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SUMMER 2018

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ON THE COVER

Using computational fluid dynamics tools and combustion visualization techniques, SwRI engineers optimized the combustion process for the ECTO-Lab™ system.

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EMPLOYMENT

Southwest Research Institute is an independent, nonprofit, applied research and development organization. The staff of nearly 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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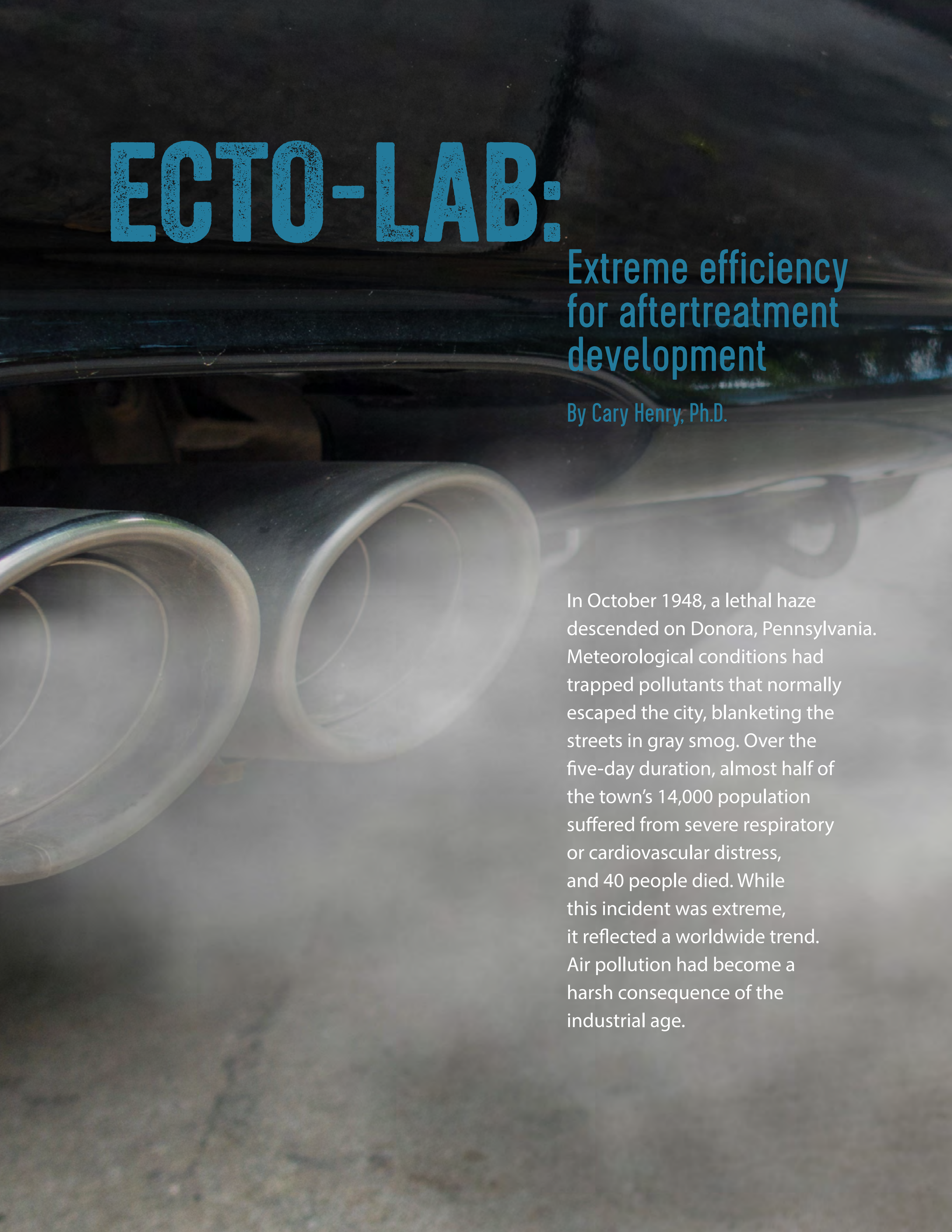

ECTO-LAB:

Extreme efficiency for aftertreatment development

By Cary Henry, Ph.D.

In October 1948, a lethal haze descended on Donora, Pennsylvania. Meteorological conditions had trapped pollutants that normally escaped the city, blanketing the streets in gray smog. Over the five-day duration, almost half of the town's 14,000 population suffered from severe respiratory or cardiovascular distress, and 40 people died. While this incident was extreme, it reflected a worldwide trend. Air pollution had become a harsh consequence of the industrial age.

Then in the 1950s, a California researcher linked automotive emissions with air pollution for the first time, revealing the role transportation played in urban air quality. In 1970, Congress passed the Clean Air Act, requiring a 90 percent reduction in emissions in new vehicles by 1975. Some of those reduction techniques were achieved in the combustion process. By the 1980s, sophisticated catalysts and other "aftertreatment" systems were introduced to treat post-combustion gases prior to release into the environment.

Since then, increasingly strict emission and fuel efficiency standards have required progressively complex engine and exhaust aftertreatment control technologies. Today's consumers demand reduced costs and increased product reliability and robustness for all phases of vehicle ownership. The combination of these challenges has vastly expanded the level of effort required to bring new engine systems to market. Product development cycles have increased, along with their associated costs.

DETAIL

The principal air pollutants produced by fossil-fuel engines are carbon monoxide, oxides of nitrogen, unburnt hydrocarbons and particulate matter. These substances or "species" not only contribute to smog and haze but also have human health effects.

Continuing its role as a pioneer in emissions research, Southwest Research Institute recently commissioned a state-of-the-art Exhaust Composition Transient Operation Laboratory known as the ECTO-Lab™ facility. Unlike its Ghostbusters-mobile Ecto-1 namesake, SwRI's facility has serious and down-to-earth ambitions: helping the transportation industry develop cleaner, more fuel-efficient vehicle technology.

The core of SwRI's ECTO-Lab facility is a fully automated, multifuel burner system designed to provide the thermal energy and chemical composition of automotive exhaust gas streams. Over the past 20 years, SwRI engineers have developed the burner system to provide controlled combustion of gasoline, diesel, natural gas and propane fuels. The SwRI facilities include six subsystems that provide additional testing capabilities. The burner system is available for purchase and installation at client facilities, and additional modules can be added on an as-needed basis to enhance exhaust gas composition control. More than a dozen patents support SwRI's cost-effective evaluation of full-size aftertreatment components and emission control systems.

The ECTO-Lab facility requires a robust control strategy to accurately replicate the complex and highly transient emission profiles of internal combustion engines. To address this challenge, SwRI engineers leveraged its successful engine control technology and adapted a pioneering model-based controller to manage ECTO-Lab combustion modes. The result is a highly transient, highly reproducible system that can replicate the exhaust gas conditions for "Any Engine, Anytime, Anywhere™."

ECTO BREAKTHROUGHS

SwRI ECTO-Lab technology redefines the new product introduction process for emission aftertreatment technology. The facility supports full-size reactor evaluations providing transient testing under varying speed and load conditions. Most small-core gas-reactor bench tests use bottled gas to simulate exhaust conditions. The ECTO-Lab combustor burns fuel and other compounds, producing a continuous exhaust flow that more accurately and precisely duplicates the array of gases created by engines. An independent, model-based control system generates exhaust gas conditions under the full range of operating conditions. It can control temperature and particulate mass as well as hydrocarbon, oxides of nitrogen (NOx) carbon monoxide, water and oxygen concentrations. Essentially, the ECTO-Lab exhaust gas simulation system can accurately and precisely replicate the exhaust gas stream from an infinite number of engines and combustion systems.

The ECTO-Lab combustor is cooled using dilution air and nitrogen. This controls gas temperature and exhaust oxygen concentration while maintaining burner integrity.

DETAIL

The "size" of an engine is typically measured by "displacement." Displacement is the combined total volume of all the cylinders in an engine. For instance, an engine with four 569-cubic-centimeter cylinders has a displacement of 2,276 cc, which rounded up is referred to as a 2.3-liter engine. Larger engines are typically more powerful but use more fuel.

ECTO-FUELED ADVANCES

The ECTO-Lab burner system fills a critical technical gap in the catalyst and aftertreatment development area. Prior to its development, OEMs and suppliers relied on synthetic gas benches for fundamental catalyst testing. These bench tests allow full control over the gas stream composition and provide rudimentary understanding of catalyst behaviors and reaction mechanisms.

However, bench results do not accurately reflect the performance of full-size aftertreatment systems. The three-dimensional impact of flow, thermal and compositional distribution in aftertreatment systems necessitates quantifying the performance of whole components. Synthetic gas benches are also limited by their ability to replicate the transient behavior of gas flow, system warm-up and heat transfer effects.

Due to these limitations, laboratory synthetic gas benches are typically used for catalyst research and benchmarking and to quantify kinetic behavior such as catalyst deactivation, poisoning and so on. In engine test stands, full-sized catalyst and aftertreatment system evaluations can capture three-dimensional and transient effects not possible with pilot-scale bench tests. While engine test stands are useful, they have practical limitations, resulting in incomplete datasets and, ultimately, reduced understanding of overall system performance.

The water-cooled ECTO-Lab system simulates both the lean and rich operating environments encountered in light-duty applications using three-way catalysts and lean NOx traps.

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The practical limitations with engine test stand evaluations include constrained exhaust gas temperature and flow rate and no independent control of NOx, particulates, hydocarbons and other emissions. Challenges associated with engine cool-down between cold-start tests and the high fuel costs associated with generating exhaust gases mean engine tests cannot efficiently evaluate service life reliability and durability issues. These practical limitations impede the development of fully optimized engine and emission control systems. SwRI's burner-based system overcomes many of these challenges, bridging the gap between pilot-scale bench reactors and full-size engine test stands.

SwRI's newest ECTO-Lab system is capable of producing exhaust streams with flow rates of up to 3,250 kg/hr.

ECTO EVALUATIONS

SwRI's ECTO-Lab facility includes a universal engine exhaust gas simulator that accurately and precisely replicates exhaust gas composition for a variety of internal combustion engines. The current configuration can simulate exhaust gas flow rates as low as 10 kilograms per hour and as high as 3,250 kg/hr. This equates to engines from approximately 1.5 L to 20 L or about 100 to 1,000 horsepower. In addition to the wide range of flow capability, the system offers an impressive range of temperature control, replicating cold-start conditions and ambient temperatures while also creating exhaust gas temperatures in excess of 1,100°C to rapidly accelerate hydrothermal aging of catalyst components.

The ECTO-Lab facility features unique, SwRI-developed stoichiometric burner technology that generates thermal energy to evaluate catalysts. Under stoichiometric combustion conditions, oxygen reacts with fuel at the point when all the oxygen is consumed and all the fuel is burned, generating little to no NOx, hydrocarbon and carbon monoxide emissions.

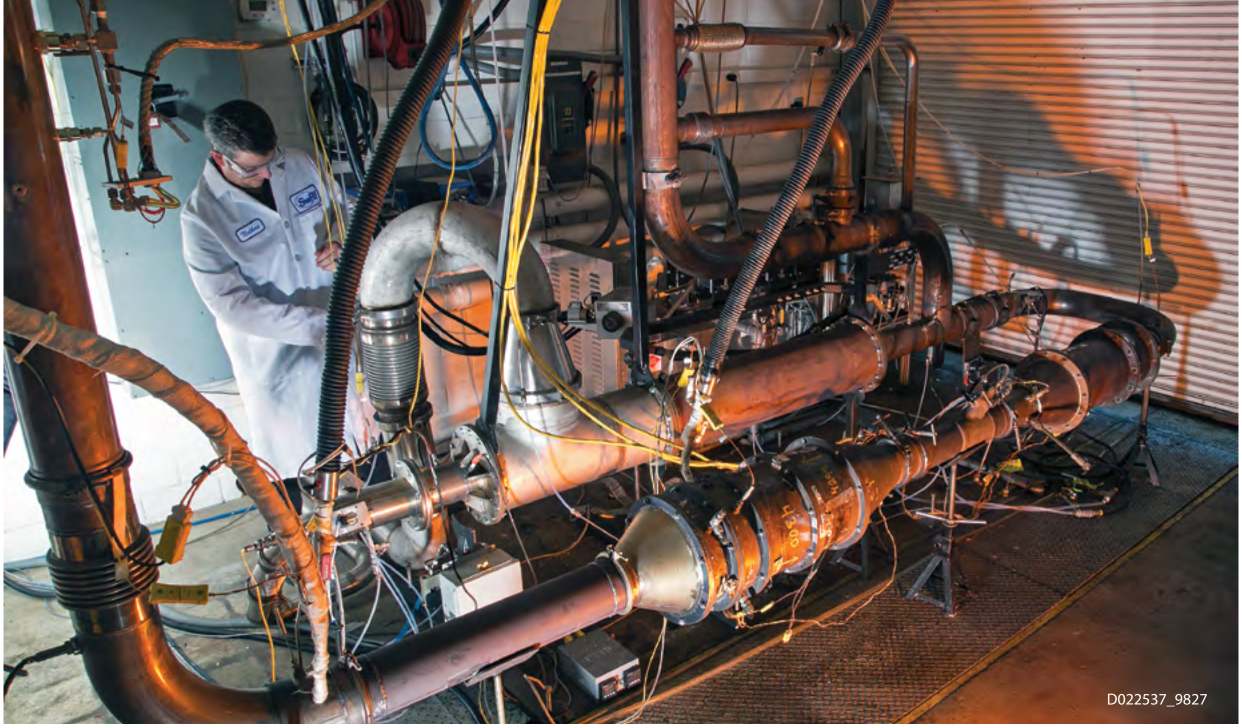
The combustor not only burns hydrocarbon fuels but also breaks down nitrogen-laced fuel components. The thermal decomposition/oxidation of these compounds provides independent and controllable generation of NOx emissions. This control is one of the most beneficial capabilities of the ECTO-Lab system for diesel and lean-burn aftertreatment system development. By controlling NOx emissions, the system operates as an engine exhaust simulator, or as a synthetic gas bench, but with many of the benefits provided by full-scale engine testing.

