SOUTHWEST RESEARCH INSTITUTE®

FALL 2019

# TECHNOLOGY TODAY®

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## BAFFLING SOUND

Sound dampening baffles line SwRI's acoustic anechoic chamber, part of a test facility that also includes a reverberant chamber and a control center. The two chambers can be used separately, or they can be connected via a removable 6-by-6-foot partition.

Connecting the chambers is useful for sound transmission loss testing, as well as response testing of flat surfaces.

**Anechoic Chamber**

- 20-by-20-foot working area
- Free-field equivalent out to a 13-foot radius, from 63 Hz to 20 kHz
- Highly absorptive up to 50 kHz

**Reverberant Chamber**

- 26-by-24-foot area
- Sound emission evaluations
- Can conform to ISO/TR 7849:1987 standards

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# TECHNOLOGY TODAY®

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Southwest Research Institute is a premier independent, nonprofit research and development organization. With nine technical divisions, we offer multidisciplinary services leveraging advanced science and applied technologies. Since 1947, we have provided solutions for some of the world's most challenging scientific and engineering problems.

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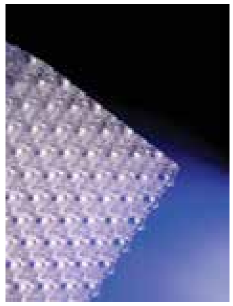

## ON THE COVER

SwRI uses 3D printers to create tightly packed, interconnected spherical voids in a bioreactor to grow profuse quantities of cells for personalized, regenerative medicine applications.

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## EMPLOYMENT

Southwest Research Institute is an independent, nonprofit, applied research and development organization. The staff of more than 2,600 employees provide client services in the areas of communication systems, modeling and simulation, software development, electronic design, vehicle and engine systems, automotive fuels and lubricants, avionics, geosciences, polymer and materials engineering, mechanical design, chemical analyses, environmental sciences, space science, training systems, industrial engineering, and more.

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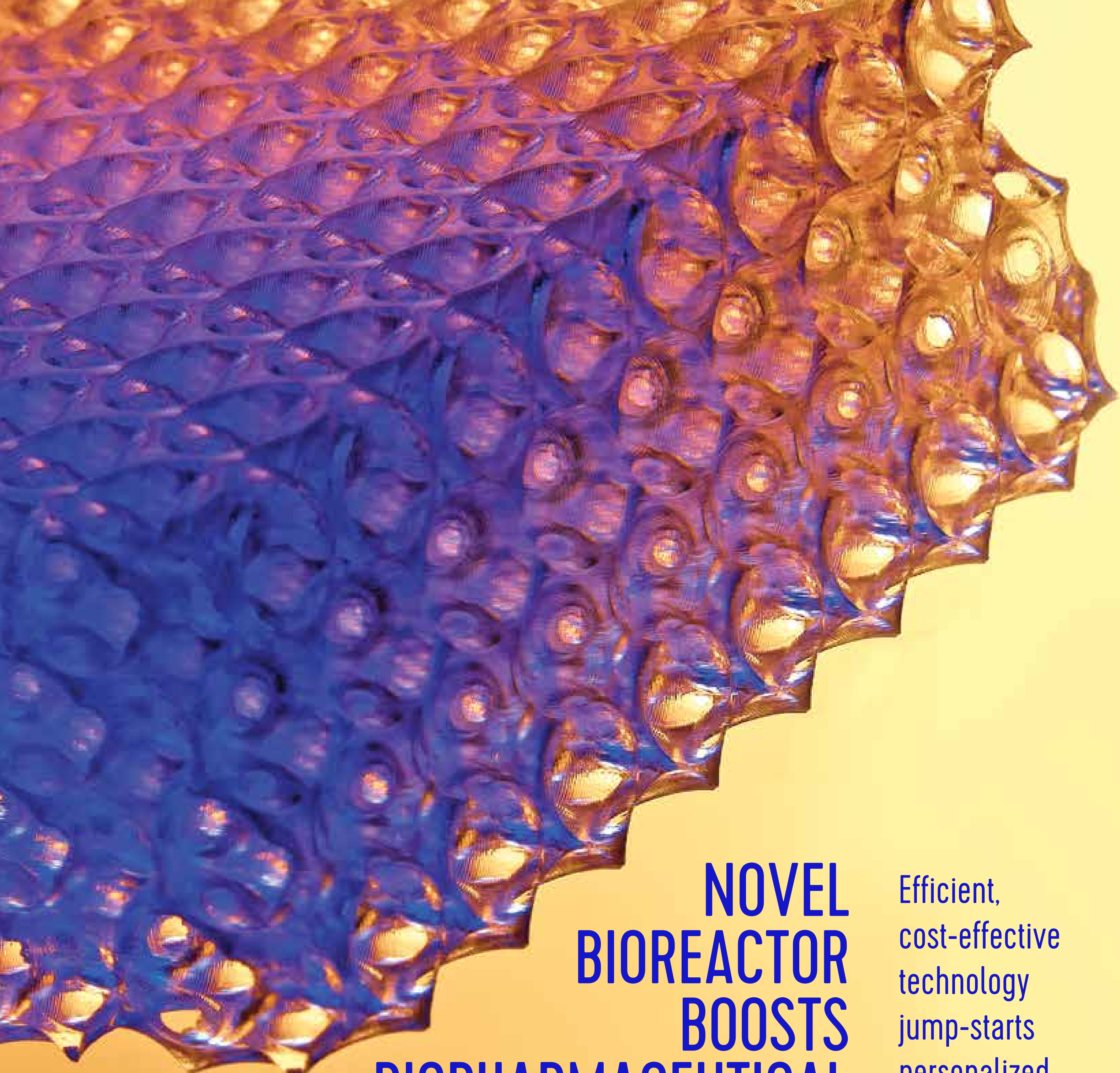

# NOVEL BIOREACTOR BOOSTS BIOPHARMACEUTICAL PRODUCTION

Efficient, cost-effective technology jump-starts personalized, regenerative medicine

By Jian Ling, Ph.D.

Imagine turbocharging your body's own defenses, using customized cells to attack a specific disease or repair an injury. That type of regenerative therapy could revolutionize how we treat diseases and degeneration using a patient's own immune or stem cells to fashion targeted treatments. For instance, a patch of stem cells could be used to repair a heart valve. Or T-cells in our immune system could be modified to seek out and destroy cancer cells. However, the promise of personalized, regenerative medicine is limited, in part, by scale. For example, only about 100,000 cells with regenerative potential can be harvested in an autologous or self-donation, but effective treatments often require a billion cells for a single dose, requiring a 10,000-fold increase for clinical applications.

**DETAIL**

An autologous donation is when blood, T-cells or stem cells are harvested from a patient for their own use in a surgical procedure or for infusion therapy.

Existing technologies do not meet the practical clinical needs for cell manufacturing. These applications typically require an expensive, labor-intensive cell culture process in high-cost cleanroom conditions. Supported by internal research funding, biomedical engineers at Southwest Research Institute have invented a novel cell expansion bioreactor to propagate cells for tomorrow's personalized medical treatments. Fabricated using 3D printers, these single-use scalable devices can expand cells in a closed-loop automated fashion with minimum human interaction and in a low-cost cleanroom, increasing yields while reducing costs.

SwRI is working with collaborators to create a standalone, programmable closed-loop cell expansion platform about the size of a minifridge to continuously propagate cells using our novel bioreactors. Much like a single-serve coffee maker can brew a variety of beverages using K-cup® pods, this turnkey perfusion-based "cell maker" system can propagate a variety of different types of cells and cell-derived biologics using SwRI's single-use bioreactors. This cell expansion platform will be integrated into new drug manufacturing systems expected to have a high impact on advancing personalized, regenerative medicine.

SwRI has funding from the National Institute for Innovation in Manufacturing Biopharmaceuticals (NIIMBL), the Advanced Regenerative Manufacturing Institute (ARMI), the Medical Technology Enterprise Consortium (MTEC) and the Food and Drug Administration (FDA) to demonstrate the technology by propagating T-cells for immunogenic therapy of cancers and mesenchymal stem cells (MSC) to treat age-related degenerative diseases.

## BIOREACTOR DESIGN

Through internally funded research, SwRI designed, developed and prototyped the bioreactor for T-cell and stem cell expansion. The patent-pending, disk-shaped design features tightly packed, interconnected spherical voids, providing a large surface-to-volume ratio for growing profuse quantities of cells. Its unique structure facilitates automatic control and delivery of nutrition and oxygen to cells.

The bioreactor can grow "suspension" cells, such as disease-fighting white blood cells known as T-cells that

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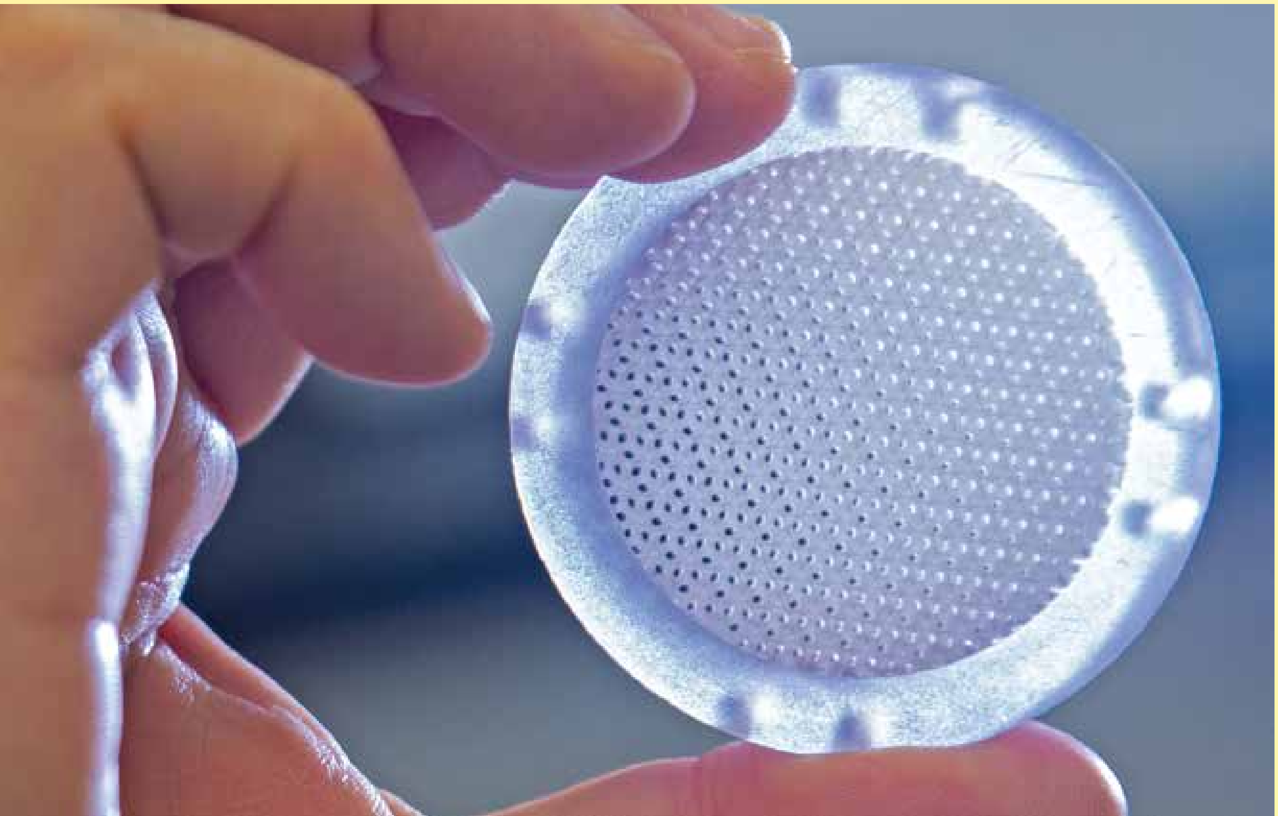
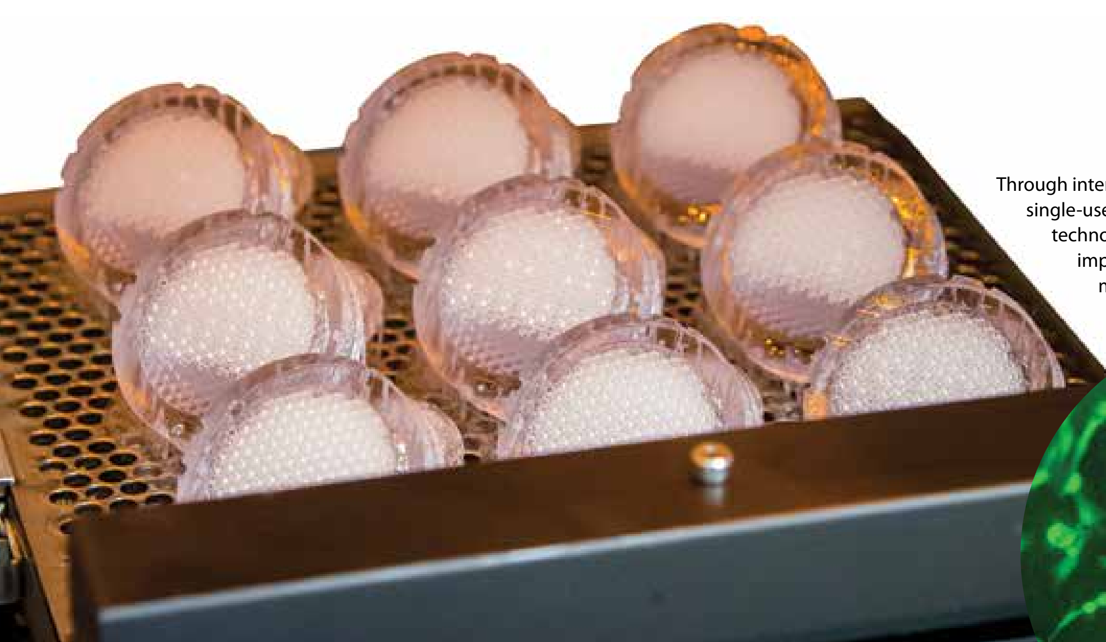


SwRI's patent-pending, disk-shaped bioreactor features tightly packed, interconnected spherical voids, providing a large surface-to-volume ratio for growing abundant quantities of cells.



