Southwest Research Institute®

FALL 2021

TECHNOLOGY TODAY®

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In the first week in October, the Lucy spacecraft was packed into the two halves of the launch vehicle fairing, which closed around it like a clamshell in preparation for launch. The SwRI-led Lucy mission will fly past eight asteroids over 12 years, traveling 4 billion miles to the Trojan asteroids. These fossils, left over from the formation of the solar system, are like time capsules orbiting in tandem with Jupiter.

"Because the Trojans are remnants of the primordial material that formed the outer planets, they hold vital clues to deciphering the history of the solar system and revolutionizing the understanding of our origins," said SwRI's Hal Levison, the principal investigator of the Lucy mission.

In early October, the encapsulated spacecraft was transported to the Vehicle Integration Facility at the Cape Canaveral Space Force Station, where it was "mated" with the United Launch Alliance Atlas V 401 rocket to carry Lucy outside Earth's atmosphere and begin the long journey to the Trojan asteroids.

"Launching a spacecraft is almost like sending a child off to college — you've done what you can to get them ready for that next big step on their own," Levison said. "It's now time to get Lucy into the sky so that it can deliver its revolutionary science about the origin of our planetary system."

D025079 IMAGE COURTESY NASA/KSC

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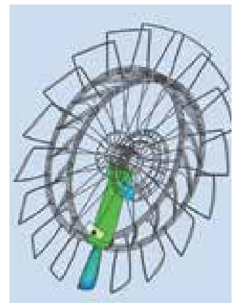


Aircraft engine manufacturers worldwide use DARWIN to ensure rotor designs are resistant to dangerous cracks. The software identifies where a crack might form, slices the model on the plane where the crack is most likely to grow, determines the stresses that would drive the crack and predicts the crack growth life and fracture risk.

D024089_2653

IN THIS ISSUE

This issue of Technology Today explores some amazing new avenues of technology and innovation.

Consider the industrial robots that collaborate with each other and humans at the vanguard of what's being called the Fourth Industrial Revolution. SwRI is one of the authors of the open-source computer platforms that make smarter manufacturing possible.

Military and commercial aircraft that were the wonder of the world when they first flew five and even six decades ago are kept relevant to their missions — and new missions as well — today. SwRI is keeping them flying through an ever-evolving system of laboratory experiments, computational modeling, diagnostic hardware and software, and intelligent maintenance and modernization.

Using some clever cosmic detective work, a trio of SwRI planetary scientists have identified a "prime suspect" for the birthplace of the asteroid believed to have wiped out the dinosaurs some 66 million years ago. Another article in this issue heralds the launch of Lucy, a new spacecraft headed on a 4-billion-mile voyage to study another mysterious group of asteroids — the Trojans, which both lead and follow Jupiter's orbit around the Sun.

But there is another, extremely important trend in research that's also celebrated in this issue. That would be the area of collaboration. Not just among scientists, but including cultural and educational groups.

NASA is funding a five-year scientific and cultural outreach program in association with an SwRI-led solar research spacecraft mission called the Polarimeter to UNify the Corona and Heliosphere (PUNCH). The outreach program, also to be led by SwRI, will collaborate with five planetariums and science centers in four states, as well as multicultural partners in the southwestern United States to support an "Ancient and Modern Sun-Watching" theme.

Then there's the collaboration between SwRI — entering its 75th year of independent research and development — and the fast-growing University of Texas at San Antonio (UTSA). The Connecting Through Research Partnerships (Connect) program has undertaken two new efforts that demonstrate the breadth of research under way at both institutions.

We hope you appreciate these interwoven themes — with Southwest Research Institute as the common thread — as you browse through the magazine.

Sincerely,

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

THE 5 Ms OF AIRCRAFT LIFE EXTENSION

Measurement
Monitoring
Modeling
Maintenance
Modernization

By Tim Fey, Roger Lopez and Edwin Aulick

Aircraft fleets around the world regularly continue flying far beyond their intended service life and frequently operate in more severe environments than their airframes were designed to withstand. Ensuring that both military and commercial aircraft fleets remain operational and flightworthy is a crucial component of our nation's defense and air travel systems.

To extend airframe life requires an understanding of aging designs, identifying critical structures prone to wear or failure, and inspecting those structures regularly. And as costly and challenging as that is, electronics, avionics and weapons systems also must be kept current to operate in an increasingly information-intensive environment. Military fleets, some of whose aircraft were designed in the 1950s and '60s, must deal with complications such as suppliers who have gone out of business and components that have become obsolete. Meanwhile, weapons and navigation systems must be updated to defend against the modern threat environment, and cockpit electronics must be adapted to enhance situational awareness.

Southwest Research Institute's military aircraft life-extension work has included avionics support to keep the A-10, B-1, B-52, F-15, F-16, F-22 and T-38 planes as well as rotary wing aircraft in service and still flying with cutting-edge capability. Commercial and space systems also are supported by SwRI-developed and -supported software tools, including several that determine how cracks grow and engines perform over a lifetime of service. We have decades of experience in this area, and in 2020 and early 2021 we received several new contracts supporting aircraft life extension. One of these is a six-year indefinite delivery, indefinite quantity (IDIQ) contract to support the U.S. Air Force Academy Center for Aircraft Structural Life Extension (CAStLE) to study the effects of aging on military aircraft. Others include multiyear redesign and modernization efforts retrofitting and sustaining several critical subsystems on the F-16, A-10 and B-1.

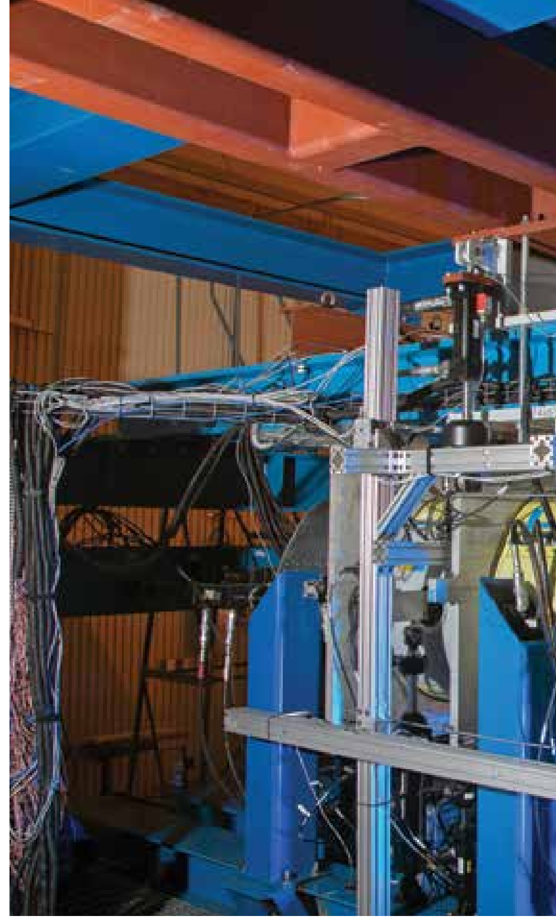
We have addressed these tasks and others through a multidisciplinary, multidivisional approach that stresses the "5 Ms" — measurement, modeling, monitoring, maintenance and modernization.

MEASUREMENT

Aging aircraft face potentially serious structural problems, including material fatigue, where cyclic loads or stresses experienced during takeoff, flight and landing can initiate and propagate cracking. Once a crack starts, it will grow a small amount with each subsequent loading cycle, until the component fails. For decades, SwRI engineers have worked with the U.S. military to develop structural integrity programs that use testing, measurement and analysis to ensure that an aircraft structure will operate as intended. This process provides information for fleet-management decisions, such as creating inspection and maintenance plans and setting modification priorities. SwRI maintains extensive facilities to measure the mechanical and physical properties of all types of structures and materials, supporting static, dynamic and fatigue tests on components, subassemblies and full-scale test articles.

Over the last several decades we have developed techniques to evaluate the structural integrity of military aircraft such as the A-10 Thunderbolt II and the T-38 Talon, developing testing and measurement methods to determine how often aircraft and components need to be inspected for flight safety. In some cases, we have developed fatigue and crack growth data using small samples, or coupons, of the materials used to make major structures. Controlled testing of aircraft materials reveals how cracks originate and determines how quickly they grow. Other times we use full-scale test setups to recreate the loads experienced in flight and collect stress data using an array of strain gauges.

We also help sustain critical systems through the USAF Aircraft Structural Integrity Program's Comprehensive Landing Gear Integrity Program. These systems contain hundreds of parts and perform a vital function. A "belly landing" due to landing gear failure can cause millions of dollars in damage and threaten the life of the crew. As components age, failures associated with metal fatigue or stress-corrosion cracking become more common. We create 3D models of components to allow static analysis, and we assess how usage affects the life of the landing gear, allowing the Air Force to maximize safety while managing maintenance costs.



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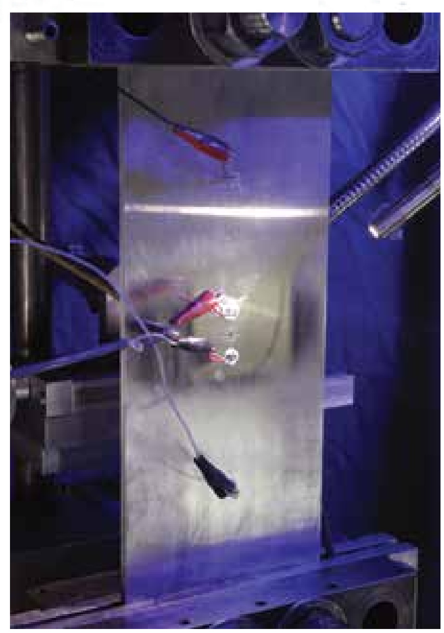

D017701

Holes are drilled in a material test sample to replicate fatigue-critical locations. The sample is then instrumented and subjected to various loads to study crack growth.

This complex custom test stand evaluates the structural integrity of next-generation jammer pods under real-world conditions. The pods are installed on EA-18G Growler aircraft to thwart enemy radar and targeting systems.

D025092

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Since the 1960s, the Air Force has structurally modified the fuselage of its advanced flight trainer, the T-38 aircraft (left), to extend its structural life. SwRI conducted a full-scale structural fatigue test, destructive teardown and economic life evaluation to help assess remaining life and identify potential fatigue-critical locations.

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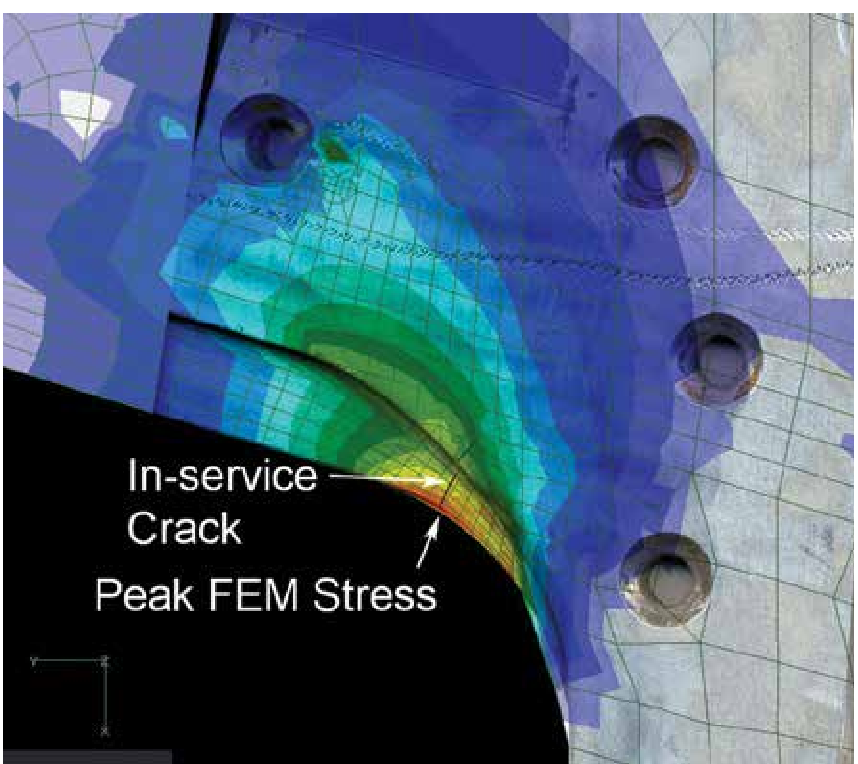


Using finite element analysis, SwRI analyzes stress in airframes and components to develop appropriate inspection and maintenance schedules.

MONITORING

To keep the T-38 in service through 2034 or later, SwRI performs usage monitoring, developing inspection methods and schedules for testing at the fleet as well as the component level and conducting analyses to ensure the aircraft structure remains viable.

D025110

IMAGES COURTESY MASTER SGT. J.S. WILCOX AND AIRMAN 1ST CLASS JENNIFER ZIMA

In addition to laboratory measurements, we install onboard monitoring systems to analyze the stresses that airframes and turbine engines undergo during various flight maneuvers. This helps engineers determine where cracks will occur and how fast they will likely grow. This also helps engineers determine how often inspections are needed. We have extensive experience monitoring how military and commercial aircraft are used to provide data for structural and engine life assessments. These flight recording programs define aircraft maneuver and stress spectra for fatigue analysis and assess the structural stresses associated with various flight maneuvers. They also define temperature and pressure limits that contribute to engine stall conditions. These are already flying on T-38 and A-10 aircraft.

The A-10, which first flew in 1972, is expected to continue in service until at least 2040. Specialized SwRI-developed inspection probes and non-destructive inspection systems include sensors that can inspect through a bushing that does not require removal. In addition, our patented magnetostrictive sensors (MsS®) provide ongoing structural health monitoring on the A-10.

Because the Air Force intends to fly the T-38 supersonic training aircraft until 2034 or longer, we have worked with the Air Force since the 1970s to maintain the plane's structural integrity. Our systems look for cracks and structural degradation that would endanger the aircraft.

In another project, SwRI conducted flight data testing on the T-38A/B to support a specialized adversary air training program for the F-22 Raptor. Over the course of nearly a decade, seven aircraft were fitted with a flight data recorder and sensors to monitor the critical structural parameters, including airspeed, altitude, vertical acceleration and strain on the horizontal stabilizer torque tube. Because most T-38 aircraft have undergone modifications and the addition of new avionics, future survey programs will be needed to assess how these modifications impact the usage severity of the aircraft. SwRI performs usage monitoring, developing inspection methods and schedules for testing at the fleet as well as the component level, plus analysis to ensure the aircraft structure remains viable.

Friendly foreign militaries using American aircraft also need to monitor and manage engine maintenance, but legacy applications are difficult to use and do not meet current demands. More than a decade ago, SwRI developed and fielded

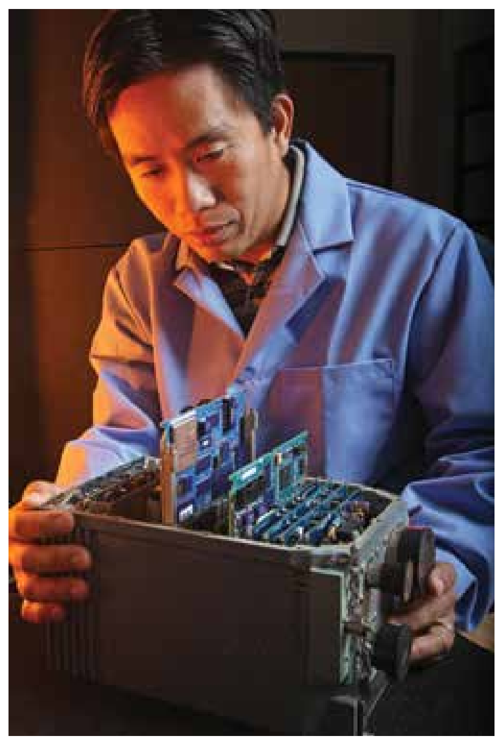
SwRI is adapting a multichannel, audio-visual mission data recording system for the Air Force's fleet of B-52 bombers. SwRI will ensure the system meets Department of Defense and other regulatory requirements.