ECTO MODULES

In the ECTO-Lab facility, the base burner is outfitted with six modules that provide additional capability and control. These subsystems include a water-to-air heat exchanger and an auxiliary hydrocarbon injector as well as dilution air, dilution N_2, nitroethane/nitromethane combustion, and steam generation modules. If an organization wishes to purchase and install ECTO-Lab technology, it can be acquired on a module-by-module basis to provide the desired capabilities. These modules control parameters such as exhaust flow rate, temperature, oxygen concentration from 0–15 percent, NOx emissions from 0–1,200 parts per million, and hydrocarbon emissions from 0–10,000+ ppm. The ECTO-Lab system provides a wider range of control than is possible with conventional engine tests, while delivering the complex exhaust gas stream needed to develop and evaluate full-sized emission aftertreatment systems.

The water-to-air heat exchanger and dilution modules are critical to controlling the temperature and oxygen concentration in the exhaust gas stream. The water-to-air heat exchanger supports stoichiometric or fuel-rich operating conditions, while maintaining independent temperature control. This capability is critical for aging and evaluating components such as three-way catalysts and lean NOx traps, systems subject to both stoichiometric and fuel-rich exhaust streams in service. The dilution module also provides fresh air and/or nitrogen to the exhaust gas stream to simulate lean-burn combustion conditions. The combination supports conventional spark-ignited stoichiometric engines and compression-ignited lean-burn engines. The net result is a single test facility capable of simulating exhaust gas conditions for a limitless number of engines.

One of the most recent advancements to the ECTO-Lab facility is the ability to control the concentration of specific hydrocarbons present in the exhaust gas stream. This capability is increasingly important for light-duty applications, where hydrocarbons are regulated as stringently as NOx emissions. Controlling the specific hydrocarbon components is important because different species have varying levels of reactivity. To accurately quantify the performance of emission control devices, it is imperative that aftertreatment components or systems be tested in an exhaust gas stream that represents actual operating parameters.



The ECTO-Lab system can evaluate the performance of complete aftertreatment systems, as well as individual components.

The ECTO-Lab burner-based system is more capable than a synthetic gas bench or engine test stand. In a synthetic gas bench, the hydrocarbon mixture is, for practical limitations, simplified to one or two components. For the engine test bench, the hydrocarbon mixture is complex, but is typically constrained by the choice of engine hardware and/or operating condition. With the ECTO-Lab system, engineers can easily and cost-effectively control complex hydrocarbons to quantify the impact of these profiles on catalyst performance. The system controls speciation with all fuels, including diesel and gasoline.

ECTO CONTROL

A driving cycle, a set of vehicle speed points over time, is used to assess fuel consumption and emissions. Transient cycles have many speed variations, typical of on-road driving conditions. ECTO-Lab control technology can replicate the emission profiles of engines operated in highly transient drive cycles, such as the light-duty and heavy-duty federal transient protocol (FTP-75 and HD-FTP). This transient capability means SwRI's burner-based system is more than just a full-size synthetic gas bench. With this transient capability, the technology supports full-size aftertreatment system and control testing.

ECTO-Lab evaluations increase efficiency. One of the biggest challenges with today's emission regulations is developing emission system cold-start strategies and control. That's because most tailpipe emissions are generated immediately after turning the ignition, when the engine and aftertreatment systems are cold. Once cars warm up, they have to travel hundreds of miles to produce the amount of pollutants emitted in the first 60 seconds of operation. With conventional engine tests, the engine and aftertreatment systems must be "cold soaked" in low temperatures for eight hours prior to a cold-start test. Because the ECTO-Lab burner-based system has no engine, only the aftertreatment system must be cooled down, and SwRI has developed rapid-cooling strategies. This allows hourly cold-start evaluations, instead of every eight hours with engine-based tests. This increases calibration throughput by a factor of eight, significantly reducing development timelines.

ECTO-LAB EFFICIENCY

SwRI's ECTO-Lab technology provides the ultimate efficiency and flexibility for catalyst and aftertreatment testing, accommodating full-sized catalysts from light-duty gasoline engines to large, heavy-duty diesel and natural gas engines. SwRI maintains ECTO-Lab facilities at its San Antonio headquarters for contracted client use. The technology is also available for purchase and installation at client facilities.

Acknowledgements: Some of the figures are also being published in ECTO-Lab articles in MTZindustrial and SAE's Truck and Off-Highway Engineering magazines.

Questions about this article? Contact Henry at 210-522-2424 or cary.henry@swri.org.

ABOUT THE AUTHOR

Cary Henry, Ph.D., is assistant director of SwRI's Diesel Engine and Emissions R&D Department. He specializes in catalysis research, exhaust aftertreatment integration and emissions measurement. Henry also manages SwRI's Advanced Combustion Catalyst and Aftertreatment Technologies (AC^2AT) joint industry consortium.

SwRI TAPPED FOR IMAP MISSION

SwRI will manage the payload and payload systems engineering for a new NASA mission that will sample, analyze and map particles streaming to Earth from interstellar space. SwRI also will provide a scientific instrument and other technology for the Interstellar Mapping and Acceleration Probe (IMAP) spacecraft, scheduled to launch in 2024.

IMAP will help researchers better understand the boundary of the heliosphere, a sort of magnetic bubble surrounding and protecting our solar system. This is where the constant flow of particles from the Sun, called the solar wind, collides with material from the rest of the galaxy. This bubble limits the amount of harmful cosmic radiation entering the heliosphere. IMAP instruments will collect and analyze particles that make it through.

"SwRI plays a major hardware role in the mission, which will allow a quantum leap forward in our understanding of our heliosphere's interaction with, and our place in, the galaxy," said SwRI Director Susan Pope, who will serve as the payload systems engineer.

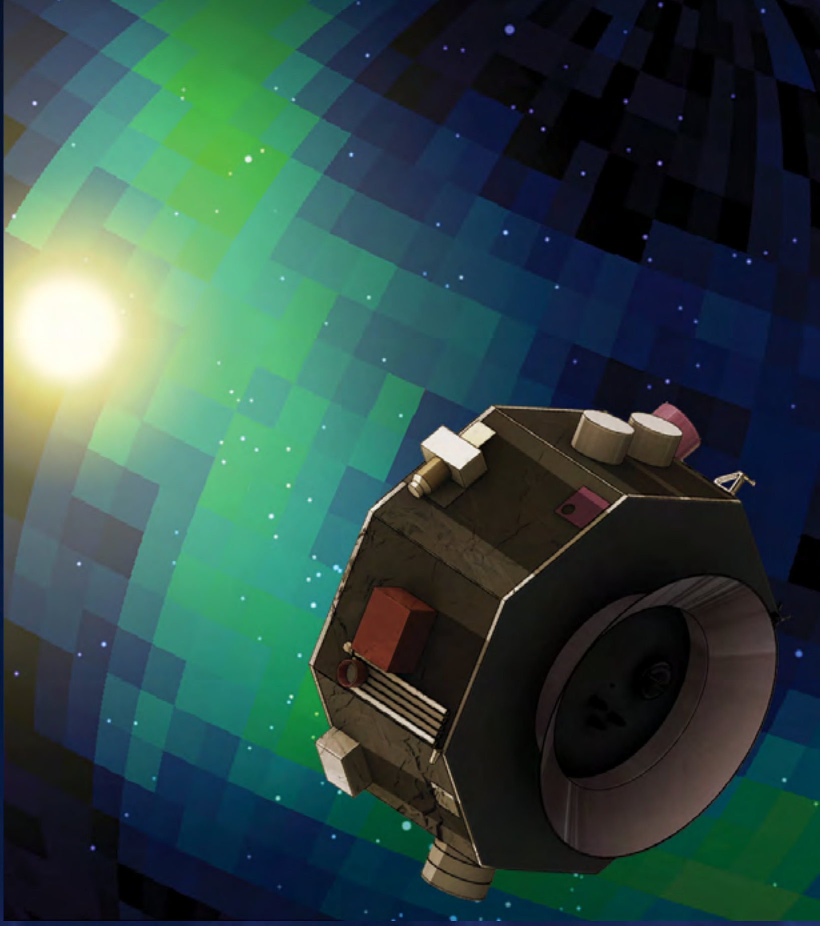
"We're also providing the Compact Dual Ion Composition Experiment (CoDICE), which was developed using SwRI internal research funding," said Dr. Mihir Desai, director of the SwRI Space Research Department and an IMAP co-investigator. "CoDICE combines the capabilities of multiple instruments into one patented sensor about the size of a 5-gallon paint bucket and weighing about 22 pounds."

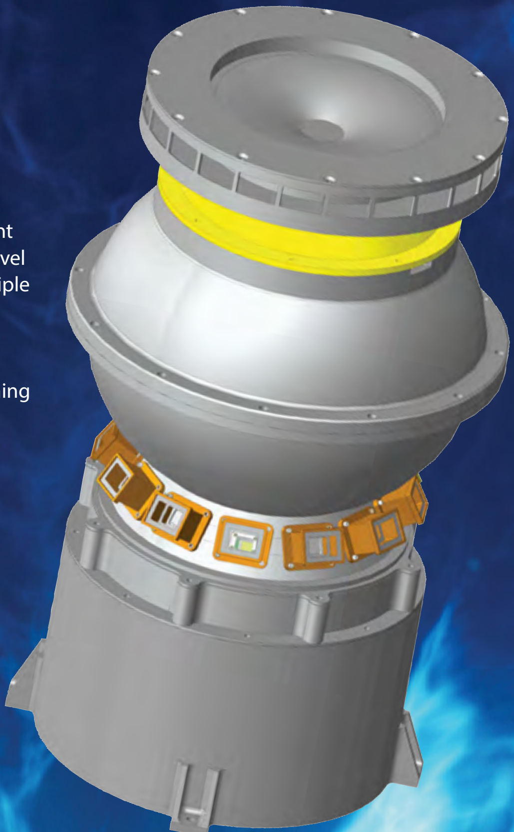
It will measure the distributions and mass, ionic charge state and composition of interstellar pickup ions, particles that make it through the "heliospheric" filter. It also characterizes solar wind ions as well as the mass and composition of highly energized particles from the Sun.

SwRI is also contributing to the development of next-generation energetic neutral atom imagers, as well as electronics for the IMAP instruments that measure solar wind electrons.

"I am looking forward to IMAP, which will help explain the discoveries that the IBEX mission is still making," said SwRI Program Director John Scherrer, who will serve as the payload manager. "IMAP will help us understand how our Sun and the solar wind affect the boundary of our solar system."

The IMAP mission principal investigator is former SwRI staff member Prof. David McComas of Princeton University. The Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland, manages IMAP and is designing, building and will operate the spacecraft. The mission is part of the NASA Science Mission Directorate's Solar Terrestrial Probes Program, managed by Goddard Space Flight Center in Greenbelt, Maryland.





SwRI is developing the Compact Dual Ion Composition Experiment for IMAP. CoDICE is a novel sensor combining multiple capabilities into one patented sensor about the size of a 5-gallon paint bucket and weighing about 22 pounds.

IMAGES COURTESY NASA/GSFC D023192 D023197

RIGHTING THE WRONG-WAY PROBLEM

Thermal cameras & connected vehicle networks offer tools for traffic safety

By Doug Brooks, Ph.D., and Cameron Mott

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Wrong-way driving is when a motor vehicle travels against the flow of traffic, often as a result of inattention or impairment. On a divided freeway, high speeds and the chance of a head-on collision make wrong-way incidents particularly perilous. In the U.S., 350 people die in 265 wrong-way driving crashes every year on average. Wrong-way driving crashes are especially lethal, causing 24 more fatalities per 100 fatal crashes than for fatal accidents in general.

This issue hit close to home for Southwest Research Institute staff when local San Antonio Police Officer Stephanie Brown was killed on duty by a wrong-way driver with a blood alcohol level three times the legal limit. That tragedy was the impetus for the Texas Department of Transportation (TxDOT) to form the San Antonio Wrong-Way Driver Task Force, a multi-agency effort addressing the issue.

DETAIL

Algorithms are computer-based procedures used to solve problems, such as data processing and automated reasoning tasks.

As a leader in intelligent transportation systems (ITS), SwRI develops advanced traffic management systems that integrate technology into highway infrastructure to improve traffic safety and flow. Real-time traffic data from cameras, speed sensors and other devices are processed by traffic management centers to control traffic routing and dynamic message sign alerts. (See infographic on page 14.)

SwRI engineers have evaluated how intelligent transportation technology can be used to mitigate wrong-way driving events. By tapping the ability of vehicles to communicate with each other and with roadside infrastructure, SwRI engineers are fighting wrong-way driving by enabling traffic management centers to detect these dangerous situations and warn drivers in real time.

The next wave of ITS technology will implement connected and autonomous vehicles to improve safety and mobility. SwRI develops and tests multiple technologies that will allow motorists, unmanned vehicles and transportation centers to share real-time data on traffic conditions and roadway incidents. The algorithms and software that enable driverless vehicles can also provide traffic management systems and connected vehicles with data on the speed, location and proximity of wrong-way drivers.

TASK ACTIONS

Shortly after its formation, the San Antonio Wrong-Way Driver Task Force conducted a study to determine when most of these incidents occur. Using the SwRI-developed TransGuide transportation management system, the task force found that more than 80 percent of wrong-way driving events occur between 10 p.m. and 6 a.m., with 45 percent between 2 a.m. and 4 a.m. The timing corresponds with impaired motorists leaving bars and clubs at closing time. Limited visibility at night exacerbates the problem. These factors pushed TxDOT to develop new countermeasures: more signs on highway exit ramps outfitted with flashing lights to alert drowsy or impaired drivers.

ABOUT THE AUTHORS

Dr. Doug Brooks (left) is a group leader in SwRI's Intelligent Systems Division who specializes in creating automated driving technologies for commercial and military vehicles to improve safety and mobility. Cameron Mott is a senior research analyst focusing on projects that improve the capability, safety and security of automobiles by leveraging connected vehicle and intelligent highway applications.

5 WAYS VEHICLES CONNECT WITH SURROUNDINGS

1

V2I: VEHICLE TO INFRASTRUCTURE technology communicates data collected by vehicles to the infrastructure and data from the infrastructure to drivers. V2I technology communicates information about safety, mobility and environment-related conditions.

