



ANNUAL REPORT 2021
SOUTHWEST RESEARCH INSTITUTE®

LUCY MISSION: 12 YEARS | 8 TARGETS | 1 SPACECRAFT

The Southwest Research Institute-led Lucy mission, NASA's first to Jupiter's Trojan asteroids, launched at 5:34 a.m. EDT October 16 on an Atlas V rocket from Cape Canaveral Space Force Station in Florida. Over the next 12 years, Lucy will fly by one main-belt asteroid and seven Trojan asteroids, making it the agency's first single spacecraft mission in history to explore so many different asteroids. Lucy will investigate these "fossils" of planetary formation up close during its journey.



Lucy Deputy Principal Investigator Cathy Olkin and Principal Investigator Hal Levison mark two days to launch of the NASA spacecraft bound for Jupiter's Trojan asteroids. The mission was named for the hominin fossil named after the Beatles' song "Lucy in the Sky with Diamonds." The Lucy spacecraft will study the ancient Trojans, considered "fossils" leftover from the formation of the outer solar system.

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Named for the fossilized skeleton of one of our earliest known hominin ancestors, the Lucy mission will allow scientists to explore two swarms of Trojan asteroids that share an orbit around the Sun with Jupiter. Scientific evidence indicates that Trojan asteroids are remnants of the material that formed the giant planets. Studying them can reveal previously unknown information about their formation and our solar system's evolution in the same way the fossilized skeleton of Lucy revolutionized our understanding of human evolution.

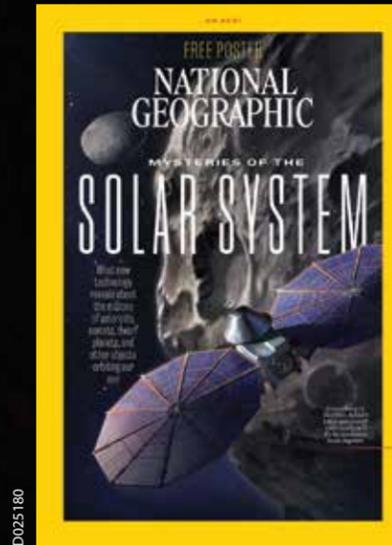
"We started working on the Lucy mission concept early in 2014, so this launch has been

long in the making," said SwRI's Hal Levison, Lucy principal investigator. "It will still be several years before we get to the first Trojan asteroid, but these objects are worth the wait and all the effort because of their immense scientific value. They are like diamonds in the sky."

After successful separation from the rocket on Oct. 16, NASA's Lucy spacecraft deployed its solar arrays. Soon after, NASA received confirmation that one of the solar arrays was fully deployed and latched, but the second solar array had failed to latch. Analysis indicates that the array is roughly 95% deployed, and both arrays are producing power, charging the spacecraft's battery.

On October 20, the spacecraft transitioned to cruise mode, and the team has successfully turned on the payload instruments. An anomaly response team continues to work on establishing what caused the solar array to not fully deploy. NASA and SwRI are evaluating a range of options, including the possibility of leaving the array in its current state and how that could affect upcoming spacecraft maneuvers.

IMAGES COURTESY NATIONAL GEOGRAPHIC/NASA/BILL INGALLS



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The SwRI-led Lucy mission to Jupiter's Trojan asteroids was the cover story for National Geographic's September 2021 issue, in advance of the spacecraft's October launch. Institute Scientist Dr. Cathy Olkin, Lucy deputy principal investigator, also participated in the podcast "Overheard" that complemented the magazine article.

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ON THE COVER:

For more than 70 years, Southwest Research Institute has developed signals intelligence technology, designing, fabricating, testing and supporting airborne, land and maritime direction finding antennas. We continue to expand radio frequency and signals analysis capabilities and facilities, completing a new antenna testing facility in 2021. The antenna test range featured on the cover includes two 70-foot towers in a 200-acre field to simulate land-based towers and the main masts of naval vessels at sea.

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FROM THE PRESIDENT

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I am pleased to present this Annual Report highlighting some of Southwest Research Institute's outstanding technical advancements, solid financial performance, and other accomplishments from Fiscal Year 2021 (FY21). Our staff showed initiative, flexibility and commitment to the Institute's mission even while navigating through a year plagued with the stubborn and persistent COVID-19 pandemic.

Our research activities continue to provide solutions to some of humankind's most difficult challenges from Deep Sea to Deep Space. In this last year, for example, our geologists and geoscientists completed research on the complex geological developments of offshore Newfoundland and Labrador, using newly available broadband seismic reflection data. And our space scientists determined the brightness of the galactic background using an SwRI-developed instrument aboard NASA's New Horizons spacecraft on an SwRI-led mission.

If this year has shown us anything, it's that time and again we respond successfully to unexpected challenges with innovation and creativity. Our consolidated FY21 revenue set a record for the Institute and our staff found ways to continue innovating and serving our clients as our contract backlog grew to a historic new level.

We were also able to expand our campus by several hundred acres, and the

Board of Directors approved two new buildings to accommodate the growth in our research programs. We also continued to invest in internally funded research by providing more than \$8 million to allow our staff to pursue innovative concepts and broaden the Institute's technology base. Our Internal R&D program is designed not only to anticipate challenges clients may face in the future, but also to begin working on them today.

I would like to thank our staff, leadership, Board of Directors and Advisory Trustees for their different contributions in FY21. Not every organization has a culture like ours, where all these stakeholders enjoy positive and productive working relationships. This pandemic year provided an excellent opportunity for us to codify the key aspects of this culture in our "Core Values." Executive management selected a team of 20 diverse staff members who identified four foundational qualities that reflect the beliefs, principles and culture of the Institute to help guide the actions and behavior of all staff members. These core values are:

- Integrity: Fulfilling our mission and serving our clients with excellence, honesty and accountability.
- Innovation: Solving problems and creating value with novel ideas and multidisciplinary collaborations.

- People: Fostering an employee-centric culture in a safe, inclusive, healthy and supportive workplace.
- Stewardship: Caring for our communities and protecting the environment now and for the future.

Additionally, we recognize that our people comprise our greatest strength and our greatest competitive advantage. Therefore, our continued success requires an understanding of how best to synergize the unique capabilities of all our team members. We recognize that the way we integrate diversity, equity and inclusion into all of our processes is a key to that continued success.

I am grateful for the agility and commitment our staff has shown this past year as we have managed the many formidable challenges of the pandemic and its impact on the research business. We look to the future and our 75th anniversary next year — a significant milestone in the life of any organization — with confidence and high expectations. Whatever challenges may lie ahead, the staff of Southwest Research Institute will rise to the occasion.

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

IR&D 2021

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 2021, SwRI initiated 98 new projects, investing more than \$8 million in internal research, including quick-look and focused research programs. IR&D fulfills the Institute's objective of conducting innovative activities for the benefit of industry, the government and humankind.

Through internal research, we increase our technical capabilities, expand our reputation as a leader in science and technology and invest in technology our clients may need in the future. The program also allows engineers and scientists to grow in their technical fields by providing freedom to explore innovative and unproven concepts without contractual restrictions and expectations. IR&D is frequently cited as a key enabling factor leading to new projects, new clients and completely new research arenas within the Institute.

Using internal funding, SwRI is evaluating a "fire whirl" technique to destroy chemical warfare agents (CWAs). This elegant approach could provide a simple, low-cost system for complete destruction of CWAs and other hazardous materials in the field.



Using internal research and capital equipment funding, SwRI added a wet gas flow loop to its Metering Research Facility, allowing engineers to inject hydrocarbon liquids into a natural gas stream to realistically test oil and gas equipment.