SwRI's patented magnetostrictive sensors (MsS®) provide ongoing structural health monitoring for military aircraft.

D017700

the Engine Tracking Database System (ETDS) for F110 engines used in the F-15 and F-16 to serve these clients. In addition, SwRI is finalizing a Jet Engine Maintenance Management Application (JEMMA) to support F100 engines that power the F-15 Eagle and F-16 Fighting Falcon. The systems support all existing engine configurations for both the F100 and F110 and can be adapted for new engines without software changes.

Both ETDS and JEMMA track maintenance cycles, engine configurations, engine/part installations and removals, maintenance time limits and periodic inspection completion. The systems track engine/part status and document the maintenance history of engines and components. Numerous reporting features alert users to missing or upcoming inspections or when parts approach their life limit. These web-based systems can be fielded in a stand-alone single-base configuration or in a "headquarters" configuration where data from multiple bases are compiled into a single database. ETDS and JEMMA provide flexibility by allowing users to add new part numbers, inspections and life limits. With SwRI's experience developing JEMMA and ETDS, support for additional engines could be accomplished at a significantly lower cost and shorter schedules than ground-up development.



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The SwRI-developed Improved Electronic Processing Unit combines engine turbine monitoring and aircraft structural integrity systems into a single, consolidated line-replaceable unit for the entire A-10C fleet.

MODELING

Measurement and monitoring data collected from an aircraft fleet can provide significant inputs to specialized software programs to model fatigue crack growth and fracture in structures and mechanical components. We have developed, and continue to upgrade, software tools to model crack growth that help predict where cracks or other integrity issues might arise and ensure the safe life of the structure. These damage tolerance analysis (DTA) software tools assess the fracture risks of critical equipment. For example, SwRI and NASA's Johnson Space Center have worked together since 2000 to develop NASGRO®, a DTA tool now used extensively by the space, aircraft, and rotorcraft industries, among others.

A separate effort to develop a probabilistic DTA tool for aircraft engine rotors began at SwRI after a passenger airliner crashed in Sioux City, Iowa, in 1989 following a catastrophic uncontained turbine disk failure in one of its three jet engines. While the captain was able to steer the disabled aircraft to an airport by skillfully alternating power between the two remaining engines, the airplane cartwheeled on landing, resulting in the death of 112 of its 296 passengers and crew.

In response, the Federal Aviation Administration (FAA) sought to improve commercial aircraft engine safety using software to model and manage the risk of fracture in high-energy rotating components. A key outcome of this work was an SwRI engineering team's development of DARWIN® (Design Assessment of Reliability With INspection), a fracture mechanics and reliability assessment software system that supports damage-tolerant design and analysis of metallic structural components. DARWIN can predict the probability of fracture during the lifetime of each engine, over the entire fleet of engines, based on the probability that an undetected anomaly may occur in the engine rotor during its manufacture.

Aircraft engine manufacturers worldwide use DARWIN to ensure their engine designs are resistant to dangerous cracks. The software helps designers visualize and manipulate a two- or three-dimensional component model, identifying locations where a crack might initiate, slicing the model along the plane where a crack is most likely to grow, and determining the stresses that will govern the crack's growth rate.

This work has continued to evolve as new incidents occur. For example, in 2016 a disk fracture and resulting engine fire aboard an aircraft at Chicago's O'Hare International Airport was caused by a material anomaly in a rotor manufactured from a nickel-based alloy. Building on 25 years of continuous funding, the FAA recently funded SwRI to address this new threat through the Probabilistic Integrity and Risk Assessment of Turbine Engines program, which is now in its third phase.

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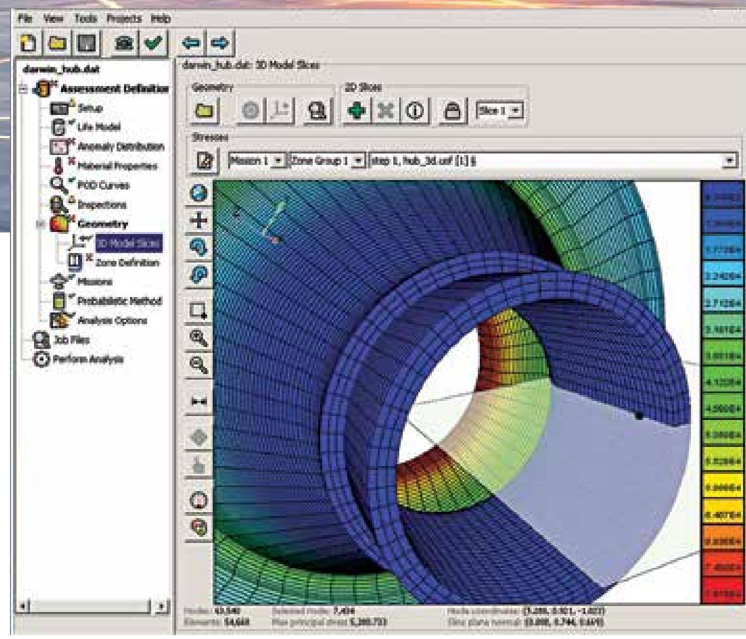

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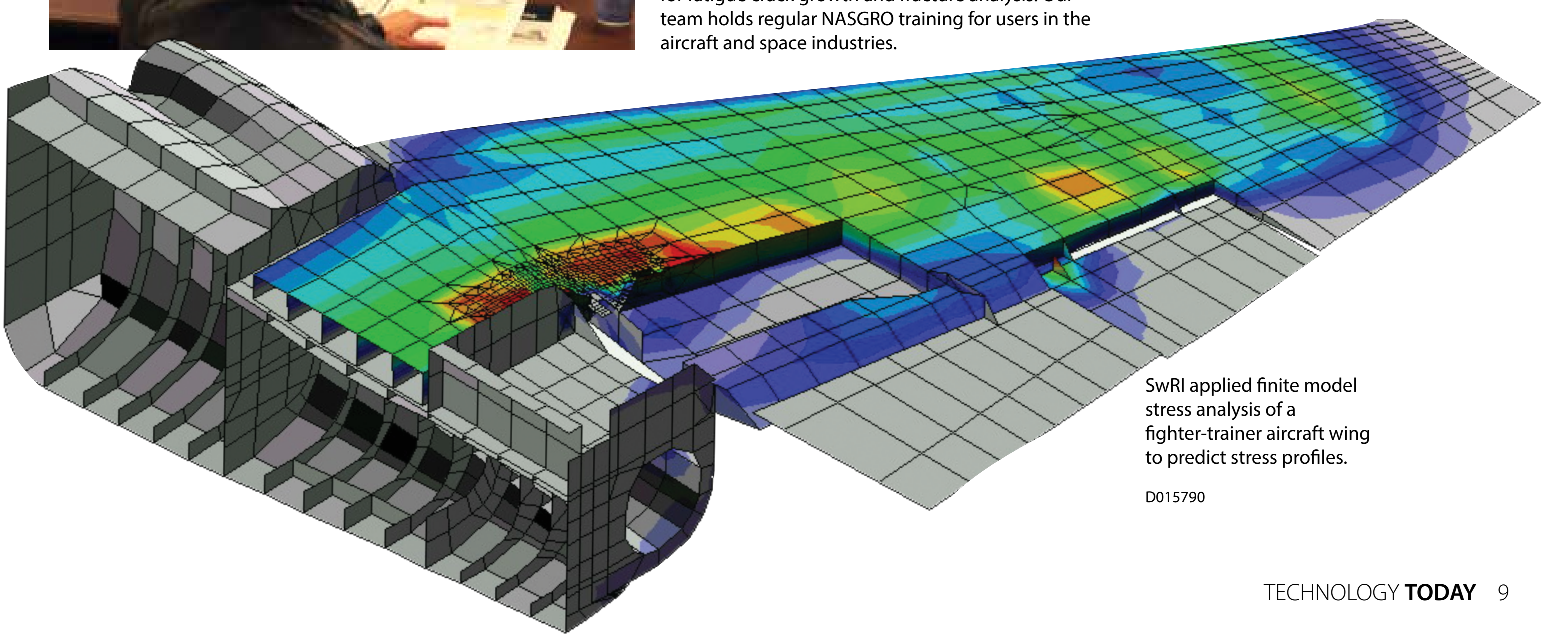
DARWIN helps a user visualize and manipulate 3D component models, identifying the surface location where a crack might initiate. The software tool then slices the model along the plane where the crack is most likely to grow to determine the stresses that will govern its growth.

In collaboration with NASA's Johnson Space Center, SwRI developed NASGRO®, a deterministic data tool for fatigue crack growth and fracture analysis. Our team holds regular NASGRO training for users in the aircraft and space industries.



SwRI applied finite model stress analysis of a fighter-trainer aircraft wing to predict stress profiles.

D015790

MAINTENANCE

Measuring, monitoring and modeling all are used in maintenance programs to prevent an aircraft from slipping into a state of unknown airworthiness. However, if airworthiness issues lead to a fleet being grounded due to some unknown risk, SwRI engineers then address specific maintenance challenges, creating better ways to test and repair components and avionics systems.

For example, NASA astronauts use the 50-year-old T-38 supersonic trainer for pilot proficiency training. Components of this legacy aircraft must be tested periodically and proven reliable. To this end, SwRI engineers developed a T-38 aircraft-mounted accessory drive test stand to autonomously perform generator and gearbox testing. In 2019, we upgraded the control hardware and software to perform additional automated generator tests. Since that upgrade, NASA has used the test stand to support U.S. Air Force F-5 fighter aircraft as well.

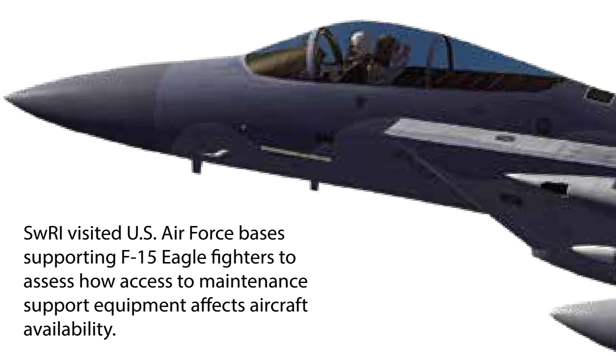
SwRI is working with the Air Force maintenance community to develop a support equipment roadmap (SER) for specific airframes. This process assesses the status of support equipment. It catalogs current deficiencies, unneeded equipment, opportunities for consolidation and current and future requirements, all while assessing the equipment's ability to support modernization and technology advancements. It also integrates data to generate a funding roadmap to help plan for needed updates or equipment replacements.

The roadmap for the F-15 fighter has completed its data collection phase, while other SERs for the B-1 and B-52 bombers are under development to maintain and modernize equipment at the organizational, intermediate and depot levels. This maintenance system analysis includes plans and procedures that address modernization and sustainment challenges. We also have applied our long experience with the A-10 community to perform studies and provide engineering support, including initiating an A-10 SER a decade ago. Since 2000, SwRI staff also have provided critical onsite engineering support for the A-10 System Program office, troubleshooting problems with field units.

From 2004–2008, we supported flight testing and maintenance activities for the last major avionics upgrade for the A-10. SwRI also helped develop the Digital Fuel Quantity Intermediate Device and Improved Electronic Processor Unit (IEPU) for the plane's Turbine Engine Monitoring System. The IEPU software is responsible for acquiring signals, detecting engine, aircraft and structural events, and storing related data for later analysis by ground personnel.

SwRI managed a program to replace the primary maintenance and repair facility at the Corpus Christi Army Depot (CCAD) from concept through equipment selection, process flow and construction requirements. The CCAD is the Army's Center of Excellence for servicing the UH-60 Black Hawk, CH-47 Chinook, AH-64 Apache, OH-58 Kiowa, and the Air Force HH-60 Pave Hawk helicopters. Since 2014, SwRI also has identified key equipment and infrastructure requirements for separate units of a new building to replace an aging and inefficient Maintenance, Repair, and Overhaul (MRO) facility, which will be added sequentially over time.

We have developed a detailed concept of operations, systems and equipment specifications for new work cells at CCAD. These concepts outline material handling, production control, cost, and equipment maintenance management methodologies or approaches. For instance, CCAD performs maintenance on the T55 family of turboshaft engines that power the CH-47 Chinook and MH-47 helicopters. The SwRI team has reverse-engineered and redesigned an engine test cell control console to replace unreliable and unsupportable technology, documenting, integrating and evaluating the newly designed console.



SwRI visited U.S. Air Force bases supporting F-15 Eagle fighters to assess how access to maintenance support equipment affects aircraft availability.

D025104 IMAGE COURTESY SPC. MATHEW POUS

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SwRI engineers are designing next-generation flexible manufacturing layouts for efficient workflows for the Army's helicopter maintenance facilities in Corpus Christi, Texas.

DM021489_0176

To support a foreign aircraft maintenance depot, SwRI designed and built an automated test system to evaluate an advanced engine control system used on the F-15.

SwRI developed inspection kits for the T-38 aircraft, including steel dorsal longeron and vertical stabilizer tip kits.

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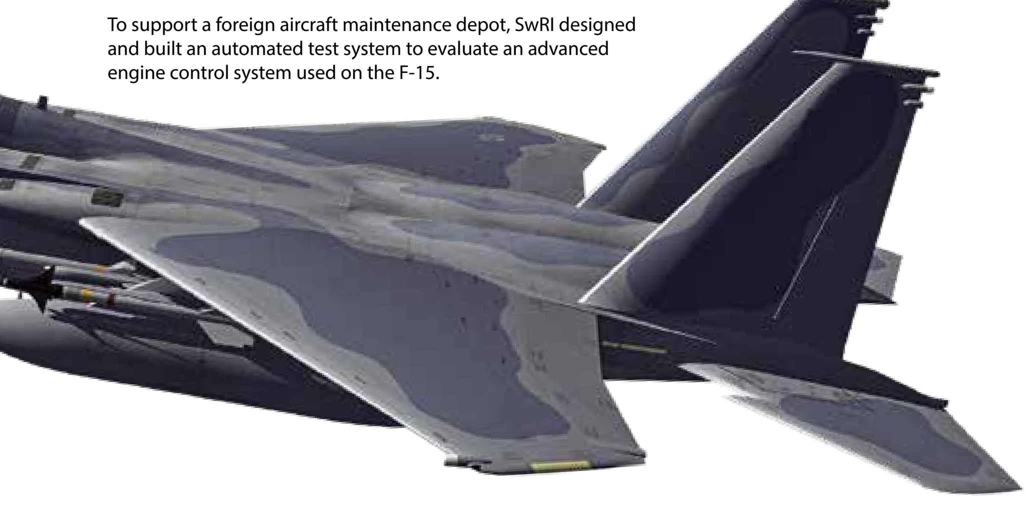

MODERNIZATION

As air fleets age, their avionics can become increasingly difficult to support and maintain, and their capabilities often do not meet today's demands. However, replacing and modernizing systems and components can be challenging, and the military must rely increasingly on commercial off-the-shelf (COTS) technologies for its avionics hardware and software.

Although COTS items are generally less expensive than comparable items designed to military specifications, the COTS technology-refresh cycle is typically 18 months or less. This exacerbates the obsolescence problem for aircraft whose lifetimes are measured in decades. The short refresh cycle is driven mostly by the tremendous advances in computer systems, which comprise an increasing percentage of avionics systems.

To address military aircraft system sustainment, obsolescence and modernization, SwRI has conducted numerous Form, Fit, Function and Interface (F3I) programs to update or upgrade aircraft components or avionics. An updated item is F3I-compatible when it can be inserted into an aircraft without negatively impacting legacy components or overall operations.

