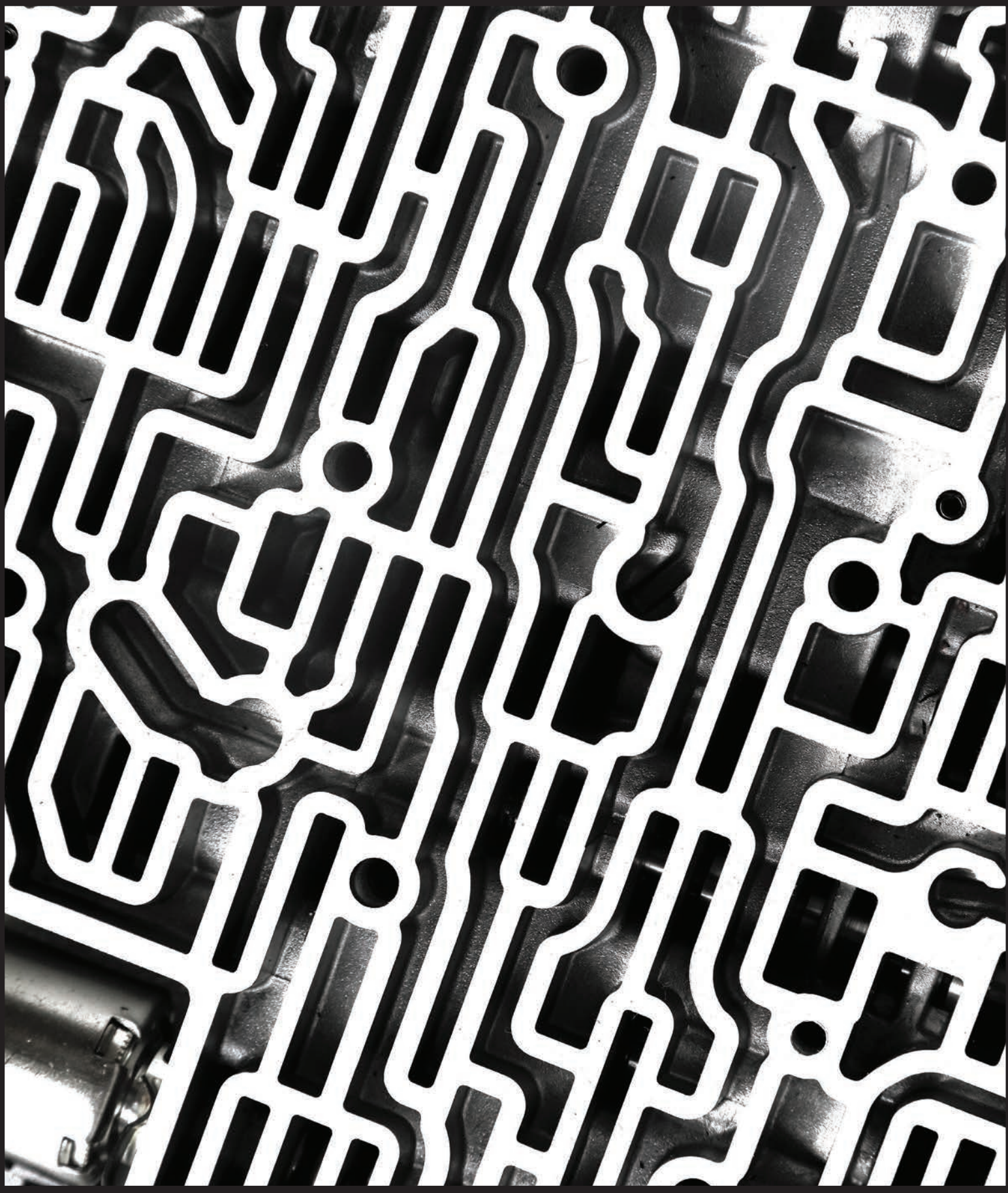

SOUTHWEST RESEARCH INSTITUTE®

2019 ANNUAL REPORT

SUPPORTING INNOVATION

To craft innovations in 2019 and beyond, Southwest Research Institute maintains extensive fabrication facilities and capabilities to create the custom components and fixtures needed for our science and applied engineering programs, from deep sea to deep space. Our master machinists and craftspeople create everything from micro-sized parts to large integrated systems using materials such as titanium, alloys and ceramics. State-of-the-art fabrication equipment includes computer-aided design (CAD) and computer numerical controlled (CNC) turning, milling and machining devices, as well as 3D printers capable of creating complex plastic and metal parts.

D024047_9892

SwRI's main machine shop created this small-scale impeller to evaluate how inlet flows associated with pipe elbows affect the performance of centrifugal compressors such as those found in natural gas compressor stations.

For decades, SwRI has developed and fabricated hundreds of shipboard direction-finding antennas for the U.S. Navy and allies. These complex, rugged devices are built from precise components fabricated in SwRI's main machine shop from aluminum alloys.

SwRI 3D printed this electrostatic analyzer component from a heat-resistant, high-strength resin. Using a magnetron sputtering technique, engineers then coated the component with gold, which allows the instrument to focus or "filter" the range of particles targeted for detection and measurement in space.

SwRI's model shop made these reflectron ring electrodes and shaped ion buncher, parts of SwRI's novel MASPEX instrument. The state-of-the-art mass spectrometer will fly on NASA's Europa Clipper mission, collecting samples of the tenuous atmosphere around Jupiter's moon Europa.

SwRI's selective laser melting device produces complex metal components using additive manufacturing technology. The 3D printing device created novel liquid cooling jackets to investigate whether intricate internal geographies (shown in this cross section) could enhance cooling of modern internal combustion engines.

D023876_2171-Sm

ON THE COVER:
For more than 70 years, a significant portion of Southwest Research Institute has been assessing vehicles and the fluids they need to run efficiently. Nearly 400 staff members are engaged in fuels and lubricants research, development and evaluation, operating hundreds of automotive test stands 24 hours a day, seven days a week, 365 days a year. We serve the automotive industry looking at nearly every aspect of a vehicle, including the fluids distributed by the transmission valve body pictured.

PRESIDENT'S MESSAGE

I am pleased to present another outstanding issue of the Southwest Research Institute Annual Report. This report provides insight into some of our technical successes and summarizes the financial accomplishments of Fiscal Year 2019. Unlike previous years, we have organized the technical content by client service areas to highlight the unique value the Institute can provide when we combine the competencies of multiple technical divisions to solve problems. This client-based perspective is much different than the usual operating division-based organization of the Annual Report. I hope this new viewpoint gives you a better sense of the tremendously important impact of Southwest Research Institute on some of humankind's most challenging problems, from Deep Sea to Deep Space®.

On the first day of 2019, the SwRI-led New Horizons mission performed humankind's most distant exploration as it flew by Arrokoth, a Kuiper Belt Object approximately four billion miles from the Earth that was previously known as 2014 MU69 or Ultima Thule. While flying by Arrokoth, NASA's New Horizon's spacecraft collected important data that is already helping us get a better understanding of the origin of our solar system, and others. And this mighty explorer now continues to work perfectly while on its one-way mission to the edge of our solar system and beyond. In contrast, SwRI was tapped by the Royal Australian Navy to develop a state-of-the-art remotely operated submarine rescue system. The system will feature both shallow and deep-water vehicles designed to connect with disabled submarines to rescue those trapped on board. Deep Sea to Deep Space is not hyperbole at Southwest Research Institute.

Other research highlights of the year include advancing novel electric energy generation and energy storage systems, as well as evaluating the fire resistance of novel construction materials. In another fast-moving field, our ballistics experts achieved speeds approaching Mach 15 with our light gas gun, which is being used for groundbreaking research in hypersonic flight. SwRI is also advancing the state of the art in

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cybersecurity for today's increasingly computerized vehicles, evaluating threats to onboard GPS receiving technology, and developing intrusion detection and isolation systems for commercial and military vehicle networks.

Two SwRI programs were selected as 2019 R&D 100 Award winners. Every year, the 100 most significant innovations are recognized by R&D Magazine, and the awards ceremony is sometimes referred to as the international "Oscars of innovation." SwRI's Lotus Superhydrophobic Compositions and Coating Process (LotusFlo™) and AF-360 VHF/UHF Terrestrial Direction-Finding Antenna were selected this year, bringing SwRI's tally to 45 R&D 100 Awards since 1963.

The fight against disease stimulated a collaborative effort by San Antonio's four largest research institutions to create the new San Antonio Partnership for Precision Therapeutics. The partnership will focus on breakthrough treatments that can benefit specific patient populations or provide devices and therapies for individualized patient care. Other collaborators include UT Health San Antonio, Texas Biomedical Research Institute and The University of Texas at San Antonio.

While our research portfolio is quite broad, our focus continues to be on serving our clients and satisfying our mission. By using this strategy, we have enjoyed successive years of growth — growth that is necessary to keep our organization healthy and enable our staff to thrive. And while our research highlights are critically important, our staff also works hard to enter new research areas and apply innovative business strategies to grow our research programs. As a nonprofit research organization, we put our net income to work by funding internal research projects, modernizing our laboratories and facilities, and adding staff members to assist with our mission. As we begin Fiscal Year 2020, we enjoy a sizable backlog of funding and contracts and expect new opportunities to arise as we maintain our commitment to be our clients' first choice for independent advanced science and applied technology solutions.

We are thankful for the support of our dedicated Board of Directors and talented Board of Advisory Trustees. And again, I want to acknowledge our incredible staff, without whose work and dedication we could not accomplish the great achievements of the past year. This next year we will continue to advance the Institute's mission and maintain our reputation for excellence in innovation.

Adam L. Hamilton, P.E.
PRESIDENT & CEO

IR&D 2019

As a nonprofit research and development organization, SwRI uses part of our net income to invest in tomorrow's innovations, to broaden the Institute's technology base and to encourage our staff's professional growth.

In 2019, SwRI initiated 106 new projects, investing more than $8 million in internal research. These efforts include focused research programs, such as the Metals Additive Kickoff Emphasizing Research Synergies (MAKERS), designed to advance SwRI capabilities in emerging additive manufacturing applications. IR&D fulfills the Institute's objective of conducting innovative activities for the benefit of industry, the government and humankind.