872



PAPERS
PUBLISHED

212



PRESENTATIONS
GIVEN

136



WEBINARS
HOSTED

17



PODCASTS
AIRED

25



U.S. PATENTS
AWARDED

46



U.S. PATENT
APPLICATIONS
FILED



48
INVENTION DISCLOSURES
SUBMITTED

2,774
EMPLOYEES



276
DOCTORATES

560
MASTERS

864
BACHELORS

226
ASSOCIATES

MILESTONES 2021

HONORS

Dr. Sidney Chocron: American Institute of Aeronautics and Astronautics (AIAA) Associate Fellow

Dr. David Ferrill: Geological Society of America Fellow

Dr. Stephen Fuselier: Elected to National Academy of Sciences

Dr. Imad Khalek: SAE Fellow

Dr. John Spencer: American Geophysical Union (AGU) Fellow

Dr. Alan Stern: AGU Fellow, AIAA Associate Fellow

Dr. Roy B. Torbert: AGU Fellow

AWARDS

Dr. Terry Alger: Meritorious Service Medal (Civilian), Army Science Board

Dr. Scott Bolton: National Space Society's 2020 Space Pioneer Award

Dr. James L. Burch: AGU's 2021 William Bowie Medal

Don Grosch: NASA's Exceptional Public Achievement Medal

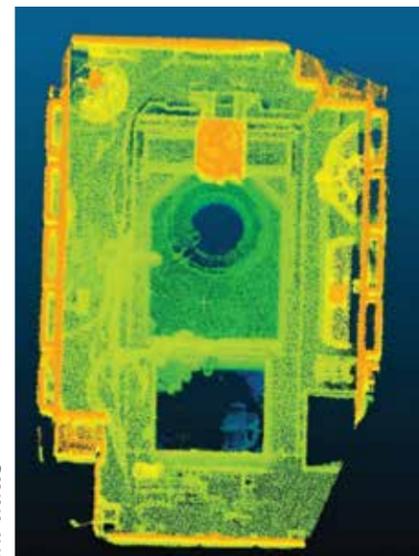
Svitlana Kroll: SAE International's Forest R. McFarland Award

Dr. Amy McCleney: 2021 New Emerging Leaders Award, Offshore Technology Conference



D025171

At an industry challenge event, SwRI demonstrated autonomy technology for an unmanned aircraft system, successfully navigating a nonoperational nuclear facility to locate radiation sources hidden inside. SwRI's drone-based system uses novel algorithms and computer vision to autonomously explore and map unfamiliar environments.



D024949_5141

Three SwRI-developed technologies were selected as winners of prestigious R&D 100 Awards, recognizing them as being among the 100 most significant innovations for 2021.



Developed with internal and Department of Energy's NEXTCAR program funding, SwRI's Eco-Mobility with Connected Powertrains technology achieves over 20% in energy savings and reduced carbon emissions in connected and automated vehicles. This breakthrough technology uses algorithms, software and testing tools to enhance vehicle route, speed profile and power flows, lowering fuel consumption by leveraging vehicle-to-vehicle, vehicle-to-infrastructure and vehicle-to-everything technologies.



D024969_0632

SwRI's Catalyzed Diesel Exhaust Fluid (Cat-DEF™) is a catalyst- and surfactant-modified diesel exhaust fluid that improves nitrogen oxide and carbon dioxide emissions by reducing deposit formation in diesel engine exhaust systems. The Cat-DEF innovation will help reduce air pollution and improve air quality, allowing automotive manufacturers to meet regulations, and can be used in new and existing vehicles without modifying existing engines.

D025113_9683

Using internal funding, a multidivisional team developed Floodlight™ software to efficiently sort through analytical data to accurately identify the chemicals present in food, air and consumer products. Using SwRI's ground-truth labeling of analytical data, machine learning specialists trained the system to identify chemicals at accuracies comparable to human experts, accelerating the process by as much as 100 percent.



D025116_9576



For nearly 75 years, Southwest Research Institute has been involved in nearly every facet of automotive and transportation research, from powertrains to fuels and lubricants to intelligent highways and connected and automated vehicles. In 2021, we saw one of the most significant industry pivots in a century, as the automotive industry embraced an unprecedented shift to electrified powertrain research and development. In response, SwRI launched new research initiatives to address greenhouse gas emissions and improve vehicle efficiency, including new efforts in electrification and connected vehicle systems.

In 2021, we completed a multiyear program to upgrade our fuels and lubricants storage capabilities. The new facilities support clients' access to the lubricants they have stored using SwRI's client portal, developed last year.

AUTOMOTIVE & TRANSPORTATION

AUTOMOTIVE

Since SwRI's founding, our engineers and scientists have evaluated functional fluids used in transportation applications to ensure they meet certification standards. SwRI has worked with engine manufacturers for decades to develop test standards and protocols that ensure fluids on the market will protect various engine designs. As the industry transitions to electrified powertrains, SwRI is working on two internal research projects studying how fluids age in electric powertrains and looking at performance properties from oil fill until oil change. Understanding how fluids age and the properties of aged fluids could support the future development of a controlled aging method. In addition to studying lubricant aging, we will assess vehicle efficiency changes associated with aging fluids. These projects use two types of electrified vehicles; a pure electric vehicle (EV) and a plug-in hybrid that has a conventional hybrid powertrain in the front and an electric rear axle. The projects will support standardized test development for EV fluids.

SwRI also launched the Advanced Fluids for Electrified Vehicles (AFEV) Consortium in 2021 to enhance the industry's understanding of the unique stressors placed on electric vehicle and hybrid vehicle fluids. Because many automakers currently use

D024949_6141



In 2021, we adapted laboratory equipment to support the continuing shift to electric and hybrid-electric platforms. New chassis dynamometers provide loads of up to 300 horsepower independently to a vehicle's front and rear axles.

D025113_9683

conventional fluids in electrified powertrains, the new research will support the development and optimization of EV fluids and advance EV powertrain design.

On the battery side of EVs, engineers are using internal research funds to tackle challenges with recharging batteries. While consumers need only a few minutes to fill a tank with fuel before they can get back on the road, an EV typically needs hours to do the same. Fast recharging maximizes the transfer of lithium ions within a battery pack. However, at high rates, ions can accumulate on the surface of the battery's anode and deposit metallic lithium through a process called "lithium plating." This phenomenon can reduce battery performance and service life and, if left unchecked, can cause it to short circuit and fail. The electrochemistry that causes lithium plating is complex and not completely understood. SwRI is developing a physics-based model that allows us to detect, in real time, the occurrence of lithium plating so we can continuously adjust the charging rate to prevent battery damage while also allowing for shorter charging times.

Working with a commercial client and the California Air Resources Board (CARB), SwRI analyzed electrified cargo-handling equipment as part of a CARB zero and near-zero emissions freight facilities initiative. SwRI used dataloggers to monitor a battery-electric locomotive, a hybrid crane, an electric side pick cargo handler and an electric Class 8 drayage truck, as well as their conventional

SwRI launched the Advanced Fluids for Electrified Vehicles Consortium in 2021 to improve the industry's understanding of the unique stressors placed on electric vehicle (EV) and hybrid vehicle fluids and how that affects components.



D024979_0886



SwRI monitored various electric/hybrid cargo-handling systems including this hybrid crane, as well as their conventional diesel-powered counterparts, to help a client optimize electrification plans for lower-emissions operations.

DO25169



SwRI recently developed a valvetrain wear test to address concerns that products on the market were causing wear issues in a popular pickup truck engine.

DO24970_6608

diesel-powered counterparts. Data collected included energy consumption, refueling and recharging times and peak electricity rates in addition to emissions for the diesel-powered equipment. At the project’s peak, 10 data-loggers monitored the energy consumption of all vehicles in operation. SwRI’s analytics team then distilled the data into objective metrics to help the client optimize its electrification plans for cargo handling equipment in California.

In the conventional fluids arena, a new API heavy-duty engine oil specification known as PC-12 is on the horizon for the trucking industry. Both CARB and EPA are moving toward tighter emissions limits and longer equipment life requirements. By 2027, the lubricants used in on-highway trucks must meet new challenges, including lower viscosity specifications and longer drain intervals, while still minimizing component wear.

In 2021, SwRI developed a valvetrain wear test to address concerns that products on the market were causing wear issues with a unique engine used in one of the most popular pickup trucks in America. Engineers developed this test as a tool to demonstrate the ideal lubricant performance needed to keep these trucks on the road. As the test moves into the PC-12 oil category, it will help ensure broader protection for diesel production engines.