Through internal funding, SwRI developed these novel, single-use bioreactors produced with 3D printing technology. Their unique structure is difficult if not impossible to fabricate using traditional injection molding techniques.

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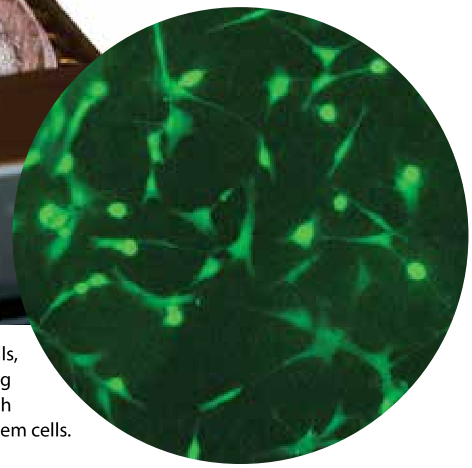


SwRI is using the bioreactors to propagate mesenchymal stem cells, which are "multipotent" with the capacity to self-renew by dividing and developing into multiple specialized cell types associated with specific tissues or organs. Most adult stem cells are multipotent stem cells.

can be engineered into T-cells with chimeric antigen receptors (CAR). These CAR T-cells can identify and kill cancer cells. The device also expands "adherent" cells, which include stem cells and primary cells such as those from bone, skin or muscle. The system also can manufacture cell-derived biologics to support gene therapy, therapeutic exosome, recombinant protein, and cell-based vaccine applications.

Using a 3D commercial printer, we created production-ready bioreactors of different sizes with the same internal structure. This maintains the cell expansion process from discovery to development and manufacturing, reducing the costs involved to move into the commercialization phase. The device is made of a biocompatible material used in many FDA-cleared or -approved medical devices. Its low cost makes single-use bioreactors feasible.

The design significantly increases the cell production capacity while maintaining the traditional monolayer cell culture during cell expansion. It reduces the shear force cells experience during production, while also preventing cell-to-cell aggregation and clumping that reduces clinical functionality and yield of cells. In addition, the bioreactor is designed to operate in a closed-loop automated process, reducing cleanroom requirements and costs.

The unique structure of the new bioreactor is difficult to fabricate using traditional injection molding techniques. SwRI has developed a proprietary technology to produce the bioreactor with a smooth surface suitable for cell growth. We are currently establishing cleanroom fabrication and radiation sterilization procedures for the bioreactor to meet the device quality and safety levels needed for clinical cell manufacturing.

**DETAIL**

Exosomes are lipid vesicles, small fluid-filled sacs, that shuttle proteins and genetic information between cells. These cellular couriers show great promise for delivering therapeutics.

**DETAIL**

Injection molding describes a manufacturing technique that melts raw plastic and injects it into a mold, where it cools and solidifies into a final part.

These images show the propagation of stem cells in the bioreactor in a week's time. Live cells are shown in green fluorescence.

AFTER SEEDING | DAY 2 | DAY 7

D023960, D023959, D023954

**DETAIL**

For CAR T-cell therapy, immune cells are collected from a patient and genetically modified in the laboratory. Millions of the CAR T-cells are grown in the laboratory and infused back into patients, binding to antigens on the cancer cells and killing them.


The SwRI team is assembling a perfusion controller system and optimizing the production processes to create a standalone, programmable closed-loop cell expansion platform about the size of a minifridge to continuously propagate cells using our novel bioreactors. SwRI's novel-single use bioreactors are ideal for pump-driven perfusion flow-based cell cultures. Perfusion technology delivers nutrition and oxygen to cells to support growth.

## TURNKEY TECHNOLOGY

SwRI's bioreactor facilitates pump-driven perfusion flow-based cell cultures. Perfusion technology mimics the human circulatory system to provide nutrition and oxygen to cells to support growth. Over long periods, a week or two, these systems culture cells continuously, providing the cells with fresh media and removing waste, similar to the circulation system in our bodies.

We are developing a turnkey, standalone system about the size of a minifridge as the demonstration perfusion unit. This includes a temperature-controlled incubator and a pump — like a heart — to deliver media to the cells inside the bioreactor. An oxygenator functions like our lungs, refreshing the oxygen concentration and removing carbon dioxide based on the "breathing rate" of the cells. We conducted computational fluid dynamics simulations to demonstrate the media perfusion flow profile across the bioreactor. We enhanced the system with a programmable controller to automate the nutrition and oxygen delivery for cell propagation. And we are integrating the bioreactor with tubing, a media storage bag and a waste collection bag to form a closed, single-use package that can be installed into the perfusion unit.

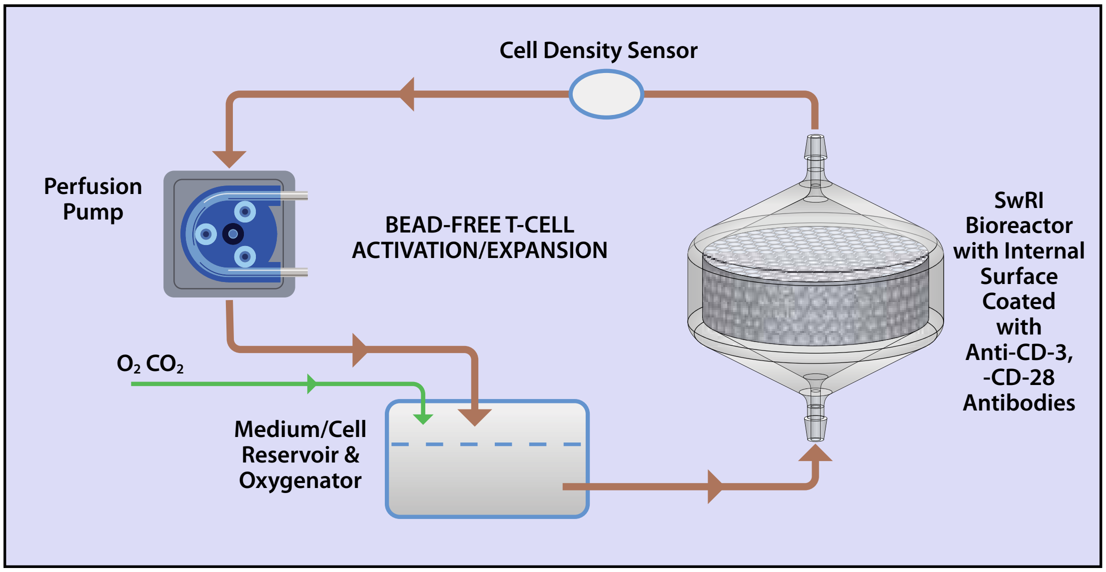
Current cell manufacturing is a complex, labor-intensive process that can cost up to $500,000 for a single treatment of personalized T-cell immunotherapy. These "open" processes require a high-cost Class 100 cleanroom environment. For CAR T-cells, magnetic microbeads are used for T-cell purification, activation and expansion. As the cells are harvested, the beads must be separated from the cells. However, it is difficult to completely remove the beads from the cells, so they often are infused into a patient along with T-cells, resulting in a potential safety issue. In contrast, our bioreactor does not require microbeads in T-cell manufacturing.

## SCALABILITY

Perfusion bioreactors offer several advantages over traditional batch bioreactors in terms of scalability. For one, perfusion bioreactors provide a large surface area for cell growth with a relatively small footprint. For example, our 8-inch diameter bioreactor with a 25,000 $cm^2$ cell surface area has the same cell production capacity as traditional cell culture flasks that would cover a 5-foot square table. These bioreactors also need less expensive cell culture media and labor to operate, significantly lowering initial capital investment and ongoing operating costs while producing the same yield.

Equipment to fabricate a larger-sized 250,000 $cm^2$ surface area bioreactor with the capacity of growing 10 billion MSCs is commercially available. 3D printers that could produce even larger bioreactors for a 100 billion to 1 trillion MSC expansion are also feasible. We expect that the cell expansion processes developed for small- and medium-sized bioreactors can be directly scaled up to a

SwRI's bead-free perfusion-based system offers closed-loop, automated T-cell activation, transduction and expansion in comparison to the complex, labor-intensive processes typically requiring Class 100 cleanrooms.




larger-sized bioreactor if the linear perfusion flow rate and the bioreactor's height remain the same, because the internal structure of the bioreactor does not change at different scales.

## APPLICATIONS

Advanced regenerative medicine therapies are exciting research topics, with more than 800 stem cell therapies currently in clinical trials. For these procedures, doctors either replace diseased or ineffective stem cells with healthy new stem cells or allow high-dose treatments for cancers and other conditions. These include autologous infusions, which use a patient's own stem cells, as well as allogenic transplants, which use stem cells from a donor.

Applications include treating diabetes, traumatic brain injuries, and Alzheimer's and Parkinson's diseases. The cells can also be used to treat spinal cord injuries, heart disease and wounds. Additional applications range from baldness to strokes, muscular dystrophy to heart disease, and deafness to dental health, learning disabilities and more.

When complete, SwRI's automated bioreactor-based system will offer a variety of cell culture surfaces based on specific needs. For example, three bioreactors with cell culture surface areas of 250, 2,500 and 25,000 $cm^2$ can replace 125 manual-operation flasks, to propagate 1 billion cells. Currently the SwRI team is assembling the perfusion controller system and optimizing the production processes. We are establishing cleanroom fabrication and sterilization procedures for the bioreactor while demonstrating the capabilities for clinical cell manufacturing.

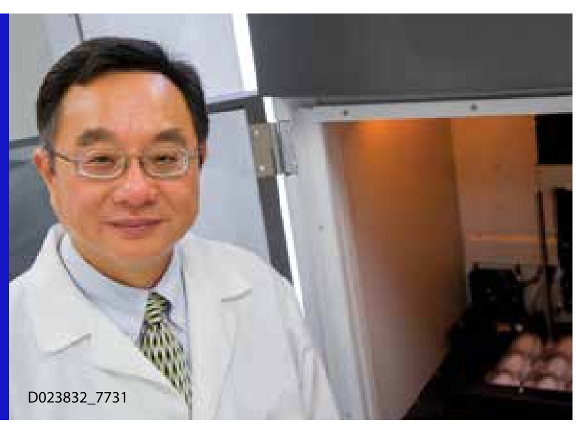
At the end of this program, a sterile fabricated bioreactor, integrated with a programmable perfusion system, will be available for clinical cell manufacturing. We will compare the bioreactor system with a commercially available microcarrier-based bioreactor to assess its performance. Lastly, we will demonstrate that it meets the cell expansion needs for mesenchymal stem cell expansion and MSC-derived exosome production in a clinical manufacturing environment.

Tailoring treatments to patients dates as far back as Hippocrates, the 400 B.C.-era physician often called the father of medicine. Today's doctors are combining increased knowledge of the human genome with data-driven diagnostics to develop bio-based therapies that will be more effective and less likely to have harmful side effects. In turn, SwRI is developing devices and technology that can make growing cells and biologics more efficient and effective, enabling the practical use of tomorrow's personalized, as well as regenerative, medicine.


*Questions about this article? Contact Ling at jian.ling@swri.org or 210-522-3953.*


ABOUT THE AUTHOR

Dr. Jian Ling is an Institute scientist who has been involved in biomedical research and medical device development for over 25 years. His research interests include the development of biomaterials, tissue engineering scaffolds, bioreactors and stem cell-based cell constructs for wound healing and regenerative medicine.



# FAST SOLUTIONS TO ENERGY STORAGE

The FAST Commissioning for Pumped Storage Hydropower (PSH) prize competition selected a Southwest Research Institute PSH concept among its four grand prize winners.

The FAST prize — which stands for "Furthering Advancements to Shorten Time" Commissioning for PSH — aims to reduce commissioning times of PSH projects by half, while reducing both cost and risk. The National Renewable Energy Laboratory (NREL) administers and executes these prizes on behalf of the U.S. Department of Energy's Water Power Technologies Office.

Electric power systems use PSH for load balancing. The method uses the gravitational potential energy of water, pumped from a lower-elevation to a higher-elevation reservoir using low-cost, off-peak surplus electric power to run the pumps. During periods of high electrical demand, the stored water is returned to the lower reservoir, driving turbines to produce electric power. Although the losses from the pumping process mean it consumes more energy than it generates, the system creates value by providing more electricity during periods of peak demand, when electricity prices are highest.

Selected from a field of 22 finalists, two SwRI concepts were among nine that moved on to the "incubation stage" of the competition. Following pitch presentations on October 8, SwRI was named one of the grand prize winners for its concept to lower the costs and construction time for building PSH reservoir dams.

"Our concept explores how to adapt a successful, but little-known 19th century steel dam construction technique to accelerate PSH development in the 21st century," said Dr. Gordon Wittmeyer, a hydrologist in SwRI's Chemistry and Chemical Engineering Division and the Institute lead for PSH. He is working with Dr. Biswajit Dasgupta, an SwRI structural engineer with significant experience in the hydropower industry, to develop a modular design concept for structural steel dams. The technique could cut dam construction costs by one-third and reduce construction schedules by half.

"It's significant that the two SwRI concepts were both selected to move forward to the incubator stage of the competition," said Eric Thompson, a program manager in SwRI's Mechanical Engineering Division. He worked with SwRI's Kevin Supak on the other concept. They analyzed the potential of using an array of shallow, interconnected reservoirs combined with packaged turbine units to reduce the PSH construction schedule, with the goal of bringing electric power to the grid sooner and improving the project return on investment and net value.

To accelerate pumped storage hydropower development, SwRI has developed a modern version of a 19th-century steel structural dam to impound water in a reservoir. The circular dam above is composed of modular sections that can be rapidly assembled using redesigned steel support frames made of standard W-beams and S-beams (left). The frame and water-tight faceplate modules are put in place using mobile heavy-lift cranes.