DSC_0218

Geologists use internal funding to study outcrops in the Wichita and Arbuckle uplifts to understand natural deformation and hydraulic fracturing in Oklahoma's Anadarko Basin.

DOM23909_9252

SwRI is building the Compact Dual Ion Composition Experiment (CoDICE) for NASA's Interstellar Mapping and Acceleration Probe mission. Developed using IR funding, CoDICE combines the capabilities of multiple instruments into one patented sensor that weighs about 22 pounds.

MILESTONES 2019

673 PAPERS published

PRESENTATIONS GIVEN **318**

HONORS

Dr. Christopher Freitas: ASME 2019 Patrick J. Higgins Medal
Adam L. Hamilton, P.E.: Named American Association for the Advancement of Science (AAAS) Fellow
Dr. Peter Lee: Elected Institution of Mechanical Engineers Fellow
Dr. Kelsi Singer: Received 2019 Harold C. Urey Prize from the American Astronomical Society's Division for Planetary Sciences
Dr. Alan Stern: Appointed to the National Science Board

SwRI's AF-360 VHF/UHF Terrestrial Direction-Finding (DF) Antenna measures the angle of arrival of signals across the VHF/UHF radio frequency spectrum. Its novel sleeved electric dipoles boast 80% more usable bandwidth than conventional dipoles, providing 10 times the sensitivity of other commercially available DF antennas at significantly reduced cost and complexity.

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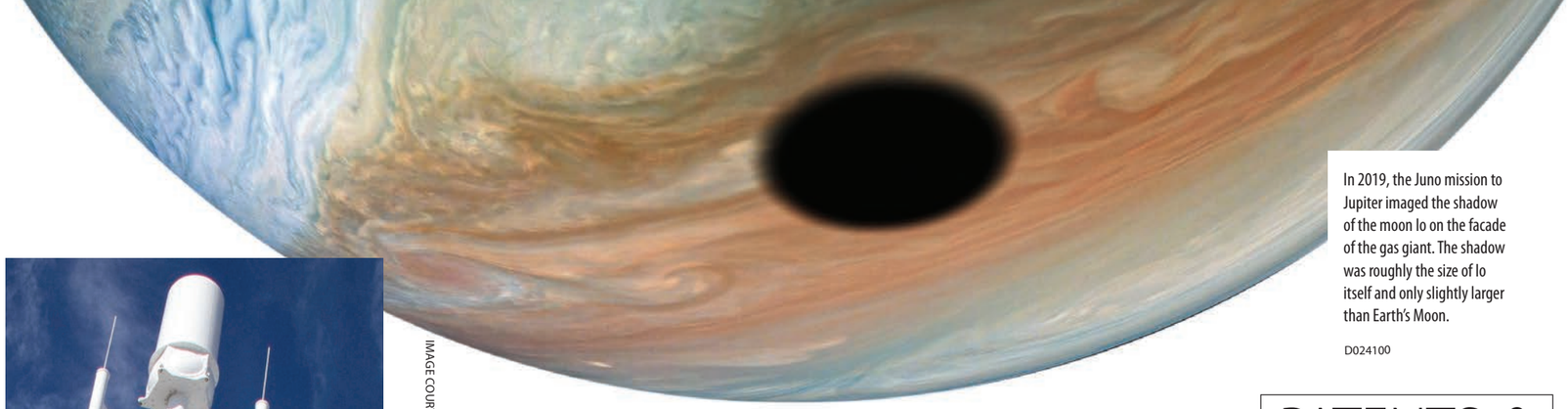


IMAGE COURTESY NASA/JPL-CALTECH/SWRI/MSSS/KEVIN M. GILL

In 2019, the Juno mission to Jupiter imaged the shadow of the moon Io on the facade of the gas giant. The shadow was roughly the size of Io itself and only slightly larger than Earth's Moon.

D024100

AWARDS

Dr. Terry Alger: 2019 Edith and Peter O'Donnell Award in Technology Innovation from The Academy of Medicine, Engineering and Science of Texas
Dr. Amanda Bayless: 40 Under 40 Award, San Antonio Business Journal
Dr. Scott Bolton: Smithsonian Magazine's American Ingenuity Award
Matthew Herron: National Safety Council Rising Stars of Safety Award
Henry Sees: Association of Old Crows Lifetime Achievement Award
George Wilson: ASTM Award of Merit and Fellow

PATENTS & inventions

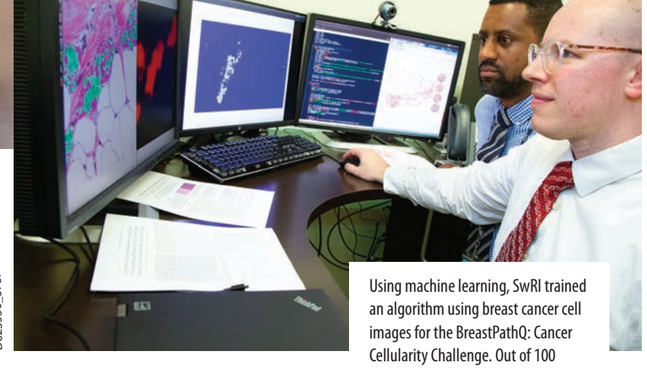
41 U.S. PATENTS awarded

U.S.PATENT applications filed **33**

48 INVENTION disclosures submitted

D024098

SwRI's Lotus Superhydrophobic Compositions and Coating Process (LotusFlo™) creates superhydrophobic coatings, designed to repel substances that often clog production piping used in offshore oil wells. The coating process involves linking 40-foot sections of pipe, creating vacuum conditions inside and accelerating ionized molecules onto the interior surfaces to create a glass-like coating.



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Using machine learning, SwRI trained an algorithm using breast cancer cell images for the BreastPathQ: Cancer Cellularity Challenge. Out of 100 submissions, our algorithm placed first in the international challenge to automate breast cancer cell detection.

2,749 EMPLOYEES

285 DOCTORATES
549 MASTERS
789 BACHELORS
258 ASSOCIATES

R&D 100 AWARDS

In 2019, SwRI won two R&D 100 awards, which recognize the 100 most significant innovations for the year.

Last year, vehicles transported 11 billion tons of freight, more than $32 billion worth of goods each day, and moved people more than 3 trillion vehicle-miles. Southwest Research Institute is involved in nearly every facet of automotive and transportation research, from powertrains to fuels and lubricants to intelligent highways and connected and automated vehicles. We also research power systems, emissions and fluids for heavy-duty, locomotive, marine and aircraft engines.

D023876_2025

SwRI outfitted this new lubricant test cell with an electrically regenerative loading system to push power generated by the Class 8 truck engine to the grid, reducing SwRI's electrical burden.

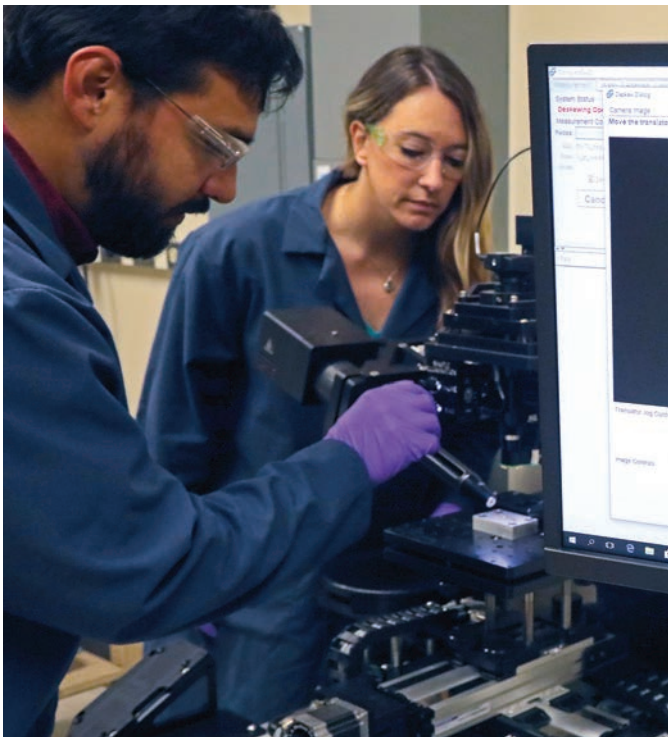
DRIVING AUTOMOTIVE & TRANSPORTATION INNOVATION

AUTOMOTIVE

New technical options are dramatically changing how the commercial and passenger vehicle industry is addressing traditional emissions and fuel economy challenges. For example, the commercial vehicle industry is now pursuing electrification for both on- and off-road equipment. New areas of SwRI research include using automated and connected vehicle technology to reduce emissions, while conventional engines and emissions technologies continue to present new challenges.

The electrification of heavy-duty vehicles today is probably where light-duty hybrid vehicles were 20 years ago. As we help the industry electrify heavy-duty vehicles, we've discovered the scale-up process is not linear. The bigger the vehicle, the bigger the challenges are to electrify it. Somewhat surprisingly, some of our most promising new research in improving vehicle efficiency does not involve the engine or the vehicle, but rather the concept of connected powertrains.

As vehicle manufacturers strive for single-digit percentage improvements in energy efficiency, SwRI powertrain engineers



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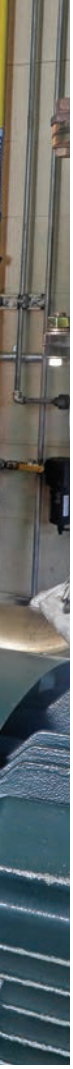

SwRI is working with a client to develop a unique diesel fuel formulation that significantly reduces both soot and oxides of nitrogen emissions. This is an important advance, considering that diesel emission control techniques typically involve a trade-off between NOx and soot reduction.