In 2021, SwRI began redesigning a system on the B-1B Lancer, a long-range supersonic bomber that the Air Force introduced in the 1980s, to allow it to remain in service until 2040. We are redesigning the Lancer's Fuel/Center of Gravity Management System (F/CGMS), which tracks fuel data and usage, controls fuel transfer to the aircraft's four turbine engines and calculates corrections to the bomber's center of gravity as fuel is depleted. The redesigned B-1B fuel-balance system can be inserted into the aircraft to provide vital in-flight data and support the aircraft's next phase of service.

Other ongoing support for the B-1 fleet involves material and structural joint testing and airframe analysis of fatigue-critical locations, including Taper-Lok™ fasteners and coldworked holes. These life-enhancement technologies are designed to strengthen metallic components and extend fatigue life but can complicate structural analysis. SwRI is helping Boeing and the Air Force understand life improvement gained using these technologies to set appropriate maintenance intervals.

After two decades of maintenance support for the A-10, SwRI was well-positioned to help with the design

IMAGES COURTESY STAFF SGT. ANDREW LEE AND MASTER SGT. WILLIAM GREER

In 2019, SwRI developed a new Sensor Integration Unit (SIU) subsystem for the F-16 Fighting Falcon to consolidate, modernize and replace legacy systems. The new technology integrates threat and target sensing while maximizing the utilization of the various RF subsystems and embedding avionics cybersecurity, a recent mandate for all new avionics subsystems.

D025105

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DETAIL

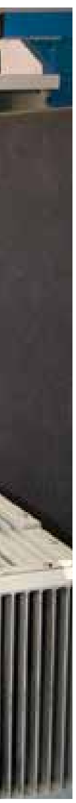
Targeting pods are tools used by ground-attack aircraft to identify targets and direct precision-guided munitions.

and implementation of upgrades. For example, we helped develop a modern Digital Stores Management System that turned unguided, free-falling bombs into precision-guided munitions. An upgraded Integrated Flight and Fire Control Computer improves computer-aided capabilities and adds symbols to the pilot's head-up display to support targeting pods, data links and smart weapons integration.

To address advances in adversarial targeting systems, signals intelligence (SIGINT) specialists at SwRI are helping U.S. and allied militaries gather communications intelligence, fueling capabilities in electronic warfare (EW) that use electromagnetic techniques to thwart hostile operations. SwRI supports EW techniques and technology to control the electromagnetic spectrum and deny advantages to an opponent, while ensuring friendly dominance of the spectrum. For example, SwRI is developing modular Ravager EW technology designed to maximize operational effectiveness and flexibility in response to emerging threats, while minimizing future supplier and parts shortages. We are integrating this advanced technology into legacy military EW systems, addressing size constraints and operational profiles of existing and future systems. SwRI engineers are currently developing and integrating Ravager proof-of-concept hardware and software into an existing military system.

Questions about this article? Go to swri.org/industries/aerospace or contact Fey at tim.fey@swri.org or 210.522.3253.

IMAGE COURTESY AIRMAN 1ST CLASS EUGENE OLIVER D025099



Above: This AF pilot is looking through the A-10's head-up display (HUD), which digitally provides important information to pilots without requiring them to look away from the flight path. SwRI is upgrading the Flight and Fire Control Computer processor and display electronics to address critical aircraft supportability issues.

Left: Engineers completed lab and flight test investigations to determine new baseline vibration and temperature environments and redesign the A-10C Thunderbolt II's central interface control unit.

Below: SwRI is redesigning various B-1 system components — including the intermediate device chassis, power supply and assembly of multiple interface module circuit cards — which must work with the new designs while maintaining compatibility with the legacy design. The redesign introduces other new challenges for SwRI engineers, as it is the first time the team will incorporate radiation hardening into flight system designs.

D025101

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ABOUT THE AUTHORS

From left, Edwin Aulick, a manager in the Defense and Intelligence Solutions Division, oversees hardware, software and firmware development efforts for embedded aerospace avionics applications. Roger Lopez, a manager in the Applied Physics Division, specializes in hardware and software systems ranging from commercial test equipment to military avionics. Tim Fey, director of the Structural Engineering Department in SwRI's Mechanical Engineering Division, oversees research supporting the aerospace, telecommunications, nuclear, marine and oil and gas industries, as well as U.S. and allied military programs.

SMARTER MANUFACTURING

Improving industrial interoperability among robots, manufacturing systems

By Matt Robinson

In the past decade, the manufacturing sector has seen significant advancements using the industrial internet of things (IIoT) to enhance robotics automation and supply chain management with machine learning and data analytics.

This type of smart manufacturing — also known as Industry 4.0 or the fourth industrial revolution — leverages interconnectivity between the physical and cyber worlds to improve data sharing between machinery and software. This helps humans make data-informed decisions as automated robots perform increasingly agile tasks, resulting in production efficiencies and improved collaboration among suppliers, vendors and customers.

Until recently, Industry 4.0 was often regarded as an interesting concept, but impractical without significant investment, which was hard to justify when many companies struggled with implementation. Recent technological advancements coupled with global supply chain impacts from the COVID-19 pandemic are changing those attitudes.

For over a decade, Southwest Research Institute has paved the way for innovations in smart manufacturing. In addition to developing automation and robotics solutions, we help improve interoperability among devices that share data across the industrial internet of things. For many of us in the industry, it feels like the proverbial overnight success that took over 10 years of hard work.

Since 2012, SwRI has championed efforts to create efficient communications between devices, first extending the open-source ROS framework to industrial communication standards. From the beginning, SwRI has tackled automating the tough-to-automate, developing tools and collaborating with other prominent industrial solution providers to move the ball forward, while providing practical resources to smaller- and medium-sized manufacturers around the world.

DETAIL

The industrial internet of things (IIoT) describes a network of physical objects — in this instance, things on a shop floor — that are embedded with sensors, software and other technologies to connect and exchange data with other devices and systems over the internet.

The fourth industrial revolution — 4IR or Industry 4.0 — is the ongoing automation of traditional manufacturing and industrial practices using modern smart technology.

The ROS-I platform provides interoperability, enabling different brands of robots to work together on complex tasks.

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THE "5 Cs" OF SMART MANUFACTURING

Industrial robotics have evolved from a single manipulator to a complex ecosystem of fixed, driving, crawling and even flying robots equipped with various sensors, ranging from simple encoders to laser scanners, all carrying out divergent concurrent tasks integrated into increasingly demanding scenarios. SwRI teams up with industrial automation hardware/software vendors to solve practical challenges to complex logistical problems. We start with looking at the "5 Cs" of smart manufacturing — communication, connection, computation, coordination and configuration.

Communication explains how data and information are exchanged between entities, while connection focuses on which computational components should communicate with each other. Computation relates to processing of information and algorithms, including machine learning and artificial intelligence. Configuration includes binding configurable parameters of individual entities and systems, while coordination relates to orchestrating activities with resource management.

Evaluating automation solutions in the 5 Cs context helps standardize data to support international Industry 4.0 and IIoT initiatives, especially with complex systems requiring interoperability.

INTEROPERABILITY VIA "INDUSTRY 4.0"

To illustrate how difficult interoperability can be, consider the difficulties your mobile phone may have syncing with your car's infotainment system or the inability of Alexa-enabled devices to work with Siri. For Industry 4.0 and similar initiatives where interconnectivity is a goal, the sticking point has long been interoperability, or the efficient movement of information between a variety of proprietary devices. Most solution providers offer proprietary frameworks, plus add-ons to facilitate this sort of agile processing. But you must purchase the elements to "capture" clients in their ecosystem.

Long-time providers of manufacturing technology have lacked incentives to enable the agility and interoperability needed to realize the full potential of smart manufacturing. This roadblock may be associated with requirements to share information about how a proprietary process would enable other branded devices to share and leverage information.

SwRI leads several initiatives to develop more flexible and open approaches that facilitate more efficient movement of data across devices. Our work includes improving interoperability among industrial robots, commercial flight test equipment and computers used in military vehicles.

BRIDGING SYSTEMS WITH ROS-INDUSTRIAL

In the automation and manufacturing space, SwRI has been developing interoperability solutions since the launch of the ROS-Industrial (ROS-I) open-source project. In 2012, SwRI established ROS-I as an open framework of libraries and tools for a wide range of industrial robotics applications.

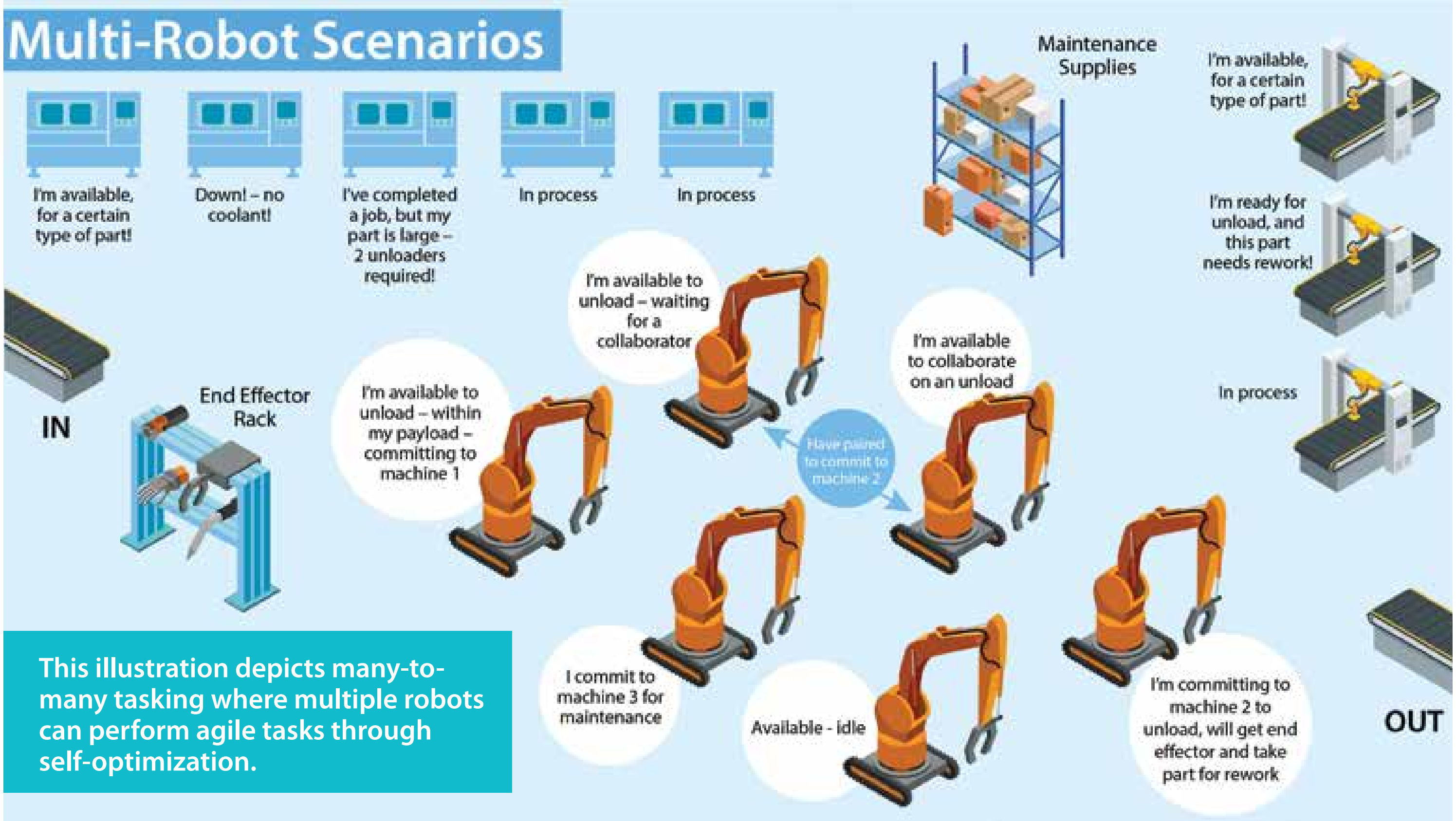
The open-source Robot Operating System — ROS, and second-generation ROS 2 — was developed at multiple institutions and for multiple robots, including many institutions that received PR2 robots from Willow Garage. ROS-I, known for enabling robots to do new things regarding capability, is a framework that enables

D025091

SwRI demonstrated a smart manufacturing implementation featuring interoperable robots and controls at the 2018 International Manufacturing Technology Show. SwRI enabled interoperability across robot controls, devices and software through a NIST-funded project that bridged two open-source platforms, ROS-Industrial and MTConnect.

DETAIL

Willow Garage created open-source hardware (Personal Robot 1, PR1) and software (Robot Operating System, ROS) development platforms. PR2 used open-source robotics "middleware," software that enables communication or connectivity between two or more applications or components on a distributed network.



This illustration depicts many-to-many tasking where multiple robots can perform agile tasks through self-optimization.

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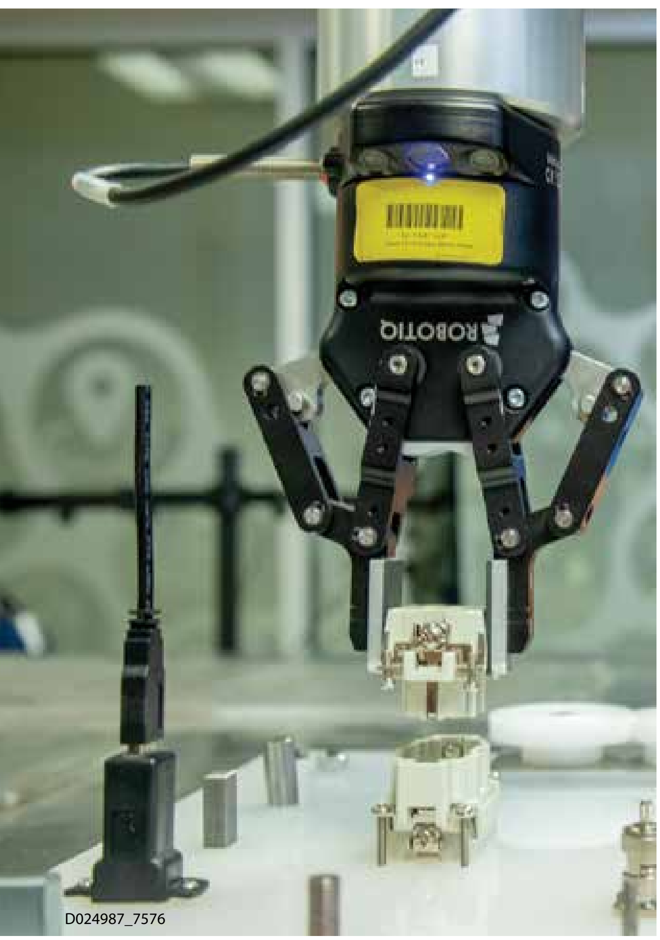


Multi-robot optimization strategies are based on many factors, including proximity to the proper end efffector to manipulate a specific payload.

different robots and mechanical devices to share information regardless of brand.

In 2013, a NIST-backed MTConnect standard project bridged ROS to another open standard to enable smooth sharing of information across proprietary devices. This delivered on the promise of a lower-cost, more flexible means to enable richer interaction between devices on a shop floor. In 2017, a follow-on project was launched, again backed by NIST, that resulted in a "many-to-many" collaboration model. Practically, this dynamic process means all the devices on the floor understand what all the other devices are doing and can respond based on rules and established priorities. SwRI demonstrated this new implementation at the International Manufacturing Technology Show in Chicago in 2018.

Since then, a recently completed program has seen the framework improved further, this time extending to additional industrial communication standards, the Open Platform Communications Foundation's Unified Architecture (OPC-UA) and the Object Management Group® Data Distribution Service (DDS™). Released in

DETAIL

The National Institute of Standards and Technology (NIST), now part of the U.S. Department of Commerce, is one of the nation's oldest physical science laboratories. Congress established the agency in 1901 to overcome challenges to U.S. industrial competitiveness, which lagged behind the capabilities of the United Kingdom, Germany and other economic rivals at that time.