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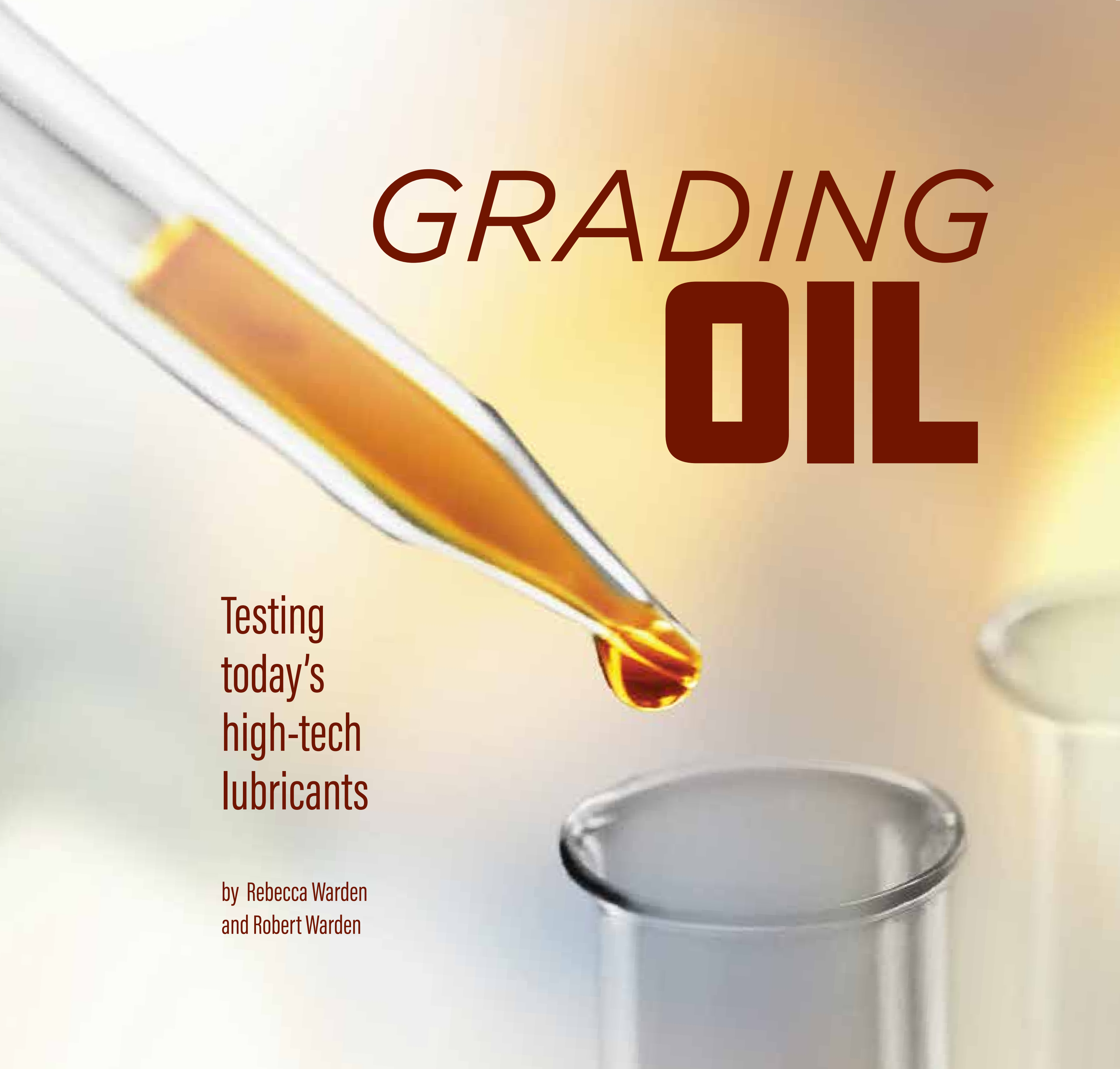

# *GRADING* **OIL**

## Testing today's high-tech lubricants

by Rebecca Warden and Robert Warden


ABOUT THE AUTHORS

Rebecca and Robert Warden are a husband-wife mechanical engineering duo who joined SwRI in 2009 after meeting at Rose-Hulman Institute of Technology in Terre Haute, Indiana. Ms. Warden manages the fleet and driveline fluid evaluation section, while Mr. Warden manages the diesel lubricants group, both in the Fuels and Lubricants Research Division.


# What is oil? Black gold? Texas tea?

These colloquial nicknames describe the crude pulled from the ground and refined into a range of products, including the fuels that power our cars and the asphalt we drive on. About 1% of each barrel of crude oil is turned into base stocks for lubricants, such as engine oil.

For engine oils, the adage that's been passed down for generations is change it every three months or 3,000 miles. However, today's modern vehicles are designed to use vastly different modern fluids. For instance, vehicle manufacturers are now working with additive companies to develop fluids designed to last 20,000 miles in a typical passenger car and up to 75,000 miles in heavy-duty trucks.

Today, using a fluid designed for one engine can have devastating effects on another. Getting top performance and durability out of your vehicle requires using the best oils specifically designed for your application.

Since 1949, a significant portion of Southwest Research Institute's 1,200 acres has been dedicated to assessing vehicles and the fluids they need to run efficiently. We operate hundreds of automotive test stands 24 hours a day, seven days a week, 365 days a year, looking at every component on a vehicle, from headlights to tailpipes. Many of those test stands are assessing the lubricants that ensure your vehicle runs smoothly (see infographic on p. 14). SwRI not only conducts regular testing of these fluids, but also helps develop the specifications and tests used to evaluate new products before they enter the marketplace.

## ADDITIVE ADVANTAGES

Today, many engine oils are 70 to 80% base stocks, ranging from minimally refined petroleum products, which can be found in conventional oils, to advanced base stocks found in synthetic products. Additive components make up the remaining 20 to 30% and play a vital role in a lubricant's performance.

So, what do all these additives do? These chemical components are mixed with an oil base stock to enhance its

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SwRI has served the automotive industry since 1949, evaluating the functional fluids that keep vehicles running. Today, nearly 400 staff members are engaged in SwRI's fuels and lubricants research, development and evaluation activities.

properties, including lubricity, viscosity, detergency and extreme pressure properties.

For example, for a multi-weight oil such as 0W-30 or 10W-30, the first number correlates with an oil's low-temperature performance, which is important at start-up and in cooler climates. A 5W-30 and a 10W-30 oil may use the same base stock but have different additives to modify its low-temperature properties, such as viscosity. Think of honey and water. Cold water pours easily while cold honey is quite thick, or viscous. Heat them both in a microwave and the honey thins out and flows easily, while the water pours about the same. Viscosity-modifier additives help the oil flow well when an engine is cold and keep it from thinning out too much once it warms up.

**DETAIL**

Viscosity is the quality of being viscous, a consistency that resists flow. Water has a small but measurable viscosity, or "stickiness," associated with the weak mutual attraction of water molecules.

Automatic transmission fluid is one of the most complex oils in a vehicle. ATF wears many hats. It protects gears and pumps from damage, wear and corrosion and acts like a hydraulic fluid to control clutches used to shift gears. ATF plays a major role in how the transmission shifts feel to the driver.

Many of these requirements are contradictory. For example: to protect gears, oil should be slippery to let gears slide off each other and minimize wear. Conversely, clutch performance requires oil to be sticky to hold the clutch plates together and prevent the transmission from slipping. Finding the right balance of additives can be critical to performance and durability.

To make things more difficult, many ATFs are now "fill-for-life" fluids, meaning the fluid must be able to hold up for over 100,000 miles and many, many years of service.

Engine oil performs many of the same functions as transmission oil but has the added requirement of absorbing and neutralizing combustion products. The byproducts from burning fuel are often acidic or abrasive and can damage an engine. The oil must capture them and neutralize their effects while maintaining its other characteristics.

While every intention of original equipment manufacturers (OEMs) is to go to market with the best products, field issues have been known to happen that can be remedied with a fluid adjustment. In many cases, tests will be developed to replicate the issue in a controlled environment. SwRI works with OEMs and additive companies to develop these tests and enable lubricant formulators to fix problems with fluid adjustments.

## STANDARDIZED TESTING

Once developed, these test procedures often become standardized and required by OEMs, the automotive industry and the military to ensure that all future lubricant blends, batches or formulations don't cause the same problems in today's vehicles.

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These two bearings illustrate the performance difference between previous generations of oil and today's products. Taken from the same modern heavy-duty diesel engine test, the image on the left shows results from an oil that was considered strong-performing in 2006. The image on the right shows the superior protection provided by a standard performance, lower viscosity oil available today.


Wet clutch friction is vital to automatic transmission performance. SwRI offers 12 test stands to assess automatic transmission fluid performance with various friction plate materials over a range of operating conditions.


SwRI engineers test motor oils to evaluate lubricant protection from low-speed pre-ignition, a potentially damaging phenomenon in today's smaller, highly efficient engines.

**DETAIL**

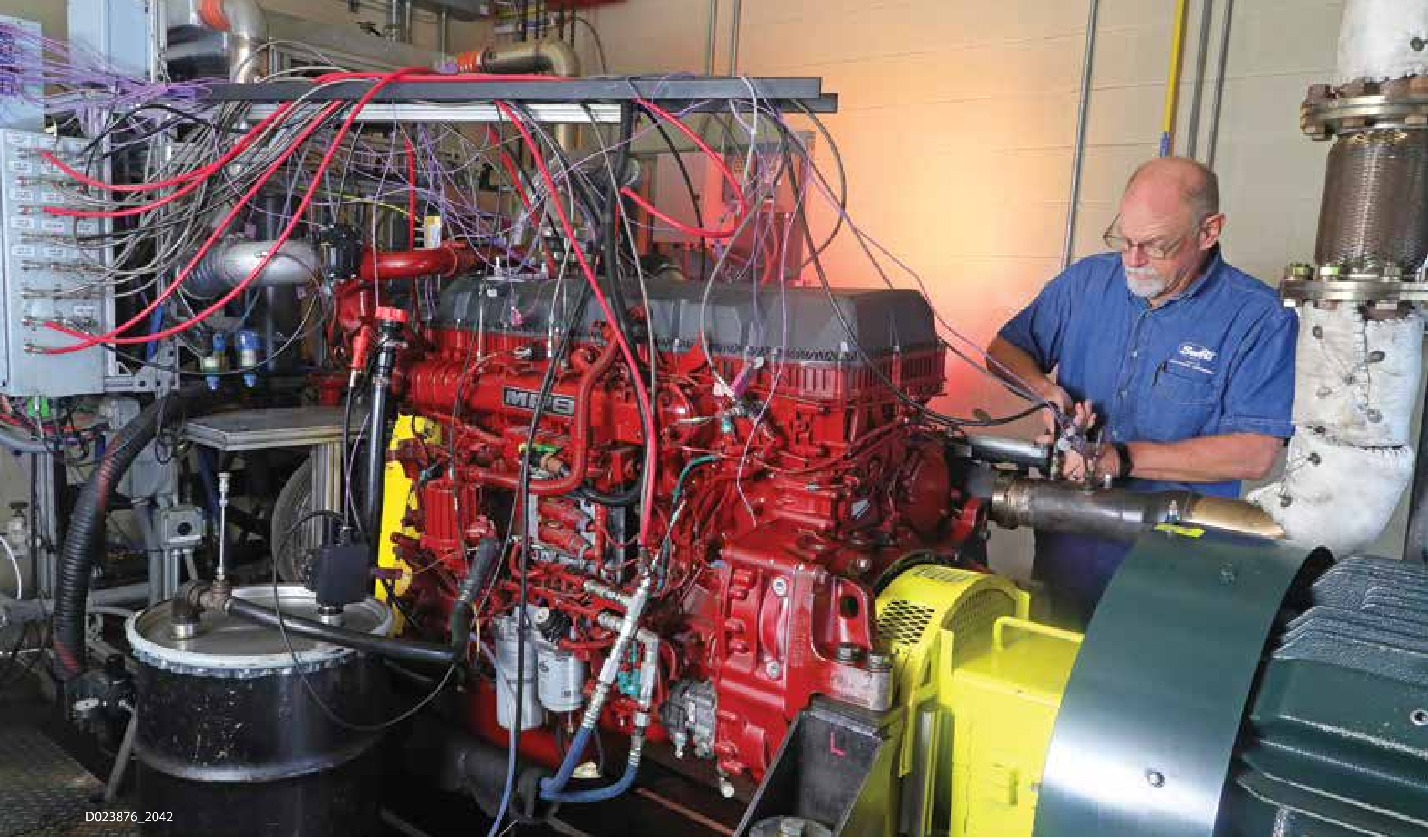
A hydraulic fluid is an oil- or water-based medium that transfers power in compression-based hydraulic machinery. While the primary function is to convey power, hydraulic fluids also protect machine components and provide other benefits including enhancing pump efficiency and the functional life of materials.

For example, one of the oldest tests is L-33-1, a gear oil rust test developed in the early days of World War II. At that time, axle lubricants were allowing components to rust, resulting in an unacceptable number of axle failures. The L-33-1 test simulates the field conditions and evaluates lubricants' ability to protect the axle from corroding. While it hasn't changed much in the decades since WWII, it is still required for all axle fluids today.

A more modern example is low-speed pre-ignition (LSPI). This phenomenon occurs in modern direct-injection engine designs. As OEMs have shrunk engine sizes to reduce emissions, they've turned to turbocharging to maintain power. This combination can cause combustion to start at unintended times with potentially devastating consequences for the engine.

To develop a new test, you must first identify a problem, such as LSPI, and design techniques to recreate it. Some test developers take this a step further, such as for gear wear tests. Some tests use gears deliberately designed for poor performance to amplify the problems and allow for better differentiation of fluids.

Some wear parameters are determined by length of time and load. Running an engine really hard for a long time will wear parts out. Others are amplified by certain operating conditions. Gear scoring is associated with transient or varying loads or impacts. Scoring is also affected by how well gears have been "broken in." Finding the right combination of surface prep and impact load to produce gear scoring is critical in developing a gear scoring test.




SwRI outfitted this new test cell with an electrically regenerative loading system to push power generated by the engine to SwRI's grid, reducing the Institute's electrical burden. Engineers use the Class 8 truck test cell to develop next-generation diesel lubricants, evaluating lubricant performance across the engine's entire operating range.

### TEST REPLICATION

Once a test is developed, designers must prove that it can be consistently replicated on multiple stands in various labs around the world. Control systems are also critical to ensuring repeatability in tests.