2

V2V: VEHICLE TO VEHICLE technology communicates information about the speed and position of surrounding vehicles through a wireless exchange of information. The goal is to avoid accidents, ease traffic congestion and decrease emissions.

3

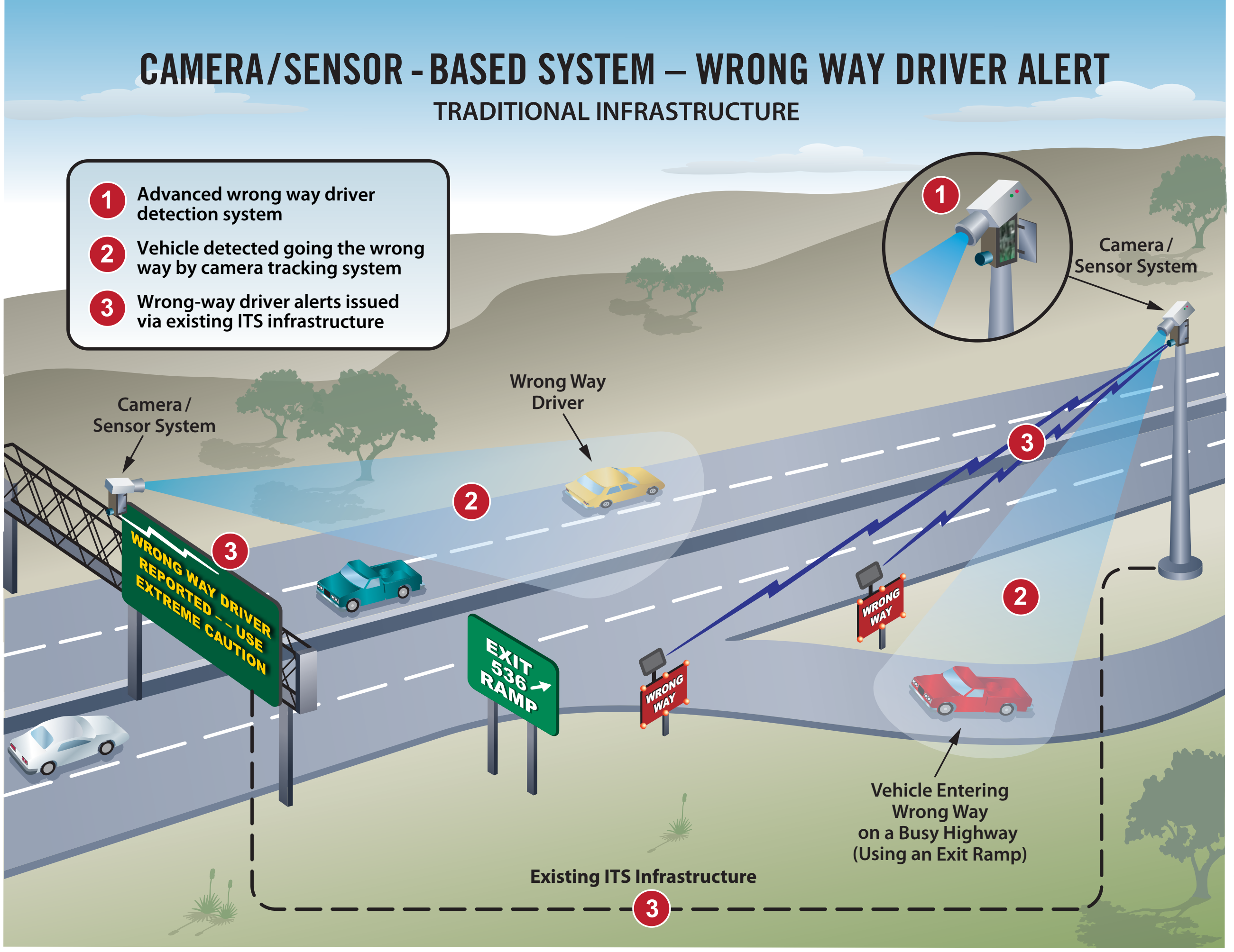
V2C: VEHICLE TO CLOUD technology exchanges vehicle and roadway information via cloud-based networks. This allows the vehicle to use information from other cloud-connected industries, such as energy, transportation and smart homes.

4

V2P: VEHICLE TO PEDESTRIAN technology senses information and conditions relevant to vehicle and pedestrian interactions and communicates it to other vehicles, infrastructure and personal smart devices.

5

V2X: VEHICLE TO EVERYTHING technology interconnects all types of vehicles and infrastructure systems with each other. This connectivity potentially includes all of the above as well as ships, trains and airplanes.



The sensor-based system takes advantage of existing advanced transportation management system technology, such as dynamic messaging systems and wrong-way signage, to warn wrong-way drivers and other vehicles on the highway.

The public uses emergency 911 calls to report wrong-way drivers. But by the time police can react, it can be difficult to locate the wrong-way vehicle. To address this limitation, the task force placed radar-based detection devices on exit ramps to identify wrong-way vehicles entering an exit and assist in apprehension. These efforts help, but the task force also saw a need for more advanced technology to alert other drivers about wrong-way drivers and improve how authorities track wrong-way vehicles.

SMART SOLUTIONS

In the seven years since Officer Brown's death, connected and autonomous vehicle technology has progressed tremendously. As SwRI developed more advanced technology, it helped TxDOT integrate it into the ongoing response to wrong-way driving. Recently, SwRI investigated two new solutions to mitigate wrong-way driving events.

One solution pairs thermal cameras with perception algorithms SwRI developed for driverless vehicles and the manufacturing industry. The perception algorithms process visual inputs from a video camera, classifying patterns to isolate a wrong-way driver from other objects and backgrounds in the visual field.

The second solution uses connected-vehicle technology that enables communication between vehicles, infrastructure and transportation agencies to warn the wrong-way driver as well as other motorists in the vicinity. The system also identifies and helps track wrong-way motorists.

These systems can both be integrated into intelligent transportation systems, such as the SwRI-developed ActiveITS™ system. Transportation agencies across the country use ActiveITS, including Texas' and Florida's statewide systems. Traffic management centers, including San Antonio's TransGuide, use the technology to communicate traffic alerts with motorists via dynamic message signs. As more vehicles are connected to intelligent traffic networks, the vehicles themselves will be able to receive traffic and safety alerts about wrong-way drivers and other roadway hazards.

Much like diet and exercise are two ways to lose weight that can work better when used together, SwRI's two solutions to address the wrong-way driver problem could potentially work better together as well.

VIDEO PERCEPTION SOLUTION

SwRI's video perception wrong-way driver solution is a simple, low-cost solution using a thermal camera and software integrated into a traffic management system. The solution applies a stabilization algorithm to raw video from a thermal camera to mitigate vibrations such as those caused by wind gusts. The images are then processed by two additional algorithms operating in parallel. A background-subtraction algorithm removes data that remain

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The video perception system offers a low-cost option for upgrading a transportation management system to accurately detect vehicles traveling the wrong way on a highway.

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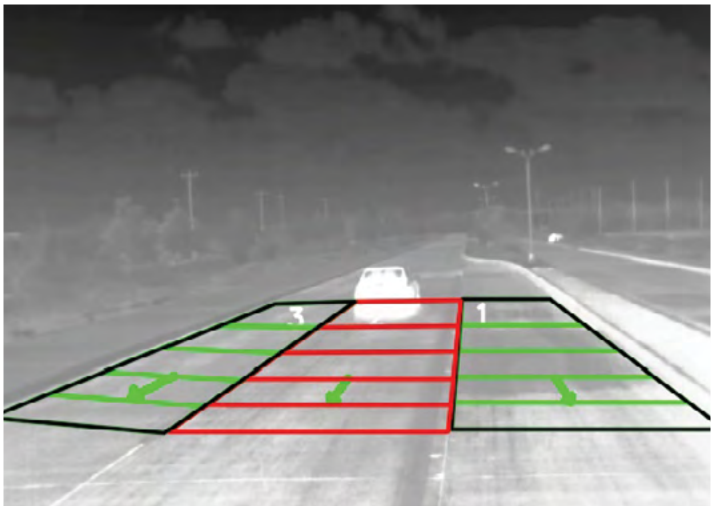


The video perception system can identify wrong-way vehicles traveling at high speeds, day or night and in adverse weather conditions with 99 percent accuracy.

DETAIL

Dedicated short-range communications (DSRC) are one- or two-way, short-range radio/antenna systems specifically designed for connected vehicle and intelligent transportation systems. DSRC wireless signals utilize the 5.9 GHz band, which the Federal Communications Commission set aside for ITS safety and mobility.

consistent between frames, enabling the system to focus on moving vehicles. A motion estimation algorithm determines the flow of pixels across multiple frames, enabling the system to determine the travel direction for vehicles. Together, the two algorithms produce regions of interest and a calculated direction of travel. The final inputs are made available via a custom user interface that allows DOT personnel to define the lanes to be monitored and the direction of travel for each lane. Then, the background-subtraction and motion-estimation algorithms determine if a vehicle in a defined lane is traveling in the wrong direction.

Adding vision-based sensing to other detection systems overcomes a major shortcoming of radar-based detection systems. While radar accurately isolates movement, it often cannot distinguish the type of object detected. This can lead to false alarms, such as mistaking moving tree branches for wrong-way vehicles. By comparison, SwRI's vision-based detection system can distinguish between a wrong-way vehicle and other objects, which greatly improves performance. The SwRI system can monitor multiple lanes, detecting vehicles up to 130 feet away at both city and highway speeds. It achieved an accuracy rate of 99 percent, or about one false positive per week. The single-unit, easy-to-deploy, low-cost system supports event logging and messaging using existing ITS infrastructure.

CONNECTED VEHICLE NETWORK SOLUTION

Working with the Texas A&M Transportation Institute (TTI), SwRI engineers also demonstrated a wrong-way driver solution that leverages connected vehicle capabilities. This system can detect wrong-way connected vehicles to immediately and directly alert connected drivers in the vicinity. The team recently incorporated this functionality into Texas' Lonestar™ traffic management system. Existing "disconnected" solutions rely on radar or image processing and 911 emergency calls. The information is processed, and then a public alert reaches travelers via dynamic message signs along the highway. The "connected" system can immediately alert a wrong-way driver in his or her own vehicle, as well as other drivers in the area. The team demonstrated functionality using multiple vehicles on a closed course at the Texas A&M University RELLIS Campus.

Drawing on extensive connected vehicle experience, the SwRI teams have developed the equipment and expertise needed to quickly prototype and prove connected vehicle functionality. Through this project, Dedicated Short Range Communications (DSRC) radio connectivity is integrated with Lonestar through roadside equipment. Acting as the infrastructure component in vehicle-to-infrastructure deployment, the equipment gathers information from, and sends alerts to, connected vehicles that are in range. It alerts both the wrong-way driver and other drivers nearby.

For now, most connected vehicle technology is limited to high-end luxury cars, but any vehicle can become a connected vehicle using a SwRI-developed portable onboard system. These systems contain a DSRC radio and antenna designed for vehicles as well as a tablet to display information to the driver. For this project, the team leveraged the lane-level accuracy enabled through algorithms running on the DSRC radio. With this lane-level position accuracy, the system establishes highly accurate wrong-way driver zones on the Lonestar system and greatly reduces false positives compared with traditional sensors.

Real-time information is essential for law enforcement officers responding to reports of a wrong-way driver. Fully equipped connected cruisers can provide law enforcement officers with additional information, including offender vehicle speed. The team overcame DSRC range limitations by propagating the alert to connected vehicles further along the road. SwRI is continuing its efforts to improve the safety of Texas drivers during wrong-way driving events. For instance, integrating additional technology, such as the aforementioned image-based or radar sensors, into the network system will improve its effectiveness.

The team will deploy the network solution on a planned Texas Connected Freight Corridor, which will use advanced communications technology to improve safety and reduce traffic congestion along some of Texas' busiest interstates. More than 1,000 freight vehicles outfitted with connected vehicle technology will benefit from the advanced real-time warnings the system offers. Through this effort, the vehicles will help protect their drivers from wrong-way driving situations.

CONCLUSION

Officer Brown's tragic death created a legacy that extends well beyond the jurisdiction where she served. At the intersection of autonomous robotics and advanced networking, SwRI is helping state and federal agencies address the critical safety issue of wrong-way driving incidents.

Questions about this article? Contact Brooks at 210-522-2668 or douglas.brooks@swri.org, or Mott at 210-522-2583 or cameron.mott@swri.org.

In the connected vehicle network solution, this right-way driving vehicle shows a wrong-way vehicle through the front window. Additionally, the in-dash display shows a warning about the vehicle and identifies the roadway that they are using.

This in-dash display warns a wrong-way driver as he enters an exit ramp.

Using the information provided in the connected vehicle solution, both travelers and first responders can be informed about the situation. Through the integration with ActiveITS software, Lonestar traffic managers are provided with an alert and a map of the area where a wrong-way driver was detected.

The connected-vehicle-based system provides law enforcement additional information, such as vehicle speed, to help apprehend the wrong-way driver.

IMAGES COURTESY TTI

D023199

The novel process creates a plasma coating along the length of the pipe.

D023201

SwRI developed a vacuum process to produce superhydrophobic coatings on internal pipe surfaces. These thin, glass-like coatings are durable and repel deposits that can block oil and gas production lines.