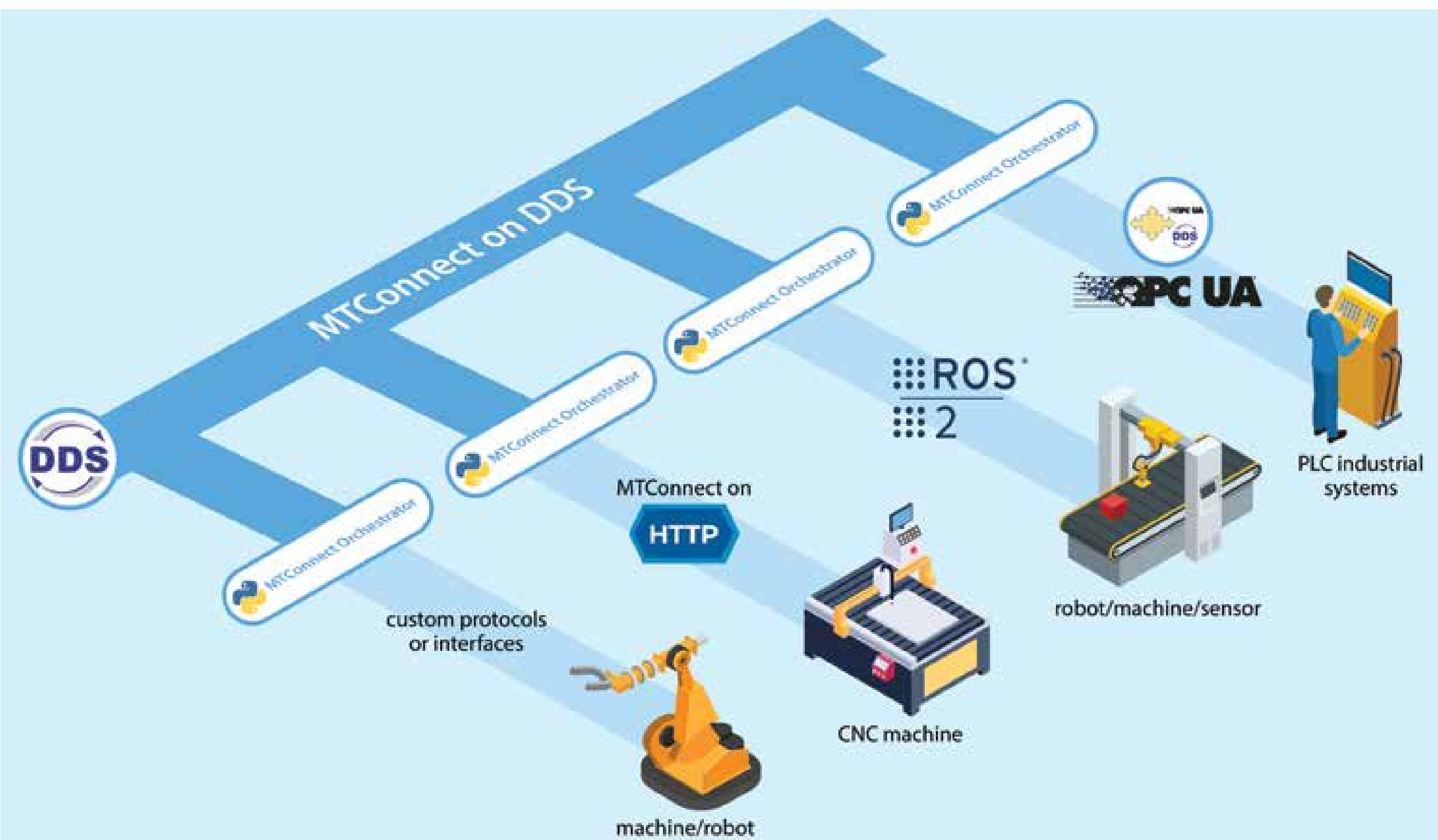
2008, OPC-UA is a machine-to-machine communication protocol for industrial automation developed by the OPC Foundation. DDS is the first open international middleware standard directly addressing publish-subscribe communications for real-time and embedded systems. This expansion demonstrated a richer and more complete tool set allowing dynamic coordination while leveraging standard industrial communications specifications. The SwRI team provided the architecture and tools to enable the coordination of tasks via a software implementation called Orchestrator. This independent library adapted prior NIST work into a stand-alone application. The team demonstrated the application using a network of devices that "spoke different languages," proving it could share information between these machines in near real time.

STANDARDIZED FRAMEWORK TO MOVE DATA

Standardized frameworks that facilitate data-sharing are key to moving interoperability forward. This type of data sharing underscores how standards in communication and coordination can enable industry-wide advancements. For example, the previously described implementation between ROS and MTConnect could serve as a foundation to improve information sharing between assets. MTConnect provides the data model for the manufacturing information, while ROS, and now ROS 2, provide architecture for moving that data. The marriage of MTConnect and ROS enables them to "ride" on top of traditional industrial communication standards including DDS, the default communication for the recently released ROS 2 platform. In the computing world, orchestration is the automated configuration, management and coordination of computer systems, applications, and services. Applying orchestration to industrial manufacturing would manage complex tasks and workflows, coordinating and optimizing material movement in real time. Because each device or family of devices had its own specific protocol, historically that is where coordination would break down. However, the MTConnect and DDS protocols provide standardized information with a bridge to MTConnect Orchestrator middleware, which interfaces with custom protocols, ROS/ROS 2 framework and other OAP-UA- or DDS-compliant applications to share all information with all devices on the shop floor.

OIL AND GAS CASE STUDY

To illustrate both the challenges and the benefits of interoperability, consider the high mix of production components used by the oil and gas industry. Challenges include vast amounts of data contained by individual pieces of equipment and the ability to report on their



D025078

This illustration depicts how various parts in a manufacturing system — a robot, computer numerical control (CNC) machine, sensors and other devices using programmable logic controller (PLC) computer-driven systems — can be orchestrated to automate tasks. Orchestrating tasks over DDS protocol provides a coordinated methodology for the MTConnect interoperability standard to communicate commands to robots and other hardware via unique software/middleware bridges.

D024796_2720

SwRI engineers develop techniques to orchestrate collaboration between different manufacturing devices using a variety of robotic arms.

condition or state when all devices in the factory "speak" a different language. Management of this data requires knowledgeable staff to create spreadsheets to effectively route materials and to understand which machines should process which product. Due to the high-mix nature of the business, the balance between creating batches of product to run and prioritization based on customer demand leads to more complications, changeovers and other possible inefficiencies.

A recent SwRI project for an oil and gas company used orchestration software components to enable different manufacturing devices to indicate their ability to collaborate with other pieces of equipment in the factory. Because this is all "online," artificial intelligence may be added "on top" to enable more efficient material routing, batch sizing and maintenance scheduling. Because this is all software, no additional hardware is needed, lowering the overall deployment cost.

This oil and gas implementation example enabled machines to interact and share information with near-real-time performance. Leveraging the cloud gave manufacturing line planners the insights to understand what they could and could not do at any time during their production cycle.

CONCLUSION

This oil and gas production application is an excellent example of how SwRI works with industry partners to solve practical challenges for industrial end users. With so many solutions available, it can be confusing to pick the right one or to continue to use the ones that originally came with a specific piece of hardware.

Data can offer many opportunities for increasing efficiency and velocity in global manufacturing. Many powerful tools exist to use data to improve a specific manufacturing process or to enhance an entire supply chain. In any case, improved interoperability is the key to unlocking data for smarter manufacturing.

Industry 4.0 and smart manufacturing can seem overwhelmingly complicated, but it helps to start by looking at the bigger picture through the lens of the 5 Cs, looking at the best ways to communicate, connect, compute, coordinate and configure data to improve automation and orchestration.

Questions about this story? Visit smartmanufacturing.swri.org or contact Robinson at matt.robinson@swri.org or 210.522.5823.

D024987_7509

ABOUT THE AUTHOR

Matt Robinson is assistant director of SwRI's Manufacturing and Robotics Technologies Department and oversees the ROS-Industrial Joint Industry Program. ROS-I develops and sustains open-source robotics capabilities to advance industrial automation. Robinson also serves on the Advanced Robotics for Manufacturing (ARM) Institute Technology Advisory Committee.

2021 R&D 100 WINNER

SwRI WINS 3 R&D 100 AWARDS

Three SwRI-developed technologies were selected as winners of prestigious R&D 100 Awards. R&D Magazine recognized SwRI's Catalyzed Diesel Exhaust Fluid (Cat-DEF™), Eco-Mobility with Connected Powertrains and Floodlight™ Non-Targeted Analysis System as being among the 100 most significant innovations for 2021.

"We are committed to solving difficult technology challenges with innovative approaches," said SwRI President and CEO Adam L. Hamilton, P.E. "I am honored that SwRI remains on the forefront of technological advancement. It is an incredible honor to be recognized for having three of the top 100 most significant innovations of the year."

The R&D 100 Awards are among the most prestigious innovation awards programs, honoring the top 100 revolutionary technologies each year since 1963. Recipients hail from research institutions, academic and government laboratories, Fortune 500 companies and smaller organizations. Since 1971, SwRI has won 50 R&D 100 Awards. This year's winners were announced October 19–21 by virtual broadcast from Cleveland.

D024781_2140

SwRI's Cat-DEF™ technology was recognized for reducing nitrous oxide (NOx) and carbon dioxide emissions by minimizing deposit formation in diesel engine exhaust systems.

CAT-DEF

Catalyzed Diesel Exhaust Fluid, or Cat-DEF, is a catalyst- and surfactant-modified diesel exhaust fluid (DEF) solution designed to reduce oxides of nitrogen (NOx) and carbon dioxide emissions from diesel engines by minimizing deposit formation in exhaust systems. The SwRI-developed Cat-DEF technology has been shown to help automotive manufacturers meet new California Air Resources Board NOx regulations without negative implications.

"This is truly a revolutionary technology," said Dr. Cary Henry, Cat-DEF principal investigator and a staff engineer in SwRI's Powertrain Engineering Division. "We are addressing future environmental regulatory challenges while minimizing cost to the market. Our novel technology is also backward compatible, which allows it to be used on older as well as current applications. This technology offers a new way to improve existing fluids onboard diesel vehicles while reducing NOx emissions and fuel consumption without negatively impacting hardware costs or durability."

Currently, selective catalytic reduction (SCR), an advanced emissions control system, is used to abate NOx emissions. DEF is injected into the exhaust stream and ideally decomposes to form ammonia, which reacts with NOx on the SCR catalyst to form N_2 and H_2O. Although this process is relatively efficient at temperatures greater than 250 °C, at temperatures below 250 °C, urea-derived deposits form within the aftertreatment system. These deposits severely limit low-temperature NOx conversion and increase fuel consumption as high-temperature engine operations are required to remove the deposits.

Cat-DEF laboratory results have confirmed a deposit reduction potential of up to 98% during low-load operations. With the reduction in deposit formation, the Cat-DEF system can support a 90% reduction in harmful NOx emissions and a 2% reduction in fuel consumption for heavy-duty diesel trucks. Rigorous engine testing shows that the solutions can help automotive manufacturers cost-effectively meet future emission regulations for heavy-duty and off-highway mobile machinery, while improving performance in existing vehicles.

ECO-MOBILITY WITH CONNECTED POWERTRAINS

SwRI's connected and automated vehicle (CAV) technology will help passenger and fleet vehicles reduce energy consumption. Developed in cooperation with the Advanced Research Projects Agency-Energy, Toyota and the University of Michigan, SwRI's Eco-Mobility with Connected Powertrains project delivered over 20% energy savings on a plug-in hybrid vehicle in real-world driving conditions by optimizing power management, routing and speed.

"Eco-Mobility with Connected Powertrains provides a breakthrough toward dramatically lowering automotive fuel consumption as government and industry seek scalable solutions to lower automotive carbon dioxide (CO_2) emissions," said Terry Alger, director of SwRI's Automotive Propulsion Systems Department.

The research vehicle features an 8.8 kW-hr battery pack and onboard dedicated short-range communication (DSRC) radio for vehicle-to-vehicle (V2V) and vehicle-to-infrastucture (V2I) communications. Algorithms optimize hybrid-electric performance through a novel strategy that improves management of power as it moves through the battery, electric motor, gasoline engine and other powertrain components. The "connected powertrain" further improves efficiency via V2V and V2I networks that communicate optimal routes and speed.


D025082

SwRI developed a connected and automated vehicle (CAV) chassis dynamometer that interfaces with traffic simulation software to provide a controllable, repeatable environment for testing tools.

"Most production hybrid vehicles use a charge-deplete then charge-sustain strategy for battery pack power management, which results in suboptimal efficiency depending on route," said Sankar Rengarajan, manager of SwRI's Powertrain Controls Section. "SwRI's algorithms leverage route information to optimize power usage and fuel efficiency by adjusting the power split between the battery/electric motor and the gasoline engine."

SwRI developed the technology through initial funding from the U.S. Department of Energy Advanced Research Projects Agency-Energy (ARPA-E) NEXTCAR program, which uses connectivity and automation to improve vehicle energy efficiency. SwRI's internal research and external client funding further developed capabilities.

"This connected powertrain technology does not require high levels of automation or redesign of powertrain systems," said Scott Hotz, assistant director of SwRI's Automotive Propulsion Systems Department. "The required connectivity already exists on some current production vehicles, and CAV networks will be ubiquitous in 5–10 years."

FLOODLIGHT

SwRI's Floodlight software aids in the efficient discovery of vast numbers of chemicals present in a wide variety of substances including food, air and consumer products. This cheminformatics machine learning tool, developed with internal funding, integrates with analytical chemistry software to provide deep analysis of two-dimensional gas chromatography mass spectrometry (GCx-GC-MS) and metadata.

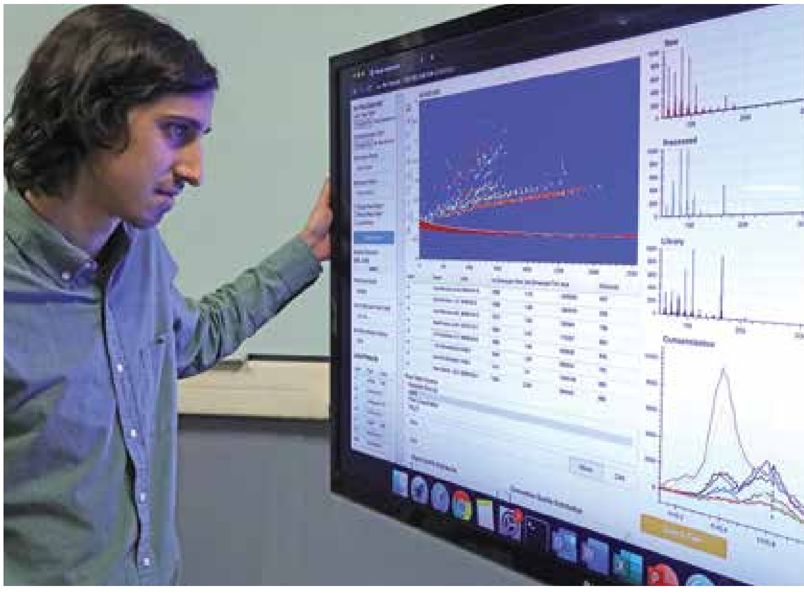
Floodlight is a game changer for processing non-targeted analysis (NTA) data. In NTA, all substances detected by GCxGC-MS instruments are evaluated, producing vast amounts of data. Targeted analyses screen for specified chemicals, producing more limited results.

"Known chemicals in a particular sample are relatively easy to find and quantify," said Dr. Kristin Favela, an analytical chemist specializing in chemical forensics and one of the leaders of the development team. "NTA is a different story. Through an extensive, multiyear NTA program of consumer products, we discovered that only about 20% of identified chemicals were listed on product labels or datasheets. The remaining 80% were previously unidentified in these products. We don't know the possible health effects of exposure to chemicals if we don't know they are in products."