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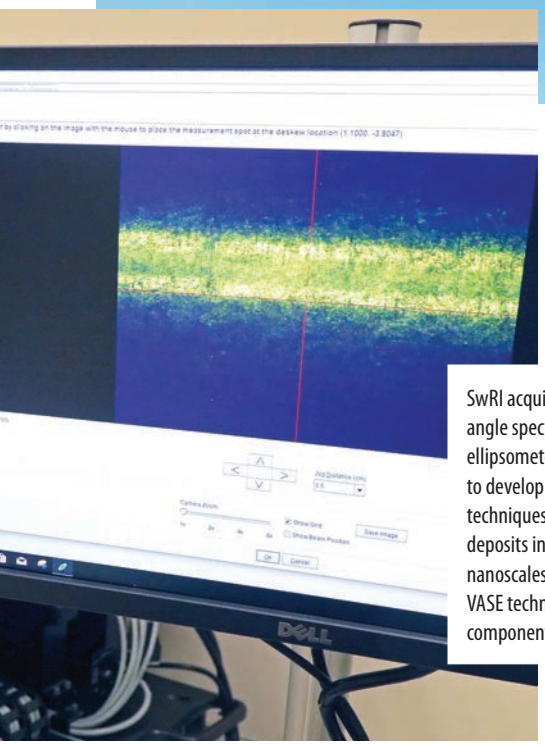


SwRI acquired a variable angle spectroscopic ellipsometer, or VASE, to develop efficient techniques for measuring deposits in fuel injectors at nanoscales. We plan to adapt VASE technology for other component tests.

are working with intelligent transportation specialists to use connected vehicle technology to produce almost 20% energy savings. Connected vehicles share information with other vehicles and roadway technology to improve traffic flow. Now the technology is allowing the Advanced Research Projects Agency–Energy NEXTCAR program to produce more than 15% savings on dynamometer tests and 30% in simulations. This represents a higher impact by an order of magnitude over typical incremental engine or transmission improvements. Two years into this three-year program, NEXTCAR project results are exceeding the 20% goal. Follow-on work awarded with the DOE Vehicle Technology Office includes adding situational awareness at intersections.

As the diesel engine continues to move most of the world's freight, SwRI is developing some of the cleanest and most fuel-efficient technology to date. A multiclient collaborative heavy-duty engine program demonstrated a 90% reduction in tailpipe NOx emissions while also achieving a 3% reduction in diesel consumption and greenhouse gas emissions. SwRI uses a systems approach to integrate novel engine, aftertreatment and control technologies with several advanced hardware technologies, including new catalyst formulations and configurations and a valvetrain-based cylinder deactivation system. Another key to the development is an internally developed model-based aftertreatment control system.

As part of the Clean High-Efficiency Diesel Engine (CHEDE) VII Consortium, SwRI is closing in on 50% heavy-duty diesel engine efficiency while achieving ultra-low tailpipe emissions. Combining combustion and boost system improvements with friction-reducing technology is helping meet this goal. The next phase, CHEDE-8, launched in November 2019.

Natural gas engines offer a low-cost pathway to near-zero emissions but are not as efficient as their diesel counterparts. Using dedicated exhaust gas recirculation (D-EGR®) technology, SwRI is working with the California Energy Commission to improve the efficiency of a compressed natural gas engine by 10% while maintaining near-zero NOx emissions using a three-way catalyst. A 10% improvement in efficiency would make operational costs comparable to diesel at a lower initial cost, reducing the overall cost of ownership.

SwRI is conducting a demonstration project using on-board spark plug-sized exhaust sensors to evaluate measurement methods to address future emissions regulations. The program grew out of SwRI's Particle Sensor Performance and Durability Consortium, which used miniaturized sensors to study particulate matter, NOx and NH_3. Initially funded by SwRI internal research, the technology transmits sensor data to a cloud server to collect, integrate and analyze real-world data. An industry-based manufacturers' association funded expansion of this work to ultimately improve enforcement of future emissions

SwRI's longest running research consortium is demonstrating a diesel engine using a combination of combustion and boost system improvements as well as friction reduction technology to reach 50% efficiency.

D024025_3393

regulations, protecting the public from exposure to dangerous levels of air pollution.

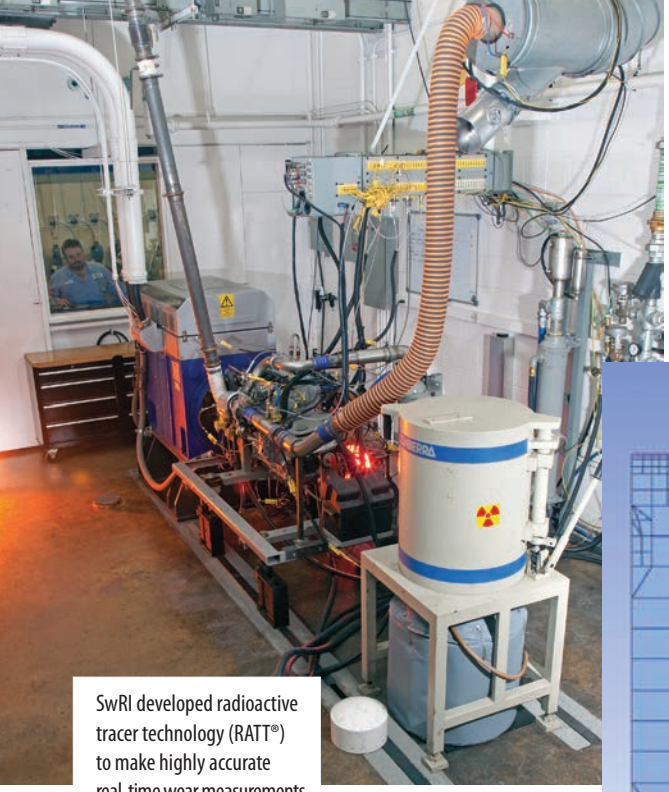
Following months of facility, equipment and calibration audits, SwRI became the first lab outside China to be granted permission to conduct certification testing for Chinese marine engines. Since then, SwRI has received several million dollars in project work to advance China's air quality goals.

In 2019, an internally funded project developed a mobile version of SwRI's Direct Electronic Control (DEVCon™) system to automate on-road vehicle fuel economy testing. We adapted the research for a National Renewable Energy Laboratory and commercial client project comparing two different powertrains for delivery vehicles using a complex three-hour test cycle that simulated an eight-hour delivery day. The Mobile DEVCon system repeatably replicated the complex cycle, run after run, with precision far beyond a human driver's capability.

Using an engine outfitted with both port and direct fuel injection systems, SwRI engineers used internal funding to implement a selective interrupt and control system that seamlessly allows the engine to operate with any combination of injection scenarios. The system also can modify fuel pressures, cam phasing, ignition timing and other engine control parameters, allowing engineers to cost-effectively evaluate how different calibration strategies affect engine performance and emissions.

For the Coordinating Research Council, we developed and demonstrated a new test that significantly reduces the time and fuel needed to evaluate internal deposits on diesel engine fuel injectors. Traditionally, these tests relied on visual assessments to characterize deposits, requiring hundreds of hours of testing using several thousand gallons of fuel. Adapting technology from the microchip manufacturing industry decreased that to seven hours and about seven liters of fuel. Using a variable angle spectroscopic ellipsometer, or VASE, engineers can measure deposits at nanometer scales, well below what a human eye can discern. We plan to adapt VASE technology to other component tests.

As the industry develops more durable materials and better friction-reduction technology for an engine's moving parts, lubricant manufacturers seeking to improve their products must search for what amounts to a finer needle in a larger haystack. To upgrade a gasoline wear test, engineers are replacing mechanical wear-measuring instruments with radioactive tracer testing, a technology that SwRI helped pioneer. The project is mapping wear patterns between every pair of metal engine parts in contact with each other when an engine operates, such as timing chains, rings, cylinder liners and main bearings. Parts under study are irradiated selectively and then installed in an engine. As the engine runs, its lubricant is pumped through a chamber where radiation associated with worn-away metal from those parts is detected and measured precisely. SwRI hopes to integrate this improved measurement process into standardized tests.



SwRI developed radioactive tracer technology (RATT®) to make highly accurate real-time wear measurements for engine components.

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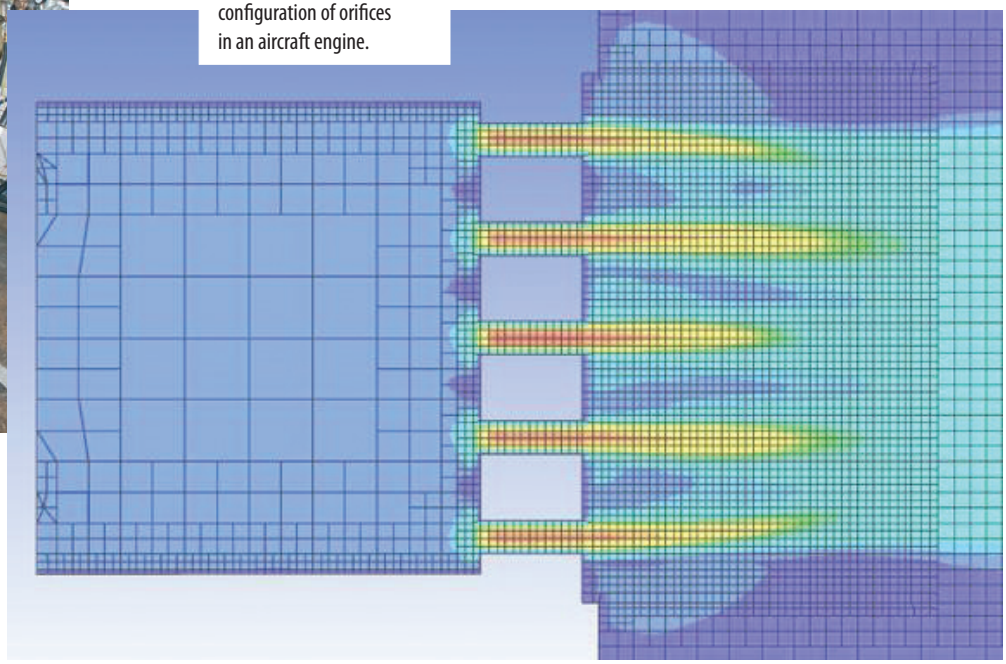
SwRI explores techniques to simulate, predict and control aerodynamic noise associated with turbulent gas flows. This simulation indicates noise intensity levels (red is highest) generated by a configuration of orifices in an aircraft engine.



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SwRI is using novel D-EGR technology to improve the efficiency of natural gas heavy-duty engines. Employing three-way catalyst technology, the engine will achieve near-zero NOx emissions.