Controlling test hardware is just as critical as controlling test conditions. At any given time, we stock thousands of components to ensure that hardware is exactly the same, test after test. This protects us from inevitable "no-change changes" that can occur in production parts. The name for these phenomena comes from relatively minor changes that likely don't affect vehicle performance but have a critical impact on a highly controlled test. They can send the industry into a tailspin when something as simple as changing a filter supplier skews oil wear test results.

The goal for standardized testing is to certify a product meets performance for the intended application. This "stamp of approval" means an oil has undergone required tests and performed within various limits set by the industry or OEMs.

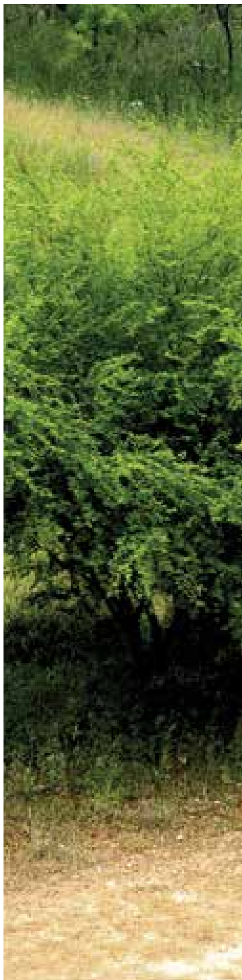
### CONSUMER CONSIDERATIONS

After evaluation and approval, oils make their way to store shelves, packaged in brightly colored containers to catch the eye. But what is most important is a small area on the back that shows a product's qualifications. If what's listed there doesn't match or exceed what's in your owner's manual, it's probably not the right product to use in your vehicle.

After standardized testing, you end up with a list of products that meet the manufacturer's expected durability. But if you're an oil marketer, how do you ensure your product is the one chosen for use? One differentiator is to prove a fuel economy benefit, which can result in a lucrative factory fill or fleet contract. To illustrate this, long-haul trucks travel an average of 70,000 miles per year getting around six miles per gallon of fuel. Increasing fuel economy by 2% can save

**DETAIL**

Factory fill refers to fluids that are added to new vehicles about to hit the market. This is the ultimate designation for an oil, because not only does it involve vast volumes of the fluids sold to an OEM, but a consumer often will stick with that brand of oil throughout the lifespan of their vehicle.

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SwRI conducts fuel economy testing in the Texas Hill Country for Class 8 tractor trailer rigs. Different oils can make minor improvements in efficiency that translate into major savings across the thousands of miles large fleets travel in a year.

**DETAIL**

The U.S. Army has studied the costs of fuel and water resupply missions in Afghanistan and Iraq, not only in dollars, but also in lives. Casualties calculated include soldiers and civilians killed or wounded while transporting fuel to consuming units. The casualty factor for fuel resupplies in Afghanistan is 0.042 or almost one casualty for every 24 fuel resupply convoys.**

almost 250 gallons of fuel per year. For a fleet of 8,000 semis at fuel prices of $3 per gallon, that 2% fuel economy benefit saves over $6 million in fuel costs each year.

### SAVING FUEL SAVES LIVES

While commercial companies operate large fleets of trucks, the world's largest owner of vehicles is the U.S. military. Recently the Army studied how using the most efficient fluids in all components of its transport fleet could affect fuel economy. As it turns out, just changing the oil products resulted in a staggering 7.8% improvement in fuel economy.*

In addition, a mere 1% increase in fuel efficiency means 6,444 fewer refueling trips for soldiers. For the military, saving fuel is about more than saving money, it's about protecting lives.*

Keeping your car running like a well-oiled machine often depends on the oil. SwRI has been evaluating how well lubricants work for almost 70 years, because a good oil can protect your vehicle and help it run for years, while the wrong one can stop it dead in its tire tracks. Plus, in military applications, the right oil can literally save lives.

*Questions about this article? Contact Rebecca Warden at rebecca.warden@swri.org or 210.522.6266 or Robert Warden at robert.warden@swri.org or 210.522.5621.*

*https://www.army.mil/article/181692/driving_the_armys_energy_efficient_future

**https://www.army-technology.com/features/feature77200/


D018424_1450

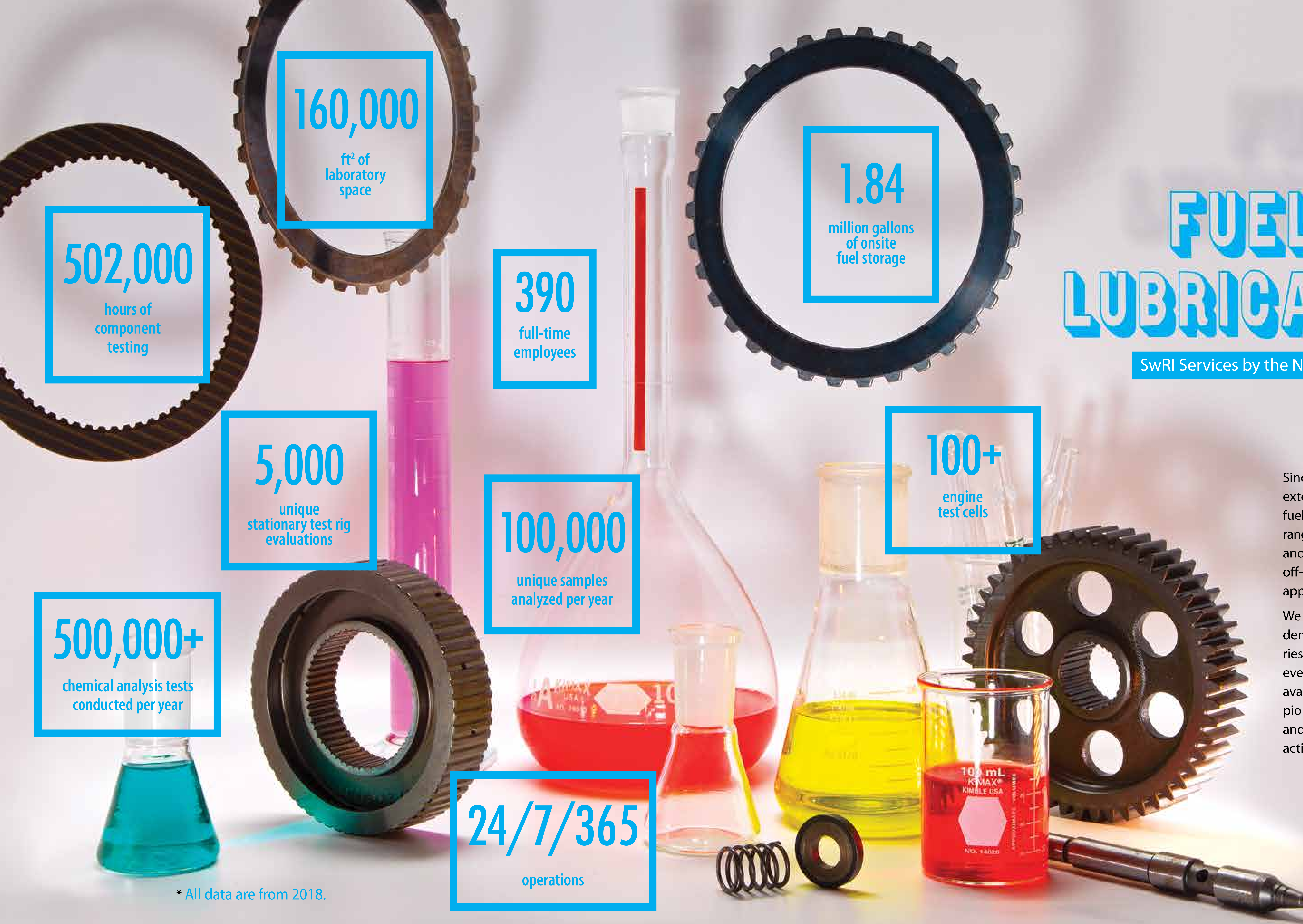
SwRI conducted fuel consumption testing on U.S. Army trucks in the field to evaluate how high-efficiency fluids could improve fuel economy fleetwide. Small improvements in fuel economy can save lives in the battlefield by reducing fuel resupply missions.

# FUELS & LUBRICANTS

SwRI Services by the Numbers

Since 1949, SwRI has dedicated extensive resources to evaluating fuels and lubricants against a full range of standards for light-, medium- and heavy-duty vehicles as well as off-road, marine and locomotive applications.

We are one of the largest independent fuels and lubricants laboratories in the world, testing virtually every engine oil and vehicle fluid available on the market. We conduct pioneering research, development and testing with these facilities and activities in any given year.*



**160,000** ft² of laboratory space

**502,000** hours of component testing

**390** full-time employees

**1.84** million gallons of onsite fuel storage

**5,000** unique stationary test rig evaluations

**100,000** unique samples analyzed per year

**100+** engine test cells

**500,000+** chemical analysis tests conducted per year

**24/7/365** operations

* All data are from 2018.

# SwRI, UTSA CONNECT THROUGH RESEARCH

## MODELING $SCO_2$ POWER CYCLES

One Connect grant is funding data acquisition to create a computational model for supercritical carbon dioxide ($sCO_2$) energy cycles. The work is led by Dr. Jacob Delimont of SwRI's Mechanical Engineering Division and Christopher Combs of UTSA's College of Engineering.

When carbon dioxide is held above a critical temperature and pressure, it reaches a supercritical state, acting like a gas while having the density of a liquid. The nontoxic, nonflammable $sCO_2$ is a highly efficient fluid for generating power because small changes in temperature or pressure cause significant shifts in its density. Typically, current power plants use water as a thermal medium in power cycles. Replacing water with $sCO_2$ increases efficiency by as much as 10 percent.

Because of the high fluid density in $sCO_2$ power cycles, power plant turbomachinery can be one-tenth the size of conventional power plant components, providing the potential to shrink the environmental footprint as well as the construction cost of any new facilities.

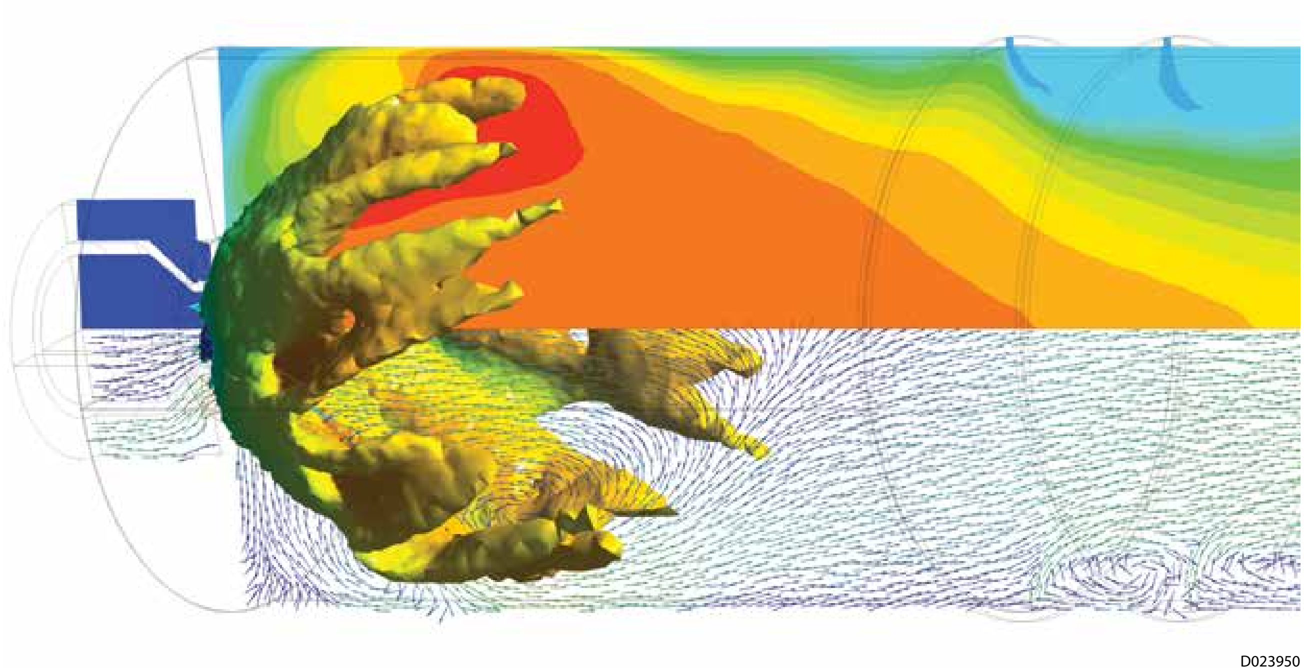
Delimont and Combs plan to work with a direct-fired $sCO_2$ cycle, which involves adding fuel and oxygen directly into the $CO_2$ stream, causing it to combust, release heat and create $sCO_2$. This new power cycle allows for higher efficiency and lower greenhouse gas emissions.

"This power cycle facilitates the capture of 100 percent of the $CO_2$ emissions that would otherwise end up in our atmosphere," Delimont said. "The captured $CO_2$ has many potential uses, including several applications in the oil and gas industry and the carbonation in everyday soft drinks."

Direct-fired $sCO_2$ power generation is such a new technology that very little is known about the combustion process. Delimont and Combs will collect data to validate a computational model for an $sCO_2$ combustor.

To visualize the burning of the $sCO_2$ fuel, UTSA will supply optical lenses and laser systems as well as Combs' expertise in the optical techniques needed to visualize the flame in the direct-fire combustor.

"Once we can visualize the combustion process, we can use computational models to design the necessary combustion equipment to make this power generation process a reality," Delimont said.



Through a Connect grant, SwRI and UTSA are collecting visual data of fuel burning in the $sCO_2$ to validate a computational model for a direct-fired $sCO_2$ combustor.

D023950

The University of Texas at San Antonio and SwRI are collaborating to understand supercritical carbon dioxide ($sCO_2$) energy cycles and metal degradation in 3D printed materials. The research projects are supported by $125,000 grants from the SwRI-UTSA Connecting through Research Partnerships (Connect) Program.

The program is sponsored by the Office of the Vice President for Research, Economic Development, and Knowledge Enterprise at UTSA and the Executive Office at SwRI. Connect grants enhance greater scientific collaboration between the two institutions and increase both UTSA's and SwRI's research funding with cross-campus programs.