SwRI was well positioned to attack this issue, with wide-ranging expertise in analytical chemistry, machine learning, data science and engineering. Key to the Floodlight technology is SwRI's experience in labeling ground-truth data for chemicals in a wide array of consumer products, ranging from food and medicine to packaging and toys. SwRI's machine learning team, led by Michael Hartnett and David Vickers, leveraged this data to train and develop new algorithms.

"The key to the Floodlight software is artificial intelligence and machine learning algorithms that enable advanced analysis of chemistry big data," said Dr. Keith Pickens, one of the leaders of the Artificial Intelligence for Mass Spectrometry (AIMS) group at SwRI. "The Floodlight software is a sophisticated software tool that can make sense of the vast amounts of data NTA generates."

SwRI's award-winning Floodlight software displays the results of processed non-targeted chemical analyses using an intuitive web interface that can be accessed using most modern web browsers.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EARTH BOMBARDMENT HISTORY

An SwRI team modeled evolutionary processes in the main asteroid belt and discovered that impactors such as the one that ended the reign of the dinosaurs are most likely from the outer half of the main asteroid belt. The team also discovered that delivery processes from that region occur 10 times more often than previously thought.

IMAGE COURTESY SwRI/DON DAVIS D025108

ZEROING IN ON SOURCE OF DINOSAUR-KILLING IMPACTOR

The impactor believed to have wiped out the dinosaurs and many other life forms on Earth some 66 million years ago likely came from the outer half of the main asteroid belt, a region previously thought to produce few impactors. SwRI researchers have shown that the processes that deliver large asteroids to Earth from that region occur at least 10 times more frequently than previously thought and that the composition of these bodies matches what we know of the dinosaur-killing impactor.

The SwRI team — including Dr. David Nesvorný, Dr. William Bottke and Dr. Simone Marchi — combined computer models of asteroid evolution with observations of known asteroids to investigate the frequency of so-called Chicxulub events. Over 66 million years ago, a body estimated to be 6 miles across hit near what is now Mexico's Yucatan peninsula and formed the Chicxulub crater, which is over 90 miles across. This massive blast triggered a mass extinction event that ended the reign of the dinosaurs.

To probe the Chicxulub impact, geologists have previously examined 66-million-year-old rock samples found on land and within drill cores. The results indicate the impactor was similar to the carbonaceous chondrite class of meteorites, which contain some of the most pristine materials in the solar system. Curiously, while carbonaceous chondrites are common among the many mile-wide bodies that approach the Earth, none of those found to date is close to the size needed to produce a Chicxulub-scale impact with any kind of reasonable probability.

"We decided to look for where the siblings of the Chicxulub impactor might be hiding," said Nesvorný, lead author of a paper in the journal Icarus describing the research.

"To explain their absence, several past groups have simulated large asteroid and comet breakups in the inner solar system, looking at surges of impacts on Earth with the largest one producing the Chicxulub crater," said Bottke, one of the paper's co-authors. "While many of these models had interesting properties, none provided a satisfying match to what we know about asteroids and comets. It seemed like we were still missing something important."

To solve this problem, the team used computer models that track how objects escape the main asteroid belt, a zone of small bodies located between the orbits of Mars and Jupiter. Over eons, thermal forces allow these objects to drift into dynamical "escape hatches" where the gravitational kicks of the planets can push them into orbits nearing Earth. Using NASA's Pleaides supercomputer, the team followed 130,000 model asteroids evolving in this slow, steady manner for hundreds of millions of years. Particular attention was given to asteroids located in the outer half of the asteroid belt, the part that is farthest from the Sun. To their surprise, they found that 6-mile-wide asteroids from this region would strike the Earth at least 10 times more often than previously calculated.

A Southwest Research Institute-led team updated planetary bombardment models with the latest geologic information and then applied those models to understand how impacts may have affected oxygen levels in the Earth's atmosphere in the Archean eon, 2.5 to 4 billion years ago. This artistic conception illustrates large asteroids penetrating Earth's oxygen-poor atmosphere.

IMAGE COURTESY SwRI/DAN DURDA, SIMONE MARCHI D025100

"This result is intriguing not only because the outer half of the asteroid belt is home to large numbers of carbonaceous chondrite impactors, but also because the team's simulations can, for the first time, reproduce the orbits of large asteroids on the verge of approaching Earth," said co-author Marchi. "Our explanation for the source of the Chicxulub impactor fits in beautifully with what we already know about how asteroids evolve."

NEW IMPACT MODEL SUPPORTS ATMOSPHERIC OXYGEN HISTORY

An SwRI-led team has updated its asteroid bombardment model of the Earth with the latest geologic evidence of ancient, large collisions. These models have been used to understand how impacts may have affected oxygen levels in the Earth's atmosphere in the Archean eon, 2.5 to 4 billion years ago.

When large asteroids or comets struck early Earth, the energy released melted and vaporized rocky materials in the Earth's crust. The small droplets of molten rock in the impact plume would condense, solidify and fall back to Earth, creating round, globally distributed sand-size particles. Known as impact spherules, these glassy particles populated multiple thin, discrete layers in the Earth's crust, ranging in age from about 2.4 to 3.5 billion years old. These Archean spherule layers are markers of ancient collisions. New spherule layers recently identified in drill cores and outcrops have increased the total number of known impact events upon early Earth.

"Current bombardment models underestimate the number of late Archean spherule layers, suggesting that the impactor flux at that time was up to 10 times higher than previously thought," said SwRI's Dr. Simone Marchi, lead author of a paper about this research in Nature Geoscience. "What's more, we find that the cumulative impactor mass delivered to the early Earth was an important 'sink' of oxygen, suggesting that early bombardment could have delayed oxidation of Earth's atmosphere."

The abundance of oxygen in Earth's atmosphere is due to a balance of production and removal processes. These new findings correspond to the geological record, which shows that oxygen levels in the atmosphere varied but stayed relatively low in the early Archean eon. Impacts by bodies larger than 6 miles (10 km) in diameter may have contributed to its scarcity, as limited oxygen present in the atmosphere of early Earth would have been chemically consumed by impact vapors, further reducing its abundance in the atmosphere. Scientists have found evidence for 'whiffs' of oxygen, relatively steep but transient increases in atmospheric oxygen, around 2.5 billion years ago. Large impacts, consistent with those recorded by spherule layers in Australia's Bee Gorge and Dales Gorge, could have removed the whiffs from the atmosphere.

SwRI's results indicate that the Earth was subject to substantial numbers of large impacts throughout the late Archean era. Around 2.4 billion years ago, during the tail end of this bombardment, the Earth went through a major shift in surface chemistry triggered by the rise of atmospheric oxygen, dubbed the Great Oxidation Event (GOE), which is attributed to changes in the oxygen production-sink balance. Among the proposed scenarios are a presumed increase in oxygen production and decrease in gases capable of removing oxygen, either from volcanic sources or through their gradual loss to space.

"Impact vapors caused episodic low oxygen levels for large spans of time preceding GOE," Marchi said. "As time went on, collisions became progressively less frequent and too small to be able to significantly alter post-GOE oxygen levels. The Earth was on its course to become the current planet."

SwRI, UTSA CONNECT THROUGH COLLABORATIVE RESEARCH

Southwest Research Institute and The University of Texas at San Antonio (UTSA) funded two projects through the Connecting Through Research Partnerships (Connect) program: one to produce cleaner renewable liquid hydrocarbon fuels for transportation, and another to create a computer model of the human heart. SwRI's Executive Office and UTSA's Office of the Vice President for Research, Economic Development, and Knowledge Enterprise sponsor the Connect program, which offers grant opportunities to enhance scientific collaboration between the two institutions.

HEART MODELS TO SUPPORT NEW TREATMENTS

SwRI and UTSA are collaborating to develop a computer model of the intricate structures of the human heart as part of a larger effort to develop a new, potentially life-saving heart surgery. The work, led by Dr. Keith Bartels of SwRI's Mechanical Engineering Division and Dr. Hai-Chao Han of UTSA's College of Engineering, is supported by a $125,000 Connect grant.

Within the human heart are numerous small muscle bundles called the trabeculae carneae. Despite their significance in the heart's anatomy, their function is not well understood and most models of the heart ignore them.

As people grow older, heart muscles can grow stiff, reducing efficiency and sometimes resulting in untreatable diastolic heart failure. SwRI and UTSA are scanning cadaver hearts using SwRI's powerful computer tomography (CT) scanner to inform a potential new surgical intervention.

"Capturing the intricate structures of the trabeculae carneae requires something more powerful than an MRI or standard CT scanner," Bartels said. "We'll utilize a micro-focus X-ray CT scanner here at SwRI to create images of explanted human hearts."

The images of the heart's intricate inner structures will help Han create a realistic anatomical model of the trabeculae carneae, building on a previous model he developed for the left ventricle.

"This collaboration with SwRI is a first step toward creating a new surgical method," Han explained. "The computer model will help provide a much deeper understanding of the trabeculae carneae."

Han has also been working with cardiologist Dr. Marc Feldman at UT Health San Antonio to develop a surgical treatment for subgroups of heart failure patients. This project is a critical step for those efforts.

"I hope this work can ultimately improve the quality of people's lives and even save lives in the long run," Bartels said. "Heart failure is a major problem that affects millions of people."

D025074

SwRI is using its micro-focus x-ray CT scanner to image the intricate inner structures of the heart. Using these images, an SwRI-UTSA team will develop a computer model of the human heart as part of a larger effort to develop a new, potentially life-saving heart surgery.

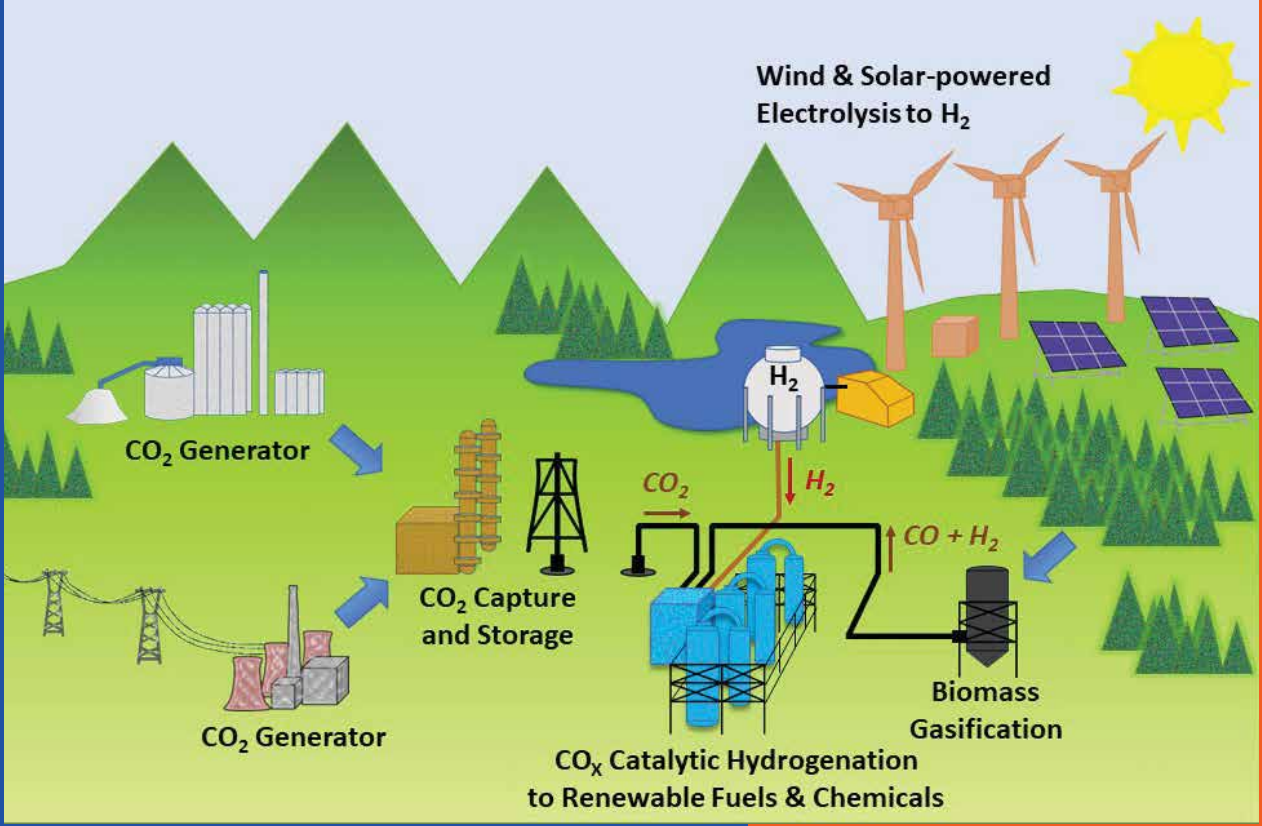


IMAGE COURTESY UTSA D025103

The graphic illustrates sustainable hydrocarbon production through recycling carbon — CO and/or CO_2, referred to as CO_x —hydrogenating CO_2 and/or biomass gasification to create renewable liquid fuels.

CLEANER RENEWABLE CO_2-BASED HYDROCARBONS

SwRI and UTSA also are collaborating to combine two catalytic processes into a single reactor, with the overall goal of recycling carbon from carbon dioxide (CO_2) to produce low-cost hydrocarbon fuels. The work, led by Dr. Grant Seuser of SwRI's Powertrain Engineering Division and Dr. Gary Jacobs of UTSA's College of Engineering, is supported by a $125,000 Connect grant.

Greenhouse gas emissions are expected to increase by about 17% by 2040 as a result of increasing energy and transportation needs in the developing world.

"We're facing a lack of renewable fuels and the technology to deliver cleaner power generation," Seuser said. "We're seeing a rise in battery-powered passenger vehicles, but the high power demands of the aviation, locomotive, shipping and long-haul trucking industries will continue to require energy-dense hydrocarbons for the foreseeable future."

Seuser and Jacobs propose using a process called CO_2 hydrogenation to produce cleaner renewable liquid hydrocarbon fuels for transportation. To accomplish this, they plan to build a single reactor capable of performing two chemical processes in one step. The first will react hydrogen with CO_2 to make synthesis gas (syngas), a combination of hydrogen and carbon monoxide; the second will convert the syngas into a liquid hydrocarbon fuel using the Fischer-Tropsch synthesis process.

"Fischer-Tropsch synthesis was discovered in Germany about a century ago and is still used in places like South Africa and Qatar to convert coal and natural gas into liquid hydrocarbon fuels. Plant capacities range from tens of thousands to hundreds of thousands of barrels of fuel per day. It will be an interesting challenge to integrate this catalytic technology into a process that uses CO_2 in the feed," Jacobs said.

Additionally, the process the SwRI-UTSA team is developing will be able to use CO_2 captured at fossil fuel-fired power plants that would otherwise be sequestered underground or emitted into the atmosphere.

"Combining the functionality of these two catalytic processes — reverse water-gas shift and Fischer-Tropsch synthesis — into a single reactor would simplify the process and increase its economic viability," Jacobs said.

The effort will also explore novel catalyst formations aimed at combining the two processes, which Jacobs will create and characterize at UTSA. Seuser will use the catalysts in an SwRI reactor to assess their industrial viability.

"Reducing the complexity of converting CO_2 into hydrocarbon fuels would have a big impact," Seuser said. "Finding a way to produce low-carbon fuels and maintain our current energy infrastructure is critical to avoid further increases in Earth's temperature."

BALLISTICS STATISTICS

SwRI offers expertise in ballistics, hypersonics, explosion loading, structural response and scale modeling. We have developed models for:

- penetration mechanics
- shot-line and shaped-charge analyses
- exterior and interior ballistics
- specialized sabot design
- explosion hazards and debris
- blast-loaded structures

State-of-the-art instrumentation records data in severe environments down to the nanosecond range.

Testing capabilities include ballistics — small arms, long-rod projectiles, fragments and shaped charges — and dynamic loading and response of mechanical systems and structures in highly transient environments.