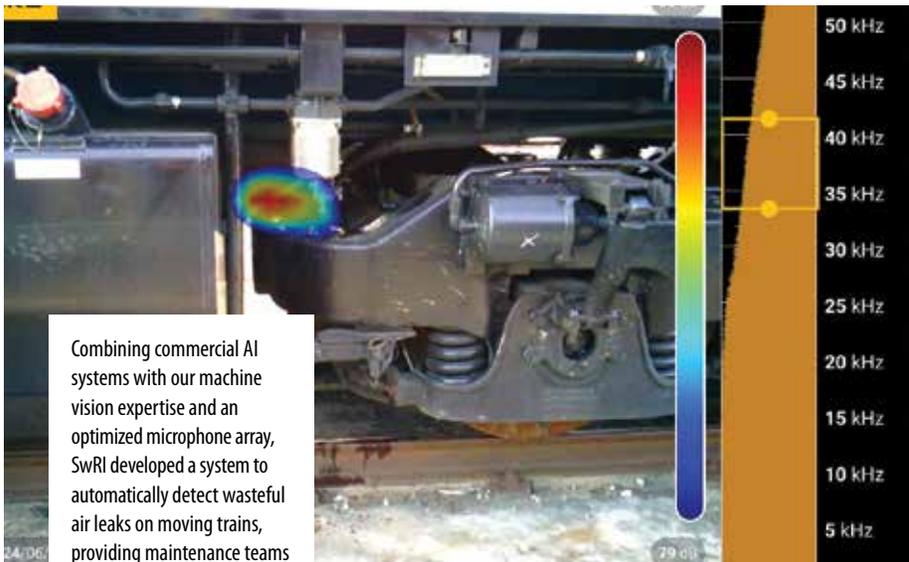
SwRI also offers a unique, 3,000-square-foot tribology lab focused on friction, wear and lubrication, particularly in automotive applications. In 2021, they continued to develop new testing techniques and tribometer modifications to meet a range of client challenges.

In a multiyear DOE Vehicle Technology Office program, SwRI is investigating “cooled spray”(CS) technologies for controlling particulate emissions from nonroad heavy-duty diesel engines. Cooled spray technology uses a monolithic insert with multiple fuel and air passages installed in the cylinder head that mounts over the fuel injector nozzle. The CS program aims to achieve a 75% reduction in particle emissions over the full operating



Through a multiyear DOE program, SwRI is investigating “cooled spray” technologies to control particulate emissions from nonroad heavy-duty diesel engines.

D025065_9909



Combining commercial AI systems with our machine vision expertise and an optimized microphone array, SwRI developed a system to automatically detect wasteful air leaks on moving trains, providing maintenance teams with a photo and location of the leaky equipment.

D025170



SwRI's multiyear low-NOx engine development program has progressed from regulatory support to new aftertreatment systems and software and hardware support. NOx is a generic term for the nitrogen oxide emissions associated with air pollution.

0025058_9600

range, while developing scaling rules for small and large engines. Engineers will conduct evaluations in a high-speed single-cylinder engine at SwRI's Large Engine Facility.

In 2021, SwRI assembled an international team to develop a system to autonomously detect compressed air leaks on moving freight and passenger trains. Trains require compressed air for brakes, horns and various other functions. Any air leaks are difficult to find and require the locomotives to pump more air to keep the train running safely. Reducing these leaks will result in significant operational, safety, fuel consumption and environmental benefits. The project goal is to combine SwRI's locomotive performance and machine vision expertise with a commercially available audio sensor to create a wayside detection system. The resulting system will automatically detect air leaks on moving trains, notifying maintenance teams with detailed information about the location of the suspected leak, including the specific car and its location within the train as well as a photo of the leak location.

0024972_0707

As hybrid vehicles proliferate, SwRI is addressing concerns about oil emulsions forming in association with short drive cycles in cold weather, developing engine tests to replicate these phenomena and evaluate whether different formulations could mitigate the effects.



0024972_0707

Through a new DOE contract, SwRI will continue developing its cutting-edge connected and automated vehicle (CAV) technologies to help passenger vehicles operate more efficiently while reducing energy consumption and carbon emissions. The award-winning Advanced Research Projects Agency-Energy (ARPA-E) Next-Generation Energy Technologies for Connected and Autonomous On-Road Vehicles (NEXTCAR) program demonstrated over 20% improvements in energy consumption in real-world driving conditions through a combination of vehicle dynamics and advanced powertrain control algorithms including eco-routing, eco-driving and power-split optimization. In the second phase, SwRI will build on those technologies and expand its predictive eco-driving feature. This algorithm helps human drivers make smarter decisions based on localized traffic through vehicle-to-everything connectivity and communications. Because of the improved perception and actuation precision of a Level 4 autonomous vehicle over a human driver, SwRI will expand the eco-driving framework to optimize for automation and multilane dynamics to further reduce energy consumption.

For more than 60 years, SwRI has hosted a government-owned, contractor-operated facility to provide advanced



In Florida, SwRI was awarded and is developing a state-wide data exchange capable of ingesting high-volume, high-velocity data from diverse transit sources, particularly connected and automated vehicles.

DO25165

vehicle fluids research, development and engineering for the U.S. Army and other government agencies. In 2021, we renewed our multiyear contract to operate the U.S. Army Ground Vehicle Systems Center Fuels and Lubricants Research Facility on our grounds.

Chemical engineers collaborated with automotive specialists to help a client develop a post-refinery process to reduce exhaust emissions from diesel engines by overcoming the soot/nitrogen oxides (NOx) reduction trade-off that has plagued engine researchers for decades. The result is a modified fuel that potentially could replace today's ultra-low sulfur diesel, biodiesel and other renewable diesel fuels.

Using internal funding, chemical engineers developed the "EZ Flow™" process to treat heavy crude oils, making pipeline transportation of the commodity more cost-effective and less energy-intensive than current techniques. The new processing

method uses a proprietary chemical treatment and mechanical technique to reduce the viscosity of heavy crude oil by more than 60%, allowing it to flow more easily through existing pipeline networks.

TRANSPORTATION

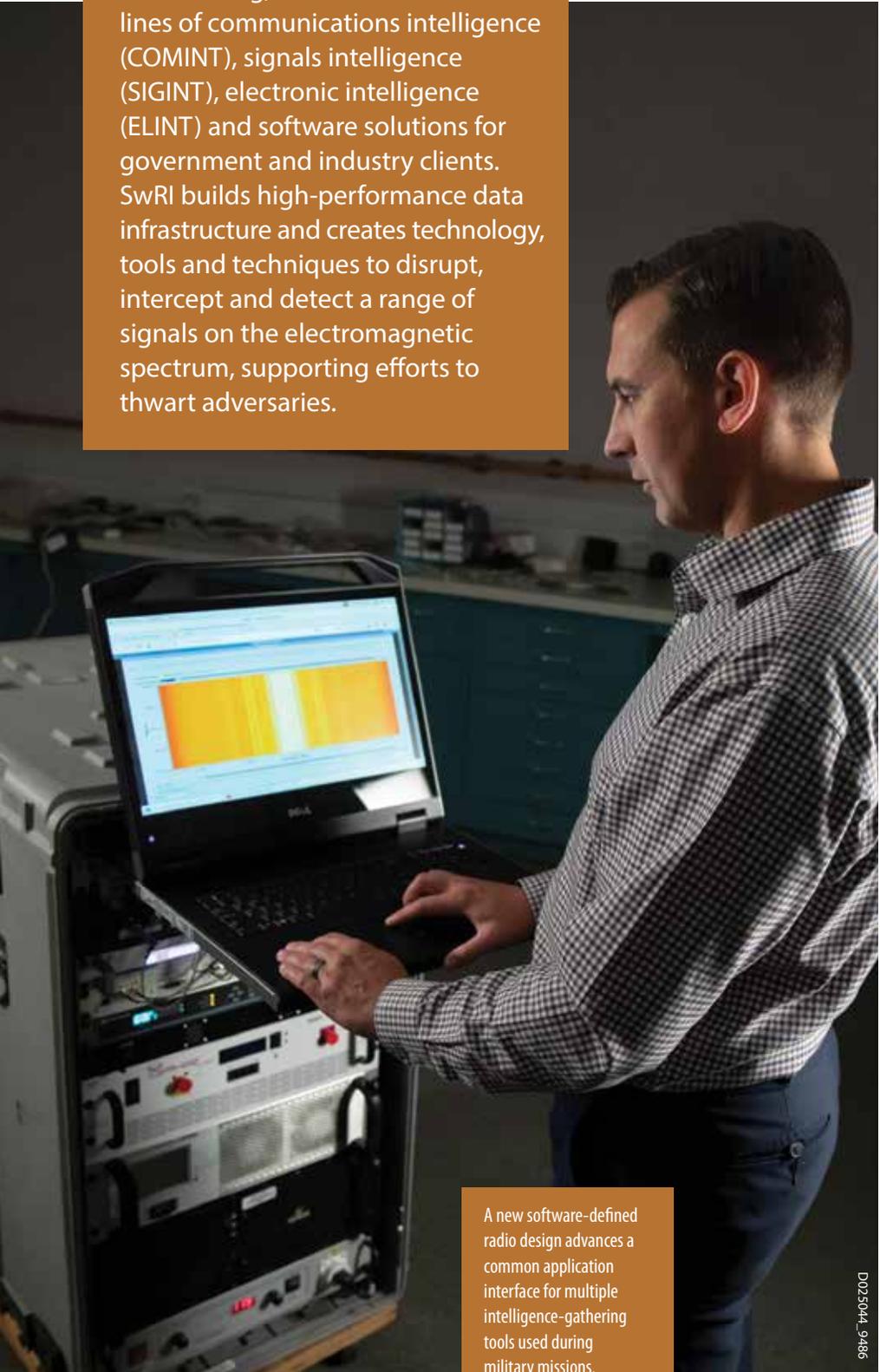
In 2021, SwRI expanded its intelligent transportation partner network to 14 states and one U.S. territory. We deployed our ActiveITS™ Advanced Traffic Management System (ATMS) in Kansas using cloud technology and began a pilot program in Albany, New York. We are also helping Pennsylvania maintain its existing ATMS while developing and integrating new capabilities.