**METAL DEGRADATION**

W. Fassett Hickey of SwRI's Mechanical Engineering Division and Brendy Rincon Troconis of UTSA's College of Engineering are studying how susceptible additively manufactured materials are to hydrogen embrittlement. Additive manufacturing (AM) is an increasingly popular method of creating meticulously designed metallic parts through 3D printing. The method's applications are practically limitless, but Hickey and Troconis are particularly interested in the performance of AM materials for aerospace and oil and gas applications.

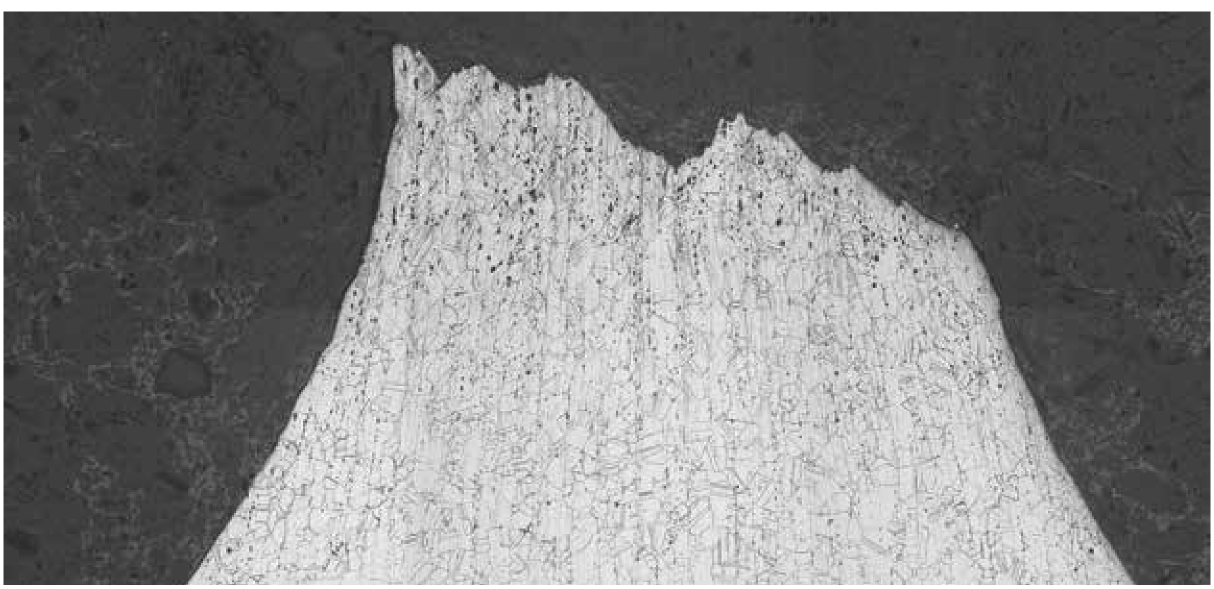
Hydrogen sulfide ($H_2S$) gas is commonly encountered during oil and natural gas production. When the atomic hydrogen in hydrogen sulfide is liberated, it can absorb into pipeline material and down-hole tools and degrade material performance through a phenomenon known as hydrogen embrittlement. The results can be devastating. For example, in 2014, the phenomenon caused large cracks in the pipelines at Kazakhstan's largest oil field, causing a two-year shutdown for repairs.

"Atomic hydrogen is an unintended alloying element that can wreak havoc on even the most advanced and modern alloy systems," Hickey said.

The project will focus on the hydrogen embrittlement mechanisms in additively manufactured nickel-based alloy 718, with future goals to design AM parts that are less susceptible or even immune to these threats.

Hickey and Troconis are studying hydrogen embrittlement on a molecular level to understand how hydrogen atom location affects the integrity of the metal material. Unique SwRI facilities allow testing materials under the high pressures and elevated temperatures typical of drilling environments, including exposure to gaseous hydrogen up to 3,000 pounds per square inch and 500 degrees Fahrenheit. Using UTSA's thermal desorption spectrometer and scanning Kelvin probe force microscope, the team will isolate the hydrogen-alloy interaction and spatially resolve where the hydrogen resides within the alloy microstructure.

"Additive manufacturing brings a lot of exciting new possibilities," Hickey said. "We're working with new designs that weren't possible with traditional machining and fabrication methods. If we can better understand the underlying mechanisms of hydrogen embrittlement in AM materials, the fabrication parameters and post-processing parameters of AM parts can be designed to prevent hydrogen embrittlement. This would ultimately expand the possibilities and applications for these AM materials."



An SwRI-UTSA Connect grant is supporting hydrogen embrittlement research, looking at material degradation mechanisms at microstructural levels with the ultimate goal of designing additively manufactured parts that are less susceptible or even immune to these threats.

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# SPOOF-PROOFING GPS-DEPENDENT TECHNOLOGY

By Victor Murray and Jimmy Li, Ph.D.

**Both individually and collectively, the entire global population has become increasingly dependent on a constellation of satellites orbiting the Earth.**

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Developed for the military beginning in the 1970s, global positioning system technology has become ubiquitous, critical to banking, communications and navigation systems worldwide since the 1990s. Most people are familiar with the navigation properties provided by our smart phones, but GPS signals also serve as the prevailing global clock used by the systems that drive our tech economy.

In fact, GPS technology is but one facet of cyber physical systems (CPSs) controlled or monitored by computer-based algorithms and integrated with the internet and its users. However, along with this connectivity comes a number of security risks and vulnerabilities.

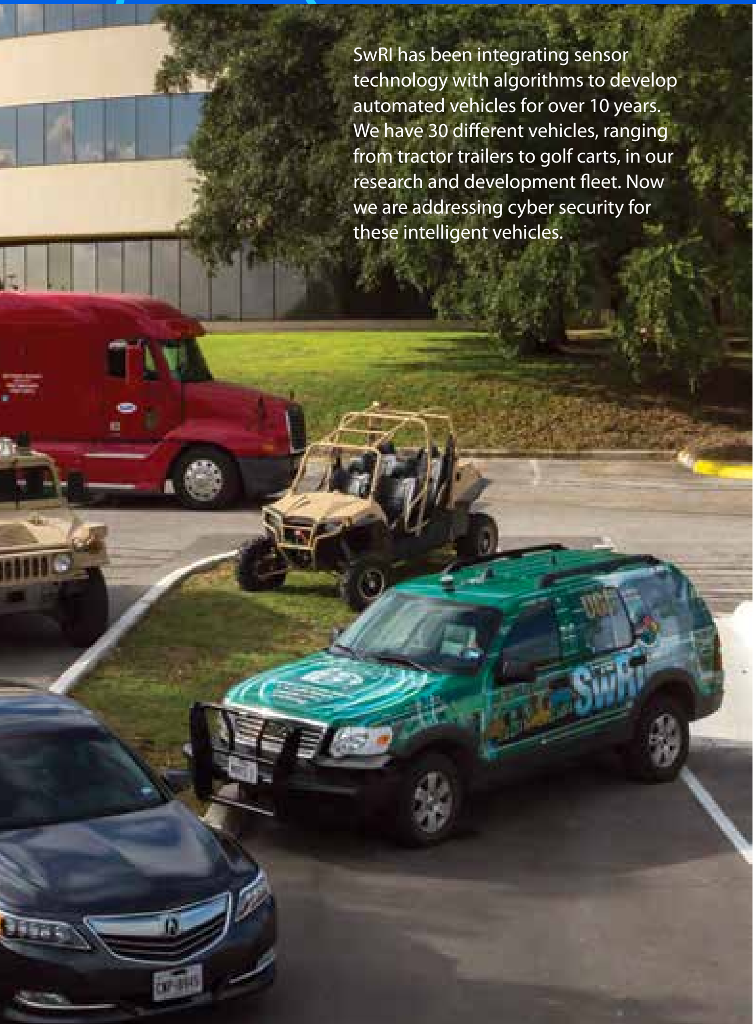
CPS security is an inherently interdisciplinary domain. Most organizations offering security services focus solely on information technology or have expertise in only one aspect of cybersecurity, such as hardware, software or communications. Southwest Research Institute takes a holistic approach to cybersecurity and has staff with experience in all relevant areas. We specialize in “white hat” techniques to evaluate networks, systems, software and embedded devices.

**DETAIL**

The term **black hat** refers to hacking that violates computer security for personal gain or malicious intent. In contrast to exploitative hackers, a **white hat** hacker uses similar techniques protectively to discover vulnerabilities in cyber systems to help identify protective measures need to secure these systems.

### GPS SPOOFING

SwRI has been developing automated vehicles for over 10 years, and we currently have 30 vehicles in our unmanned systems research fleet. We develop low-cost, high-performance




SwRI has been integrating sensor technology with algorithms to develop automated vehicles for over 10 years. We have 30 different vehicles, ranging from tractor trailers to golf carts, in our research and development fleet. Now we are addressing cyber security for these intelligent vehicles.

perception, localization, path planning and control technologies for intelligent vehicles ranging from golf carts to SUVs to Class 8 tractor trailers. Automated driving uses a number of different localization technologies including GPS and vision- and LIDAR-based solutions as part of their localization and navigation packages.

Sensors, including GPS, are vulnerable to external interference, from both natural conditions and malicious actors. For example, GPS is often blocked, distorted or reflected by buildings, tunnels, overpasses or other structures. On the other hand, an attacker can block GPS data or transmit inaccurate coordinates using inexpensive, readily available radio devices.

The various industries dependent on GPS must evaluate the vulnerability of GPS receivers and their systems' responses to interference in natural environments. However, because U.S. federal law prohibits over-the-air retransmission of GPS signals without appropriate authority, addressing this problem has been challenging. Fortunately, SwRI has recently developed a "legal" technique to spoof a GPS signal to understand the effects, particularly for automated vehicles that use GPS for positioning, navigation and timing.

So what is allowed? In general, the Federal Communications Commission (FCC) only allows entities to reradiate GPS signals inside a fully enclosed Faraday cage, under either an experimental license or a waiver, greatly limiting research and testing.

Velocity manipulation experiments with GPS signals caused vehicles to turn early or late, leaving the roadway.


**NORMAL**


**ALTERED GPS**

In response, SwRI has developed and demonstrated a mobile GPS spoofing system that allows legal, real-world evaluations of GPS vulnerabilities. The two-component system includes a box placed on top of the vehicle's GPS antenna and a separate ground station that controls the attacks remotely.

**DETAIL**

A Faraday cage is a mesh enclosure of conductive materials used to block electromagnetic fields.

The system receives the actual GPS signal from an on-vehicle antenna, processes it, inserts a spoofed signal and broadcasts it to the vehicle's GPS receiver. This gives the spoofing system full control over the vehicle's GPS receiver and allows for real-time manipulation while a receiver is in motion. The operator can modify the signal in real time through a remote graphical user interface.

### ATTACK MODES

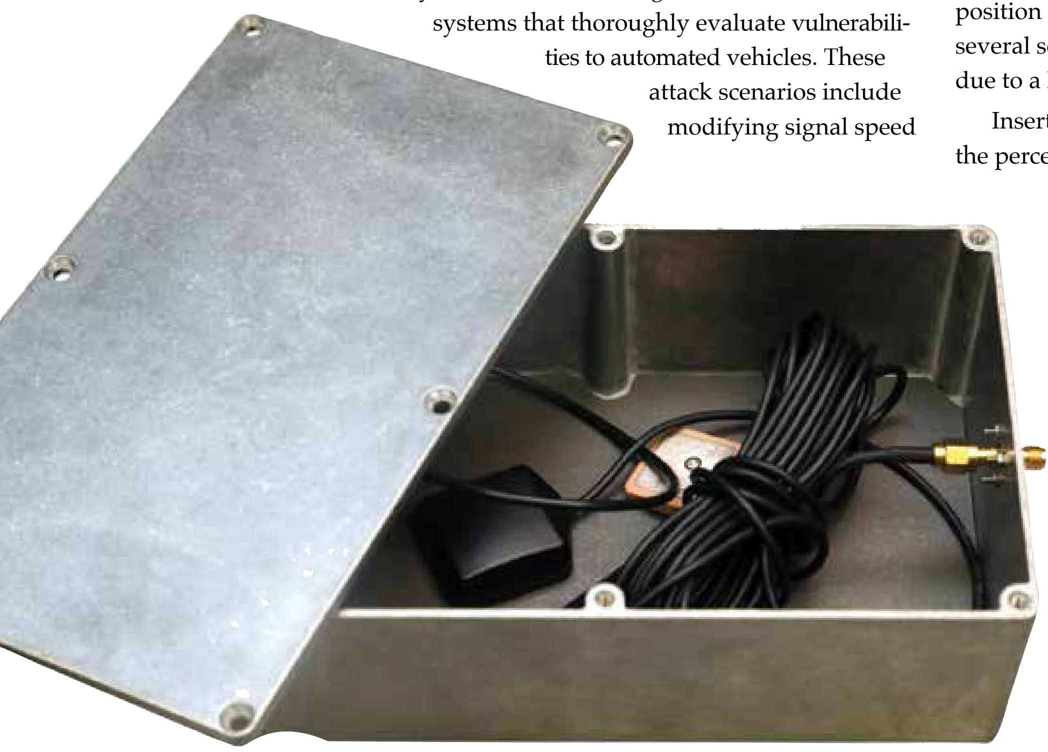
The system offers a full range of attacks to the GPS systems that thoroughly evaluate vulnerabilities to automated vehicles. These attack scenarios include modifying signal speed and timing as well as offsetting the location data or jamming.

A speed attack intentionally changes the speed associated with GPS signals, which can have various results. When implemented during a turn, the vehicle could turn too far and run off the road. When implemented before a turn, the vehicle could turn early or late, again potentially leaving the roadway. On straightaways, the effects are less apparent because the vehicle relies on another sensor for controlling speed.

When GPS signal speed is slowly brought to a halt, as the speed is reduced, the vehicle continues to drive at the same rate. Then, when the GPS location signal halts, the vehicle's control system becomes unstable due to a lack of accurate positional feedback.

Timing attacks involve having the actual vehicle position relayed to the GPS receiver but delayed by several seconds, causing the vehicle to steer randomly due to a lack of current positional feedback.