SwRI conducts hypersonics and other high-speed research using this unique two-stage light-gas launcher, featured here by the numbers.

Gun: **72** feet long

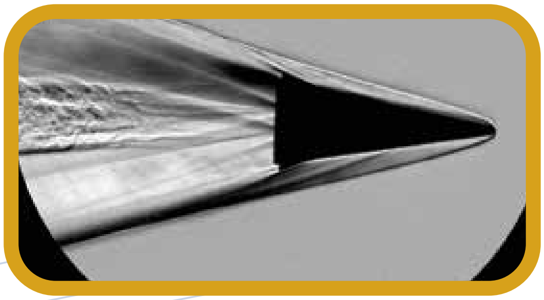
Number of tests: **>500** since 2017

For light-gas gun testing, SwRI encases test projectiles in a sabot, a structural device used to keep smaller projectiles in the center of the barrel when fired. The sabot separates from the projectile and is stripped away when it hits an impact plate.

Flight speeds:
Mach 1.5 to 17.4
supersonic to hypersonic

Mach 1: Flow speeds equal the speed of sound

Hypersonics: Flight in excess of Mach 5



D025086

Multiple view ports along the flight path allow high-speed imaging, including schlieren photographs that show the flow of air around the projectile.

Launch velocities:
0.5 to 6.0 km/s
(or 1,118 to 13,422 mph)

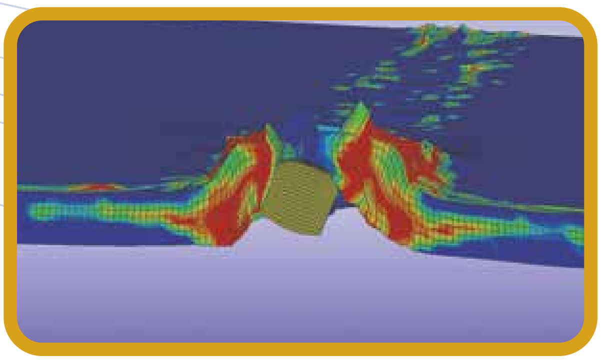
Total time of flight:
1 to 5 milliseconds

Bore diameter:
1.5 inches

D023365

Peak air temperature around object flying at Mach 16.4 (5.65 km/s):
7,100 K (12,320 F)

Surface temperature of the Sun: 5,778 K (9,940 F)



D025093

SwRI integrates data from experiments to develop models that simulate the effects of ballistic impact on armors and other materials.

PUNCH MISSION ANNOUNCES NOVEL OUTREACH PROGRAM

MISSION PASSES LATEST NASA REVIEW

The SwRI-led PUNCH mission passed its latest mission review and moved into the final phase of mission design and instrument fabrication. This image illustrates how the four PUNCH satellites will spread out around Earth along the day-night line to create a complete view of the corona and solar wind. Three of the PUNCH satellites will carry identical Wide Field Imagers, and one will carry the Narrow Field Imager.

D025076

NASA has funded a five-year outreach program in association with the Polarimeter to UNify the Corona and Heliosphere (PUNCH), a solar mission led by Southwest Research Institute. The PUNCH Outreach Program, also led by SwRI, is collaborating with five planetariums and science centers in four states, plus other multicultural partners in the southwestern United States. The mission has also achieved an important milestone, passing its latest NASA review and entering the final mission design phase with a new launch-readiness target of October 2023.

For national impact, the outreach team is forging strong connections with NASA-sponsored educational programs and with other solar missions, including the Parker Solar Probe (PSP). Working with PUNCH and PSP scientists, the team will develop a suite of enduring products and events using an "Ancient and Modern Sun-Watching" theme.

"There is worldwide evidence that all humans are descended from Sun-watching cultures," explains PUNCH Outreach Director Dr. Cherilynn Morrow, who consults for SwRI. "Our theme portrays NASA's exploration of the Sun as a natural extension of humanity's long-lived dedication to observing the Sun's rhythms and mysteries. In this way, we can reveal how NASA science is relevant to the cultural history of diverse peoples."

When PUNCH launches in 2023, it will increase the understanding of the Sun's corona — the outer atmosphere that becomes visible during total solar eclipses. The mission will study how the corona transitions to the "solar wind" with charged particles and magnetic fields speeding outward from the Sun, filling our solar system and interacting with the planets.

"PUNCH cameras are uniquely capable of imaging the solar wind continuously from the time it leaves the Sun until it engulfs our world, affecting spacecraft and astronauts and causing auroral lights," said Principal Investigator Dr. Craig DeForest of SwRI's Space Science and Engineering Division. "This Sun-Earth connection offers pathways for sharing our science more broadly. I am so pleased with the capability of our outreach team and the inclusivity of our outreach program."

The program's motto is "shining a new light on diverse views of the Sun," be they scientific, artistic, cross-cultural, historic or the result of first-person observations. The team will also use solar eclipses visible from the U.S. in 2023 and 2024 to help motivate public engagement in multicultural, arts-integrated opportunities for learning about NASA-related science, technology, engineering and mathematics (STEM).

PUNCH Outreach draws particular inspiration from Chaco Canyon, a cross-cultural site in the New Mexico high desert where a total solar eclipse in 1097 may have been recorded as rock art and where examples of age-old Sun-watching practices are abundant. Chaco includes thousand-year-old remnants of monumental architecture built by Ancestral Puebloan people and oriented in accordance with their knowledge about the movements of the Sun and Moon. The history of Chaco also interweaves with that of the Navajo people as well as the indigenous peoples of Mexico and Central America.

"This project's emphasis on ancestral connections to Chaco Canyon can provide a valuable way for our youth at Acoma and Laguna Pueblos to experience NASA science and envision a future career in science without losing touch with their culture," said PUNCH outreach partner Joe Aragon, a retired STEM educator and tribal elder from the Acoma Pueblo in New Mexico.

PUNCH Outreach emphasizes collaboration with diverse partners to engage populations that are currently underrepresented in STEM fields. The program intends to benefit and learn from Native American and Hispanic youth and their families, Girl Scouts pursuing STEM-related patches and badges, and blind or visually impaired learners.

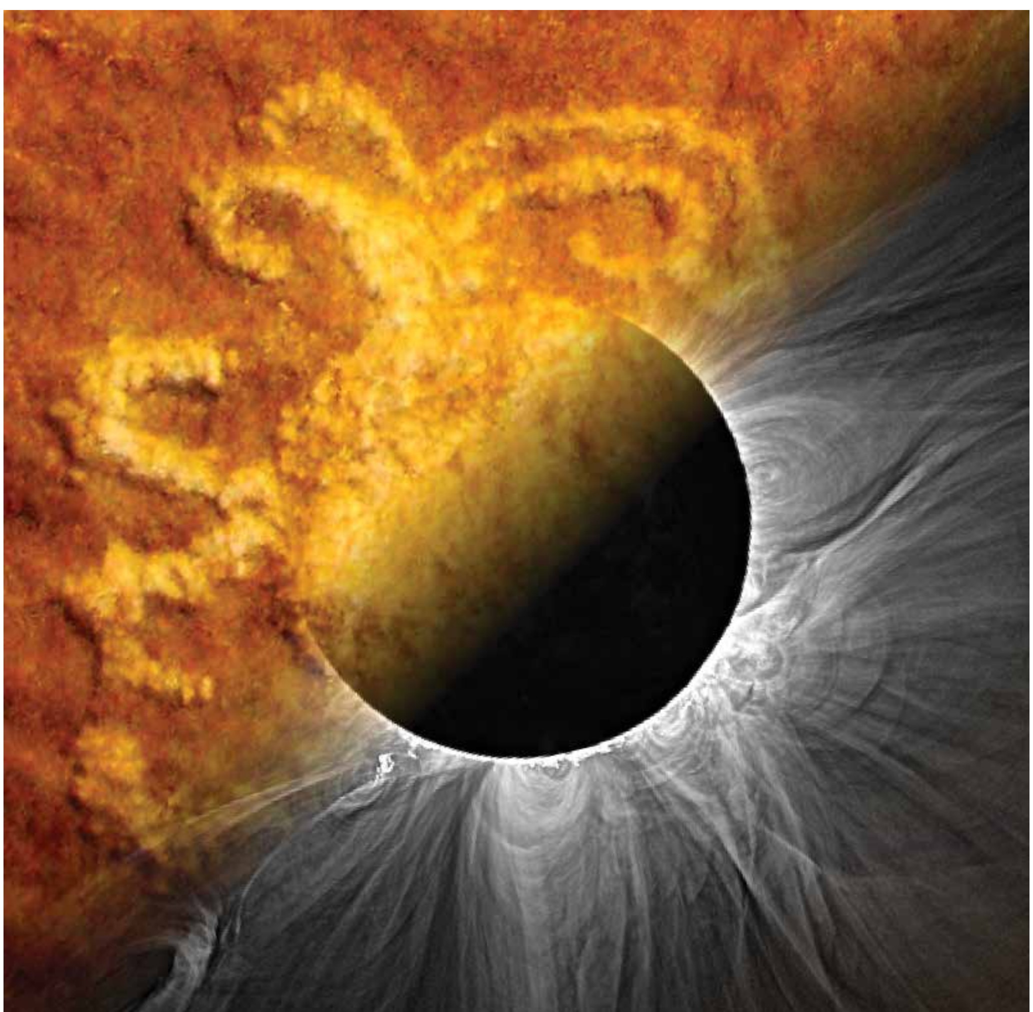
"Our science team is really excited about contributing to the outreach effort," said PUNCH Project Scientist Dr. Sarah Gibson of the High-Altitude Observatory in Boulder, Colorado. "We have a high percentage of women scientists compared to other NASA missions and this makes us a great source of role models to support our STEM collaborations with Girl Scout Councils."

In addition to developing live-interaction planetarium shows with musical, kinesthetic and social learning dimensions, PUNCH Outreach is consulting with Jeff Killebrew, a science teacher at the New Mexico School for the Blind and Visually Impaired, to translate dramatic solar events into meaningful tactile experiences.

To implement the PUNCH Outreach Program, SwRI is collaborating with the Fiske Planetarium at the University of Colorado in Boulder, the Clark Planetarium in Salt Lake City, the New Mexico Museum of Natural History and Science and the National Hispanic Cultural Center in Albuquerque, the New Mexico Museum of Space History in Alamogordo and the Lowell Observatory in Flagstaff, Arizona.

NASA's Small Explorers program provides frequent flight opportunities for world-class scientific investigations such as PUNCH. SwRI is building and will operate the spacecraft. PUNCH instruments are being built by SwRI, the U.S. Naval Research Laboratory and RAL Space in England.

IMAGE COURTESY GB CORNUCOPIA/CONSTANTINOS EMMANOULIDIS/MILOSLAV DRUCKMÜLLER/DON KOLINKSI D025107



This composite image represents the Ancient and Modern Sun-Watching theme of the SwRI-led PUNCH Outreach program. The image combines an Ancestral Puebloan petroglyph from Chaco Canyon, interpreted by solar astronomers as the 1097 total solar eclipse with an active solar corona (upper left), with a high-resolution observation of the 2013 solar eclipse (lower right).

GRID-SCALE BATTERY JIP LAUNCHED

SwRI has launched a new Joint Industry Program (JIP) to investigate energy storage systems for the electric grid. JIP efforts will include developing new test cycles for batteries used in grid applications and estimating the life span of batteries and their potential for failure while reducing the likelihood of battery fires.

"The energy industry has seen a tremendous increase in renewable resources, such as power generated by wind turbines and solar panels," said Dr. Jayant Sarlashkar, an Institute engineer in SwRI's Powertrain Engineering Division. "These renewable sources tend to be highly variable, so it becomes necessary to store excess energy in a battery for use during periods of high demand. The increased role of renewable resources in the energy mix has led to a greater demand for batteries to store energy to balance supply and demand."

Tokyo Electric Power Company (TEPCO), ENGIE, EnBW, the Central Research Institute of Electric Power Industry (CRIEPI) and CEZ have joined SwRI's Energy Storage for Electric Grid JIP, which will address questions about the risks and reliability of energy storage systems, including battery degradation.

"Once we deploy a battery for grid applications, we need to know how long we can rely upon it," Sarlashkar said.

Over the course of its life, a grid-connected battery must be able to respond slowly or suddenly, depending on grid demands. On a normal evening, a battery might supply 1,000 houses with continuous power, which is a slow and sustained behavior. But in an emergency, that same battery could be called upon to supply an immediate surge of electricity to prevent a blackout. The program will investigate how these two very different demand scenarios affect the life of a battery.

The Energy Storage for Electric Grid JIP will also investigate battery flammability, particularly the explosion and fire risks associated with large, grid-scale batteries.

"Actions such as aggressive load-shifting and deploying a battery to prevent a blackout could increase fire risks," Sarlashkar said. "The current monitoring standards are insufficient."

Understanding how a battery degrades and the likelihood of its failure could shed light on what causes battery fires. SwRI is working on methods to estimate performance degradation in grid-connected batteries and establish a correlation with battery fires. One known risk for a lithium-ion battery fire is the presence of dendrites, spiky structures deposited during the charging process, which can cause short-circuits and fires.

"We want to know how fast these dendrites grow, because that will tell us when it's time to replace a battery," Sarlashkar said. "The more we know about what causes these fires, the better we can develop maintenance protocols to prevent them by replacing batteries before they cause damage and injury."

Joining the JIP requires signing a cooperative research agreement and providing operational field data from a grid battery the JIP participant has deployed. SwRI is funding this JIP through internal research, with the other JIP members providing in-kind support, so there is no fee to join.

Participants can guide JIP research to keep it true to the needs of the industry. They also have the opportunity to license any intellectual property developed before SwRI offers it to JIP non-participants, which may provide a competitive advantage by reducing life-cycle costs.

This new JIP will utilize SwRI's grid-connected energy storage facilities at its San Antonio headquarters.

D025081

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As part of a new collaboration, Virgin Orbit and SwRI will evaluate opportunities to jointly develop and launch missions to space, including the deployment of satellite constellations similar to NASA's Cyclone Global Navigation Satellite System. SwRI designed, built and operates the eight CYGNSS microsatellites for a NASA weather monitoring mission.

SwRI COLLABORATES WITH VIRGIN ORBIT

Virgin Orbit, a California-based small satellite launch company, and SwRI have signed a memorandum of understanding (MOU) establishing a new collaboration. Under the terms of the agreement, Virgin Orbit and SwRI will explore specialized mission opportunities using the LauncherOne rocket coupled with SwRI's deep expertise in space mission development. Additionally, the two organizations will explore potential opportunities for joint manufacturing of SwRI's space platforms and delivery of space services to Virgin Orbit's customers.

Virgin Orbit is interested in developing collaborations to offer its government, civil and commercial customers turnkey bundled services, such as satellite platforms, mission management and downstream value-added services and applications. Virgin Orbit and SwRI are particularly interested in collaborating on stewardship programs that would leverage space data to inform critical decisions around weather and for environmental monitoring purposes.

As part of the agreement, Virgin Orbit will assess the possibility of manufacturing SwRI space vehicle platforms at the company's manufacturing hub in Long Beach, California. SwRI has two small satellite platforms available through NASA's Rapid Spacecraft Development Office IV catalog, which is used by the U.S. government to rapidly contract for flight-proven spacecraft. Virgin Orbit and SwRI will also evaluate opportunities to jointly develop and launch missions to space, including the deployment of satellite constellations, to provide comprehensive space service offerings to customers.