In Florida, SwRI launched a state-wide data exchange capable of ingesting high-volume, high-velocity data from diverse transit sources, particularly connected and automated vehicles. Once complete, the platform will facilitate real-time detection/ notification of actionable conditions while archiving data for advanced analytics and machine learning applications in the future. This data exchange platform, ActiveDX, can be licensed to other public agencies.

SwRI is using machine learning and connected vehicle technology to expedite public transportation using an exclusive bus lane in the Lincoln Tunnel to improve flow between New Jersey and Manhattan. The goal is to increase bus trips using a narrow lane that reverses direction to accommodate morning and evening commuter traffic.

SwRI develops automotive cybersecurity solutions to protect proliferating embedded electronics and networks in newer vehicles. SwRI evaluated multiple ethernet intrusion detection systems for a leading automobile company. In addition, we analyzed EV charging protocols to identify potential security risks through internal research funding.

From shoring up the nation's electronic warfare (EW) and cybersecurity defenses to developing secure networks for remote work and learning, SwRI is on the front lines of communications intelligence (COMINT), signals intelligence (SIGINT), electronic intelligence (ELINT) and software solutions for government and industry clients. SwRI builds high-performance data infrastructure and creates technology, tools and techniques to disrupt, intercept and detect a range of signals on the electromagnetic spectrum, supporting efforts to thwart adversaries.



A new software-defined radio design advances a common application interface for multiple intelligence-gathering tools used during military missions.

D025044_9486

DEFENSE

SwRI continues to expand geolocation and network development to support the U.S. government as well as clients abroad. With a solid foundation developing coordinated worldwide geolocation networks, we developed new software capabilities and used various algorithmic techniques and control methods to provide interoperability and collaboration of existing networks and sensors for geolocation operations. With an emphasis on developing intelligence community message and interface standards, our focus is improving mission capabilities, while reducing client costs.

SwRI designed, developed and demonstrated a multichannel, software-defined radio (SDR) prototype to perform simultaneous COMINT, ELINT and electronic attack and cyber operations for the U.S. military. The prototype relies on a new microservices software architecture that accelerates the development of SDR functions and hosts existing SDR applications.

Using sensor open system architecture and commercial off-the-shelf products, SwRI is further developing the Ravager Electronic Warfare System, an advanced and highly adaptable modular system that allows rapid technology updates and improves interoperability with existing and future military systems. Ravager addresses supplier and parts shortages,

DEFENSE & SECURITY

D025124_9937



SwRI demonstrated a miniaturized system for detecting and characterizing tactical frequency-hopped radios that provide real-time situational awareness on the battlefield. This capability is targeted for deployment on mobile platforms such as aircraft and ships.

Our engineers are developing the modular, government-owned Ravager electronic warfare system designed to maximize operational effectiveness and flexibility, while improving the sustainability of fighter aircraft EW systems.



D025173

while extending the life of existing technologies. Using internal funding, our engineers continue to discover adaptive EW technologies to integrate into Ravager.

SwRI's powerful Ultra-Wideband Receiver (UWR) technology, another sensor open system architecture developed with internal funding, allows EW systems to review a wide range of the radar spectrum at once, instead of slowly scanning it. The approach cost-effectively yields fast detection of all radar types. SwRI is developing the UWR technology, supported by a high-speed, high-performance interoperable system.

In 2021, the U.S. Air Force implemented SwRI's Adaptive Threat Environment Acquisition (ATHENA) technology, an advanced ELINT receiver, on multiple systems. High-resolution measurements, instantaneous broad bandwidth and added detection capabilities set ATHENA apart from other ELINT systems. Using internal funding, SwRI designed ATHENA to identify current and future threats, making it a long-term intelligence solution for the Air Force.

This year, SwRI developed a Low Probability of Intercept (LPI)/Low Probability of Detection (LPD) high-frequency communications subsystem, which uses a new waveform. The waveform operates at ultra-low power levels making it difficult for adversaries to detect, while randomized bandwidth and baud rate, or information transfer speed, obscures its characteristics. As a complementary capability, SwRI developed new techniques to detect and characterize multiple,



Fire technologists performed flame propagation tests to assess the performance of different coating configurations for cables used in nuclear submarines.

D5C_0188

simultaneous LPI/LPD waveforms of interest. SwRI successfully demonstrated its LPI/LPD detection techniques deployed on a U.S. government-operated unmanned aerial vehicle.

SwRI is expanding radio frequency and signal analysis capabilities and facilities, completing a new antenna testing facility in 2021. A new anechoic chamber will be completed in 2022, allowing broader data collection of antenna patterns, including frequencies, elevation angles and polarizations. A three-story building addition, slated for completion in early 2023, will house new laboratory and office space.

SwRI is discovering and delivering system solutions for national security and business applications, expanding our reach in signals intelligence, electronic warfare systems and aerospace and defense software design. Looking ahead, we are focused on creating products and tools that offer connection, interoperability and adaptability for increased productivity and long-term utility.

Harnessing hypersonic flight capabilities at speeds five times the speed of sound, or in excess of Mach 5, is important to national security. It could also revolutionize the air travel industry. In response, SwRI advanced higher-temperature capabilities to understand material deformation and failure associated with the extreme heat — with temperatures up to 5,500 degrees Fahrenheit — that hypersonic flight bodies experience. Using our large two-stage light-gas gun, we conducted



In 2021, SwRI conducted environmental and electromagnetic interference and compatibility testing of A-10 central interface control units, designed to replace legacy systems and modernize aging aircraft.

D025127_0015



Pharmaceutical researchers continue to develop antidotes for chemical warfare agents, particularly neurotoxins that attack the central nervous system. In 2021, chemists scaled up pilot plant production of a countermeasure for a class of nerve agents.

D025023_8451

the first flyer plate impact tests at elevated temperatures, accomplished using a laser to preheat the target in a vacuum chamber. Engineers are using “free flight” techniques to obtain aerodynamic data free of support interference and exhibiting more realistic flows around various flight bodies. These tests are supporting advanced optical and spectral diagnostics. Engineers performed plate impact tests to understand the high-pressure, high-speed nonlinear response of carbon-carbon thermal protection materials. The teams are looking at techniques to improve the

manufacture of carbon-carbon materials and are developing computational and design tools for hypersonic scramjets.