Inserting an offset into a GPS signal can manipulate the perceived location of the vehicle. During our



Critical to creating a legal technique for evaluating vehicle responses to spoofed GPS signals is a shielded communications box to interface with a vehicle's GPS antenna.

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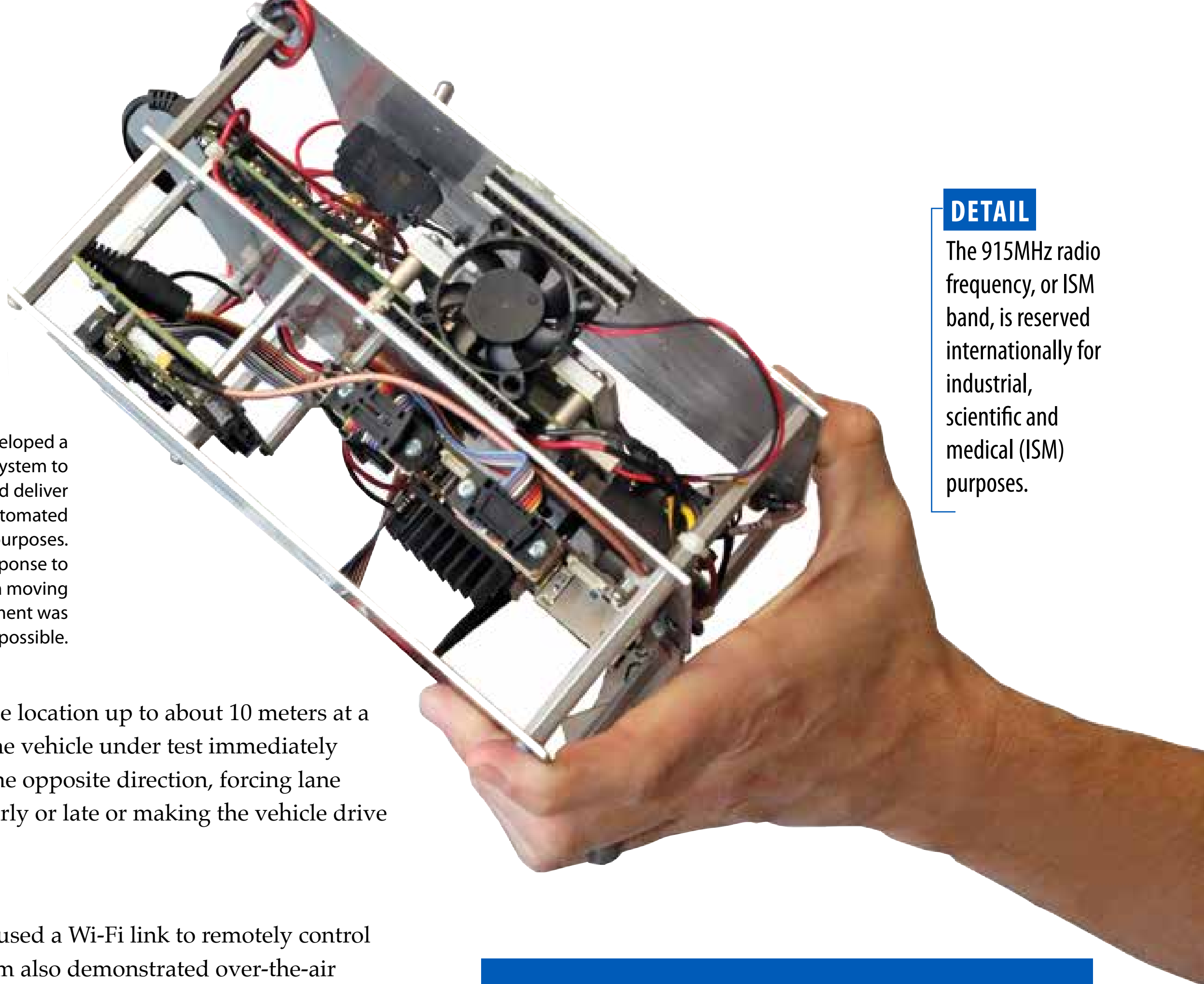

SwRI engineers developed a frequency translation system to receive, scramble and deliver modified GPS signals to automated vehicles for evaluation purposes. Legally evaluating the response to spoofed GPS signals in a moving vehicle in a natural environment was not previously possible.

**DETAIL**

The 915MHz radio frequency, or ISM band, is reserved internationally for industrial, scientific and medical (ISM) purposes.

experiments, we offset vehicle location up to about 10 meters at a time in various directions. The vehicle under test immediately compensates and moves in the opposite direction, forcing lane changes, causing it to turn early or late or making the vehicle drive off the roadway.

## FREQUENCY TRANSLATION

Most of the SwRI project used a Wi-Fi link to remotely control the spoofing system. The team also demonstrated over-the-air broadcast of the analog GPS signal using frequency translation to shift the base band to a frequency dedicated to industrial, scientific and medical purposes. On the receiver side, the signal was reconverted to the original base band using a similar setup and then sent to the GPS receiver.

## EXPOSING VULNERABILITIES

As the vital role GPS plays in many modern-day systems continues to grow, exposing any inherent vulnerabilities of GPS is critical. Because U.S. federal law prohibits over-the-air spoofing, testing these vulnerabilities outside of an enclosed laboratory environment is problematic. SwRI has demonstrated the ability to legally transmit a spoofed GPS signal to a moving automated vehicle to analyze the system responses. We have demonstrated the technique in a relevant environment and are ready to help clients identify vulnerabilities and spoof-proof their technology.

*Questions about this article? Contact Murray at victor.murray@swri.org or 210-522-6589.*


ABOUT THE AUTHORS

Vic Murray (left) is a manager in the Intelligent Systems Division leading automotive cybersecurity initiatives. He is a Certified Information System Security Professional (CISSP®). Dr. Jimmy Li is a research engineer specializing in antenna design, satellite communications and wireless communications for embedded systems.


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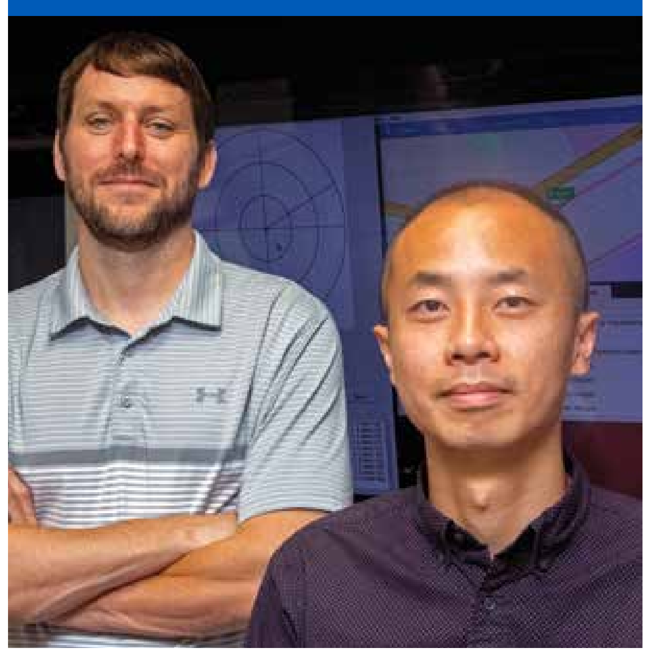
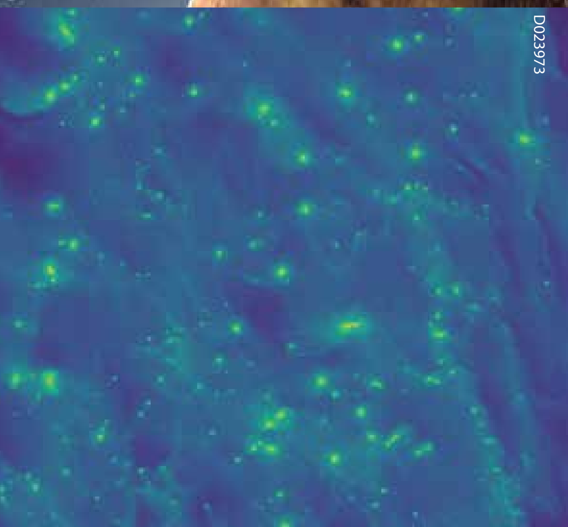





An SwRI-led team performed 3D simulations of the streaming instability model of planet formation, where particle clumping triggers gravitational collapse into planetesimals. This snapshot from the simulation shows the vertically integrated density of solids, projected on the protoplanetary disk plane.


SwRI scientists used Hubble Space Telescope images of Kuiper Belt binaries to determine that 80% orbit in the same direction as the planets. This research helps scientists improve planet formation models. Kuiper Belt object 2006 CH69, imaged on Jan. 26, 2017, is shown here.

## STUDYING BINARIES TO MAKE HEADS OR TAILS OF PLANET FORMATION

SwRI led a team studying the orientation of distant solar system bodies to bolster the "streaming instability" theory of planet formation.

"One of the least understood steps in planet growth is the formation of planetesimals, bodies more than a kilometer across, which are just large enough to be held together by gravity," said SwRI scientist Dr. David Nesvorny, the lead author of the paper "Trans-Neptunian Binaries as Evidence for Planetesimal Formation by the Streaming Instability" published in Nature Astronomy.

During the initial stages of planet growth, dust grains gently collide and chemically stick together to produce larger particles. However, as grains grow larger, collisions likely become more violent and destructive. Scientists have struggled to understand how planetary growth passes the 'meter-size barrier.'

The streaming instability theory posits that as large dust grains interact with the gas that orbits young stars, streaming mechanisms cause grains to clump into dense regions and collapse under their own gravity to form planetesimals.

The team studied objects beyond Neptune that orbit each other as binary pairs in the Kuiper Belt. Unlike comets flung past Jupiter or asteroids bombarded by radiation or colliding into each other, the distant Kuiper Belt has not been disturbed much since it formed, so these primordial objects provide hints about the early solar system. If a pair orbits in the same direction as the planets, it's considered heads-up. It's tails-up if it orbits in the opposite direction.

Using the Hubble Space Telescope and the Keck Observatory in Hawaii, the team found that most binaries, about 80%, orbit heads-up, which astronomers call "prograde." This finding contradicted the theory that binaries form when two passing planetesimals are captured into a binary. That theory predicts mostly tails-up or "retrograde" orbits.

To test whether the streaming instability could explain these Kuiper Belt binaries, the team analyzed simulations on large supercomputers. They found that the dense clumps formed by the streaming instability rotated heads-up 80% of the time, in agreement with Kuiper Belt objects.

"While our simulations can't yet follow the collapse all the way to forming binaries, it appears we are on the right track," said SwRI's Dr. Jacob B. Simon, who coauthored the paper.

"The solar system offers many clues to how planets formed, both around our Sun and distant stars," Nesvorny said. "Although, these clues can be difficult to interpret, observers and theorists working together are starting to make heads or tails of these clues — and the evidence is mostly heads."

IMAGES COURTESY STEWARD OBSERVATORY/UNIVERSITY OF ARIZONA/LI/YOUDIN/ HST/STSCI/SwRI/SIMON PORTER

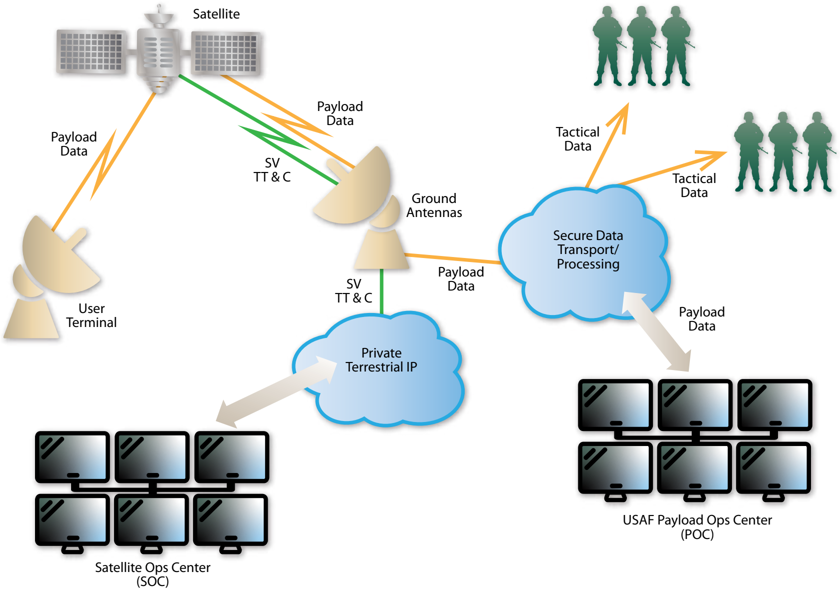
## SwRI Wins Contract for Military Support

The U.S. Department of Defense awarded an SwRI-led team a contract to prototype a system to process, exploit and disseminate data from satellites for tactical use by military units. SwRI is collaborating with commercial entities to support the Space and Missile Systems Center CASINO PED ground station initiative.

The Commercially Augmented Space Inter-Network Operations (CASINO) Processing, Exploitation, and Dissemination (PED) program seeks to produce and relay more timely combat information and actionable intelligence to the field. Over the past decade, the military has significantly increased the intelligence, surveillance and reconnaissance (ISR) data it collects. Unfortunately, this data surplus has created a processing and analysis bottleneck. The DoD's Defense Innovation Unit (DIU) will facilitate this technology demonstration and support the tempo needed to address future tactical threats.

"This prototype will demonstrate rapid delivery of processed satellite data to the tactical units needing the information in areas of conflict," said Debi Rose, SwRI senior program manager leading the effort. "Through this demonstration project, we will integrate a ground network supporting a constellation of satellites with unique processing capabilities and cloud access to deliver data needed to meet military objectives."

As the systems engineering lead, SwRI will integrate commercial technology including data networks, processing capabilities and delivery. The system will acquire raw data from the satellites and transport it through a commercial gateway to cloud-based services. The data will be processed en route to support rapid delivery of tactical products to in-theater users with minimal human-machine interface.

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For more information, visit **swri.org/industries/space-research-technology**.