Heavy Ion Acceleration in Cosmic Rays

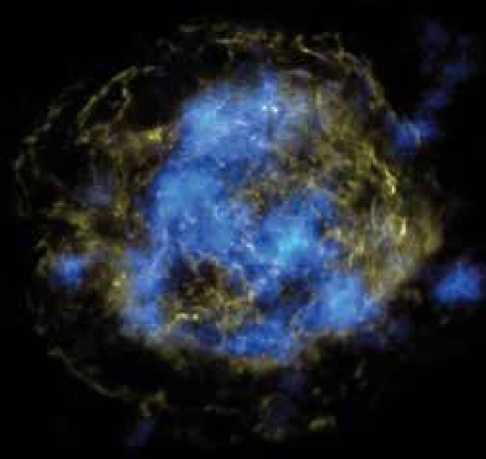
Using data from the SwRI-led Magnetospheric Multiscale (MMS) mission, scientists can explain the presence of energetic heavy elements in galactic cosmic rays (GCRs). GCRs are composed of fast-moving energetic particles, mostly hydrogen ions called protons, the lightest and most abundant elements in the universe. Scientists have long debated how trace amounts of heavy ions in GCRs are accelerated.

The supernova explosion of a dying star creates massive shockwaves that propagate through the surrounding space, accelerating ions in their path to very high energies, creating GCRs. How heavy ions are energized and accelerated is important because they affect the redistribution of mass throughout the universe and are essential for the formation of even heavier and more chemically complex elements. They also influence how we perceive astrophysical structures.

"Heavy ions are thought to be insensitive to an incoming shockwave because they are less abundant, and the shock energy is overwhelmingly consumed by the preponderance of protons. Visualize standing on a beach as waves move the sand under your feet, while you remain in place," said SwRI's Dr. Hadi Madanian, the lead author of the paper about this research published in Astrophysical Journal Letters. "However, that classical view of how heavy ions behave under shock conditions is not always what we have seen in high-resolution MMS observations of the near-Earth space environment."

The Sun's magnetic field is carried through interplanetary space by the flow of the supersonic solar wind, which is obstructed and diverted by the Earth's magnetosphere, a bubble of protection around our home planet. This interaction region is called the "bow shock" due to its curved shape, comparable to the bow waves that occur as a boat travels through water. The Earth's bow shock forms at a much smaller scale than supernova shocks. However, at times conditions of this small shock resemble those of supernova remnants. The team used high-resolution in-situ measurements from the MMS spacecraft at the bow shock to identify evidence for an acceleration process that drives heavy ions.

IMAGE COURTESY NASA/GSFC/JPL D025098



Supernovas, such as this Cassiopeia A supernova remnant, are a source of galactic cosmic rays.

EZ FLOW FOR HEAVY CRUDES

SwRI scientists and engineers used internal research funding to develop "EZ Flow," an innovative process that makes pipeline transportation of heavy crude oil more cost-effective and less energy-intensive than current techniques.

"Our team developed the new method for processing heavy crude oil using a proprietary chemical treatment and mechanical technique," said James Wood, a principal scientist in SwRI's Chemistry and Chemical Engineering Division. "The new process reduces the viscosity of heavy crude oil by more than 60%, allowing it to flow more easily through existing pipeline networks."

The U.S. has more than 190,000 miles of liquid petroleum pipeline networks, providing an environmentally friendly, economic way to move oils over long distances. However, transporting heavy crude oil and bitumen via pipeline is challenging at best and impossible at worst due to its high density and viscosity and very low mobility at reservoir temperatures. SwRI's proof-of-concept EZ Flow technology offers a cost-effective means for conveying heavy and extra-heavy crude oils over long distances without heating the pipeline and/or adding large amounts of chemical or diluent. Conventional techniques are costly because they often use large volumes of chemicals or diluents and frequently require multiple treatment techniques to be applied simultaneously.

"According to industry experts, over the next 80 years, heavy crude oil production will increase exponentially as lighter crude oil reserves dwindle and those that are available become more expensive and difficult to recover," Wood said.

The low concentrations of proprietary additives needed for EZ Flow make it environmentally friendlier and less expensive than other currently available commercial technologies. SwRI is also investigating whether EZ Flow could be adapted to upgrade, or chemically treat, heavy crude oil. SwRI's patent-pending EZ Flow proof-of-concept technology is available for commercial development.

Enabling Instrument for Lunar Surveys

NASA has funded SwRI's Environmental Analysis of the Bounded Lunar Exosphere (ENABLE) project, which aims to return mass spectrometry to the lunar surface. The three-year, $2.18 million program seeks to adapt a commercial off-the-shelf mass spectrometer into a design to identify materials present on the Moon.

Mass spectrometry instruments can identify unknown compounds, quantify known compounds and determine the structure and chemical properties of molecules. The proposed lunar design could be deployed on multiple spaceflight platforms, including lunar surface landers and robotic rovers, as well as a handheld tool suitable for operation by future astronauts.

"Whether it's prospecting for lunar volatiles, monitoring spacecraft exhaust byproducts, probing the eons-old history of the lunar subsurface or hunting for leaks from micrometeoroid impacts, we believe mass spectrometry is going to lead the way in surveying the Moon's harsh environment," said SwRI's Edward Patrick, ENABLE principal investigator.

Nearly half a century after Apollo, NASA lunar missions such as the Lunar Crater Observation and Sensing Satellite, the Lunar Reconnaissance Orbiter and the Lunar Atmosphere and Dust Environment Explorer have conducted remote sensing to search for trapped volatiles, chemical substances that can be readily vaporized. These discoveries have jump-started the field of "in situ resource utilization" or ISRU, which would allow explorers to "live off the land" at target worlds such as the Moon and Mars.

ISRU holds the promise of reducing the size of payloads necessary for future missions by excavating reservoirs of natural resources for breathable air and rocket fuel or producing engineered materials for space architecture and construction. It could also increase science payload capacity, reduce mission risks, support extended human-crewed missions, and, ultimately, allow a permanent human presence on the Moon and beyond.

"It's past time for mass spectrometry to return to the Moon," Patrick said. "With the armada of multinational space missions currently under development and on the drawing board, mass spectrometry is a priority diagnostic tool necessary for ISRU success."

D025109

CREATING WATER OUT OF THIN AIR

SwRI engineers and chemists teamed up to create a low-cost method of harvesting water from atmospheric air on a much larger scale than previously attempted. Supported by internal research funding, the group is using silica gel beads, commonly used to keep items from gathering moisture during shipment, to capture water molecules from the air.

"The air around us always contains some water vapor," said Program Manager Kevin Supak. "For instance, a cold beverage on a humid day will form liquid water on the glass, condensed from the air. We can capture that moisture and turn it into a resource."

Communities around the world are facing water shortages. The SwRI solution uses adsorption to harvest atmospheric water. Even at low humidity, water vapor molecules in the air attach to the surface of materials called desiccants, such as the low-cost silica gel beads used in the SwRI process. Atmospheric air is blown through a bed of silica gel beads to adsorb the water vapor molecules.

"The water vapor will attach to the adsorbent material through hydrogen bonding. When we introduce heat, the water is exuded in gaseous form, but at much higher humidity," Supak said. "This high-humidity air can be more easily condensed, and the result is potable water."

SwRI is using a fluidized bed process to increase the water production by flowing air through the pellets of material to enhance adsorption and desorption rates. Other researchers use a simpler fixed bed of adsorbent material and rely on day/night cycles to produce water. The SwRI system is designed to yield about 5 liters of water a day, about 10 times more water than techniques demonstrated by other researchers.

The team plans to test the system for up to 1,000 cycles — 10 times more than any previous demonstration — to understand if material performance degrades over time.

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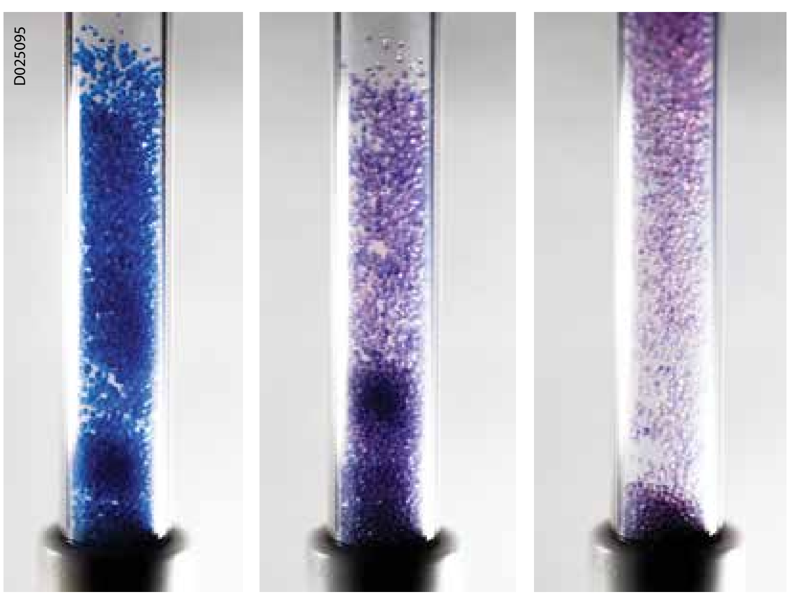
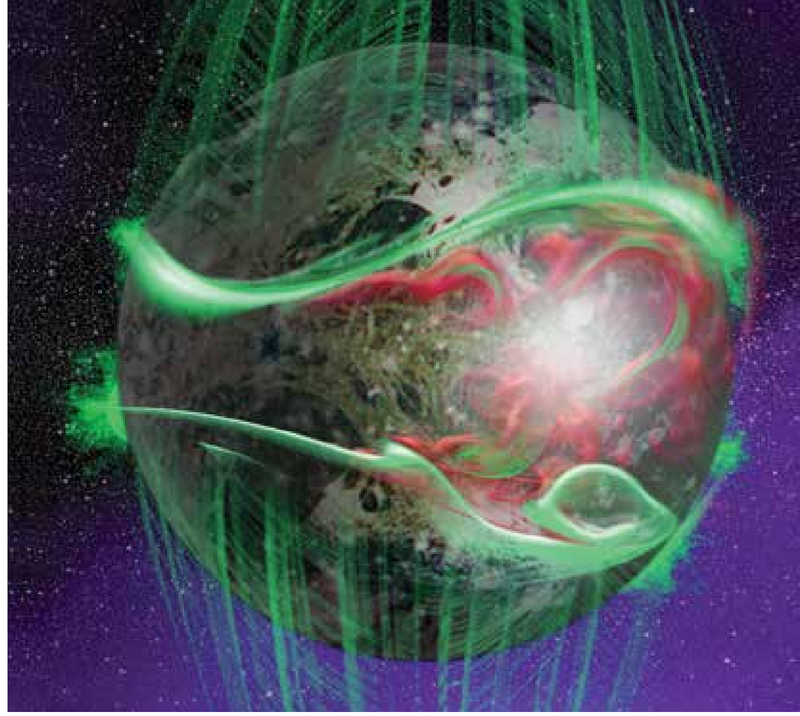


SwRI researchers are using these silica gel beads as part of a low-cost, large-scale method to harvest water molecules from the air. As they expel moisture, the beads turn from blue to pink.

IMAGE COURTESY NASA/ESA/K. RETHERFORD/SwRI D025106



This artist's depiction of Ganymede's atmosphere shows molecular-oxygen-produced ultraviolet emissions in green and water-vapor-produced UV emissions in red. SwRI scientists helped determine that Ganymede's water atmosphere is concentrated at the equator near noon when the Sun is directly overhead.

HIGH NOON ON JUPITER MOON

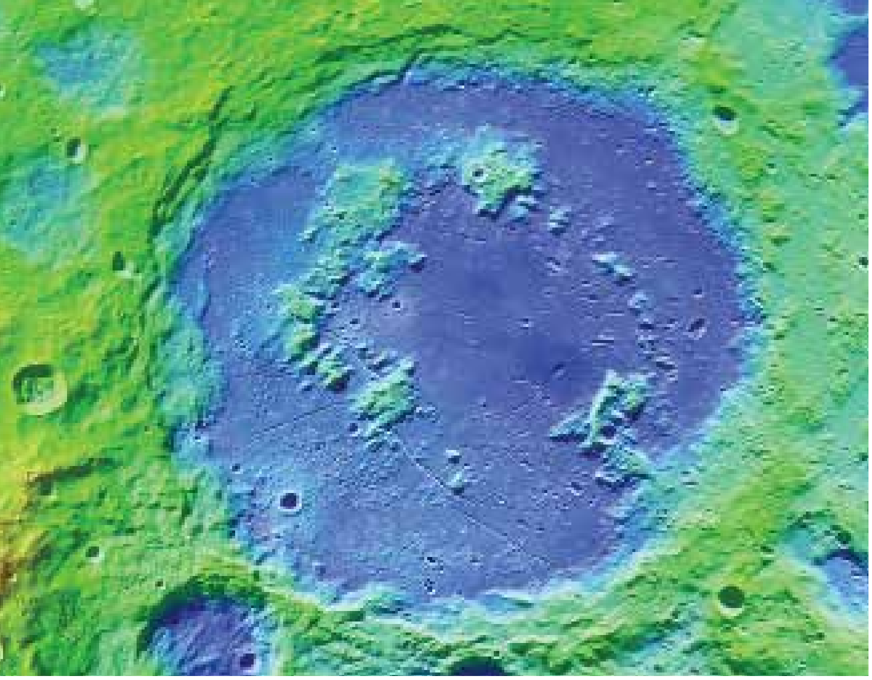
Using spectral images from the Hubble Space Telescope (HST), a team of scientists led by Dr. Lorenz Roth of the KTH Royal Institute of Technology in Stockholm, Sweden, has determined that water vapor forms a large fraction of the atmosphere of Jupiter's icy moon Ganymede. SwRI scientists played a crucial role in this discovery, looking at the HST datasets and comparing them to the expected values of atmospheric emissions.

Ganymede's atmosphere is produced by charged particle erosion and sublimation of its icy surface. Sublimation occurs when an ice changes directly into a gas without first turning into a liquid. The new observations find that H_2O is more abundant than oxygen when the Sun is directly overhead where its rays strike the surface most intensely.

"Sublimated water vapor at high noon on Ganymede, where the surface is relatively warm, is likely a key feature of the tenuous atmospheres of Jupiter's icy moons," said SwRI's Dr. Kurt Retherford, a co-author of the Nature Astronomy paper describing this research. "As we prepare to launch NASA's Ultraviolet Spectrograph (UVS) instrument, built and led by SwRI, aboard the European Space Agency's (ESA's) Jupiter Icy Moons Explorer (JUICE) mission next year, this new understanding of Ganymede's atmosphere will let us better plan our observations and enhance our the quality of the scientific data we gather."

Scientists expect that molecular oxygen is globally the most abundant constituent in Ganymede's atmosphere, as it is gravitationally bound, stable and less likely to react with surface materials.

"It's interesting to think of an atmosphere that has a very different composition on its dayside relative to its nightside, with completely different processes driving the production of gases at different locations," said Dr. Philippa Molyneux, an SwRI co-author. "Imagine if Earth's atmosphere worked that way, and how life might have evolved to adapt to that changing environment."



SwRI's Lunar Interior Temperature and Materials Suite will be one of two investigations to land on the far side of the Moon — a NASA first — here in Schrodinger's basin, to study the thermal evolution, differentiation and asymmetry of Earth's closest neighbor.

IMAGE COURTESY LPI/USRA/NASA

Landing on the Far Side of the Moon

To advance understanding of Earth's nearest neighbor, NASA has selected three new lunar investigations, including a payload suite led by SwRI. The Lunar Interior Temperature and Materials Suite (LITMS) is one of two packages that will land on the far side of the Moon, a first for the agency, as part of NASA's Commercial Lunar Payload Services, or CLPS, initiative.

"With LITMS, we hope to get a better understanding of the thermal evolution, differentiation and asymmetry of the Moon," said SwRI's Dr. Robert Grimm, LITMS principal investigator. "This will help us interpret how the lunar crust, mantle and core formed. And we can contrast these far-side measurements with those done by the near-side Apollo missions to unravel the origin of the 'Man in the Moon.'"

The moon is "tidally locked," meaning that one side is always facing Earth. The far and near sides of the Moon are remarkably different in crustal thickness, composition and cratering. The near side — the side we see — contains an area of high volcanic activity where lava has frozen into dark "seas" called maria. Nearly two-thirds of the maria are on the western near side of the Moon. Throughout history, people have linked the dark maria with fanciful shapes, including a "Man in the Moon" visage.