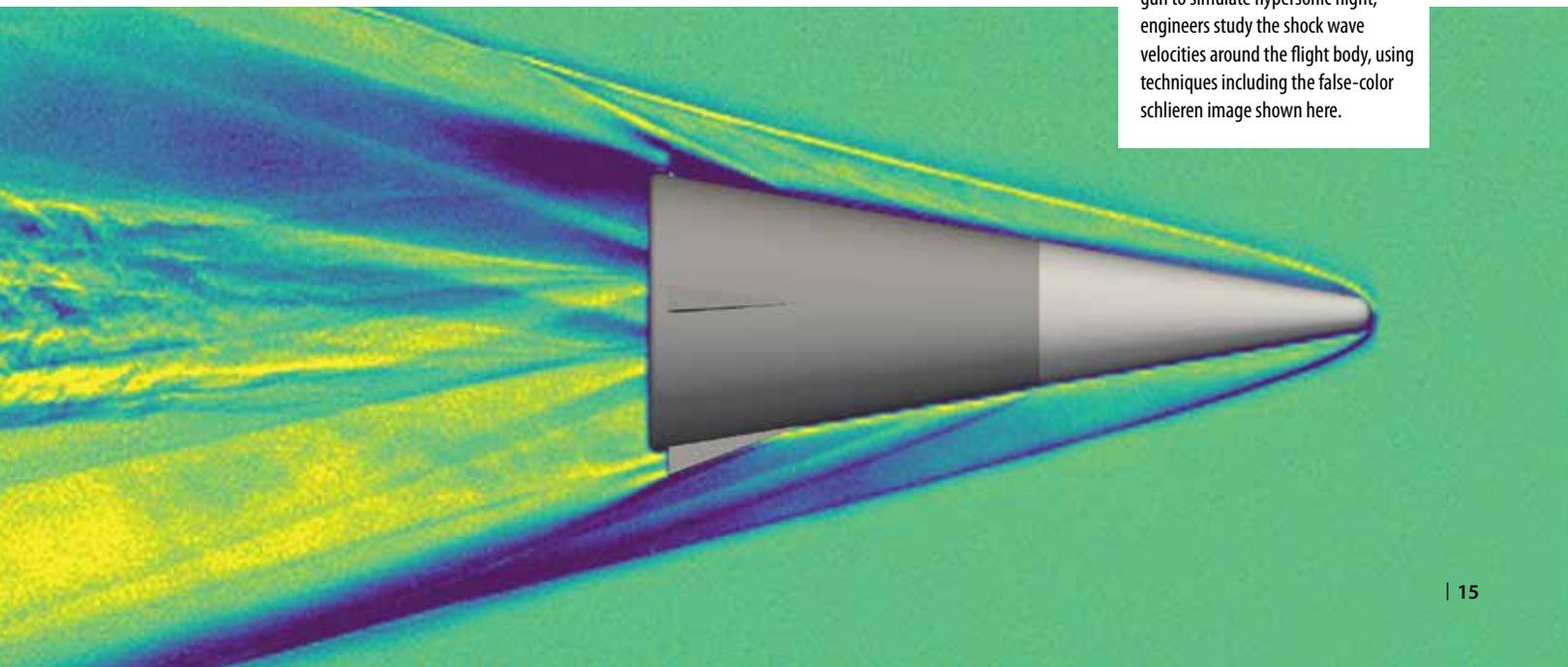
SECURITY

In 2021, SwRI received several contracts to support work in developing autonomous and robotic military vehicles. In addition, we developed intrusion detection systems to help secure military as well as commercial ground vehicles from cyberattacks via embedded systems and connected vehicle networks.

SwRI is helping address cybersecurity

concerns associated with intelligent transportation systems, developing strategies to balance digital asset protection and cybersecurity risk with data and information sharing that supports increasingly data-driven operations. We are working with national, state and law enforcement agencies to develop a framework for communication and information sharing between transportation roadway stakeholders when detecting and responding to a cyberattack or vulnerability issue that spans across multiple devices or other industries.

D025174



Using SwRI's two-stage light-gas gun to simulate hypersonic flight, engineers study the shock wave velocities around the flight body, using techniques including the false-color schlieren image shown here.



Southwest Research Institute offers one of the nation's leading space science and engineering programs, conducting fundamental and applied research and developing innovative technology for commercial companies and agencies worldwide. Our strong Earth science expertise complements our space research programs.

Findings from NASA's Juno mission provide a fuller picture of how Jupiter's distinctive atmospheric features offer clues to unseen processes deep below the planet's cloud tops.

EARTH & SPACE

In addition to investigating space phenomena and developing payload instruments, electronics and spacecraft, SwRI scientists lead missions to explore the cosmos, including the Lucy mission, the first mission to Jupiter's Trojan asteroids, which launched in October 2021 (see inside cover). SwRI is home to principal investigators of four other current NASA missions, including the Polarimeter to UNify the Corona and Heliosphere (PUNCH), Magnetospheric Multiscale (MMS), Juno and New Horizons. In 2021, NASA extended the Juno mission to Jupiter until September 2025. The PUNCH team demonstrated the Institute-developed Wide Field Imager, which will fly on three of the mission's four SwRI-built smallsats, finding that it met its imaging requirements, attenuating sunlight to image the Sun's outer corona in the eternal noontime of space.

Space scientists are also developing a Medium-Class Explorers mission to study the Sun's poles, which are considered among the last unexplored regions of the solar system. Solaris will image the Sun's poles from high latitudes to help scientists understand how polar magnetic fields and flows shape the solar activity cycle.

SwRI is also finalizing production of two instruments — the Mass Spectrometer for Planetary Exploration (MASPEX) and the latest generation of the Ultraviolet Spectrograph (UVS) — for NASA's Europa Clipper mission. The spacecraft will orbit



Engineers integrate the electronics box for SwRI's novel MASPEX instrument, which will sample gases in Europa's faint atmosphere and possible plumes of materials escaping from surface cracks to determine the chemistry of the moon's surface and suspected internal ocean.

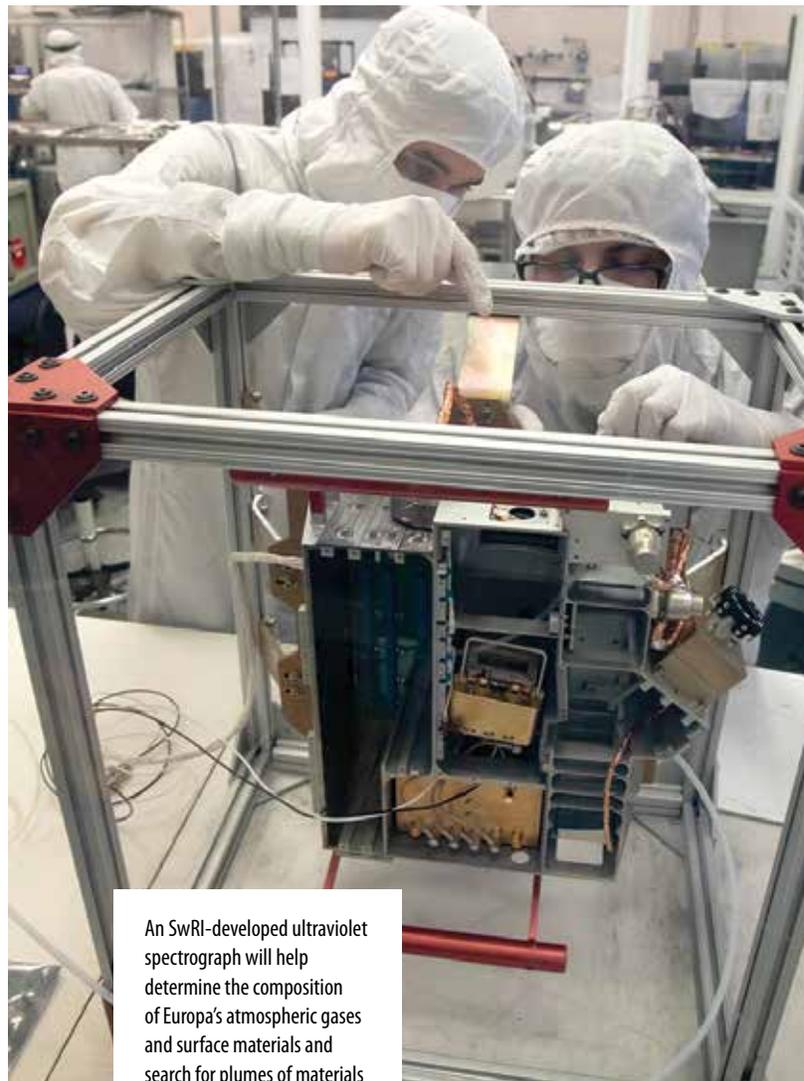
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Jupiter and perform multiple flybys of the moon to characterize the habitability of its internal ocean. To meet NASA's planetary protection requirements, SwRI microbiologists are testing the instruments for microbial contaminants to avoid carrying terrestrial organisms and organic materials to other worlds.