D023953

## ActiveVision Automates Traffic Monitoring

SwRI has released ActiveVision, a machine vision tool that transportation agencies can use to autonomously detect and report traffic condition changes. ActiveVision's algorithms process camera data to provide real-time information on weather conditions and other issues affecting congestion. Designed for integration with intelligent transportation systems (ITS), ActiveVision can be configured with existing traffic cameras to analyze roadway conditions with no human monitoring required.

"The goal is to help transportation officials enhance their ITS capabilities with advanced algorithms that autonomously scan vast amounts of visual data, extracting and reporting actionable data," said Dan Rossiter, an SwRI senior research analyst leading ActiveVision development.

ActiveVision integrates with the SwRI-developed ActiveITS software as well as other ITS and advanced traffic management systems used by state and local agencies across the country. A leader in transportation and traffic management software, SwRI has over 20 years of experience developing and deploying ITS software for state and local agencies. SwRI-developed intelligent transportation systems have been applied to more than 13,000 miles of urban and rural managed roadways in 10 states and Puerto Rico.

"Work in the ITS arena inspired our team to find a solution that could be integrated agnostically into just about any advanced traffic management system using existing cameras and infrastructure," added Dr. Steve Dellenback, vice president of SwRI's Intelligent Systems Division.

## MODELING MATERIAL FAILURES TO IMPROVE ARMOR

SwRI is one of three organizations to win $127,000 in funding at the Ground Vehicle Materials Flash-to-Bang (GVM F2B) Pitch Day. Dr. Alexander Carpenter, Dr. Sidney Chocron and Dr. James Walker of SwRI's Mechanical Engineering Division proposed developing a computer model to ultimately help make armored vehicles stronger and less susceptible to failure and cracking in combat situations.

The GVM F2B Pitch Day is an innovative procurement approach to jump-start ideas in the accelerating technology ecosystem. Organizations pitched science and engineering proposals focused on significantly lightening or considerably improving ground vehicles or support systems to a panel of U.S. Army officials.

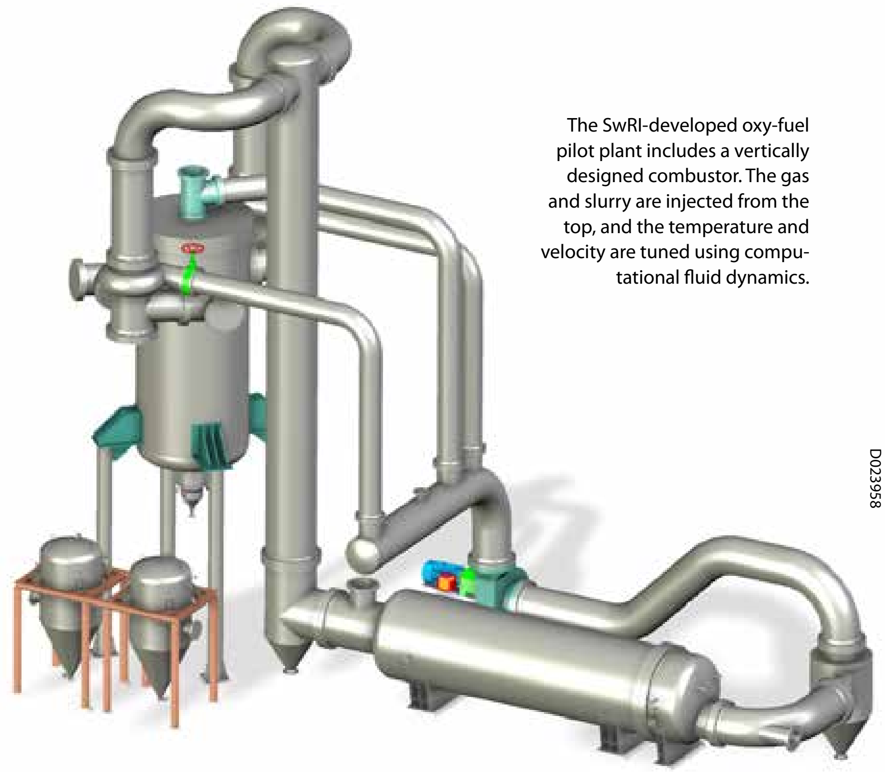
"Normally, armored vehicles are covered in these thick pieces of aluminum that eventually fail as a result of an impact," Chocron said. "We want to know how that failure starts and propagates. Current computer analyses cannot tell us that."

In a combat zone, armored vehicles are subjected to ballistic impacts, mine blasts and gunfire. The military relies on computational modeling as well as active testing of the armor on vehicles. However, the Army cannot currently predict the severity or extent of failure in the armor.

"We believe we can do a lot better," Carpenter said. "By properly modeling the onset and growth of failure, we can increase the accuracy and efficiency of the computational model, making the entire evaluation process more cost-effective because fewer tests are needed."

The team will create their computational model over the next six months in collaboration with the Army Futures Command and the Ground Vehicle Systems Center.

"Our goal is to improve the modeling the Army does every day for these types of systems," Carpenter said. "We're making it more cost-effective and user-friendly with the ultimate goal of helping create tougher, safer vehicles for our soldiers."




The SwRI-developed oxy-fuel pilot plant includes a vertically designed combustor. The gas and slurry are injected from the top, and the temperature and velocity are tuned using computational fluid dynamics.

## SwRI DESIGNING NOVEL PILOT PLANT FOR DOE

SwRI is designing a large-scale flameless pressurized oxy-fuel combustion pilot plant for the U.S. Department of Energy. Nearly $3 million in DOE funding will be augmented by $760,658 from industry collaborators to fund the demonstration plant, which will be located near the University of Wyoming.

"This will be a completely new type of power plant," said Joshua Schmitt, the SwRI project lead. "Oxy-fuel combustion plants generally don't exist at this scale because the technology is so new."

The process uses 95% pure oxygen combined with a fuel, typically coal or natural gas. The mixture is fed into a stream of carbon dioxide ($CO_2$) and water inside a combustor. The fuel and oxygen chemically react, producing hot gas that heats the water into steam, which drives a turbine and generates power. Pressurized oxy-fuel combustion has the potential to actuate a turbine directly, potentially improving the overall cycle efficiency.

Oxygen-rich combustion emits nearly pure $CO_2$ that can be captured and stored or reused rather than released into the atmosphere as a pollutant.

The proposed pilot plant will use coal, which also produces incombustible ash. A novel combustor design mechanically incorporates the ash into small, manageable pellets for disposal.

"One of the most exciting aspects of oxy-fuel combustion is its potential for power generation with almost no $CO_2$ emissions in the atmosphere," Schmitt said. "Burning coal is often associated with harmful emissions, but this is a way to utilize it for power generation with very limited emissions."

Over the next year, Schmitt and his collaborators will produce a front-end engineering design study to detail the basic engineering, full design, cost analysis and schedule metrics for building the large-scale pilot plant.

## AQUIFER MEMOIR

Four SwRI scientists lent their groundwater management expertise to a new book about the Edwards Aquifer, the primary water source for the San Antonio area. The 27-chapter memoir, titled "The Edwards Aquifer: The Past, Present and Future of a Vital Water Resource," compiles research spanning decades and addresses emerging challenges facing the aquifer.

"This first-of-its-kind, comprehensive memoir pulls together all of the information we have about the Edwards Aquifer to date in one place," said Dr. Ronald Green, an Institute scientist and groundwater hydrologist who co-edited the book and coauthored several chapters. "Researchers, regulators and water authorities can use this memoir to manage the aquifer and build upon the work that's already been done."

The book covers a range of topics, characterizing the aquifer's components and hydrogeologic structure and how climate and urbanization affect the system. Green says thoroughly understanding the demands on the aquifer, which provides water to millions of people, is key to preserving the resource for future Texans.

"Over time, the aquifer has been used and developed more," Green said. "Understanding the limitations of the aquifer will help guide its management to protect the availability and quality of the water. This book can provide policymakers with a roadmap of where to develop and at what levels."

All contributors are recognized experts on the Edwards Aquifer, including SwRI scientists Dr. David Ferrill, Dr. Beth Fratesi and Rebecca Nunu, who coauthored chapters of the book.

Published by the Geological Society of America (GSA), the memoir is currently available in print and digital versions. Proceeds from the sale of the book will go to GSA, a nonprofit, international scientific society that supports Earth science education.

D023948

## SATURN'S RINGS

No one knows for certain when Saturn's iconic rings formed, but a new study cotauthored by an SwRI scientist suggests that they are much older than some scientists think.

The study takes a closer look at 2017 Cassini spacecraft data that inspired several research papers suggesting that the rings were formed around the time dinosaurs roamed the Earth. Those studies, published in 2018 and 2019, challenged long-held models that put the formation of the rings several billion years earlier, around the time Saturn formed with the rest of the solar system.

In the latest twist, SwRI scientist Luke Dones and his collaborators argue that the historic models probably had it right in the first place. The age debate centers around a trove of Cassini data that revealed dazzling images of Saturn's rings composed of clear, almost pure water ice.

"After Cassini's mission ended, some research claimed the rings must be younger than we had considered them to be. Scientists argued that if the rings were much older, they would have become much more polluted as a result of meteoroids crashing into them," Dones said.

The studies suggested that the rings would have absorbed portions of dark, dusty material from the meteoroids and gradually dimmed. Therefore, the rings appeared too bright and clean to have existed in the solar system for billions of years.

Dones and his collaborators pointed out that Cassini measurements also show the rings are constantly losing matter to Saturn. The mysterious process could very well be "cleaning" the icy rings and making them brighter over time. One of the clearest indications that the rings are old is that their mass is consistent with researchers' current understanding of how primordial rings change.

"It's not impossible to determine the age of the rings, but to do so we'll need a future mission to Saturn to study the rings themselves as well as the relationship between them and the gas giant," Dones said.

D023975

IMAGE COURTESY NASA/JPL-CALTECH

## HYPERSONIC FLIGHT

SwRI engineers used high-speed video to image a conical flight body launched from our two-stage light gas gun at Mach 14.8 or 11,400 mph. Material stripped off the flying object is so hot that it glows, allowing the object to be photographed in flight.

D023947

To advance hypersonic flight research, SwRI conducted a series of sub-scale tests to elucidate the conditions future aircraft may experience traveling faster than 10 times the speed of sound.

"Hypersonic speed is defined as faster than five times the speed of sound or greater than Mach 5. When something is flying that fast, the air will chemically decompose around the craft," said SwRI's Dr. Nicholas J. Mueschke, who led the internally funded research. "Some points behind the shock-wave created by the vehicle are hotter than the surface of the sun. Essentially, it's flying through this strange chemical environment that causes whatever is traveling through it to heat up, melt and chemically react with the air."

Because that environment is so unique, recreating realistic flight conditions to test vehicles for hypersonic flight is a challenge. Wind tunnels can match some of the conditions, but don't fully replicate the pristine atmospheric and chemical reactions that a hypersonic vehicle experiences in flight. Mueschke and his colleagues used SwRI's two-stage light gas gun system to reproduce realistic hypersonic flight conditions.

The 72-foot gun system is designed to generate very high velocities — up to15,660 miles per hour — and is typically used to study ballistics. SwRI engineers used the system to propel sub-scale objects at speeds from Mach 10 to 15 to study how hypersonic flight conditions affect a variety of materials and geometries.

The facility mimics a broad range of flight altitudes in an acoustically and chemically pristine environment. The flights of these smaller projectiles replicate the true hypersonic flight conditions full-scale vehicles will experience. The research simulates the intense heating and vehicle material loss hypersonic vehicles will experience due to turbulent boundary layer transitions and complex shock wave interactions.

"This research will help us address material problems associated with hypersonic flight, the first step toward the technology of tomorrow," Mueschke said.

## NEW TRIBOLOGY TEST RIG

SwRI recently added an additional single cam rig (SCR) to its considerable array of tribology test equipment. The rig investigates wear mechanisms in engine valvetrain components.

Tribology is the study of interacting surfaces in relative motion, focusing heavily on friction, wear and lubrication. Though it's most often applied to the automotive industry, SwRI has used tribology to solve problems in areas ranging from aerospace to cosmetics to manufacturing.

"We don't just answer a question," said Dr. Peter Lee, who led the SCR development team. "We offer the entire package. We address the problem, provide answers and find a solution. If there isn't a device to help us do that, we create it ourselves."

Lee and his group created the first SCR in 2014 to make the ASTM D7484 wear test for engine oil more efficient and cost-effective. The custom-designed SCRs serve as platforms for detailed lubricant research. Using actual engine components in the rig reduces costs while providing more detailed understanding of wear mechanisms over standard tribology equipment.

"In the years since we created the first single cam rig, the demand for tests has become so high that it became necessary for us to build a second one," Lee said.

Both rigs have the unique capability to measure a lubricant's effect on the rotation of the lifter, a vital engine component that actuates the intake and exhaust valves, without interfering with the natural motion of the other valvetrain components. The tests help to understand properties such as wear and film formation. Computer control allows the replication of any engine test cycle.

"The fun of tribology is that it enables us to tackle so many unique challenges with a great deal of ingenuity and creativity," Lee said. "Tribology feeds into practically every industry there is."

SwRI designed this single cam rig to investigate wear mechanisms in an engine's valvetrain components.

D023957

## 2D Radar Retroreflector Measures Subtle Ground Movements

An SwRI team designed a two-dimensional radar retroreflector that remotely monitors subtle shifts in the Earth's crust. The patent-pending Van Atta retroreflector works in conjunction with satellites to precisely measure ground movement caused by earthquakes, oil production, mining and other processes. Movement can pose a risk to critical infrastructure such as nuclear facilities, airports and bridges.