SUPER-HYDROPHOBIC COATING

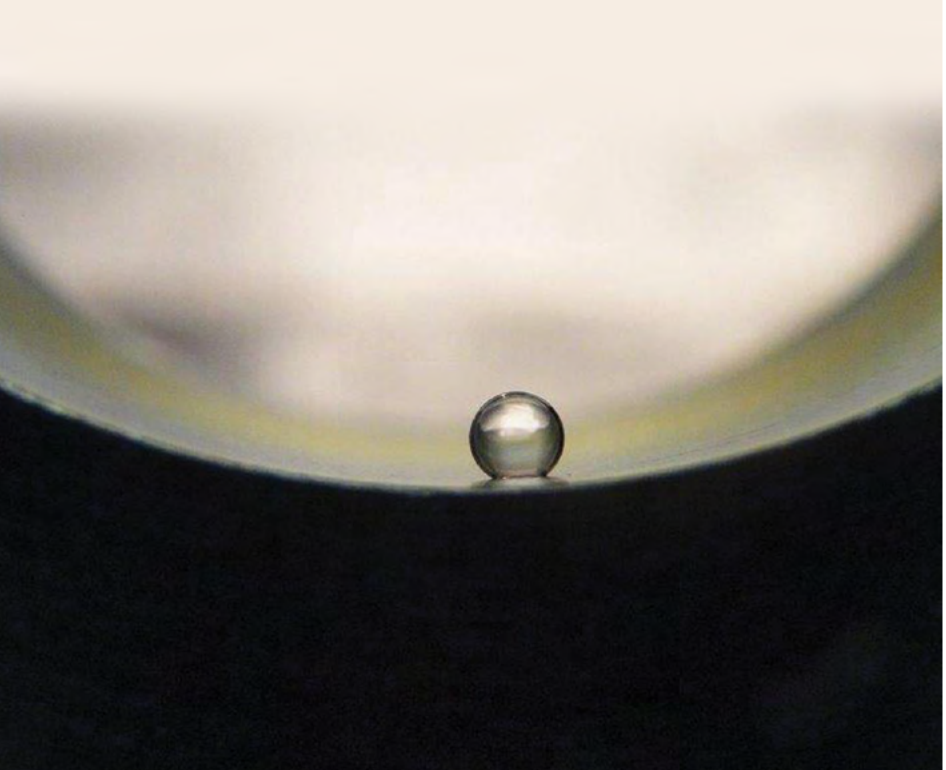
SwRI has developed a superhydrophobic — or water-repelling — coating and a process for applying it to internal surfaces of long tubular structures. The coatings passively prevent hydrates and other deposits from adhering to subsea pipelines and clogging oil and gas transmission lines.

"The Lotus coating technology is named for the flower that has similar superhydrophobic, water repelling properties," said Institute Scientist Dr. Michael Miller. "We produce these coatings using a vacuum process in which a plasma — a state of matter with free electrons and ionized atoms and molecules — is ignited inside the entire length of the pipe while introducing one or more chemicals. The process selectively fragments the chemicals, accelerating the ions, which adhere to the pipe surface. There, they immediately undergo polymerization to form a thin, glass-like, durable coating that repels water and deposits."

SwRI's Lotus production process can be tailored chemically to create different surface properties, such as surface energy or tension, to repel different kinds of deposit materials.

For instance, hydrates are slushy solids composed of water and a gas that have a density close to that of ice but form at temperatures as high as 70 degrees Fahrenheit. In hydrocarbon production lines, hydrates can adhere to a pipe's inner wall and build until they completely block the flow line and halt the transport of hydrocarbons to the processing facility. Similarly, in deep petroleum wells, paraffin (wax) and asphaltene components can create pipeline deposits and impede product flow from the well. Removing these pipeline plugs is time-consuming and costly, so a passive prevention technique is ideal.

SwRI has licensed the Lotus coating technology exclusively to its client, which is transitioning the process for full-scale production of coated pipes.



A water droplet on the inside surface of a coated pipe illustrates the hydrophobicity of the coating.

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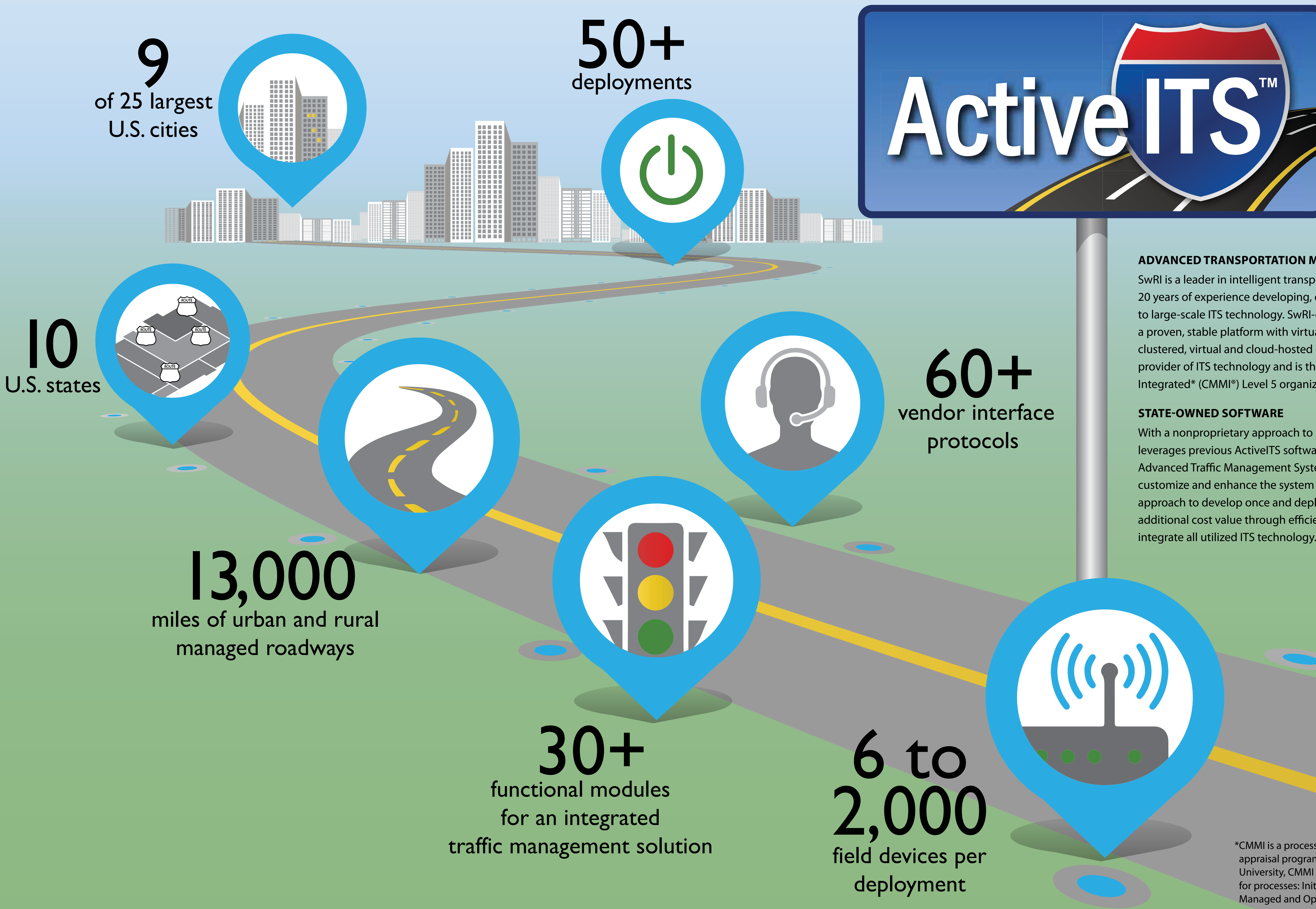


ADVANCED TRANSPORTATION MANAGEMENT SYSTEMS

SwRI is a leader in intelligent transportation systems (ITS) with over 20 years of experience developing, deploying and maintaining small- to large-scale ITS technology. SwRI-developed ActiveITS technology is a proven, stable platform with virtually no downtime, running in clustered, virtual and cloud-hosted configurations. SwRI is a premier provider of ITS technology and is the only Capability Mature Model Integrated* (CMMI®) Level 5 organization in the ITS industry.

STATE-OWNED SOFTWARE

With a nonproprietary approach to ITS software solutions, SwRI leverages previous ActiveITS software deployments as the baseline Advanced Traffic Management Systems solution. Engineers then customize and enhance the system based on client requirements. SwRI's approach to develop once and deploy repeatedly provides clients additional cost value through efficiency as well as freedom to openly integrate all utilized ITS technology.

*CMMI is a process level improvement training and appraisal program. Developed at Carnegie Mellon University, CMMI defines the five maturity levels for processes: Initial, Managed, Defined, Quantitatively Managed and Optimizing.

FRACKING *with* FOAM

SWAPPING NATURAL GAS FOAMS FOR WATER IN HYDRAULIC FRACTURING

By Griffin Beck

Hydraulic fracturing, also called “fracking,” allows the U.S. to tap vast oil and gas reserves previously locked away in shale and other unconventional reservoirs.

Hydraulic fracturing treatments inject high-pressure fluids into wells that run thousands of feet below the Earth’s surface. This high-pressure fluid breaks apart or “fractures” rock formations containing trapped oil and natural gas resources. To prevent the fractures from closing again, sand or tiny particles called “proppant” are pumped into the fracture network to prop the fractures open. The vast underground network of fractures releases trapped hydrocarbon resources, which flow back to the wellhead for collection and processing.

DETAIL

Unconventional reservoirs require special recovery operations and include coalbed methane, gas-hydrate deposits, and tight-gas, heavy-oil or tar sands.

Hydraulic fracturing is a remarkable process, but there are also some real challenges with conventional fracturing methods. Conventional treatments use enormous amounts of water, as much as 11 million gallons per well depending on geographic location. That water adds tremendous financial and environmental costs. First, water is often scarce at drilling sites. Trucking water to the wellhead burns fuel, increases traffic and emissions, and inflicts wear and tear on roads. Once used, the salt- and chemical-laced wastewater poses environmental challenges. Either the water must be disposed of in injection wells or trucked away for treatment. And wastewater injection wells have contributed to an exponential growth in minor earthquakes in oil and gas producing areas (see “Triggered Tremors” in the Spring 2018 issue of Technology Today). To address these challenges, industry, government and the public are looking for alternative fracturing methods to minimize or possibly eliminate water use in hydraulic fracturing.

Southwest Research Institute is exploring one alternative to water-based methods that would use natural gas as the primary fracturing fluid. Working with the National Energy Technology Laboratory and a commercial partner, SwRI engineers are developing an alternative hydraulic fracturing process that would generate a natural gas-based foam for injection into a well, a process that could reduce water consumption by as much as 80 percent. This alternative method is advantageous for several other reasons as well. For one, natural gas is typically available at the wellhead or from nearby processing plants, which could reduce the amount of traffic to and from the site. Furthermore, in America’s current energy marketplace, natural gas is a relatively low-cost commodity and the natural gas from the foam could be recovered, processed and sold rather than creating waste that requires cleanup or disposal.

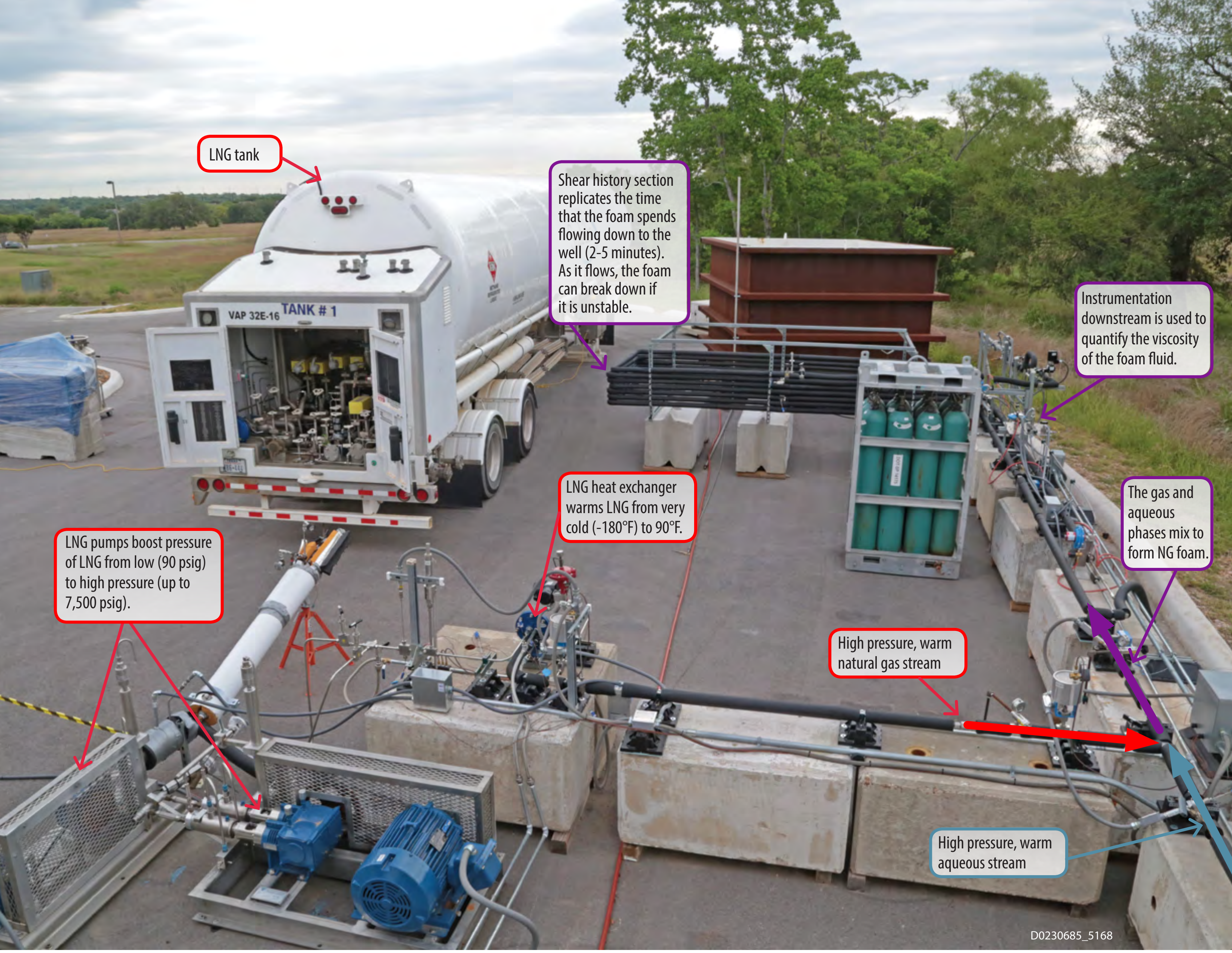
ABOUT THE AUTHOR

Griffin Beck is a research engineer in SwRI’s Propulsion and Energy Machinery Section. He designs and analyzes fluid machinery systems with a focus on steady-state and transient models of systems used in the oil & gas and propulsion industries.