LITMS is headed to a far-side location chosen by NASA; specifically, the 200-mile diameter Schrödinger basin located in the ancient South Pole-Aitken basin. The suite includes two instruments: The Lunar Instrumentation for Thermal Exploration with Rapidity (LISTER), led by Texas Tech University, and the Lunar Magnetotelluric Sounder (LMS). LISTER measures heat flow using a pneumatic drill to probe up to 10 feet into the subsurface. LMS will determine the electrical conductivity of the Moon's interior by measuring natural electric and magnetic fields.

"Joint measurements of heat flow and electrical conductivity allow us to separate the temperature and material dependence of each," Grimm said. LITMS is scheduled to launch in 2024.

LAD FLIES AGAIN

Blue Origin's New Shepard suborbital rocket launched from Van Horn, Texas, August 26 carrying five variations of the SwRI-developed tapered liquid acquisition device (LAD) for testing. Designed to safely deliver liquid propellant to a rocket engine from fuel tanks, the devices must be evaluated in microgravity.

SwRI collaborated with NASA to develop the tapered LAD in the late 1990s and early 2000s as part of cryogenic fluid management capabilities for long spaceflights. Most rocket engines use cryogenic liquid propellants as fuel. A long spaceflight would require large amounts of fuel to be stored at low temperatures and then transferred to the rocket engine, but the straight channels in current LADs are vulnerable to internal vapor bubbles.

"LADs have historically been used in spacecraft, but low-gravity cryogenic applications require a more robust design for managing internal vapor bubbles," said Kevin Supak, the project's principal investigator. "The tapered LAD is being developed to offer a simple, low-cost solution to delivering vapor-free liquid to a fuel tank or an engine."

Supak, along with SwRI engineers Dr. Amy McCleney and Steve Green, designed the LAD's tapered channel, which passively removes the bubbles through surface tension. This is the third time SwRI has tested the LAD aboard Blue Origin's New Shepard rocket. The 10-minute flight was ideal for the experiment, providing roughly three minutes of high-quality microgravity, significantly more than the 25 seconds of microgravity achieved in parabolic flights.

The team tested five different versions of LAD to see if the angle or surface properties affect the device's ability to passively remove gas bubbles in microgravity. A camera recorded the behavior of vapor bubbles inside the five LADs.

"Every test moves us closer toward what we believe a tapered LAD inside an actual rocket would look like," McCleney said.

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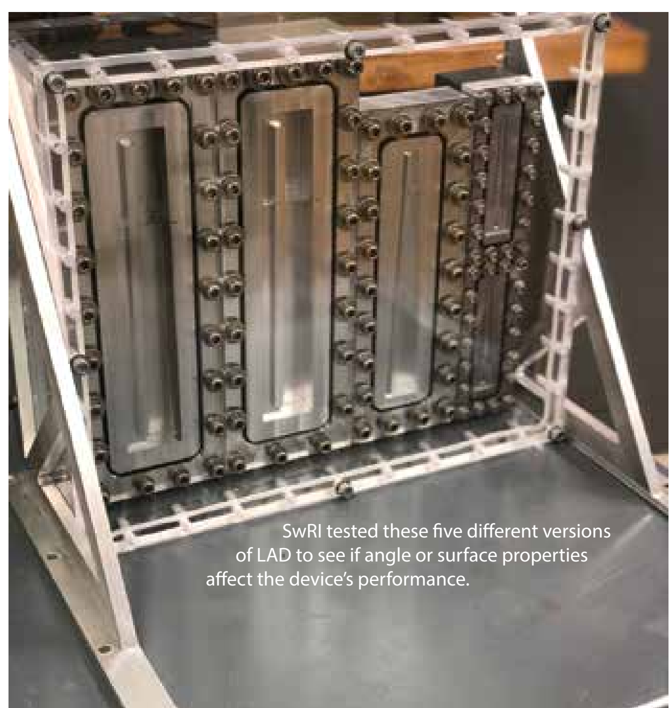


SwRI tested these five different versions of LAD to see if angle or surface properties affect the device's performance.

AUTOMATING ARMY VEHICLES

SwRI has received an indefinite delivery, indefinite quantity (IDIQ) contract worth up to $34 million over five years to support the U.S. Army Ground Vehicle Systems Center through research and development of autonomous and robotic vehicles.

"SwRI is proud to continue developing the latest autonomous and robotic systems for the U.S. military," said Joseph Hernandez, a principal engineer overseeing the program. "This IDIQ contract offers a more direct link to our end customers and allows us to provide innovative solutions to support our warfighters."

Through the Defense Technical Information Center Information Analysis Center Multiple Award Contract, SwRI will support project management, research and development, modeling and simulation, software development, systems integration, testing and data analysis services, focusing on robotics and autonomous systems.

D025097

SwRI's work focuses on developing autonomous capabilities on mobile platforms ranging from compact, purpose-built autonomous vehicles to automated high-mobility, multipurpose wheeled vehicles (HMMWV) and larger tactical vehicles. The Institute also has developed aerial drones integrated with military ground vehicles.

SwRI began developing automated vehicle technology in 2006 through a multidisciplinary internal research program, the Mobile Autonomous Robotics Technology Initiative, or MARTI. The project has evolved to serve military and commercial clients with development of automated systems using sensors, machine learning and connected and automated vehicle technologies.

For more than a decade, SwRI has supported the Army with development of autonomous vehicle systems. These robotic systems have been integrated onto more than 15 unique military ground vehicle platforms, some of which were deployed overseas as part of the Dismounted Soldier Autonomy Tools program. SwRI also played a key role in developing the Robotic Technology Kernel, an autonomy software library that provides a set of common robotic capabilities across a variety of vehicle platforms.

SEARCHABLE ADDITIVE MANUFACTURING DATABASE

SwRI is creating a searchable database of additive manufacturing (AM) projects and components. Funded with $50,000 from America Makes, the project will use data management tools that were created through SwRI's internal research program.

Additive manufacturing is a novel process that uses 3D printing, or rapid prototyping, to build an item by layering plastic, metal and other materials using a computer-generated design. The additive manufacturing industry is expected to grow to $51 billion by 2030, according to an April 2021 report by Lux Research. Because it creates sturdy components with intricate design qualities, additive manufacturing appeals to a wide range of users, including the aerospace, medical and manufacturing industries.

"Additive manufacturing is a complex process," said SwRI Research Engineer Shengyen Li. "There are hundreds of variables involved, so a searchable database would be an exceptional tool."

AM projects begin as computer-aided design models, which can be uploaded into 3D printers to produce metal and plastic components. Using an existing database of more than 200 AM projects, Li will use an SwRI-developed tool to add metadata and keywords from the files into the database to make them searchable.

"It's a potential gold mine," said Li, a member of SwRI's Materials Engineering Department, which is leading several additive manufacturing research projects. "With a searchable database, if you're creating an engine blade using additive manufacturing, you could search the database for similar designs instead of starting from scratch."

The searchable database will be available to members of America Makes, the nation's leading public-private partnership for AM technology and education. More than 200 members from industry, academia, government, workforce and economic development organizations work together to accelerate the adoption of AM and the nation's global manufacturing competitiveness.

D025096

SwRI used additive manufacturing to create this build of its logo. With funding from America Makes, SwRI will create a searchable database of additive manufacturing projects and components, using internally funded data management tools.

WEBINARS, WORKSHOPS and TRAINING COURSES HOSTED by SwRI:

Life-Cycle Analysis for Transportation, November 3–4, 2021. Virtual symposium.

Tribology and Lubrication for E-Mobility Conference, November 3–5, 2021, San Antonio. In-person/virtual conference.

Pulsation Analysis — API 618 Requirements, Modifications to Legacy Units, Mixed Compression, November 3, 2021. Free webinar.

Gas Turbine & Compressor, November 15–18, 2021, San Antonio. In-person short course.

Rotordynamics Tutorial, November 17, 2021. Free webinar.

Gas Turbine RCFA, December 1, 2021. Free webinar.

Lateral & Torsional Rotordynamics, December 7–8, 2021, San Antonio. In-person short course.

Developments in Non-Battery Grid-Scale Energy Storage, December 8, 2021. Free webinar.

ISO 9001 Internal Auditor, December 9–10, 2021. Virtual course.

Purchasing and Supply Management, January 10–February 8, 2022 (Mondays and Wednesdays). Virtual course.

ASCM Supply Chain & Operations Management, January 11, 2022. Virtual course.

CONFERENCES/MEETINGS:

ASNT Annual Conference, Phoenix, November 15, 2021. Booth No. 659.

Aircraft Structural Integrity Program (ASIP) Conference (hybrid), Austin TX, November 29, 2021. Booth No. 3.

ITS America Annual Meeting, Charlotte NC, December 7, 2021. Booth No. 1311.

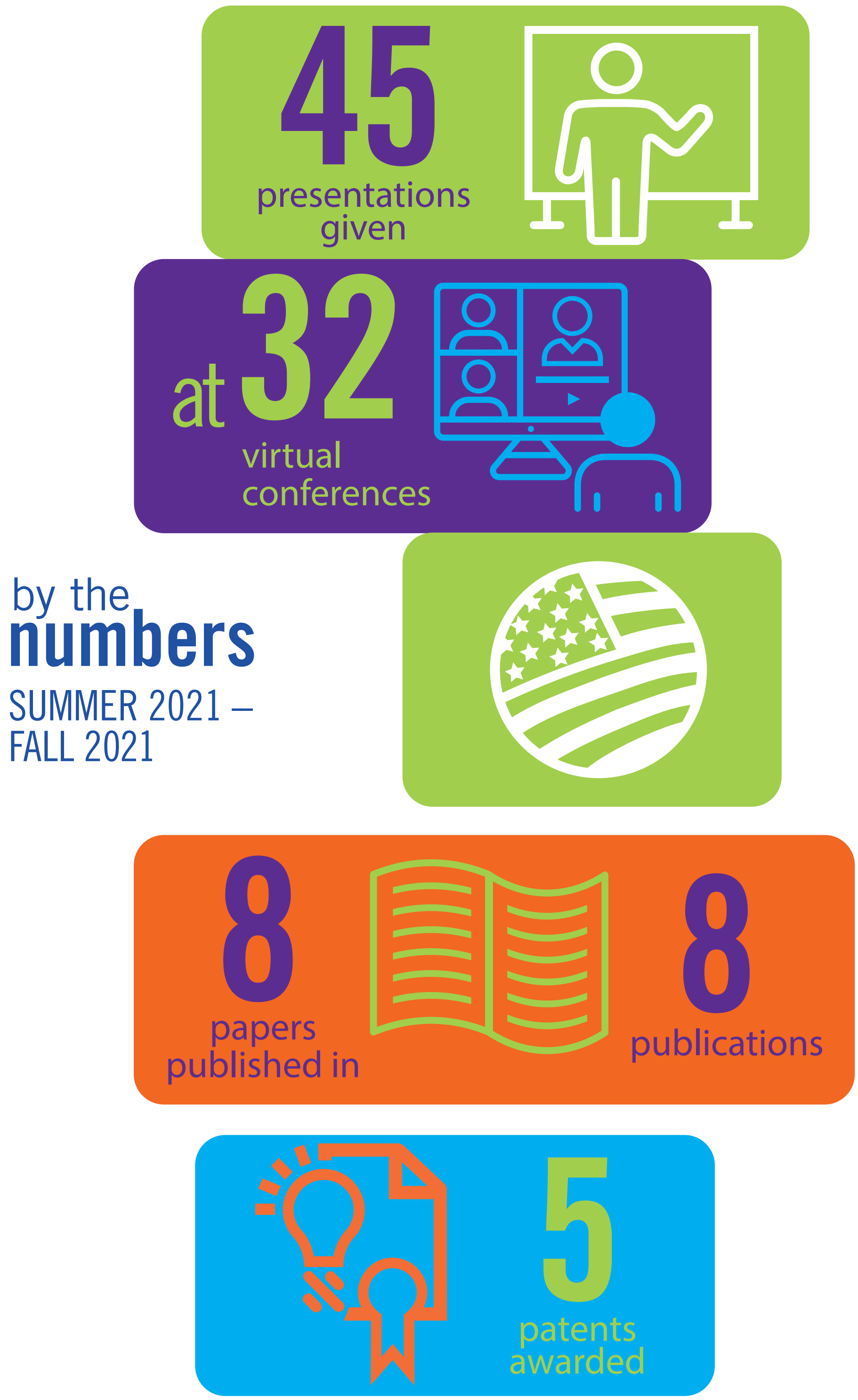
Defense Manufacturing Conference (DMC), Aurora CO, December 13, 2021. Booth No. 331.

Turbomachinery & Pump Symposia, Houston, December 13, 2021. Booth No. 1720.

Feedwater and Secondary Systems Reliability Users Group (FSRUG) Conference, San Antonio, January 17–20, 2022.

Automotive World, Tokyo, Japan, January 19–21, 2022.

PrecisionAg Vision Conference, Glendale AZ, January 21–22, 2022.

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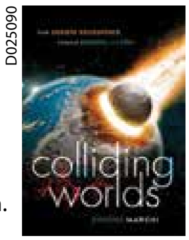
Vice President Dr. James L. Burch was selected to receive the American Geophysical Union's 2021 William Bowie Medal, the organization's highest honor, on behalf of the Earth and space science community. The medal honors Burch's pioneering achievements and contributions to the frontiers of Earth and space science.


D025080

Technical Advisor Dr. Gordon Johnson received the Belytschko Medal from the U.S. Association for Computational Mechanics at the organization's recent biennial meeting. The medal recognizes outstanding and sustained contributions to computational solid mechanics.


D022612

Principal Scientist Dr. Simone Marchi has published a new book, "Colliding Worlds: How Cosmic Encounters Shaped Planets and Life." The book presents the emerging story of how cosmic collisions shaped both the solar system and our own planet, from the creation of the Moon to influencing the evolution of life on Earth.



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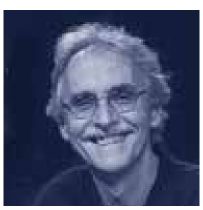
Senior Research Engineer Dr. Amy McCleney has been named to the inaugural class of Offshore Technology Conference (OTC) Emerging Leaders, a group of young professionals who are making key contributions to the offshore energy sector in their field of work, service to the industry, innovation and focus on safety.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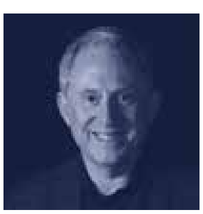
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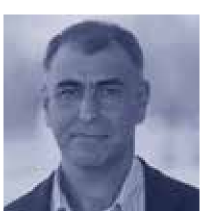
Three SwRI Scientists have been named 2021 Fellows of the American Geophysical Union (AGU), which recognizes exceptional scientific contributions in the fields of Earth and space science. Institute Scientist Dr. John Spencer was recognized for his studies of moons and other small bodies of the outer solar system, particularly the nitrogen frost on Pluto and Triton, water frost on Jupiter's moons and heat radiation from asteroids. Dr. Roy B. Torbert, a program director in Southwest Research Institute's Earth, Oceans, and Space Department at the University of New Hampshire in Durham, was recognized for his work in heliophysics, particularly the interaction between the solar wind and the Earth's magnetosphere. Associate Vice President Dr. Alan Stern was recognized by the AGU for leading the NASA's New Horizons mission, which made headlines worldwide over several years when the spacecraft returned fascinating data and imagery of Pluto, its moons and Kuiper Belt object Arrokoth. Stern was also named an Associate Fellow of the American Institute of Aeronautics and Astronautics (AIAA), AIAA Associate Fellows, which honors individuals advancing the aerospace profession.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Dr. Sidney Chocron, manager of SwRI's Computational Mechanics Section, was also named an AIAA Associate Fellow, recognizing his work in numerical and computer modeling of ballistic impacts, most recently in the emerging field of hypersonics.

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TECHNOLOGY **TODAY**

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