In 2021, SwRI acquired the parts for SCORPIO, a Spectrograph and Camera for Observations of Rapid Phenomena in the Infrared and Optical for the Gemini South Observatory in Chile, and began the assembly, integration and verification phase. SCORPIO's eight independent arms will offer diverse groundbreaking observations from trans-Neptunian objects and centaurs within the solar system and to exoplanets, neutron stars, supernovae and gamma-ray bursts beyond.

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 NASA, as part of the agency's Commercial Lunar Payload Services, or CLPS, initiative.

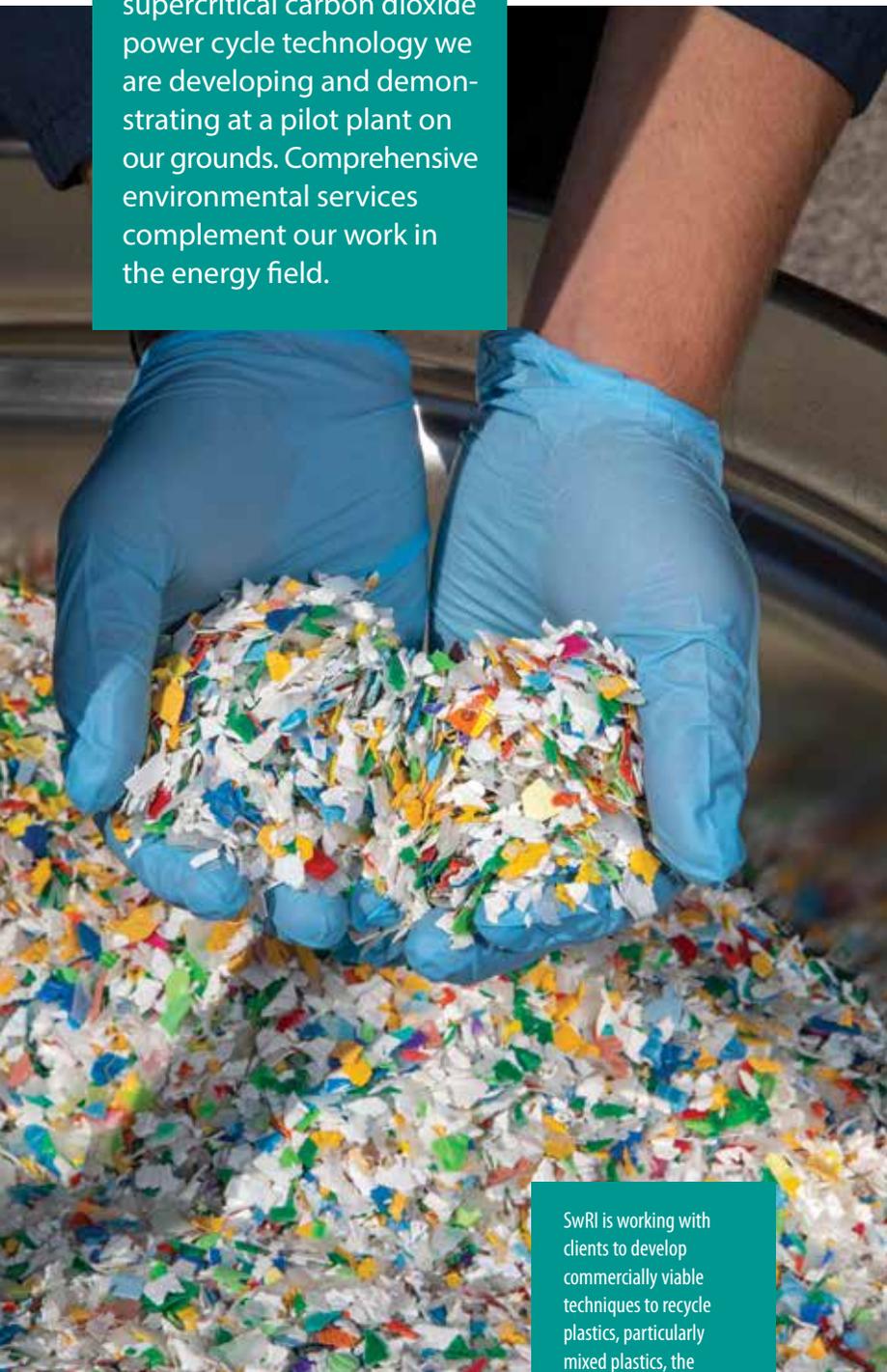
Specialists in the bombardment history of the Earth have modeled evolutionary processes in the main asteroid belt and discovered that impactors such as the one that ended the reign of the dinosaurs 66 million years ago likely came from the outer half of the main asteroid belt between Mars and Jupiter. The team also discovered that these events happened 10 times more often than previously thought. SwRI scientists also updated bombardment models with the latest geologic evidence of ancient large collisions and demonstrated how these impacts may have delayed the development of life on Earth.



An SwRI-developed ultraviolet spectrograph will help determine the composition of Europa's atmospheric gases and surface materials and search for plumes of materials escaping from cracks in the moon's icy surface.

D024978_7065

In 2021, SwRI saw an increased focus on transitioning to clean energy technologies, including the supercritical carbon dioxide power cycle technology we are developing and demonstrating at a pilot plant on our grounds. Comprehensive environmental services complement our work in the energy field.



SwRI is working with clients to develop commercially viable techniques to recycle plastics, particularly mixed plastics, the variety of items found in a typical recycle bin.

DD25029_9037

ENERGY & ENVIRONMENT

ENERGY

In 2021, we hosted the Thermal-Mechanical-Chemical Energy Storage (TMCES) workshop, bringing together industry and government representatives to address the need for long-duration energy storage to enable renewable energy integration and industrial decarbonization. SwRI is also demonstrating a scaled Pumped Heat Energy Storage (PHES) facility that will verify system operation and controls concepts for the emerging technology.

Worldwide natural gas production has steadily increased with population growth and demands for lower emission energy sources. When natural gas is extracted from reservoirs, liquids often enter pipelines as well, so it is critical to ensure that only the gas is ultimately delivered to compression equipment and industrial processes. To better characterize equipment exposed to liquid in the process, SwRI engineers designed and fabricated an addition to our Metering Research Facility. Using this wet gas flow loop, engineers can characterize separation equipment, gas sampling techniques and flow measurement technology with liquid present in high-pressure natural gas flows.

Since 1987, SwRI has operated the Center for Nuclear Waste Regulatory Analyses (CNWRA[®]) to assist the Nuclear Regulatory Commission (NRC) with responsibilities associated with radioactive waste storage, transportation, disposal and related areas. This year, a CNWRA scientist participated in the Senior Seismic Hazard Analysis Committees (SSHACs) evaluating hazards at the Idaho National Laboratory and Pantex, two Department of Energy (DOE) sites involved in nuclear research and security and not regulated by NRC. Previously, CNWRA staff assisted NRC in writing the SSHAC

guidance for the process that shapes how hazard evaluations such as these are conducted in the U.S. and around the world. In addition, CNWRA staff worked with NRC to develop guidance related to volcanic hazard assessments. Other teams supported NRC to complete Environmental Impact Statements for proposed centralized interim storage facilities for high-level nuclear waste in West Texas and New Mexico and to assess a complex uranium production site in Church Rock, New Mexico.