THIS LATTE IS A GAS

So how do you turn natural gas into foam? To answer this question, look no further than your local coffee shop. A barista creates your foamy latte by injecting steam (a gas) into milk (a liquid). To create the whipped cream that tops your favorite frappé, heavy cream (a liquid) is whipped and air bubbles (a gas) permeate the liquid to create foam. Essentially, foam is formed by trapping pockets of gas in liquid.

Though the tools are different, foamed fracturing fluids are created by mixing gas with a liquid counterpart. Generally, the



SwRI developed a test setup to demonstrate the feasibility of using a natural gas foam as a hydraulic fracturing fluid. For the test scenario, the team used LNG, heaters and pumps to create the natural gas foam. Instrumentation quantified the viscosity of the foam fluid and a "shear history" section replicated the time the foam would spend flowing down the well, to ensure that the foam was stable.

volumetric concentration of the gas in these fluids will range from 50 to 85 percent, so the water need is reduced by that same amount. With the right ingredients, this mixture of liquid and gas can form stable foam that is a lot like your latte topping.

FIVE DECADES OF FOAMED FLUIDS

The use of foams in the oil and gas industry is not new. In fact, foams have been used in various oil and gas applications for more than 50 years. Foams were first used in the 1960s as drilling fluids to minimize downhole formation collapse and swelling. In addition, industry used foams to complete wells in low-pressure reservoirs. In the mid-1970s, operators began to use foams in hydraulic fracturing. By the turn of the century, foam fracturing accounted for more than 40 percent of all the hydraulic fracturing applications in North America, although this number has since declined. These applications have primarily used nitrogen, carbon dioxide or a binary mixture of these two gases to create the foam. While natural gas foams have been discussed in patents, no field application is known at this time.

Foams have some unique properties that make them particularly well suited for hydraulic fracturing. For one, foams can minimize formation damage in water-sensitive reservoirs. In certain formations, water can swell the rock that contains the trapped hydrocarbons, which impedes oil and natural gas recovery from the reservoir. Reducing the water content of the fracturing media minimizes this type of damage. Another benefit is that after fracturing, the compressed gas in the foam expands and helps to rapidly unload the fracturing fluid from the well. Studies have shown that wells fractured with foam clean up faster than wells treated with gelled aqueous fluids.

CHALLENGES WITH NATURAL GAS FOAMS

While nitrogen- and carbon dioxide-based foams have been used in oil and gas production for more than five decades, the SwRI team is investigating key challenges and technology gaps using natural gas-based foams.

One of the main challenges relates to the processing equipment used on site to generate injection-ready natural gas foam. To date, all other fracturing methods have liquid assets trucked to the site and then pressurized by positive displacement pumps to the required injection pressure. For N_2 and CO_2 foams, positive displacement pumps designed for cryogenic temperatures pressurize the liquefied gases before heating them to a gaseous state. To create foam from the natural gas available at the wellhead, another process is needed to pressurize natural gas before combining it with a significantly reduced amount of water. SwRI engineers and their government and industry collaborators developed and analyzed six processes to prepare natural gas at supply conditions to create high-pressure, natural gas foam. In these analyses, the most straightforward process considered used multiple stages of compression equipment to boost the gas pressure from 500 pounds per square inch (psi) to a final discharge pressure of 10,000 psi. The other five processes analyzed by the team used liquefaction cycles, where the natural gas is first liquefied and then pressurized using typical cryogenic pumps.

DETAIL

Liquefied gas has been cooled and/or compressed to turn gaseous elements into liquids.

SwRI engineers compared the compression cycle and the liquefaction cycles based on efficiency, safety and process footprint criteria, determining that the compression cycle was best suited for onsite applications. While compressors needed to achieve this process are commercially available today, making a mobile version for use at well sites will require significant additional development efforts.

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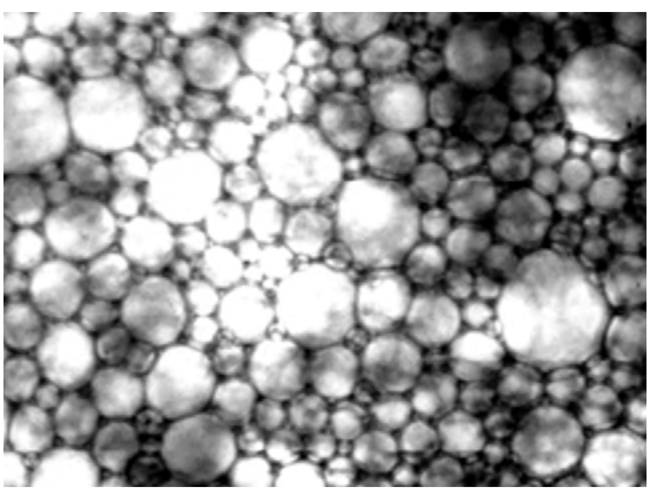


This magnified image of carbon dioxide foam illustrates important properties needed for a stable, viscous natural gas fracking foam.

Shaving cream is a much lower pressure analog for natural gas foams that could significantly decrease water use in hydraulic fracturing production wells.

Another key question addressed by the SwRI team was whether natural gas foam would make an appropriate hydraulic fracturing fluid. Literature searches found no evidence for a demonstrated ability to create or use natural gas-based foams in hydraulic fracturing applications.

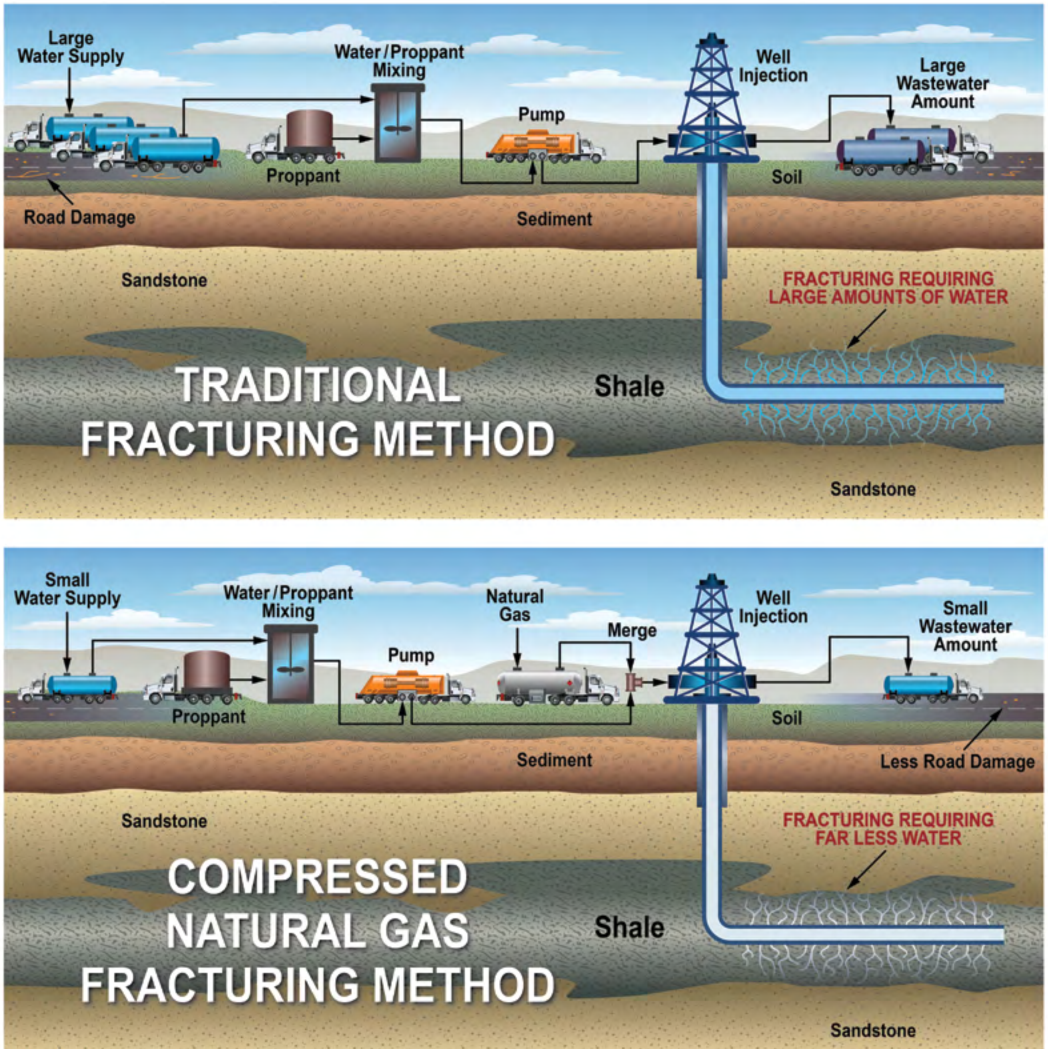
With that in mind, SwRI engineers designed and constructed a pilot-scale test facility to generate high-pressure natural gas foam and evaluate its performance in comparison to other fracturing media. SwRI engineers designed the test facility to replicate field conditions and mixing methods. Under these realistic operating conditions, the project team can generate reliable data on natural gas foam rheology, or flow properties, and evaluate how best to create a consistent natural gas foam that can survive the harsh, downhole conditions.

DETAIL

Rheology is the study of material flow and deformation under applied forces.

These laboratory tests have provided some important insights. First and foremost, SwRI demonstrated that stable, natural gas-based foam can be created using standard chemicals and methods currently employed by the industry for foam fracturing. Furthermore, the properties of the foam suggest that it is appropriate for use as a fracturing fluid.

More recently, SwRI modified the pilot plant itself to enhance measurement capabilities. Future testing will examine new fluid chemistries for compatibility with natural gas foam and will evaluate new foam mixing methods.



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LOOKING AHEAD

SwRI has demonstrated that natural gas-based foams are a viable alternative to the conventional, water-based fracturing methods used almost exclusively in industry today. The foams created at SwRI's pilot-scale facility are expected to provide the same beneficial qualities as other fracturing foams while making use of an abundant natural resource that is available near the wellhead. SwRI engineers also have demonstrated that a simple compression process using machinery available today is an optimal method to take onsite natural gas and prepare it for fracturing applications.

Still, more work needs to be done. Hydraulic fracturing in North America's unconventional reservoirs is not a "one-size-fits-all" type of application. Reservoir characteristics, locally available resources and site-appropriate hydraulic fracturing techniques vary widely in different geographic locations and geologic formations. More work is needed to identify where and when fracturing with natural gas-based foams is the best option.

Perhaps the main area for further investigation is determining whether using natural gas-based foams can provide any production benefits. In other words, can natural-gas foam improve oil and gas recovery when compared to water-based treatments? Currently, reservoir recovery rates in North America are surprisingly low, ranging from 10 to 20 percent. So somewhere between 80 and 90 percent of the hydrocarbons remain locked underground, providing tremendous possibilities for improvement. Previous studies that compared production from wells fractured with foams to similar wells fractured with conventional fluids have been inconclusive. In some cases, no statistically significant difference in production was observed while in other cases, wells fractured with foams had significant production improvements. As such, the production advantages of natural gas foams versus water-based media need further investigation. To this end, SwRI sees the need for field demonstrations to measure potential benefits of natural gas-based foams in real-world oil and gas production.

It is an exciting time for the oil and gas industry. The challenges with accessing the vast hydrocarbon resources trapped in unconventional reservoirs in an efficient and environmentally prudent manner are driving real innovation. The SwRI team has demonstrated that alternatives to the conventional methods exist, and it's likely that many more are on the horizon… something to think about over your next latte.

Questions about this article? Contact Beck at 210-522-2509 or griffin.beck@swri.org.

TEN HIGHLIGHTS FROM TWO YEARS AT JUPITER

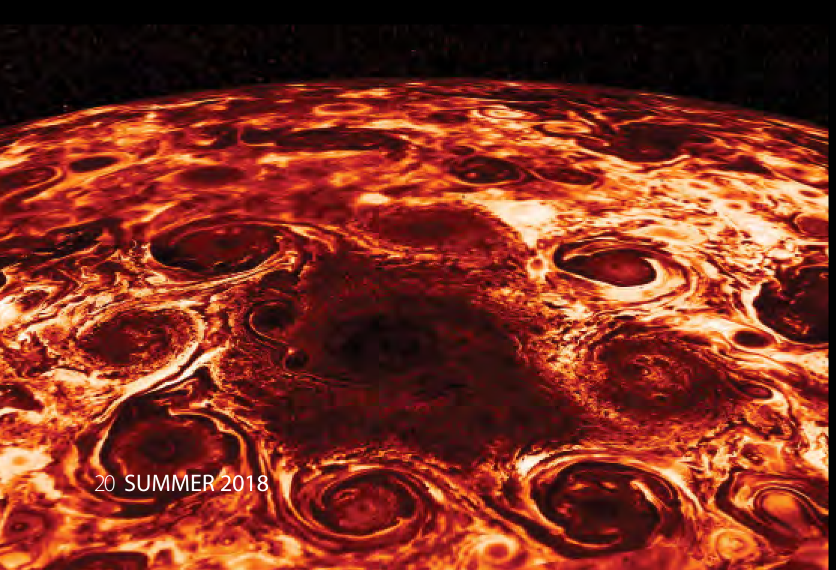
NASA's Juno spacecraft arrived at the King of Planets in July 2016 and has been revealing Jupiter's secrets ever since. Here are 10 highlights from the Juno mission, led by SwRI's Dr. Scott Bolton.

1. Arrival at a Colossus

After an odyssey of almost five years and 1.7 billion miles, NASA's Juno spacecraft entered Jupiter orbit on July 4, 2016. Juno, with its suite of nine science instruments, is the first mission to make repeated excursions scraping the cloud tops, deep inside the planet's powerful radiation belts.