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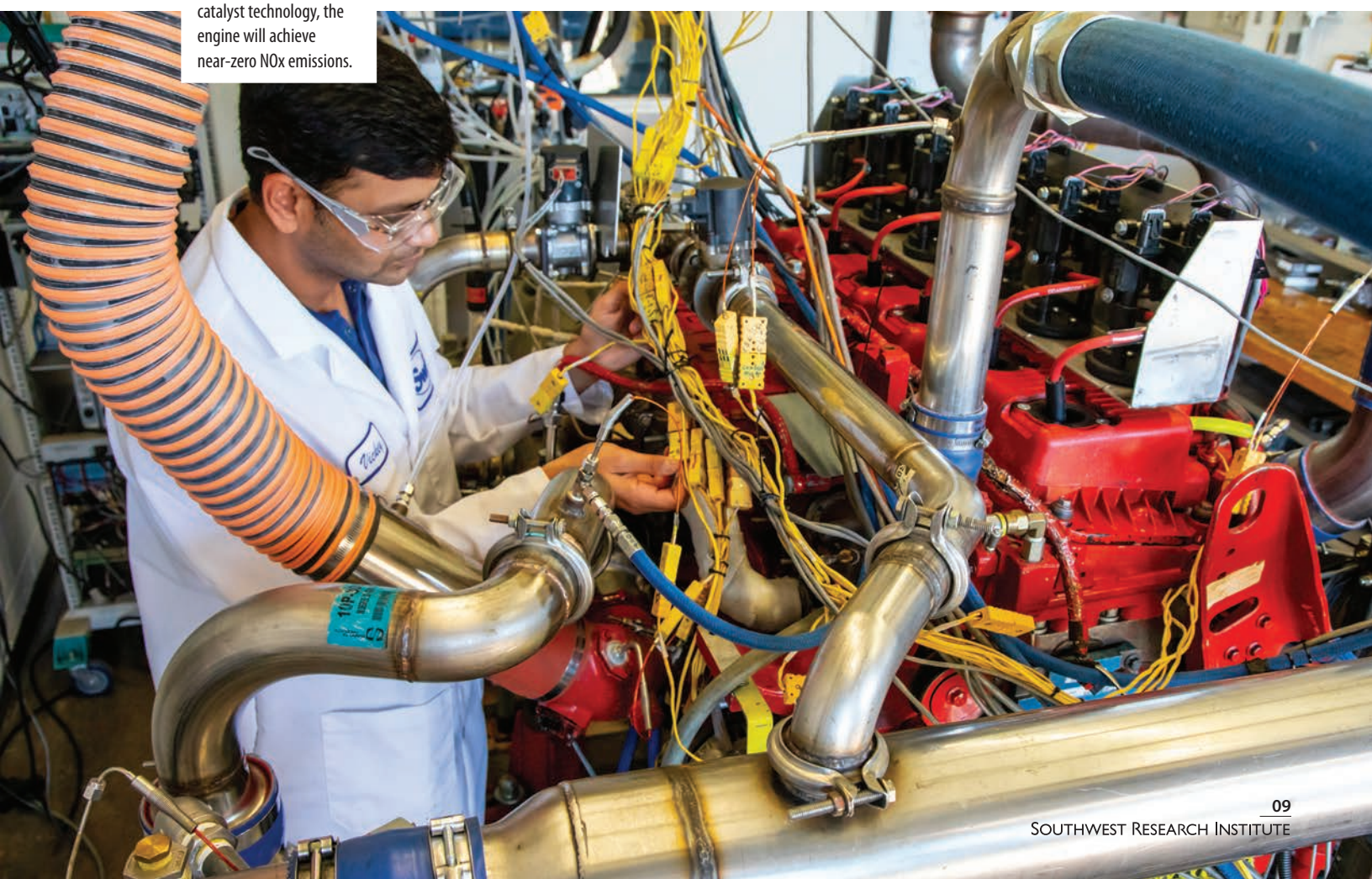


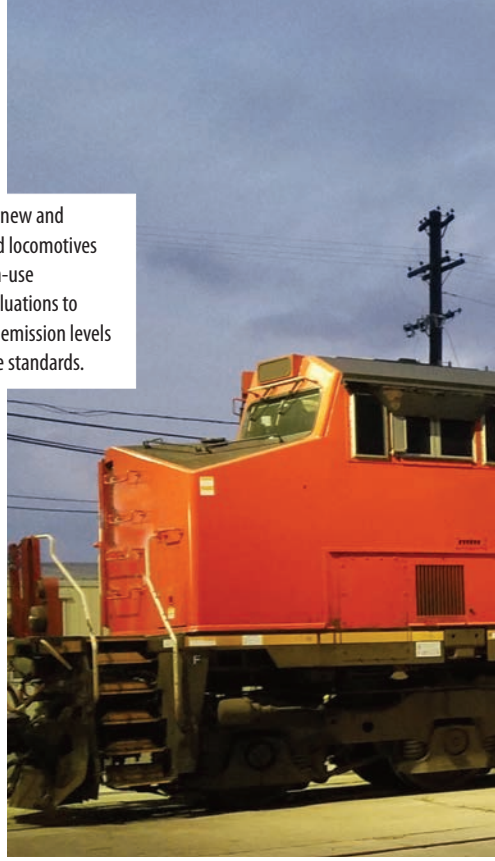
We are investigating how regenerative dynamometers for heavy-duty diesel engines could help SwRI improve its environmental impact. As test cell dynamometers absorb engine power, they produce friction heat, which is typically dissipated with water from a cooling tower, wasting both energy and water. Attaching the dyno to an electrical generator not only produces energy and water savings but also generates electricity that can be sent to the grid to offset SwRI's power consumption.

TRANSPORTATION

Building highways in U.S. cities can cost millions of dollars per lane, per mile, making it financially impossible to build our way out of traffic congestion. Instead, 12 states and Puerto Rico use SwRI's advanced transportation management system (ATMS) technologies to help traffic flow more efficiently and safely. In 2019, we deployed SwRI's ActiveITS™ ATMS software in New Mexico and Tennessee. For metropolitan regions, we are developing an integrated corridor management system to fuse real-time and historical traffic conditions from arterial, expressway and transit systems. The system uses traffic models and "big data" processing techniques to optimize route diversions and traffic signal timing for an entire region. We recently launched ActiveVision, a machine learning-based tool that uses existing roadside camera data to autonomously detect and report traffic conditions. ATMS applications include identifying wrong way drivers, detecting incidents and assessing traffic speed, density and volume.

In a related area, SwRI is also a leader in connected vehicle (CV) and automated driving technologies. Connected vehicles communicate with the infrastructure and other vehicles to enhance mobility and vehicle fuel efficiency. In 2019, we supported the installation of Georgia's comprehensive CV system in the Atlanta area, including 350 of over 1,700 dedicated short-range communication roadside units. SwRI is leading the extensive project, which includes configuring and integrating technology with existing traffic signal controllers, testing and validating systems interoperability, and ensuring standards compliance. In partnership with local agencies, we are developing a range of CV applications such as signal phase countdown, green speed recommendations, red light violation warnings, and signal prioritization and preemption for transit vehicles and emergency responders.

CV technology is a cornerstone for tomorrow's automated vehicles, which also use sensor and localization technologies to navigate and maintain roadway position. SwRI fuses these technologies for diverse applications, from passenger cars to military vehicles designed to keep soldiers out of harm's way. In 2019, SwRI worked with a commercial client to develop a low-cost, low-speed public personal mobility service using an automated golf cart. The application uses SwRI-developed localization technology to navigate via maps of road surfaces and a vehicle control server.



SwRI evaluates new and remanufactured locomotives and conducts in-use compliance evaluations to ensure exhaust emission levels meet applicable standards.

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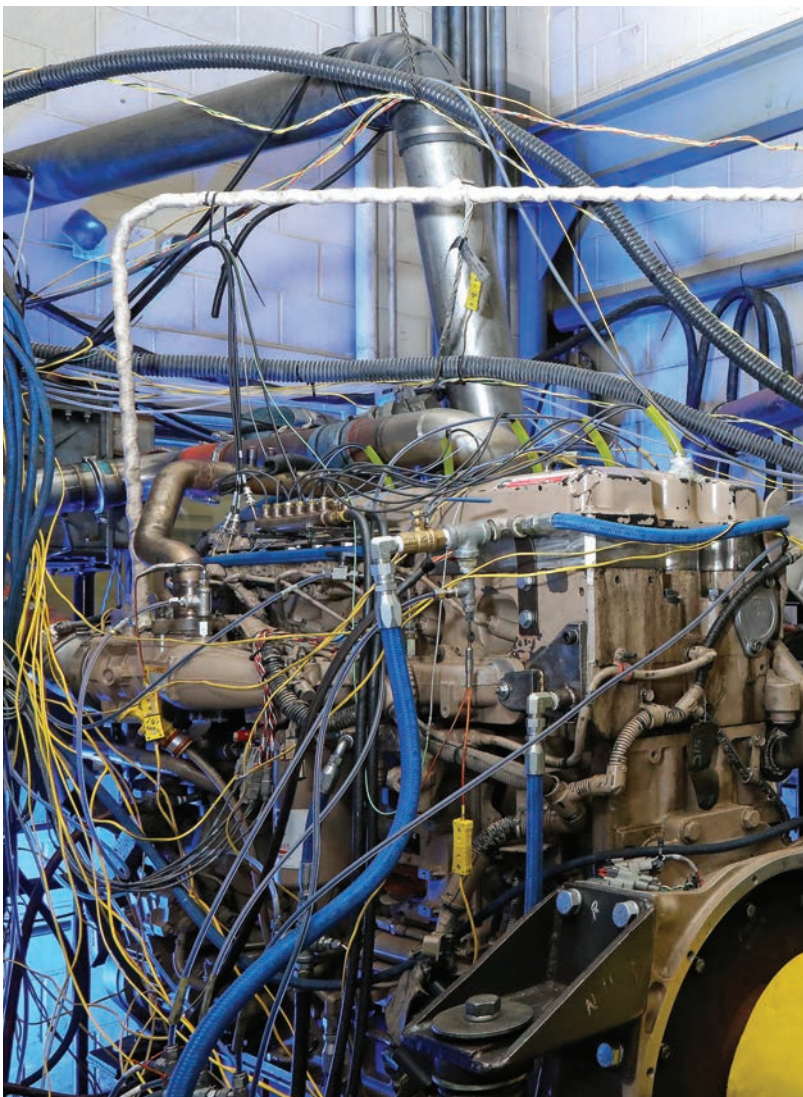