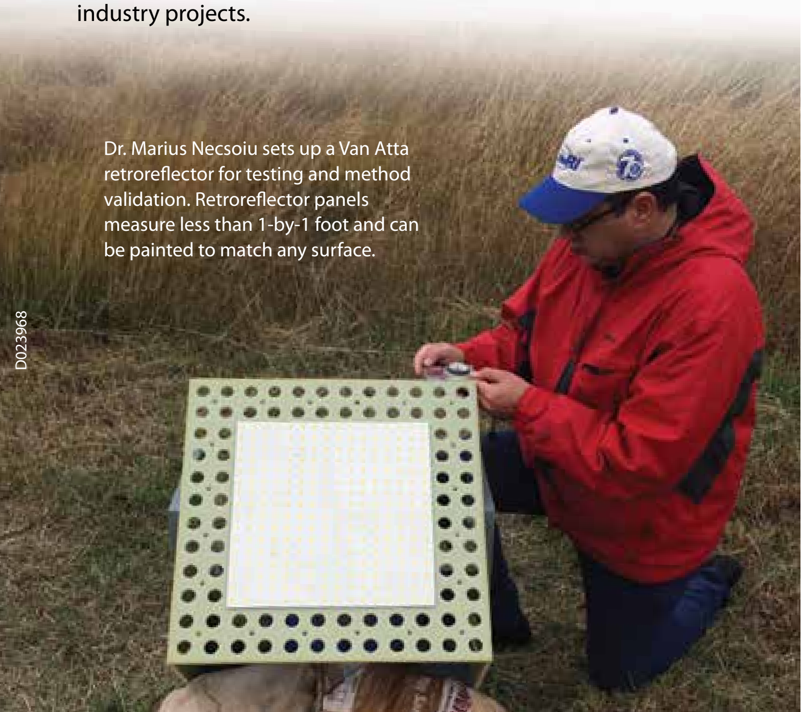
"By monitoring shifts in the Earth's crust, emergency managers, city leaders or anyone with an interest in community safety can detect and anticipate instabilities in a particular area," said SwRI Senior Research Scientist Dr. Marius Necsoiu, who created the Van Atta retroreflector concept with support from SwRI engineers Emilio Martinez and B. David Moore.

The device incorporates an antenna array patented by Dr. L.C. Van Atta in 1959 that reflects energy over a wide range of angles. SwRI's retroreflector merges Van Atta's principles with radar interferometry, a satellite-based method of measuring ground movement with radar signals. When monitored over time, the reflected signals show whether the ground in a particular location is shifting, detecting even slight movement.

"Analyzing subtle changes from space requires markers on the ground that don't change over time," Necsoiu said. "The compact Van Atta retroreflector provides that consistency. The flat design allows secure, flush mounting to structures or the ground. In addition, the retroreflector can withstand a range of challenging environments and temperatures, making it ideal for this type of data collection."

Traditional 3D reflectors are bulky and susceptible to damage or vandalism. SwRI's 1-by-1-foot panels can be painted to match any surface and configured in various patterns, making them easier to conceal and less prone to damage.

SwRI's Van Atta retroreflector can be adapted for a range of frequencies, making it compatible with any satellite, drone or radio device. This technology is currently available for government and industry projects.



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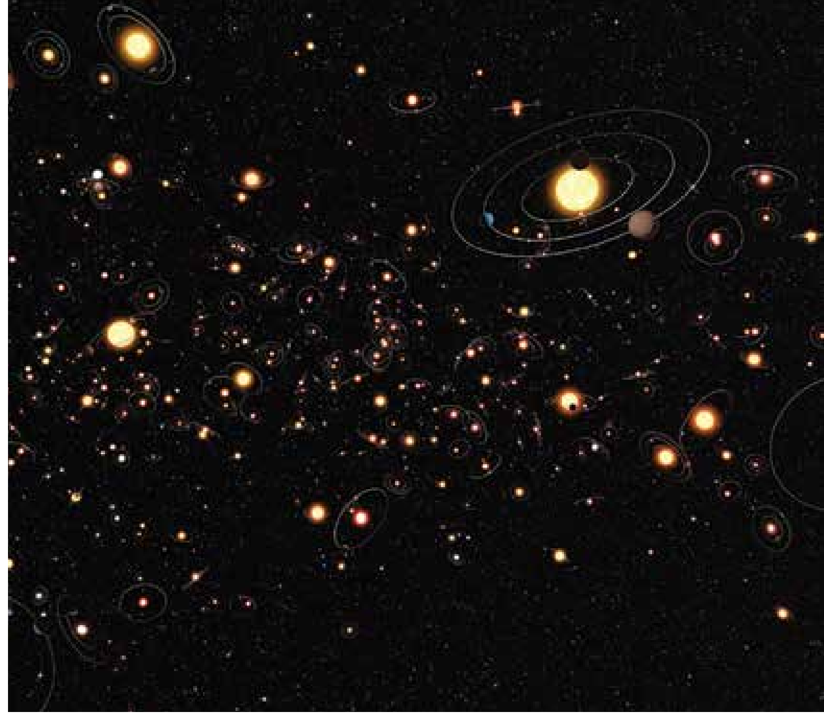
Dr. Marius Necsoiu sets up a Van Atta retroreflector for testing and method validation. Retroreflector panels measure less than 1-by-1 foot and can be painted to match any surface.



D023976

COURTESY ESO/M. KORNMESSER

This artist's impression (not to scale) illustrates how common star-exoplanet systems may be in the Milky Way. An SwRI scientist has developed an algorithm to predict the likelihood that a star hosts giant planets, based on the composition of known star-exoplanet systems.

## ALGORITHM AIDS SEARCH FOR EXOPLANETS

Inspired by movie streaming services such as Netflix and Hulu, an SwRI scientist has developed a technique to look for stars likely to host giant, Jupiter-sized planets outside of our solar system. She developed an algorithm to identify stars likely to have these exoplanets based on the composition of stars known to have planets.

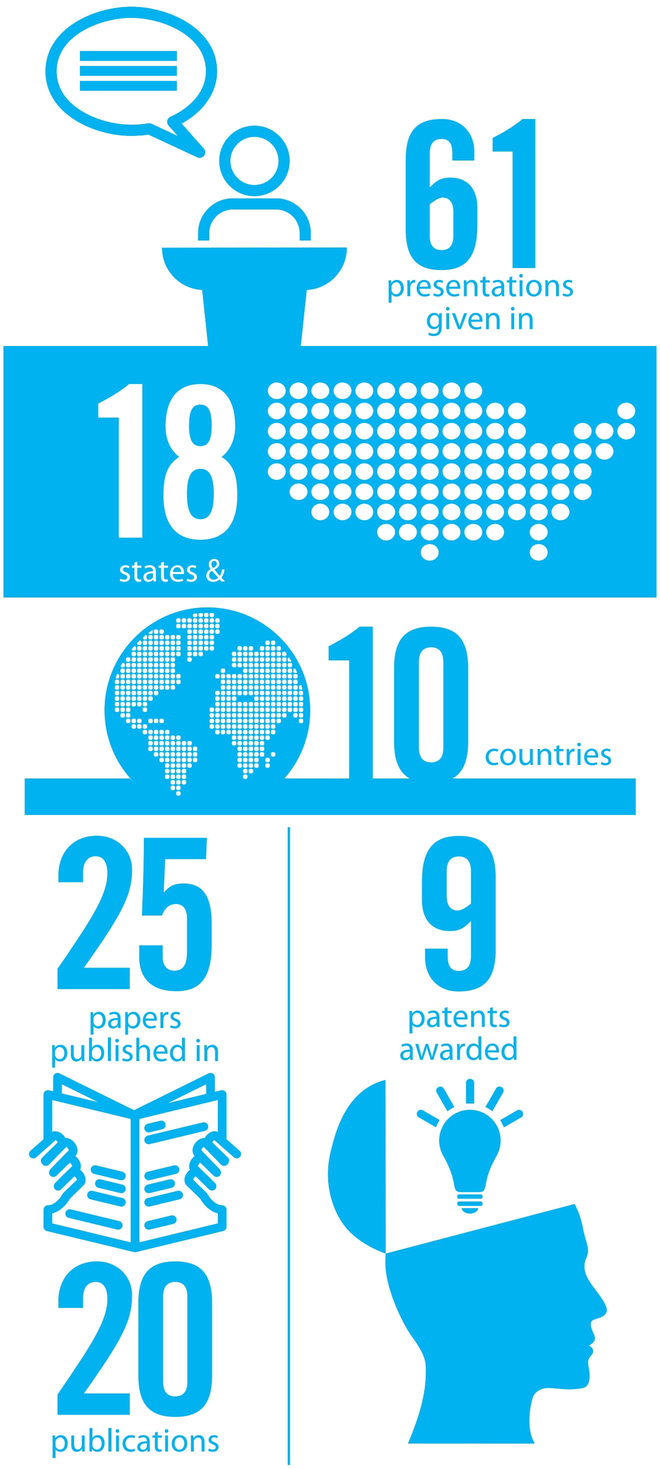
"My viewing habits have trained Netflix to recommend sci-fi movies I might like — based on what I've already watched. These 'watched movies' are like known star-exoplanet systems," said Dr. Natalie Hinkel, a planetary astrophysicist at SwRI. "Then, the algorithm looks for stars with yet-undetected planets — which are comparable to movies I haven't watched — and predicts the likelihood that those stars have planets."

Hinkel used the Hypatia Catalog (hypatiacatalog.com), a publicly available stellar database she developed, to train and test the algorithm. It's the largest database of stars and their elements for the population within 500 light years of our Sun. At last count, Hypatia had stellar element data for 6,193 stars, 401 of which are known to host planets. The database also catalogs 73 stellar elements from hydrogen to lead.

Hinkel's team identified around 360 potential giant planet host stars that have more than a 90 percent probability of hosting a giant exoplanet. "We were excited, so we used archival telescope data to search for any signs of planets around these likely host stars," Hinkel said. "We identified possible Jupiter-sized planets around three stars predicted by the algorithm."

When asked about how reliable her algorithm is, she explained that "We don't have any true-negatives in our data — that is, stars that we know don't have planets — so we 'hid' some known planet-hosting stars in the data to see what their prediction score would be like. On average they scored more than 75%, which is great! That's probably a higher average than me liking the sci-fi movies Netflix picks for me."

## BY THE NUMBERS JULY TO SEPTEMBER





## HPI SUMMIT

The 2019 International Human Performance Summit (IHPS) held at SwRI July 18–19 united sport scientists with high-performing athletic and military teams to explore practical applications for innovative research.

"Many complex factors affect the performance of athletes and elite military units, from neuroscience and sleep to strength and conditioning," said Kase Saylor, co-lead of SwRI's Human Performance Initiative. "IHPS 2019 provided a venue where collegiate and professional sports and military organizations could learn how science and technology are helping others gain a competitive advantage."

Now in its third year, the summit featured seven experts discussing sleep, nutrition, genetics, training and neuroscience, among other topics.

## COMING UP

D019368

Program Director **Dr. Christopher J. Freitas** received the American Society of Mechanical Engineers 2019 Patrick J. Higgins Medal. The award acknowledges Freitas' work developing and promoting verification and validation (V&V) in computational modeling and simulation standards and his leadership as chair of the V&V Standards Committee.

D023680_2796

Senior Safety Engineer **Matthew Herron** received the National Safety Council's prestigious Rising Stars of Safety award, which honors individuals under the age of 40 who play a significant role to positively influence and promote their company's safety culture and leadership. Herron accepted the award during the NSC2019 Conference and Expo in San Diego.

D023964

**Henry Sees**, director of SwRI's office in Warner Robins, Georgia, has received the Association of Old Crows' Anton D. "Tony" Brees Lifetime Service Award. The association's most prestigious award recognizes Sees' outstanding contributions to the field of electronic warfare throughout his career.

D019617

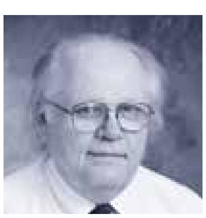
**Dr. Kelsi Singer**, a senior research scientist, was awarded the 2019 Harold C. Urey Prize by the American Astronomical Society's Division for Planetary Sciences. The prize is the highest DPS honor for a young planetary scientist, recognizing outstanding achievements in planetary research. Singer accepted the prize at the joint 51st meeting of DPS and the 14th European Planetary Science Congress in Geneva, Switzerland.

D015678

Institute Scientist **Steven Westbrook** received ASTM's Kurt Strauss Steady Hand Award for meritorious service in efforts to keep diesel and aviation fuel specifications and test methods true to their essential purpose. The award recognized decades of contributions to maintaining general distillate fuel quality issues shared by jet fuel.

D022479_6154

**Angel Wileman**, manager of fluid dynamics at SwRI, won the Empowering Women in Industry "2019 Leadership in STEM Award." Wileman was recognized for mentoring college students, hosting tours of SwRI and outreach to undergrads on behalf of the Society of Women Engineers to encourage women to pursue careers in STEM.



D018058

Principal Scientist **George Wilson** has received the Award of Merit from ASTM. The prestigious award, which includes the accompanying title of Fellow, is ASTM's highest recognition for individual contributions to developing standards. ASTM recognized Wilson for his contributions to improve aviation fuels and lubricants and for his leadership activities within the organization.

### TRAINING

**SwRI is hosting these events in San Antonio:**

GD&T (Geometric Dimensioning and Tolerancing) Fundamentals, November 5, 2019.

Gas Turbine & Compressor Short Course, November 18, 2019.

Lateral & Torsional Rotordynamics for Centrifugal & Reciprocating Machinery, December 3, 2019.

8D Problem Solving, December 4, 2019.

Liquid Propulsion Systems Propellant Tank and Pressurization System Modeling Webinar, February 5, 2020.

Turbomachinery Design Training Week, February 10, 2020.

Penetration Mechanics Short Course, March 16, 2020.

### CONFERENCES

SupplySide West, Las Vegas, October 15, 2019, Booth 1702.

2019 TMAC Smart Manufacturing Conference, Addison, Texas, October 22, 2019.

Automotive Testing Expo, Novi, Michigan, October 22, 2019, Booth 3024.

2019 Central Texas Manufacturing Expo and Conference, Austin, October 24, 2019.

Global Syngas Technologies Conference, Austin, October 27, 2019, Booth 10.

American Association of Pharmaceutical Scientists (AAPS) PharmSci 360, San Antonio, November 3, 2019, Booth 1313.

Natural Gas STAR & Methane Challenge Workshop, Pittsburgh, November 4, 2019.

ASNT Annual Conference, Las Vegas, November 18, 2019, Booth 1921.

ASIP Conference, San Antonio, December 2, 2019, Booth 24.

Technology & Maintenance Council (TMC) Annual Meeting, Atlanta, February 24, 2020, Booth 3827.

Waste Management Symposia, Phoenix, March 8, 2020, Booth 411.

For more information, visit **swri.org/events**.

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