2. Heat from Within

Juno scientists discovered densely packed cyclones and anticyclones that dominate the planet's polar regions, and the first detailed indications of an extraterrestrial dynamo, the engine creating Jupiter's magnetic field. Data collected by the spacecraft's Jovian InfraRed Auroral Mapper captures light emerging from deep inside Jupiter, probing the weather layer 30 to 45 miles below Jupiter's cloud tops.



3. The Ultimate Classroom

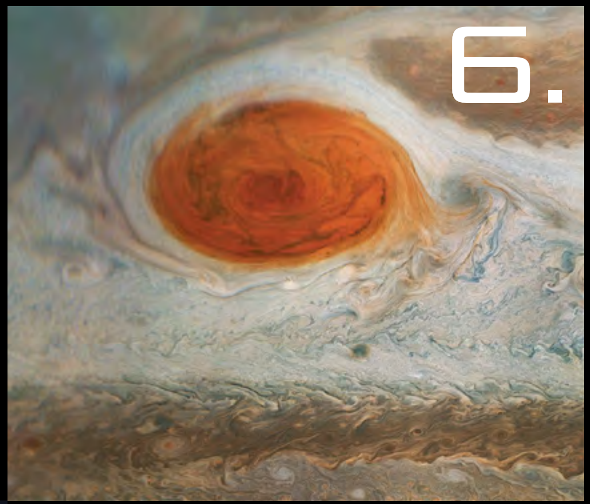
The Goldstone Apple Valley Radio Telescope (GAVRT) project lets students do real science with a large radio telescope in collaboration with Juno scientists. GAVRT data include Jupiter observations relevant to the mission.

4. Science, Meet Art

Juno carries JunoCam, a public outreach instrument. In a remarkable first for a deep space mission, the Juno team enlists the general public not only in planning what images JunoCam takes, but also in processing and enhancing the visual data. The results include some of the most stunning images in the history of space exploration.

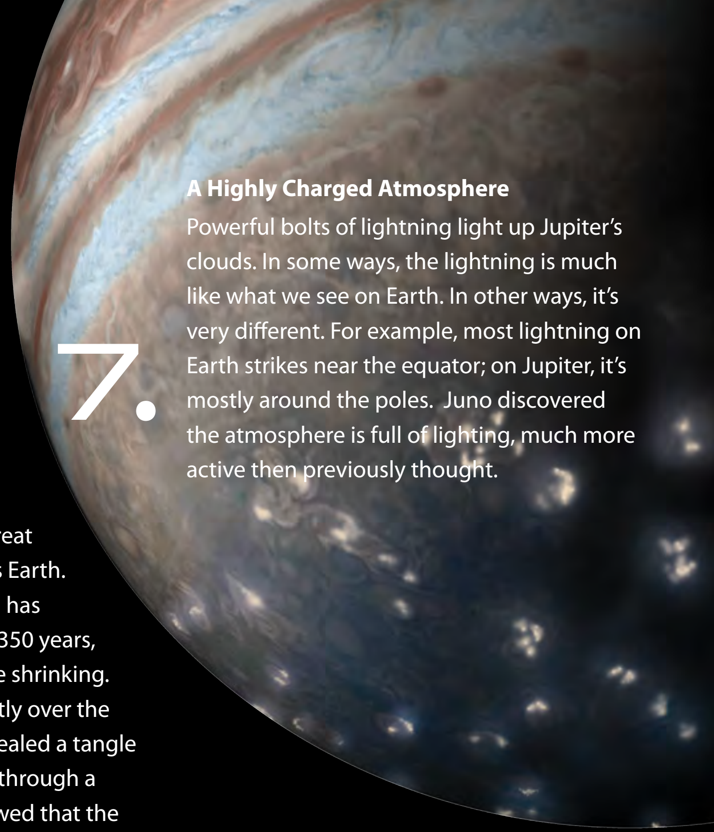
5. Beauty Runs Deep

Data collected by the Juno spacecraft during its first pass over Jupiter's Great Red Spot in July 2017 indicate that this iconic feature penetrates well below the clouds. The solar system's most famous storm appears to have roots that penetrate about 200 miles into the planet's atmosphere.



6. Spotting the Spot

Measuring 10,159 miles wide (as of April 3, 2017), Jupiter's Great Red Spot is 1.3 times as wide as Earth. First spotted in 1830, the storm has possibly existed for more than 350 years, although lately, it appears to be shrinking. In July 2017, Juno passed directly over the spot, and JunoCam images revealed a tangle of dark, veinous clouds woven through a massive crimson oval, and showed that the giant storm appears to float between layers in Jupiter's deep atmosphere.

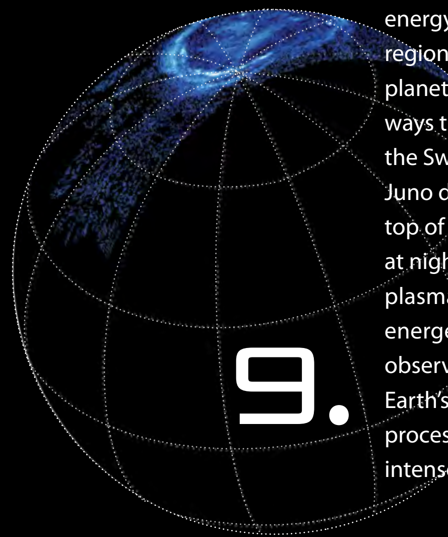


7. A Highly Charged Atmosphere

Powerful bolts of lightning light up Jupiter's clouds. In some ways, the lightning is much like what we see on Earth. In other ways, it's very different. For example, most lightning on Earth strikes near the equator; on Jupiter, it's mostly around the poles. Juno discovered the atmosphere is full of lighting, much more active then previously thought.

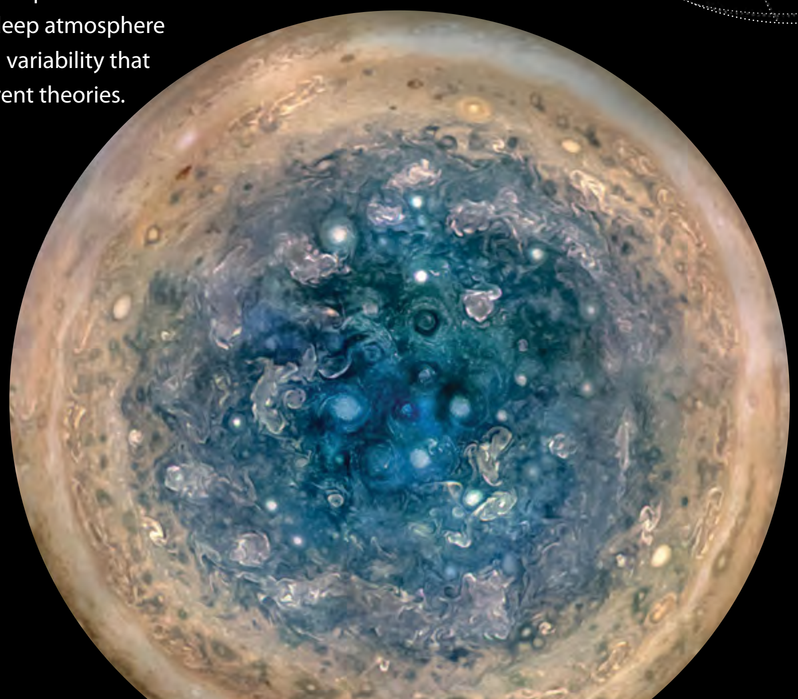
8. A Whole New Jupiter

It didn't take long for Juno to turn theories about how Jupiter works inside out. Among the early findings: Jupiter's poles are covered in giant cyclones nearly the size of Earth, swirling in dense, interactive clusters. Jupiter's iconic belts and zones also revealed surprises. The belts and zones were discovered to penetrate to a depth of 3000 km, while a newly discovered band near the equator persists far beneath the clouds, similar to Earth's tropical belt. Juno provided the first look into a giant planet's deep atmosphere and discovered variability that challenges current theories.



9. Powerful Auroras, Powerful Mysteries

Juno has observed massive amounts of energy swirling over Jupiter's polar regions that contribute to the giant planet's powerful auroras — only not in ways the researchers expected. Using the SwRI-led ultraviolet spectrograph, Juno discovered the aurora at the very top of Jupiter's poles appears to turn off at night. Using data from the SwRI-led plasma instrument and APL-led energetic particle detectors, scientists observed physical processes that drive Earth's aurora, but at Jupiter, these processes are not the source of the most intense aurora, as they are at Earth.



10. Extra Innings

In June, NASA approved an update to extend Juno's science operations until July 2021. This provides for an additional 41 months in orbit around Jupiter. Juno is in 53-day orbits instead of the originally conceived orbits of 14 days. The larger orbit will allow Juno to explore Jupiter's giant magnetosphere and monitor atmospheric storms for years, providing information on how the giant planet works. The spacecraft and all its instruments are healthy and operating normally.

IMAGES COURTESY: NASA/JPL/SWRI/MSS CODY AUSTIN/JPL-CALTECH/MSSS/BETSY ASHER HALL/ GERVASIO ROBLES/GERALD EICHSTÄDT/ SEAN DORAN/ASI/INAF/JIRAM/JUNOCAM

FINDING WATER IN MOONSHINE

Using uncommon expertise in how water reacts with lunar soil, an SwRI scientist contributed to studies indicating that water and/or hydroxyl may be more prevalent on the Moon's surface than previously thought.

"Water on the Moon is of intense interest for many reasons," said SwRI's Dr. Michael J. Poston, a coauthor of the paper, "Widespread Distribution of OH/H_2O on the Lunar Surface Inferred from Spectral Data," published in Nature Geoscience online. Water has been the focus of many lunar missions, largely because it is a critical resource for a Moon habitat.

"When you split water molecules, you end up with oxygen and hydrogen, critical components for breathable air and rocket fuel. Hydroxyl (OH) is also useful, but takes more energy to access and provides less hydrogen, making it less attractive."

Up until the past decade or so, scientists thought the Moon was arid, with water existing perhaps only as ice in the permanently shaded craters near the poles. In the late 2000s, however, analysis of lunar samples and data from new spacecraft instruments showed evidence to the contrary.

To understand how tightly water is bound to lunar surface materials, Poston conducted extensive experiments with water and lunar samples collected by the Apollo missions in the late 1960s and early 1970s. Using detailed surface temperature maps and thermophysics modeling, the team estimated the amount of Moon glow to subtract from the reflected sunlight to better characterize the inferred measurements of water on the lunar surface. Based on the results, it appears that OH/H_2O is present on lunar surfaces under much more wide-ranging conditions than previously understood.

"The next step is to determine whether it's water, hydroxyl, or a mixture of the two — and where it came from," Poston said.

IMAGE COURTESY: NASA/JPL/USGS D022925

PUTTING REGENERATIVE MEDICINE INTO PRODUCTION

SwRI has joined the Advanced Regenerative Manufacturing Institute (ARMI) to help advance large-scale manufacturing of engineered tissues and related technology. ARMI is a consortium of nearly 100 organizations dedicated to developing next-generation manufacturing processes and technologies for cells, tissues and organs.

"The next frontier of regenerative medicine is manufacturing," said Dr. Jian Ling, an Institute scientist in the Chemistry and Chemical Engineering Division. "By joining ARMI, SwRI can work with other members to transition regenerative medicine technologies to manufacturing and bring significant additional benefits to patients. SwRI has the experience and resources, especially in product development and technology commercialization. Through the consortium, we can collaborate with other members and accelerate transition of our technology."

SwRI expertise aligns well with ARMI's strengths. Our staff has extensive experience in regenerative medicine, including engineering skin, bone, tendon and blood vessel materials for novel wound-healing applications. SwRI offers bioreactors to scale-up stem cell production and facilities to encapsulate cells, growth factors and drugs for bioprint applications.

"ARMI membership allows SwRI to be at the cutting edge of regenerative medicine when R&D is beginning to transition out of the lab into large-scale commercial operations," said SwRI Vice President Dr. Michael MacNaughton. "SwRI chemists can collaborate with our robotics, automation, modeling and simulation experts to improve manufacturing processes, data analysis and control software."

In addition to CGMP laboratories for pilot production, SwRI offers an established ISO 13485 Quality System for medical device design, prototyping and testing.

According to ARMI, approximately $80 million in federal funds awarded by the Department of Defense will be combined with more than $200 million in cost-sharing investments to support the development of tissue and organ manufacturing capabilities.

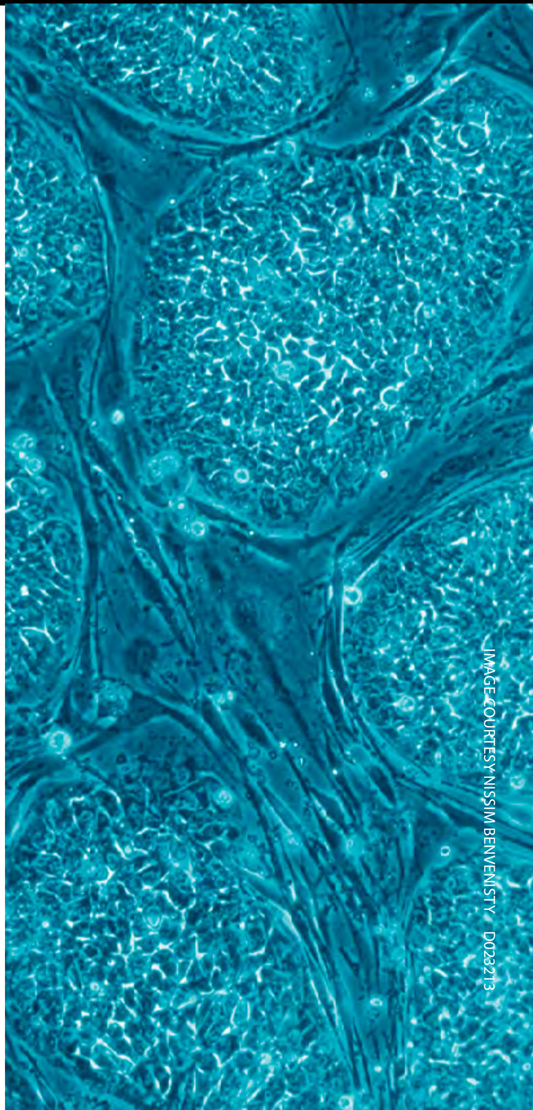


IMAGE COURTESY: NISSIM BENVENISTY D023213

Adapting Drones to Inspect Nuclear Power Plants

An SwRI-led team is developing unmanned aerial system (UAS) technology to autonomously fly into the containment vessels of the damaged units at Japan's Fukushima Daiichi nuclear power station and assess conditions.