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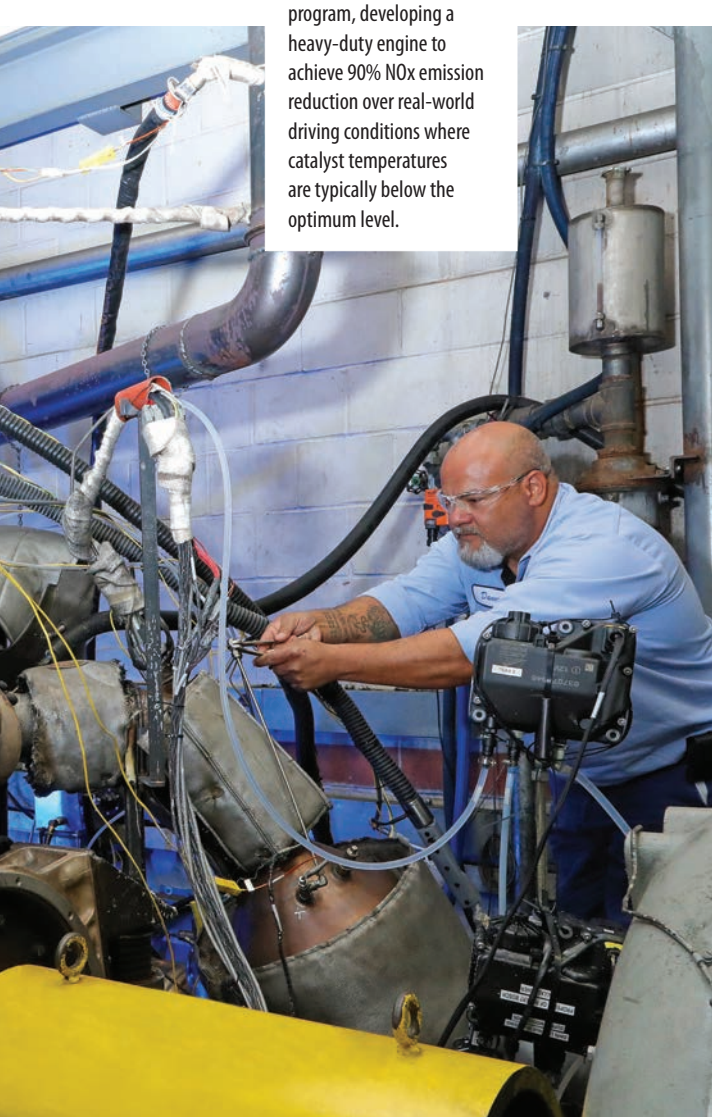
SwRI developed a heavy-duty, low-load cycle to evaluate emissions aftertreatment systems under real-world operating conditions. The graphs display emissions in real time.

In 2019, SwRI conducted a multiclient collaborative program, developing a heavy-duty engine to achieve 90% NOx emission reduction over real-world driving conditions where catalyst temperatures are typically below the optimum level.



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Engineers successfully installed and calibrated this antenna along with SwRI's first shipboard direction-finding system using parallel channel processing.

D022930_9225

DEFENSE & SECURITY SOLUTIONS

Almost since its inception, Southwest Research Institute has supported the U.S. military and homeland security, pushing the boundaries of engineering, electromagnetics and physics to create advanced technologies, software and systems that meet our clients' challenging demands.

DEFENSE

One of the longest-standing programs at SwRI is our research in radio frequency (RF) surveillance and communications intelligence, particularly in antennas and signals processing. Signals intelligence (SIGINT) specialists help U.S. and allied militaries gather communications intelligence, fueling capabilities in electronic warfare (EW) that use electromagnetic techniques to thwart adversarial operations.

For nearly 60 years, SwRI has developed and fabricated antennas, including radio direction-finding (DF) systems to discern the track of an RF signal. For the U.S. military, SwRI built and delivered several AF-369 DF antennas, now improved to operate at frequency ranges in excess of 9 GHz. These advanced systems sense and compensate for ionospheric conditions to improve RF geolocation capabilities. We also deployed new advanced airborne DF pods for military aircraft.

Software engineers analyzed various alternatives for geolocation technology to be deployed in 2020. This effort supports multidomain operations allowing the military to rapidly and continuously integrate the efforts of land, air, sea, space and cyber forces.

SwRI is evaluating a hydrophone sensor array compact enough to be worn by divers, assessing subsurface acoustic DF capabilities and the ability to communicate directional and audio information to the diver. We performed mathematical array modeling as well as array construction and open-water tests to develop algorithms that add directional cues to received audio in real time. Because this application targets waterborne sounds, cues must be modulated to be understood.

Electronic countermeasures (ECM) are signals designed to impede radar or other detection systems to prevent targeting. We developed a System Performance and Real Time Analysis (SPARTA) test system to verify ECM system performance with easy-to-understand, automated test solutions. Processing terabytes of sample

data in a short period, SPARTA's software is optimized for multiple false target analyses as well as ECM validation in a congested spectrum.

In 2019, we developed our Adaptive Threat Environment Acquisition (ATHENA) receiver, which rapidly detects all signals of interest, extracting signals from a single radar burst or in a congested or contested signal environment, acquiring radar and tracker parameters. We also developed and installed field kits for Canadian naval ships to upgrade shipboard climate research systems to meet specific technology standards.

Military aircraft fleets are aging, with the age of U.S. Air Force planes averaging 27 years. SwRI specializes in assessing airframe fatigue and upgrading old planes with new systems and electronics, in addition to developing new or improved support equipment.

For instance, maintenance equipment for a wide array of aircraft is aging and becoming less reliable, which can negatively affect military readiness. This year, we completed nationwide visits to U.S. Air Force bases supporting F-15 Eagle fighters to assess how access to support equipment impacts aircraft availability.

To maintain piloting proficiency, NASA astronauts use the T-38, the world's first supersonic trainer, which has been in service for more than 50 years. Components of this legacy aircraft must be periodically tested and proven reliable. In 1997, SwRI developed a T-38 aircraft-mounted and accessory drive test stand to autonomously perform generator and gearbox testing. In 2019, SwRI upgraded the control hardware and software to efficiently perform additional automated generator tests. Since the upgrade, NASA has used the test stand to support U.S. Air Force F-5 aircraft as well.

SwRI's two-stage light gas gun system (in background) reproduces realistic hypersonic flight conditions, from Mach 5 to 15. SwRI engineers used the system to study how hypersonic flight conditions affect a variety of materials and geometries.

D023986_0833

In 2019, SwRI delivered several AF-369 DF antennas to the U.S. military. Improvements allowing them to operate at frequency ranges in excess of 9 GHz make them particularly attractive to our international allies.

D024005_2124

The F107 engine used in missile systems employs an igniter and exciter system to fire engine plugs at critical intervals in flight. Traditionally, the Air Force tested the system on an engine running in a test cell. To save time and money, SwRI developed benchtop tests to assess the system off-engine, to ascertain the functionality of the assembly prior to installation. The tester incorporates actual igniter plugs on a drive system interfacing with the accessory generator and rotor. Optical sensors measure the spark rate of the igniter and exciter assembly at speeds up to 15,000 RPM.

To address tomorrow's defense technology, SwRI is conducting research in the cutting-edge field of hypersonic flight, defined as traveling through the atmosphere at more than five times the speed of sound (Mach 5). Our hypersonic flight research includes working with heat-resistant materials, particularly to advance manufacturing processes that reduce cost and increase yield of the material. We are also examining the response of these materials to impact at high temperatures, up to 4,000 F. Using internal research funding, engineers are machining these materials and characterizing their performance at high temperatures and at quasi-static and high strain rates. In addition, we are researching hypersonic munitions, including testing protocols for asymmetric warheads. These hypersonics programs aim to advance missile system development as well as defenses against maneuverable, hypersonic missiles from adversaries.

SwRI continued more than 30 years of supporting chemical weapons destruction. In 2019, we initiated a U.S. Department of Defense application to use a thermite burn bag to disable chemical and biological weapons. Developed with internal funding, the patent-pending technology combines SwRI expertise in explosives, thermal barrier materials and the destruction of chemical and biological weapons. Ultimately, this lightweight battlefield solution will destroy small containers, 172 mm artillery shells or other smaller munitions without exposing soldiers or the environment to contamination.

SECURITY

Understanding risks and protecting computer-based systems is of concern to the military, businesses and individuals alike. SwRI specializes in both physical and cybersecurity applications for the military, as well as addressing cyberthreats to intelligent vehicles and transportation systems.

To protect assets in remote locations, SwRI is developing and improving access denial techniques in various operational scenarios. Using human trials in a mock test environment, engineers assessed the effectiveness of using nonlethal pyrotechnics

IMAGE COURTESY DDR & D/IMOD

SwRI is designing a hybrid drivetrain for a future combat vehicle featuring lightweight active protection systems and enhanced mobility.

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

as a psychological tactic to impair task performance. SwRI automated the test sequence and collected data related to performance and biological responses.

In 2019, we demonstrated cyberattack detection systems for the U.S. Army and evaluated potential vulnerabilities in avionic systems using penetration testing in 2019. We also demonstrated a software system that will serve as the foundation for a scalable, reconfigurable, hardware-agnostic airborne payload designed to conduct a variety of radio spectrum operations. Its microservice-based architecture uses virtual hardware and operating systems to support SIGINT, EW and RF-enabled cybersecurity operations.

SwRI is also advancing the state of the art in cybersecurity for today's vehicles and transportation management infrastructure and tomorrow's automated and connected vehicle technologies. This year, we developed techniques to assess the vulnerability of onboard GPS receivers in automated vehicles as well as intrusion detection and threat isolation systems for onboard networks in commercial and military vehicles.

D024004_2048

In 2019, we 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.

