov. 29, 2023.

Introduction to Additive Manufacturing in Turbomachinery Applications, Nov. 29, 2023. Free webinar.

Introduction to Microencapsulation Workshop, Dec. 4, 2023.

Fundamentals of Turbomachinery Failure Analysis, Dec. 5, 2023.

Introduction to Propulsion Simulation Using NPSS – Winter Short Course, Dec. 5, 2023.

Introduction to Launch Vehicle Pogo Stability, Dec. 6, 2023. Free webinar.

Tolerance Stack Analysis, Dec. 12, 2023. Virtual webinar.

Introduction to Inventory Management, Feb. 21, 2024.

TRADESHOWS:

Aircraft Structural Integrity Program (ASIP) Conference, Denver. Nov. 27, 2023, Booth No. 1.

ChemE Show, Galveston, TX. Nov. 27, 2023, Booth No. 1502.

Conference on Composites, Materials and Structures, St. Augustine, FL. Jan. 21, 2024, Booth No. 8.

Waste Management Symposia, Phoenix. March 10, 2024, Booth No. 623.

Dixie Crow Symposium, Warner Robins, GA. March 24, 2024, Booth Nos. 59 & 60.

AIChE Spring Meeting & Global Congress on Process Safety, New Orleans, LA. March 24, 2024.

Interphex, New York City, April 16, 2024, Booth No. 3653.

ITS American Conference & Expo, Phoenix. April 22, 2024, Booth No. 1641.

Modern Day Marine, Washington, DC. April 30, 2024, Booth No. 736.

For more information on upcoming events visit newsroom.swri.org.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The Association of Old Crows (AOC), an international organization for the electronic warfare (EW) community, has recognized three early-career Defense and Intelligence Solutions engineers for their role in developing advanced EW technology to protect military personnel and assets. All three serve in SwRI's Advanced Electronic Warfare Department in Warner Robins, Georgia. In 2022, AOC recognized SwRI Research Engineer **Madeline Vaughn**, the first-ever recipient of the new Electronic Warfare Professional Outstanding Young Crow Award, recognizing her work in receivers, open-source software solutions and advanced digital radio frequency memory. This year, SwRI Research Engineer **Alexander Davis** received the award, recognizing excellence in EW solutions, such as an internally funded airborne wideband direction-finding project and advanced aircraft electronic countermeasure testing. Each year, AOC also names the Future 5, five EW professionals who actively innovate and strive for excellence. SwRI Research Engineer **Jarrett Holcomb** is part of the 2023 Future 5 group, which recognizes his contributions to SwRI's award-winning System Performance and Real Time Analysis (SPARTA) software and other EW hardware and software systems.


D024673

The Division for Planetary Sciences (DPS) of the American Astronomical Society (AAS) has awarded its 2023 Carl Sagan Medal to **Dr. Tracy Becker**, a group leader in SwRI's Space Science Division. The Sagan Medal recognizes outstanding scientific communication to the public by a planetary scientist. The award acknowledges Becker's innovative scientific outreach to underserved populations, including Spanish-speaking audiences and visually and hearing-impaired students. She also serves as a NASA Solar System Ambassador and successfully co-created and continues to organize Astronomy on Tap in San Antonio.


D024453_0407

The Geological Society of America (GSA) has elected SwRI Staff Scientist **Dr. Danielle Wyrick** as a Fellow, recognizing her exemplary scientific achievements, support of young geoscientists and excellent service to GSA. Wyrick is a planetary geologist who has played a significant role in GSA's Planetary Geology Division leadership and committees, including service as a board member and chair of the division. Among her many achievements in these roles are recruiting and mentoring students and younger members and expanding and diversifying the field over the years.

TECHNOLOGY **TODAY**

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