With one of the world's largest organizations dedicated to fire technology, SwRI offers a range of services, including testing to industry standards, listing and labeling products, and developing new test protocols. In 2021, we evaluated the fire performance of nuclear waste containers using a new protocol to simultaneously test multiple containers more cost-effectively.

SwRI has launched a new Joint Industry Program (JIP) to investigate energy storage systems for the grid. JIP efforts will include developing new test cycles for batteries employed in grid applications, estimating the life span of batteries and their potential for failure while reducing the likelihood of battery fires. The new program will investigate how responses to different demand scenarios affect the degradation of a battery.

SwRI provides exploration and production support to oil and gas companies, using a range of structural geology and geomechanics techniques. Staff members analyzed rock cores from the Uinta Basin in Utah and the Eagle Ford Formation in South Texas to characterize the natural deformation that influenced the evolution of unconventional reservoirs in these basins, ultimately to optimize hydrocarbon production.

ENVIRONMENT

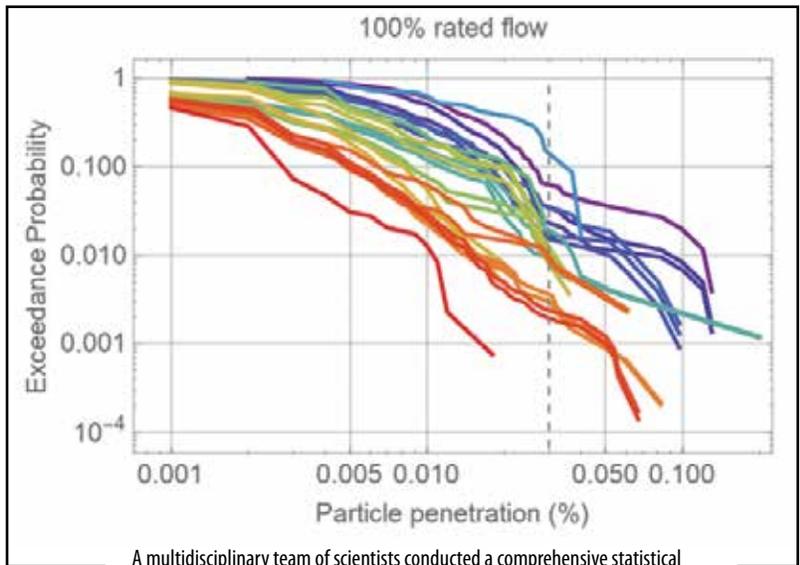
SwRI engineers and scientists develop and validate novel processes to produce fuels and other high-value products from unconventional sources, using custom catalysts, pilot plants and laboratory facilities, including using pyrolysis for processing mixed plastic waste.

Water quality and availability remain important global and local concerns, particularly in association with climate change. SwRI is characterizing aquifer recharge-discharge relationships in West Texas and analyzing transboundary water resources along the U.S.-Mexico border. These studies, along with our ongoing water budget investigations, are essential for protecting and managing critical groundwater aquifer resources threatened by development, industrialization and climate change.



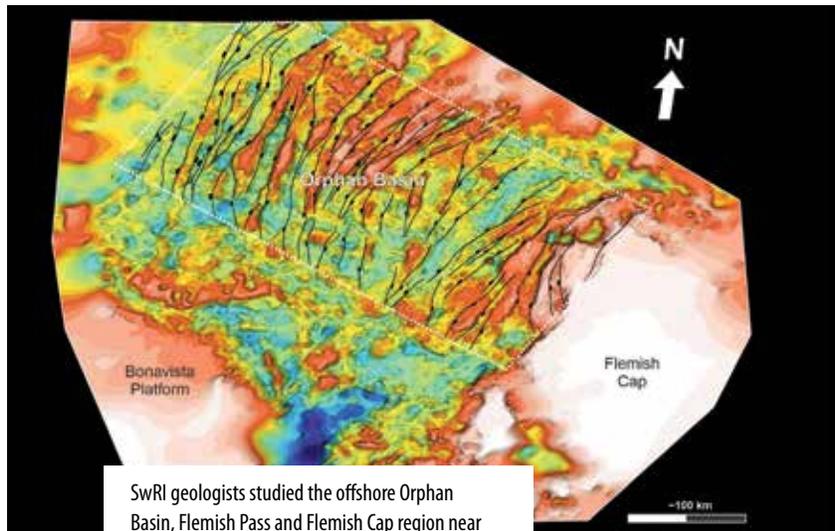
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In 2021, SwRI realized two key milestones in advanced supercritical carbon dioxide (sCO₂) power cycles, installing a high-temperature, integrally geared compressor and key process hardware at the 10 MWe Supercritical Transformational Electric Power (STEP) pilot plant.



D025168

A multidisciplinary team of scientists conducted a comprehensive statistical evaluation of the DOE's High Efficiency Particulate Air (HEPA) Filter Test Facility, informing potential alternatives to the current 100% sampling protocol required for filters installed in certain safety confinement systems at DOE nuclear facilities.



D025175

SwRI geologists studied the offshore Orphan Basin, Flemish Pass and Flemish Cap region near Newfoundland to provide insights into the structural evolution of this frontier oil and gas province.

Southwest Research Institute supports the manufacturing industry with advanced automation technology and workforce training. We also help ensure that aging aircraft and new engine designs meet or exceed standards for safety, durability and performance.



SwRI is developing an automated process for manufacturing aerospace parts using robotic placement of composite sheets.

MANUFACTURING

SwRI's robotics and automation engineers developed a system that adapts to a wide range of parts for high-mix, low-volume surface-processing applications, such as sanding or painting. Engineers used this Scan-N-Plan™ technology in a system that can paint any component by simply scanning, planning and painting the part.

SwRI has operated the Texas Manufacturing Assistance Center in South Central Texas for 26 years, supporting local small and medium manufacturers and helping them integrate process improvement, robotics and industrial techniques and technologies.

SwRI continues to advance the science of manufacturing, developing new materials and processes as well as data analysis and computational modeling tools. Factories and supply chains are using these tools to enable digital twin/digital thread initiatives. A digital twin models a current product or system, mimicking a company's machines, controls, workflows and systems. The digital thread is a record of its lifetime, from its creation to its removal. These software techniques can predict distortions and defects in parts made by additive manufacturing, model damage in composite aerospace structures based on their design, and use or model how novel coatings could improve the performance and extend the life of manufacturing tools and forging dies.

RELIABILITY

SwRI advances materials and manufacturing processes for commercial and defense applications. We continue sustaining aging military aircraft such as the T-38 supersonic trainer and A-10 Warthog under the

MANUFACTURING & RELIABILITY

D025117_9645



SwRI developed a sanding process that uses 3D sensing and perception, automated path planning and intelligent decision making to assess the quality of sanded finishes on parts.



D024987_7409

When improvements to the CH-47 Chinook introduced new actuators to the military helicopter, SwRI added capabilities to an existing test stand to evaluate new cockpit control drive and longitudinal cyclic trim actuators.

U.S. Air Force’s Aircraft Structural Integrity Program. As the prime engineering support contractor to the Air Force Center for Structural Life Extension and the Air Force Comprehensive Landing Gear Integrity Program, SwRI conducts component and full-scale aircraft testing.

For several years, SwRI has helped revamp maintenance facilities at the Corpus Christi Army Depot, which supports the Army’s rotary aircraft. As part of this effort, our engineers also develop test stand technology to support depot maintenance requirements, including two test stands deployed nine years ago that automated several manual actuator test processes. Since then, improvements to the CH-47 Chinook introduced new actuators to the helicopter. In response, SwRI added test stand capabilities to evaluate the new cockpit control drive and improved longitudinal cyclic trim actuators while maintaining the ability to test legacy equipment. These updates included adding time synchronization compatible with a newer flight computer and instrumentation to monitor environmental stresses on the trim actuator.