Southwest Research Institute offers one of the nation's leading space science and engineering programs, developing innovative technology as well as conducting fundamental and applied research. Our staff investigates space phenomena, develops payload instruments and electronics, and leads space missions. Earth science expertise complements our space research.

EXPLORING EARTH & SPACE

Deep learning is revolutionizing how scientists interact with data from space technology. SwRI is developing machine learning techniques to search for exoplanets around neighboring stars and to combine data from multiple instruments to more cost-effectively measure the energy of our Sun.

SwRI is home to principal investigators for five pioneering NASA missions, including the Polarimeter to UNify the Corona and Heliosphere (PUNCH) mission funded in 2019. Scheduled to launch in 2022, PUNCH will use four microsatellites in Earth orbit to create a seamless 3D view of the outer solar corona as it transitions into the solar wind.

The SwRI-led Magnetospheric Multiscale mission is continuing its study of magnetic processes that drive aurorae and other energetic events in the Earth's magnetosphere, while the Juno mission to Jupiter is more than halfway through with its survey of the gas giant. The SwRI-led Lucy mission recently completed its critical design review, taking it one step closer to its 2021 launch to explore the Trojan asteroids, a population of ancient small bodies that share an orbit with Jupiter.

As the rest of the world welcomed in 2019, the New Horizons science team celebrated another first: visiting the Kuiper Belt Object now officially named Arrokoth, the farthest, most primordial object ever explored. This followed its historic flyby of the Pluto system in 2015. Recently, NASA funded an SwRI study to investigate the attributes, feasibility and cost of a possible future Pluto orbiter/Kuiper Belt Object flyby mission. This year, we also initiated the largest Hubble Space Telescope survey of the Kuiper Belt, studying binary objects to learn what they can tell us about the formation of our solar system.

IMAGES COURTESY NASA/SwRI/JAMIE ADKINS

D024102

Two NASA sounding rockets carrying SwRI-developed ion instruments studied the electrodynamics of the polar cusp. The instruments will fly on an upcoming heliophysics mission to study how the Earth's and Sun's magnetic fields interact.

D024101

This artist's concept shows one of seven asteroids NASA's Lucy spacecraft will fly by during its 12-year, 4-billion-mile journey. The SwRI-led mission will explore one main belt asteroid and six Trojans orbiting in tandem with Jupiter.

Engineers are finalizing construction of SwRI's state-of-the-art COSMIC facility, designed to calibrate mass spectrometry instruments at extremely low pressures. Initially, the facility will qualify SwRI's MASPEX instrument for NASA's Europa Clipper mission.

D023935_0088

SwRI space scientists and engineers are building the engineering models for the Ultraviolet Spectrograph (UVS) and MAss Spectrometer for Planetary EXploration (MASPEX) instruments slated to fly on NASA's Europa Clipper mission. MASPEX will sample the Jupiter moon's atmosphere to characterize the potential habitability of its internal ocean. Of highest priority is the search for organic compounds present on Europa's icy surface and in its subsurface liquid ocean.

Looking for water in our solar system and studying its origin is an ongoing area of research at SwRI. Lunar scientists are studying how water molecules move around the surface of the Moon while planetary scientists study the surface characteristics and water-bearing minerals on near-Earth asteroid Bennu.

Closer to home, NASA has extended the Cyclone Global Navigation Satellite System (CYGNSS) mission. From low-Earth orbit, the constellation of microsatellites designed and built by SwRI penetrates thick clouds and heavy rains to accurately assess wind speeds and better understand hurricane intensification. The extended mission has expanded research to include imaging of flood inundation and measuring subsurface soil moisture on land masses.

Looking at other hazards on Earth, SwRI launched the development of a liquefaction database and models to help characterize how earthquakes can liquify solid ground layered over sandy, water-saturated terrain. We also initiated seismic and volcanic hazard evaluations for agencies in the U.S. and abroad.

Energy fuels the global economy, and Southwest Research Institute is a leading provider of technical solutions that improve the efficiency, reliability, safety and impact of energy, from electric power plants to oil and gas production to nuclear and renewable resources. Comprehensive environmental services complement our work in the energy field.

ENERGY & ENVIRONMENT INGENUITY

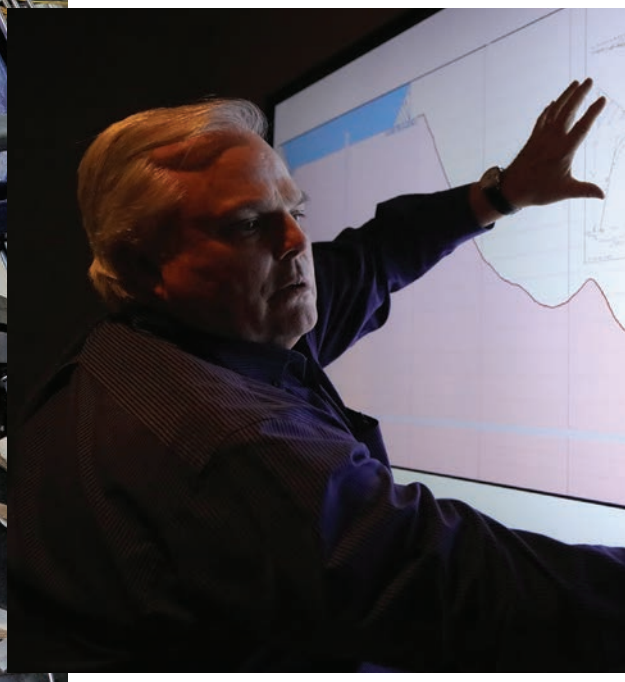
D023899_3395

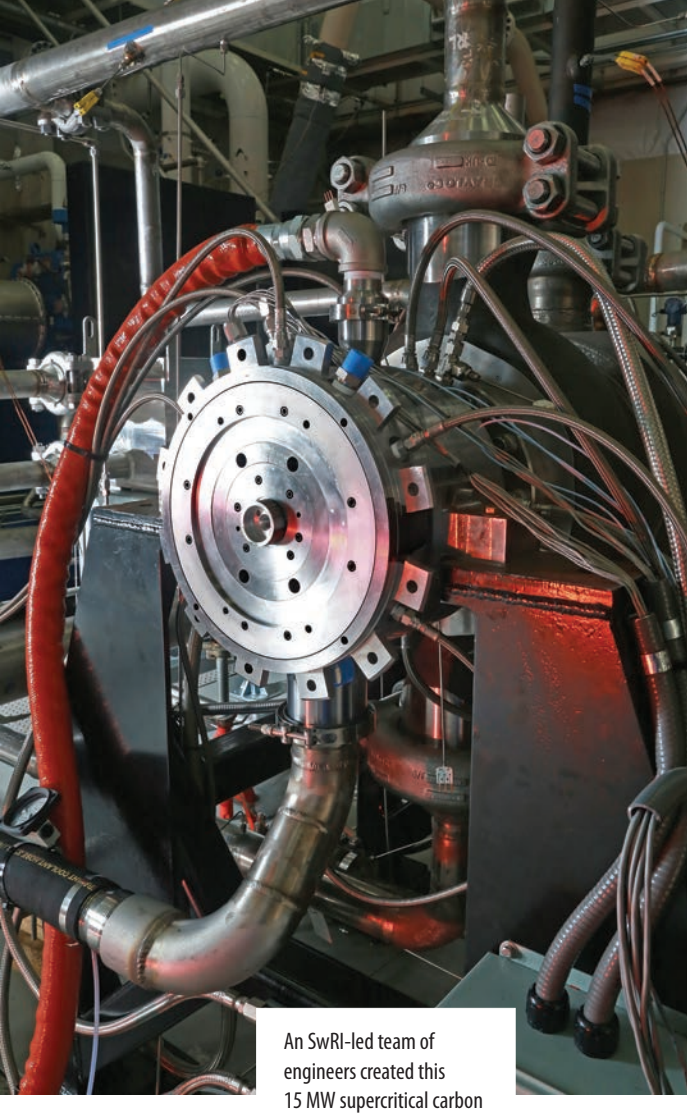
SwRI designed and built this circulating fluidized bed system, modified for industrial catalytic cracking technology, to convert bioderived feedstocks to produce new fuels.

ENERGY

SwRI has a broad program in advanced power systems, including work on supercritical carbon dioxide (sCO_2) power cycles, hydrogen compression, oxy-fuel combustion, hydraulic fracturing with natural gas-based foams and flameless coal combustion. These efforts are largely funded by the U.S. Department of Energy and several commercial partners. We are developing new turbomachinery including a 15 MW sCO_2 turbine, unique high-pressure compressors with variable inlet geometries, and novel integrally geared machinery suitable for waste heat recovery applications. Next year, SwRI will put several oxy-fuel combustion prototype rigs online, positioning our engineers to develop a zero-emission sCO_2 power cycle.

Since 1987, SwRI has operated the Center for Nuclear Waste Regulatory Analyses (CNWRA®) to assist the Nuclear Regulatory Commission (NRC) with regulatory responsibilities associated with radioactive waste storage, transportation, disposal and related areas. This year, CNWRA provided essential inputs to new NRC guidelines for evaluating





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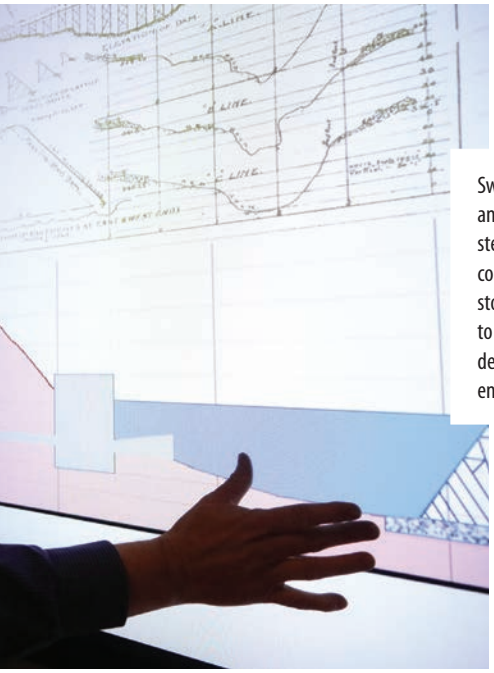
An SwRI-led team of engineers created this 15 MW supercritical carbon dioxide turbine designed to increase the efficiency and lower the cost of power generation for solar power plants.