SwRI teamed with the General Robotics, Automation, Sensing and Perception (GRASP) Lab at the University of Pennsylvania (Penn) to successfully demonstrate the feasibility of the approach in a test fixture at SwRI. The team also verified that the UAS components could survive the harsh radiation conditions within the containment.

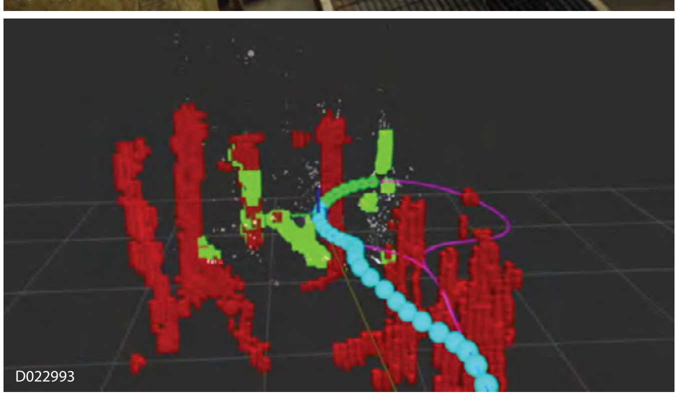
"The conditions inside the containment at Fukushima Daiichi are quite possibly the most challenging environment that the SwRI–Penn team has had to address," said Project Manager Dr. Monica Garcia of SwRI's Intelligent Systems Division. "We will be pushing the envelope in terms of the technology."

When a 9.0 magnitude earthquake and a 13-meter-high tsunami struck the power station in 2011, this one-two punch initiated a series of events that ultimately caused three reactors to fail. Since then, a number of ground- and underwater-based robotic systems have been sent inside the containment to investigate. However, damage and high radiation levels have limited access to information vital to decontamination and decommissioning efforts.

"The team is adapting high-speed, advanced mobility drones to collect key information about the current status," said Dr. Richard Garcia, SwRI's technical lead. "This information will play an important role in future decontamination and decommission efforts at Fukushima Daiichi."

"As robots get smaller, faster and smarter, this is exactly the kind of problem we want them to address," said Dr. Vijay Kumar, the Nemirovsky Family Dean of Penn's School of Engineering and Applied Science. "Challenges like this are what push research in our field forward."

Tokyo Electric Power Company Holdings Inc. (TEPCO Holdings) contracted SwRI to explore the use of UASs, or drones, within the containment at Fukushima Daiichi. Working with Penn's GRASP Lab, SwRI engineers are helping adapt small drones to autonomously operate in this challenging environment.



The team developed an enclosed obstacle course to simulate potential conditions inside the containment at Fukushima Daiichi. The photo on the top shows the UAS autonomously traveling around obstacles in the test fixture. The image on the bottom depicts the original (purple line), actual (blue circles), and upcoming (green circles) flight paths as the UAS travels around the obstacles (red blocks).

FATIGUE FAILURE PREVENTION

SwRI's 25th NASGRO® short course at our San Antonio headquarters will be presented on October 23-25, 2018. The last five classes for the fatigue and fracture analysis tool have sold out.

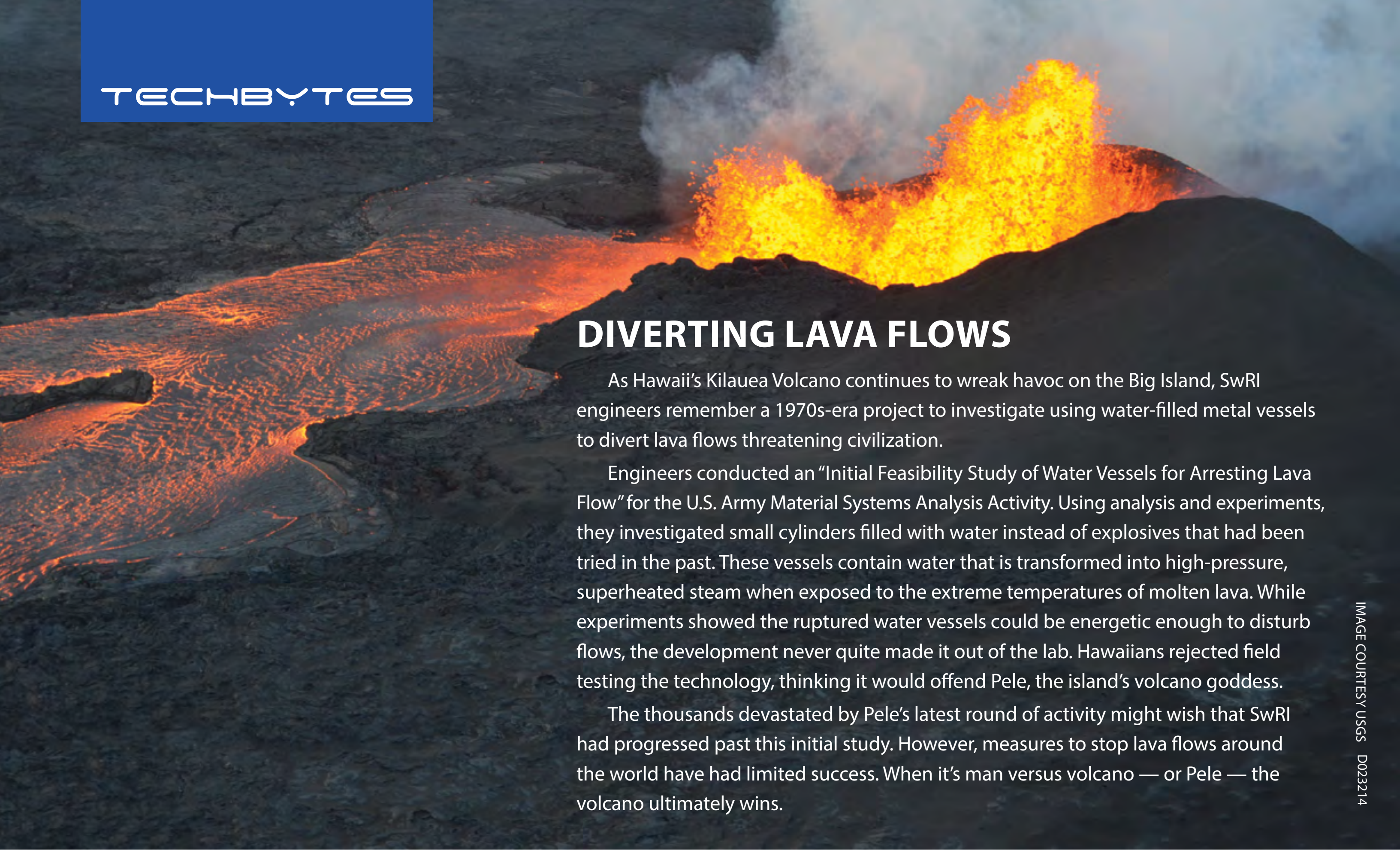
NASGRO, the most widely used fracture mechanics and fatigue crack growth software in the world, is used to evaluate structural components of aircraft, spacecraft, rotorcraft, gas turbine engines, pressure vessels, aging infrastructure and more.

"NASGRO is a suite of computer programs to analyze fracture and fatigue crack growth in structures and mechanical components," said Dr. Craig McClung, who along with Joe Cardinal has also traveled the world teaching these short courses at client locations. "In more than 60 total courses, SwRI has trained more than 1,100 people to evaluate and demonstrate that aircraft, spacecraft, rotorcraft and gas turbine engines are safe for flight."

Developed by SwRI engineers and NASA under a Space Act Agreement, NASGRO is also supported by the NASGRO Consortium and the Federal Aviation Administration. NASGRO's integrated modules calculate stress intensity factors, compute crack growth, and determine critical crack sizes. The software stores fatigue crack growth and fracture toughness data in an extensive material property database enabling the evaluation of many different types of materials and structures.

To register for the NASGRO training, go to **swri.org/nasgro-training**.

For more information on NASGRO and the NASGRO Consortium, visit **nasgro.swri.org**.



DIVERTING LAVA FLOWS

As Hawaii's Kilauea Volcano continues to wreak havoc on the Big Island, SwRI engineers remember a 1970s-era project to investigate using water-filled metal vessels to divert lava flows threatening civilization.

Engineers conducted an "Initial Feasibility Study of Water Vessels for Arresting Lava Flow" for the U.S. Army Material Systems Analysis Activity. Using analysis and experiments, they investigated small cylinders filled with water instead of explosives that had been tried in the past. These vessels contain water that is transformed into high-pressure, superheated steam when exposed to the extreme temperatures of molten lava. While experiments showed the ruptured water vessels could be energetic enough to disturb flows, the development never quite made it out of the lab. Hawaiians rejected field testing the technology, thinking it would offend Pele, the island's volcano goddess.

The thousands devastated by Pele's latest round of activity might wish that SwRI had progressed past this initial study. However, measures to stop lava flows around the world have had limited success. When it's man versus volcano — or Pele — the volcano ultimately wins.

IMAGE COURTESY USGS D023214

COSMOCHEMICAL MODEL OF PLUTO FORMATION

SwRI scientists integrated NASA's New Horizons discoveries with data from ESA's Rosetta mission to develop a new theory about how Pluto may have formed at the edge of our solar system.

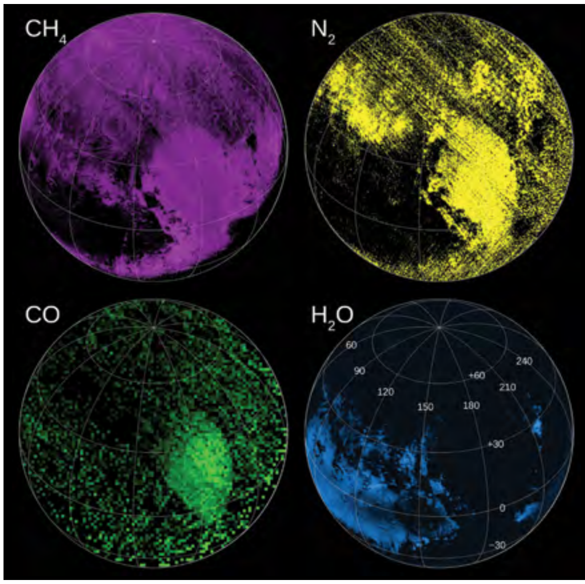
"We've developed a cosmochemical model of Pluto formation," said Dr. Christopher Glein. The research is described in a paper published in Icarus. At the heart of the research is the nitrogen-rich ice in Sputnik Planitia, a large glacier that forms the left lobe of the bright Tombaugh Regio feature on Pluto's surface.

"We found an intriguing consistency between the estimated amount of nitrogen inside the glacier and the amount that would be expected if Pluto was formed by the agglomeration of roughly a billion comets or other small Kuiper Belt Objects similar in chemical composition to 67P, the comet explored by Rosetta," Glein said.

Scientists needed to understand not only the nitrogen present at Pluto now — in its atmosphere and in glaciers — but also how much of the volatile element potentially could have leaked out of the atmosphere and into space over the eons. They then needed to reconcile the proportion of carbon monoxide to nitrogen to get a more complete picture. Ultimately, the low abundance of carbon monoxide at Pluto points to burial in surface ices or to destruction from liquid water.

"Our research suggests that Pluto's initial chemical makeup, inherited from cometary building blocks, was chemically modified by liquid water, perhaps even in a subsurface ocean," Glein said. However, a solar model also satisfies some constraints. While the research pointed to some interesting possibilities, many questions remain to be answered.

"This research builds upon the fantastic successes of the New Horizons and Rosetta missions to expand our understanding of the origin and evolution of Pluto," said Glein. "Using chemistry as a detective's tool, we are able to trace certain features we see on Pluto today to formation processes from long ago. This leads to a new appreciation of the richness of Pluto's 'life story,' which we are only starting to grasp."



These maps — assembled from New Horizons' Ralph instrument — indicate regions rich in methane (CH_4), nitrogen (N_2), carbon monoxide (CO) and water (H_2O) ices. Sputnik Planitia shows an especially strong signature of nitrogen near the equator. SwRI scientists combined these data with Rosetta's comet 67P data to develop a proposed cosmochemical model for Pluto formation.

IMAGE COURTESY: NASA/JHUAPL/SwRI D023202

NICKNAME FOR ULTIMATE TARGET

As NASA's New Horizons spacecraft continues exploring the unknown, the SwRI-led mission team has selected a nickname for the Kuiper Belt Object (KBO) it will visit on Jan. 1, 2019.

After being nominated and voted on by the public, the name "Ultima Thule" (pronounced ultima too-lee) was chosen for the spacecraft's next target at the edge of the solar system. Officially known as 2014 MU69, the KBO will be the most primitive world ever explored, and the farthest exploration of any world in history — a billion miles beyond Pluto.

In ancient literature, Thule is a remote mythical island referenced as the "ends of the Earth." Ultima Thule means beyond Thule, beyond the borders of the known world. This moniker epitomizes New Horizons' journey to a distant place never visited before.

"MU69 is humanity's next Ultima Thule," said SwRI's Dr. Alan Stern, New Horizons principal investigator. "Our spacecraft is heading beyond the limits of the known worlds, to what will be this mission's next achievement. Since this will be the farthest exploration of any object in space in history, I like to call our flyby target Ultima, for short, symbolizing this stage of ultimate exploration by NASA and our team."

After the flyby, NASA and the New Horizons team will choose a formal name to submit to the International Astronomical Union, based in part on whether MU69 is found to be a single body, a binary pair or perhaps multiple objects.

This illustration depicts NASA's New Horizons spacecraft encountering 2014 MU69, aka Ultima Thule, a Kuiper Belt object that orbits the Sun a billion miles beyond Pluto.