In 2021, SwRI also finalized a Jet Engine Maintenance Management Application system to support the F100 engines that power

F-15 Eagles and F-16 Fighting Falcons used by friendly foreign militaries. The system supports all existing engine configurations and can be adapted for new engines without software changes. The system tracks engine status, documents the maintenance history of engines and components, and allows users to add new part numbers, inspections and life limits. The web-based system can be fielded in a stand-alone, single-base configuration, or it can be used in a “headquarters” configuration where data from multiple military bases are compiled into a single database.

SwRI has decades of experience developing advanced computational modeling software tools to analyze how materials behave under a range of operating scenarios. For instance, SwRI’s NASGRO® Consortium marked its 20th year of supporting the fracture and fatigue crack growth software tool used worldwide to make aircraft and other structures safer. SwRI engineers also continue to enhance, utilize and train users on the NASGRO, NESSUS®, DARWIN® and NPSS® software systems to improve the reliability of structures and mechanical systems for the aerospace industry.



An SwRI team developed balance algorithms for a robotic line crawler designed to install fiber optic cable.

D025122_9786

Southwest Research Institute supports the health care industry, developing biomaterials and pharmaceuticals and supporting product evaluation and food safety studies.



Researchers are not waiting for the next pandemic to begin before seeking ways to stop it. SwRI leveraged its Rhodium™ drug discovery software to screen thousands of chemicals that could bind with and thwart Nipah, a potential pathogen.

BIOMEDICAL & HEALTH

0025172

SwRI's analytical chemists worked with several academic institutions, processing fast food samples looking for plasticizers known as phthalates. Most of the samples contained these chemicals, which are linked to health problems, including endocrine system disruption and reproductive issues, as well as learning, attention and behavioral disorders in children.

Leveraging more than 70 years of expertise in microencapsulation, SwRI is developing controlled release and targeted drug delivery technology, including subdermal implants. Using hot melt extrusion, we have developed a flexible delivery platform by mixing a drug or other active ingredient with a binder to produce a rod-like device that can be inserted just below the skin. Drug-eluting implants offer efficient, effective controlled release of pharmaceuticals that enhance patient compliance. SwRI has helped develop implants to treat opioid addiction, chronic pain, dry itchy skin, and Parkinson's disease and to protect against malaria and relapse following opioid detoxification.

SwRI continues to evaluate and develop treatments for COVID-19 and other infectious diseases. Medicinal chemists have identified multiple therapeutic candidates using virtual screening and synthesized chemical derivatives with greater potency and less toxicity. Laboratory tests have demonstrated improvements by a factor of ten in potency against multiple virus strains. The antiviral efficacy of these candidates against COVID-19 in animal models is under evaluation at Texas Biomedical Research Institute.

SwRI's microbiological laboratories have several ongoing projects in the areas of toxin detection, microbial-influenced corrosion, environmental simulation and antimicrobial textile and surface studies. For instance, SwRI microbiologists recently evaluated the design, function, operation and performance of a toxin detector using Centers for Disease Control permissible levels of ricin and botulinum toxins, providing the client with critical feedback on the detector's operation as well as suggested modifications.

SwRI microbiologists performed multiphase laboratory testing to evaluate the antimicrobial properties of various products, such as textiles. They also investigated unique antibacterial coatings for implants designed to enhance surgical site healing and infection control. The staff compared coated implants against control samples, such as bare titanium.

Chemistry and materials affect our everyday lives, from the water we drink to the products we use and the cars we drive.



D024983_7628

Microbiologists study how additives, biocides and storage conditions affect microbial growth in stored fuels. Environmental chambers control temperature and humidity through programmed exposure cycles, and fuel samples are monitored for microbiological activity and overall integrity.

CHEMISTRY & MATERIALS

Material scientists worked with microbiologists to identify possible corrosion-causing bacteria in oil, gas and locomotive coolant samples. Using NACE International standards and other techniques, the team monitored growth in oil and gas systems to estimate the number of acid-producing aerobic and anaerobic bacteria in a sample. Microbiologists also conducted laboratory-scale environmental simulation studies to investigate how additives, biocides and storage conditions affect the integrity of stockpiled fuel.

SwRI is developing a large-scale, cost-effective approach to extract potable water from the atmosphere. Current atmospheric water harvesting technology relies on refrigeration and high-humidity conditions. SwRI is combining its extensive experience in fluidized bed processes with fluid mechanics and heat transfer expertise to develop atmospheric harvesting technology that increases water yields at lower costs.

Silica gel beads are used to develop a low-cost, large-scale method of harvesting water molecules from the air. As they expel moisture, they turn from blue to pink.



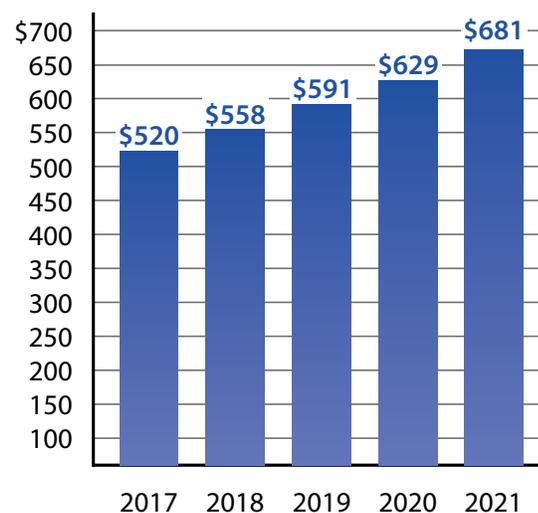
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FINANCIAL STATEMENT 2021

STATEMENTS OF FINANCIAL POSITION | in thousands of dollars

	For the year ended September 24, 2021	For the year ended September 25, 2020
Current Assets	\$428,571	\$417,628
Property & Equipment, Net	350,920	309,238
Other Assets	115,122	93,611
Total Assets	\$894,613	\$820,477
Current Liabilities	\$146,004	\$121,446
Noncurrent Liabilities	67,183	70,142
Net Assets	681,426	628,889
Total Liabilities and Net Assets	\$894,613	\$820,477

NET ASSETS | in millions of dollars



Consolidated revenues hit a record high at nearly
\$726 million — up over **4%** from 2020

Capital expenditures exceeded
\$71 million — up **21%** from 2020

Internal research spending exceeded
\$8 million — and funded **98** new projects in 2021

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2021 COMMUNITY CONTRIBUTIONS

In 2021, Southwest Research Institute continued its long history of support to the San Antonio community, including contributing more than \$1.2 billion to the local economy. SwRI employees and their families, the Board of Directors, advisory trustees, retirees, Signature Science and contractors donated to the United Way, upholding our Core Value of “Stewardship in Serving our Community.” Our 2021 United Way campaign raised a record-breaking \$1.1 million, exceeding a million dollars for the second year in a row, and SwRI staff logged nearly 1,000 volunteer hours serving 59 different community groups during the campaign.

Throughout the year, staff members continued to volunteer with local agencies, including participation in large-scale distribution events for the San Antonio Food Bank. As blood supplies fell during the lingering pandemic, SwRI continued on-campus blood drives once a month. In 2021 our staff members donated more than 1,000 pints of blood. In addition, the staff collected and donated 19 boxes of school supplies for local students in need. As the year came to a close, the staff donated seven boxes of gifts and bikes to the Marine’s Toys for Tots program.

To address the unique remote learning needs of a local underserved rural community during the pandemic, Bexar County contracted SwRI to design, configure and deliver a private wireless network for Southwest Independent School District students. Within three months, SwRI designed, integrated, installed, tested and deployed a fully managed private wireless network utilizing the Citizens Broadband Radio Service frequency bands. SwRI and our pilot partners will provide network support through December 2022 to meet the community’s remote education needs.

More than
\$1.2 billion
contributed to the local economy



D024655_9007



D024655_9113

More than
\$1 million
raised in SwRI's United Way campaign

Nearly
1,000 hours
volunteered serving
59
community organizations

More than
1,000 pints
donated in on-campus blood drives



D025159_9552



D024927_5988

19
boxes
of school supplies collected & donated

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United States

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