D024033_0061

SwRI engineers developed an award-winning modular steel dam to accelerate construction of pumped storage hydropower plants to meet the growing demand for grid-scale energy storage.

natural hazards such as earthquakes, volcanos, tornados and high winds, and assisted NRC in evaluating nuclear plant license renewal applications. We also supported environmental evaluations for a depleted uranium munitions test range, proposed spent nuclear fuel storage facilities and a legacy uranium mine on Navajo land.

Meanwhile, SwRI provides exploration and production support to oil and gas companies, using a range of applications in structural geology and geomechanics. Services include conducting field seminars in petroleum production regions. Geologists also conducted special projects in the Vaca Muerta Formation in Argentina and faulted sandstone reservoirs offshore Newfoundland.

Phase 1 of SwRI's Permian Basin Consortium completed initial investigations of the mechanical layering, fracturing and deformation in rock formations across Texas and New Mexico. In 2019, SwRI initiated the consortium's second phase to develop predictive models of tectonic and hydraulic fracturing to support oil and gas production.

The hydraulic fracturing industry uses switch-based systems to selectively detonate explosives used to perforate downhole oil and gas formations. SwRI analyzed two different electronic switch designs to characterize failure modes for each circuit component, identifying any single failure mode that could result in hazardous operations.

SwRI engineers and scientists develop and validate novel processes to upgrade and refine hydrocarbon products from conventional, bio-based feedstock and other alternative sources using custom catalysts, pilot plants and laboratory facilities. In 2019, we helped the refinery and coal industries adapt processes to create new chemical products and alternative fuels.

Across the United States, data centers now account for over two percent of the nation's total energy consumption. Rising energy costs at Air Force data centers have resulted in ambitious goals to reduce power usage. SwRI modeled energy usage from data centers at Edwards, Lackland and Wright Patterson Air Force Bases and NASA's Johnson Space Center to recommend configuration strategies based on heat transfer, building and computational fluid dynamics models for each data center.

ENVIRONMENT

Ensuring availability of clean water is considered among the world's most significant challenges in the coming years. SwRI studies groundwater resources such as San Antonio's Edwards Aquifer and assesses how factors such as urbanization and climate change will affect future supplies. The Institute is also creating significant initiatives to improve the reliability of water supplies, including projects in wastewater management as well as water treatment, desalination and conservation. For instance, SwRI is exploring using wastewater to create electricity during peak demand by storing excess wind energy in pumped hydropower reservoir systems.

Meanwhile, SwRI's Smart LEak Detection (SLED) System uses computer vision and machine learning to detect liquid and gaseous pipeline leaks. SwRI is expanding SLED's capabilities to detect offshore oil spills on water from aerial platforms such as drones.

D023841__8637

To validate a client's computational models with real-world experimental data, SwRI exposed a bare structural I-beam to a 1.8 MW fire scenario. Scientists successfully recorded temperature and displacement data as the beam buckled under the extreme conditions.

Southwest Research Institute supports the manufacturing industry with advanced automation technology, creating adaptable tools while providing workforce training. We also help ensure that aging infrastructure and new construction products meet or exceed standards for safety, durability and performance.

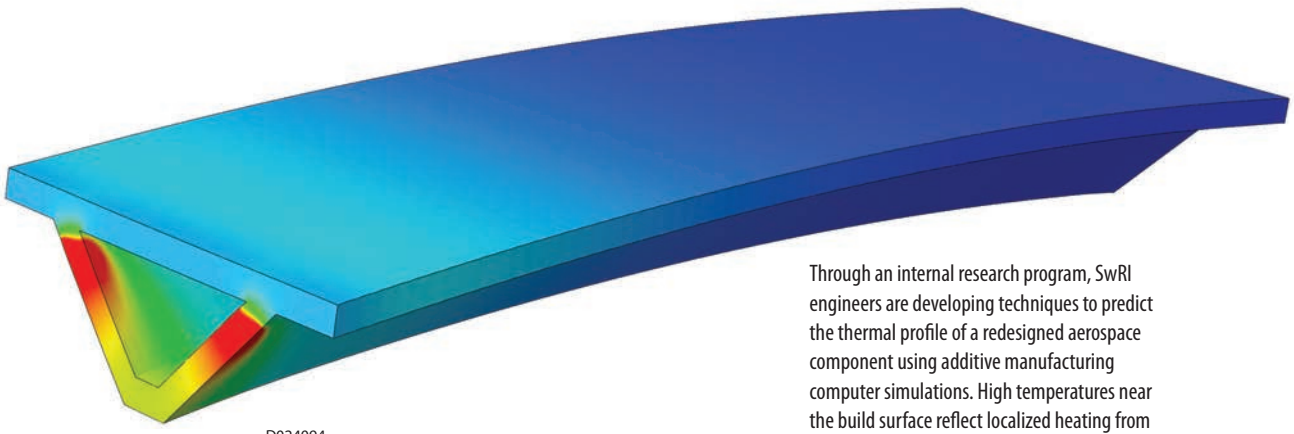
MANUFACTURING

SwRI uses the ROS-Industrial open-source project to extend the capabilities of the Robot Operating System (ROS) to advance manufacturing. The ROS-I program and consortia have experienced strong growth over the past year, presenting new opportunities to use ROS-I capabilities in new manufacturing applications. For instance, we used ROS-I to generate world-class tool path planning capabilities that SwRI is applying in a wide range of industrial processes.

SwRI continued its long history of developing large robot depaint systems for the military and commercial aerospace industry. In 2019, we completed construction of the world's largest mobile manipulator that precisely strips coatings from aircraft using a laser.

Additive manufacturing (AM) uses 3D printing technology to fuse metal powders layer-by-layer to build complex components. Predicting the material properties, strength and durability of these components is complicated. The additive buildup of material could

TRANSFORMING MANUFACTURING & CONSTRUCTION



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Through an internal research program, SwRI engineers are developing techniques to predict the thermal profile of a redesigned aerospace component using additive manufacturing computer simulations. High temperatures near the build surface reflect localized heating from the laser heat source.

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We used ROS-I software to automate paint stripping from a variety of aerospace parts using either chemical or media blast processes. SwRI's unique solution automatically generates paths from CAD drawings or 3D scans.

SwRI built and demonstrated the world's largest mobile robot system. This first-of-its-kind automated system uses a laser to remove coatings from large aircraft.

D023802_8968

produce potentially severe residual stresses that distort components, introduce heterogeneous microstructures and alter material properties as compared to conventionally wrought materials. As part of an internal research program, SwRI is building a computational model of the selective laser melting AM process to rapidly qualify new components. This model uses thermal histories to drive computational predictions of residual stress and average grain size in the material microstructure.

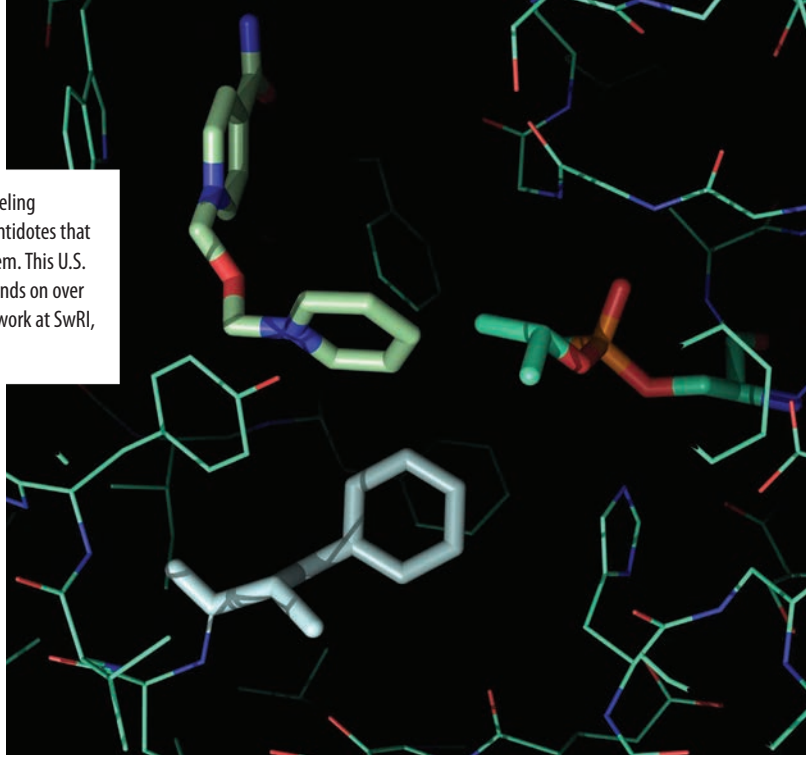
SwRI operates a Texas Manufacturing Assistance Center, helping small and medium manufacturers in Central Texas compete in the global economy. We have expanded staff resources in Austin to address the area's considerable manufacturing market.

CONSTRUCTION

In the U.S. and abroad, pipelines, offshore platforms, railway bridges, dams and power plants are nearing, or have surpassed, their original design life. Because this infrastructure is considered too costly to replace, SwRI offers a portfolio of fitness-for-service evaluations and potential life extension solutions for these aging systems. Our engineers offer a multidisciplinary approach to assessing these structures with nondestructive evaluation techniques to inspect, monitor and analyze data under real-life operating conditions. SwRI performs fatigue life assessments using classical methods and tools such as ANSYS® and NASGRO® fracture mechanics and fatigue growth analyses, all with the goal of cost-effectively addressing the challenges of aging infrastructure.

Another challenge with aging systems is difficulty finding replacement parts and technology. Aging equipment often requires components to be deconstructed to produce a functional replacement. In 2019, SwRI performed a functional analysis and reverse engineered a telecommunications data transmission system. Engineers disassembled two of the units, producing a complete electrical diagram of the system, including connections and components.

To ensure the safety of manufactured building and transportation components, we operate one of the world's largest organizations dedicated to fire technology, research and testing. In 2019, we studied how utility poles stand up to high-intensity, relatively short-duration wildfire flame fronts. To evaluate fire performance, we conducted a series of tests on 22 types of utility poles. We subjected them to up to three minutes of high-intensity fire exposure, measuring pole and flame temperatures, fire exposure heat fluxes and pole deflection.



SwRI is using novel molecular modeling software to discover nerve agent antidotes that penetrate the central nervous system. This U.S. Department of Defense effort expands on over 15 years of antidote development work at SwRI, spanning multiple programs.

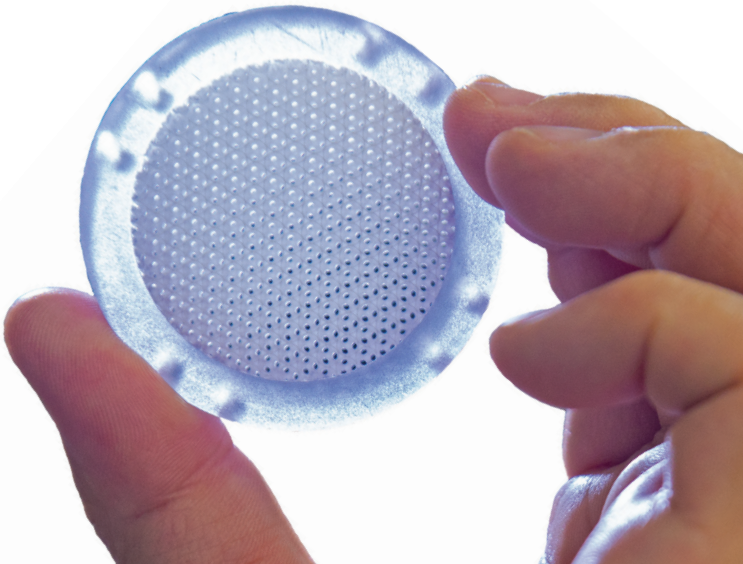
Southwest Research Institute supports the healthcare industry, providing biomaterials and pharmaceutical development as well as food safety and microencapsulation research. We are applying machine learning technology to automate and improve medical diagnostics.

HEALTH & BIOMEDICAL BREAKTHROUGHS

Using machine vision, SwRI engineers track a barbell's path during weight training to automatically track workloads and adherence to proper lifting techniques. This markerless technology can be used to cost-effectively enhance performance.

We are leveraging our 70 years of experience in microencapsulation to meet client needs in pharmaceutical, veterinary, food, nutraceutical, agricultural and consumer products. In 2019, we worked with a pharmaceutical client to microencapsulate multiparticle formulations using spinning disk technology. The goal is to improve patient compliance by masking the taste of a pediatric drug without decreasing its efficacy.

Through internally funded research, SwRI designed, developed and prototyped a novel cell expansion bioreactor to propagate stem cells and T-cells for advanced personalized and regenerative medical treatments. Produced by a 3D printer, SwRI's patent-pending, disk-shaped bioreactor features tightly packed, interconnected spherical voids, providing a large surface-to-volume ratio for growing abundant quantities of cells. The team is creating a standalone, programmable closed-loop cell expansion platform about the size of a minifridge to continuously and cost-effectively propagate cells using the single-use bioreactor.



SwRI developed these patent-pending, single-use bioreactors. The tightly packed, interconnected spherical voids provide a large surface-to-volume ratio for growing abundant quantities of cells.

CHEMICAL & MATERIAL MATTERS

Chemicals and materials affect our everyday lives, from the products we use to the foods we eat to the homes we occupy. Southwest Research Institute uses sensitive laboratory equipment and powerful microscopy to examine the properties of materials.

D023565_9846

SwRI's new corrosion facility evaluates materials in isolated cells, giving engineers the ability to change samples without disturbing others still under test.

SwRI offers extensive expertise in corrosion evaluation and mitigation for a range of applications. Scientists recently patented a technique to accurately quantify and characterize pitting corrosion using a laser profilometer to measure pit depths and surface area.

We are collaborating with the University of Texas at San Antonio to study the deleterious effects of gaseous hydrogen on critical components for the aerospace and oil and gas sectors. We are studying the mechanisms of hydrogen embrittlement in additively manufactured materials with the ultimate goal of designing AM parts that are less susceptible or even immune to hydrogen embrittlement.

SwRI staff are collaborating on a multidisciplinary project to advance our understanding of chemicals in the food, air, drugs and products we are exposed to every day, as shown in this spectrometric data.

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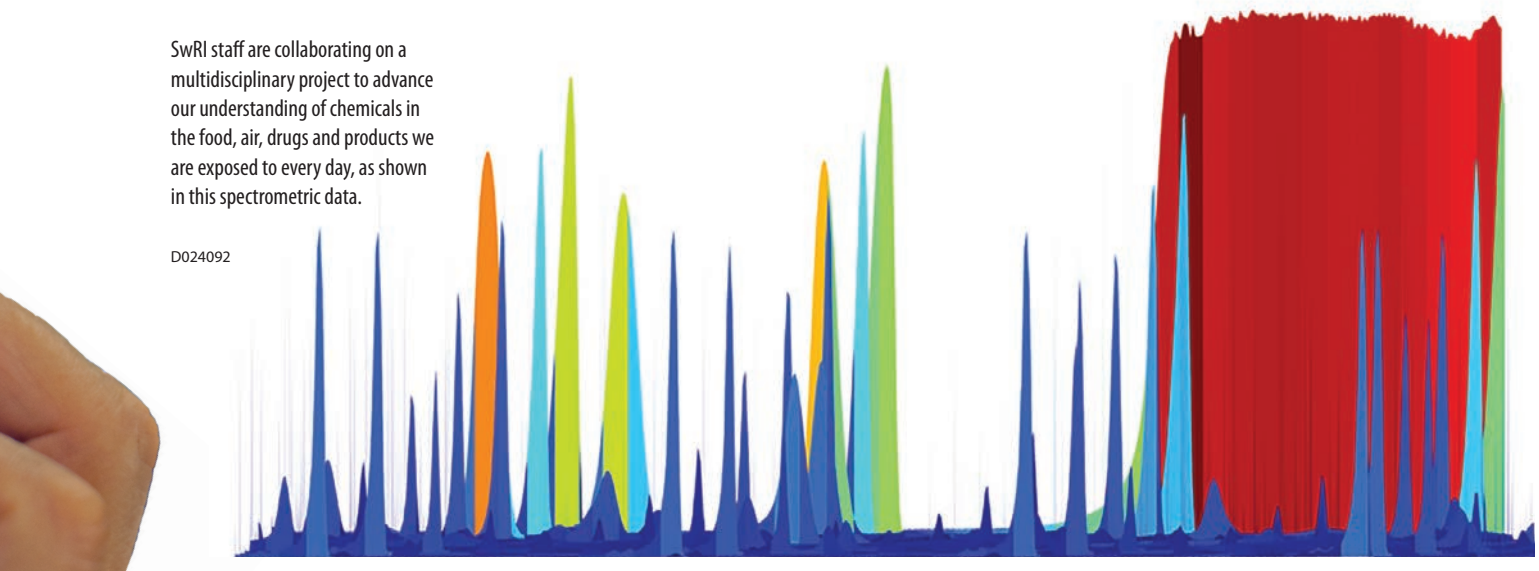


CONSOLIDATED FINANCIAL HIGHLIGHTS

STATEMENTS OF FINANCIAL POSITION | in thousands of dollars

	For the year ended September 27, 2019	For the year ended September 28, 2018
Current Assets	$396,206	$353,039
Property & Equipment, Net	278,335	282,372
Other Assets	87,417	85,926
Total Assets	$761,958	$721,337
Current Liabilities	$103,823	$102,484
Noncurrent Liabilities	66,655	60,870
Net Assets	591,480	557,983
Total Liabilities and Net Assets	$761,958	$721,337

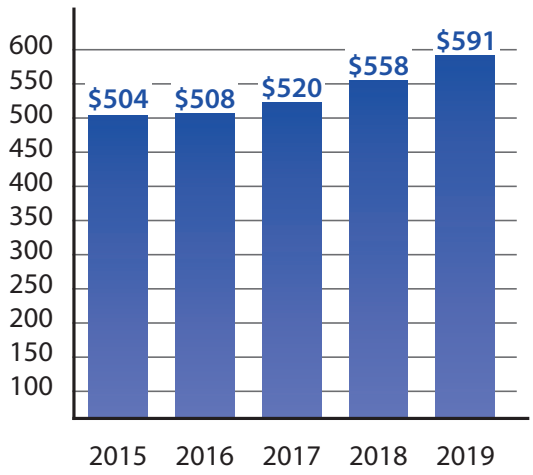
Consolidated revenues hit a record high at nearly **$674** million – up over **15%** from 2018

Consolidated net income from operations was **$34.3** million – up **8%** from 2018

Capital expenditures exceeded **$24** million – up **30%** from 2018

Internal research spending reached a record high of **$8.1** million – up **20%** from 2018

NET ASSETS | in millions of dollars



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The Honorable Nelson W. Wolff
Bexar County Judge
Commissioners Court
San Antonio, Texas

Dr. Sharon L. Wood
Dean, Cockrell School of Engineering
The University of Texas at Austin
Austin, Texas

Mr. Gary V. Woods
President
McCombs Enterprises
San Antonio, Texas

ADVISORY TRUSTEES EMERITI

Gen. William V. McBride, USAF (Ret.)
San Antonio, Texas

Mr. H. Bartell Zachry Jr.
President
Zachry Interests
San Antonio, Texas

COMMUNITY CONTRIBUTIONS

All inquiries should be
addressed to:
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Southwest Research
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P.O. Drawer 28510
San Antonio, Texas
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210.522.2257
or solutions@swri.org

In 2019, Southwest Research Institute continued its long history of support to the San Antonio community, including contributing more than $1 billion to the local economy. We are hosting a 50-acre solar farm for San Antonio's local power utility, 17,000 panels producing 5 MW of power in the first demonstration project for CPS Energy. The facility includes four battery storage containers, each about the size of a railroad stock car, storing 10 MWh of energy power for release during peak demand. Each container can power about 400 homes.

In other community activities, more than 300 volunteers participated at SwRI Cares events at local United Way affiliate agencies, and our United Way campaign raised $833,906. Staff members delivered more than 5,000 "Meals on Wheels" to senior neighbors, logged 750 hours working at the San Antonio Food Bank and donated 804 pints of blood in 2019.

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