IMAGE COURTESY NASA/JHUAPL/SWRI/STEVE GRIBBEN D023209

ADVANCING ENERGY TECHNOLOGY

The U.S. Department of Energy has awarded SwRI three contracts worth more than $2 million to advance turbine technology for power plants.

"These projects are a part of SwRI's continuing contribution toward DOE's goal of developing the most efficient and reliable energy infrastructure," said Dr. Klaus Brun, a program director in SwRI's Mechanical Engineering Division.

In one effort, SwRI will develop a concept for a supercritical carbon dioxide (sCO_2), coal syngas or natural gas-fired oxy-fuel turbine. The goal is to improve high-cycle efficiencies and increase power output, thus reducing both the size and cost of a power plant. SwRI will lead a team in this effort.

For the second project, SwRI will develop a modular, highly efficient combined-cycle power system. The system will be cleaner and more fuel-efficient, reducing operating costs and plant size. In addition, an sCO_2-based waste-heat recovery system will be added to an existing gas turbine to increase efficiency and environmental performance. This effort is also led by SwRI and includes several collaborators.

A third project is developing coal-fired flameless pressurized oxy-combustion technology for a 50-megawatt pilot power plant. The project has three phases. The first phase seeks to reduce pilot plant costs, begin an environmental impact study and secure a host site for a pilot plant. Engineers also will work with collaborators to develop an advanced turbo-expander that will extract extra power from flue gases.

SwRI is a leader in research and development of oxy-combustion cycle technology, which aims to provide high-efficiency electricity generation for next-generation power plants.

FLASH SPACE STORAGE

SwRI engineers patented a flash memory storage system that allows satellites to collect and store vast amounts of data for later transmission to ground stations.

"The technology provides high-speed, high-capacity storage of satellite data," said Michael Koets, a staff engineer in the Space Science and Engineering Division. "A representative application is storing weather satellite data."

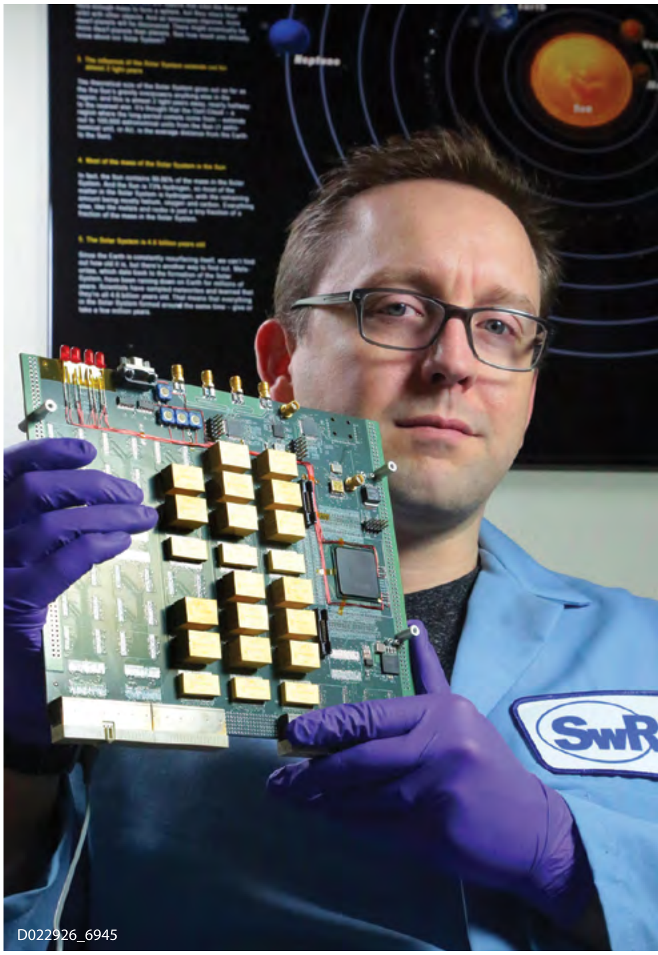
Weather satellites rapidly generate high volumes of high-resolution images. However, the satellites can only download data to receivers on the ground in certain locations..

"All that data needs to be stored to memory on the satellite as it is collected," Koets said. "Our system can record data to flash memory up to 100 times faster than previous approaches."

Flash memory is efficient and compact, allowing smaller, less expensive satellites to gather much more scientific data than conventional data recording devices. Flash memory is ubiquitous in consumer electronics such as mobile phones and thumb drives, but the rigors of the space environment have slowed its adoption for satellites and interplanetary spacecraft. The SwRI technology allows the use of slower but more robust flash memories that can operate in space while achieving performance close to that of contemporary consumer electronics.

Other potential applications include storing radar data collected by Earth-monitoring satellites studying glaciers or earthquake zones, or storing scientific data collected by deep space missions, such as those sent to investigate asteroids.

The patented technology was developed by Koets, Larry T. McDaniel III and (at right) Miles R. Darnell.



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CNWRA Contract Renewed

The U.S. Nuclear Regulatory Commission (NRC) has renewed its contract with SwRI to operate the Center for Nuclear Waste Regulatory Analyses (CNWRA).

The contract is valued at up to $52 million over a five-year period of performance, including a one-year base period and four one-year option periods. Under this contract, CNWRA continues to provide technical assistance and research support to NRC activities related to storage, transportation, possible reprocessing and ultimate geological disposal of spent nuclear fuel and high-level radioactive wastes.

"For 30 years, CNWRA has been central to supporting NRC's mission through evaluations of engineering and environmental and scientific factors affecting management of radioactive wastes," said Dr. Wesley C. Patrick, CNWRA executive director.

Recognized as a center of excellence in earth science and engineering, CNWRA supports the NRC with a broad range of technical assistance and research. CNWRA expertise includes environmental evaluations, fire protection engineering, hazard assessments, materials degradation and aging management. The center provides performance and probabilistic risk assessments, risk-informed license review and site characterization. It also supports public outreach and stakeholder engagement associated with rule-making and licensing activities.

CNWRA®
A center of excellence in earth sciences and engineering

"SwRI is proud that our CNWRA operations support the NRC's mission to protect public health and safety," said SwRI President and CEO Adam Hamilton. "Our staff members have expertise spanning the environmental, geological and material sciences, as well as the engineering disciplines needed to evaluate safety and environmental compliance of nuclear facilities."

With facilities in San Antonio and Rockville, Maryland, CNWRA also conducts independent research and peer reviews related to radioactive waste management for foreign governments and regulatory agencies around the world.

MARTIAN MOON MODELS

SwRI scientists believe Martian moons formed following a cosmic collision, but on a much smaller scale than the giant impact thought to have resulted in the Earth-Moon system. Their work shows that an impact between proto-Mars and a dwarf-planet-sized object likely produced Deimos and Phobos, as detailed in a paper published in Science Advances.

The origin of the Red Planet's small moons has been debated for decades. The question is whether the bodies were asteroids captured intact by Mars' gravity or whether the tiny satellites formed from an equatorial disk of debris, as is most consistent with their nearly circular and coplanar orbits.

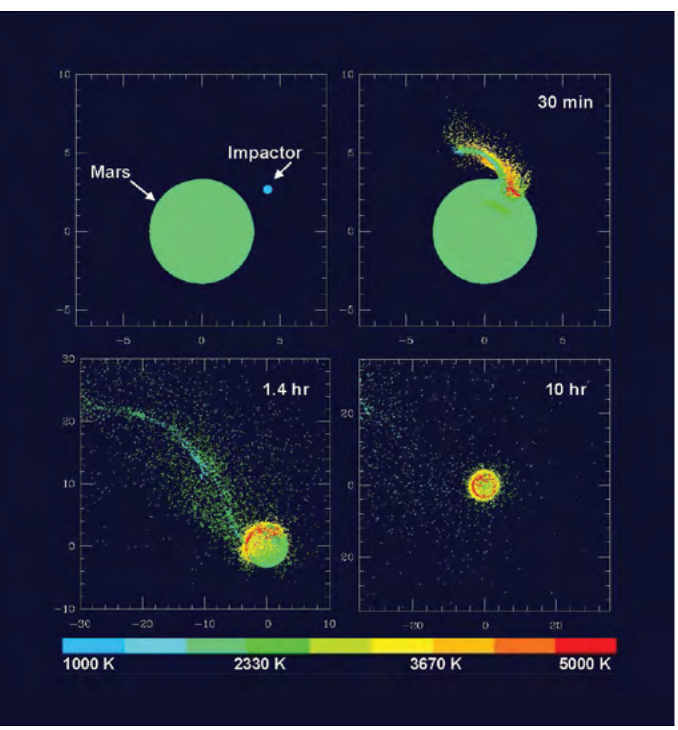
"Ours is the first self-consistent model to identify the type of impact needed to lead to the formation of Mars' two small moons," said SwRI's Dr. Robin Canup, one of the leading scientists using large-scale hydrodynamical simulations to model planet-scale collisions, including the prevailing Earth-Moon formation model.

"A key result of the new work is the size of the impactor," Canup said. " We find that a large impactor — similar in size to the largest asteroids — is needed, rather than a giant impactor."

Deimos and Phobos are very small, with diameters of only 7.5 miles and 14 miles respectively, and orbit very close to Mars. The proposed Phobos-Deimos forming impactor would be between the size of the asteroid Vesta, which has a diameter of 326 miles, and the dwarf planet Ceres, which is 587 miles wide.

"Our state-of-the-art models show that a Vesta-to-Ceres-sized impactor can produce a disk consistent with the formation of Mars' small moons," said the paper's coauthor, Dr. Julien Salmon. "The outer portions of the disk accumulate into Phobos and Deimos, while the inner portions of the disk accumulate into larger moons that eventually spiral inward and are assimilated into Mars."

The research was funded by NASA's Solar System Exploration Research Virtual Institute (SSERVI) in Silicon Valley, and by NASA's Emerging Worlds program. The research was conducted as part of the Institute for the Science of Exploration Targets (ISET), a SSERVI team from SwRI's Boulder, Colorado, branch.



SwRI scientists modeled a Ceres-sized object crashing into Mars at an oblique angle. These four frames from the 3-D simulation show that the impact initially produces a disk of orbiting debris primarily derived from Mars (bottom right frame). The outer portions of the disk later accumulate into Mars' small moons, Phobos and Deimos. The inner portions of the disk accumulate into larger moons that eventually spiral inward and assimilate into Mars.

D02318511

PROPELLANT DELIVERY

NASA has tapped SwRI to test new technology to more efficiently and reliably deliver liquid propellants for future space missions. SwRI and NASA's Glenn Research Center developed the tapered liquid acquisition device (LAD), which will be evaluated in microgravity.

The device is designed to deliver cryogenic liquid propellants to a rocket engine from fuel tanks. The tapered LAD also can transfer fuel between tanks. Existing LAD designs with straight channels generate vapor bubbles in the delivery channel. SwRI's tapered design passively removes the bubbles through surface tension forces to substantially improve the transfer of cryogenic fluids at lower costs.

SwRI will adapt the ground-tested hardware for an autonomous experiment that will fly on New Shepard, Blue Origin's reusable launch vehicle.

"New Shepard provides approximately three minutes of high-quality microgravity, which is significant when compared to the 25 seconds of microgravity achieved in parabolic flights," said Kevin Supak, who is leading the project. "Once flight testing in microgravity is completed, the device potentially could be tested onboard the International Space Station in extended microgravity and eventually be incorporated into future cryogenic propellant tank designs."

The flight test will take place early 2019 in West Texas at Blue Origin's launch site near Van Horn. SwRI researchers will be onsite to oversee experiment preparation and view the launch.

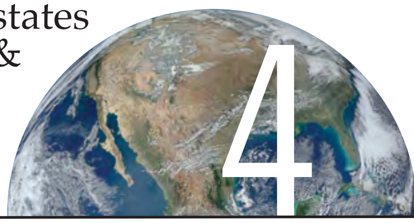
SwRI has more than 60 years of experience studying propellant dynamics for launch vehicles and spacecraft propulsion systems. For more information, visit **swri.org/space-propulsion-propellants**.

IMAGE COURTESY BLUE ORIGIN D000000

BY THE NUMBERS

March — May 2018

78 presentations given in



18 states & 4 COUNTRIES

23 papers published in 16 PUBLICATIONS

8 patents awarded

SwRI has been named as one of the 500 "America's Best Workplaces" in 2018 by Forbes magazine. The Institute came in at No. 321 in the America's Best Midsize Employers ranking of 500 employers with 1,000 to 5,000 employees.

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COMING UP

D021785

Dr. Tracy M. Becker is one of 30 members of the American Geophysical Union's inaugural "Voices for Science" program. The outreach program will build public support for Earth and space science, protect critical science funding and advance federal support for science policy. The group shares its expertise with a variety of important audiences in key locations.

D023203

Executive Vice President and COO **Walt Downing** was selected as a member of the University of Texas at San Antonio (UTSA) Research External Advisory Council. The council, established in Spring 2018, advises UTSA's vice president for Research, Economic Development and Knowledge Enterprise. The group is comprised of professionals in industry, military, nonprofit, cybersecurity, biosciences, and research institutions, locally and nationally.

D019357

D018124_9774

Assistant Director **Dr. Cary Henry** and Staff Engineer **Chris Sharp** received the Society of Automotive Engineers' (SAE) 2017 John Johnson Award for Outstanding Research in Diesel Engines for a journal article published in the March 28, 2017, issue of SAE International Engines. "Achieving Ultra Low NO Emissions Levels with a 2017 Heavy-Duty On-Highway TC Diesel Engine — Comparison of Advanced Technology Approaches" detailed work performed on a heavy-duty diesel engine exploring traditional and advanced technologies to demonstrate ultra-low NO_x emissions. Sharp and Henry are two of five coauthors of the paper.

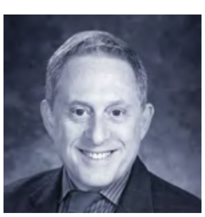
D022262_0019

Senior Program Manager **Mike Ladika** was elected president of the National Advanced Mobility Consortium Board of Directors. Ladika has served on the board since fall 2016 as the nonprofit representative. NAMC partners with the government to refine business processes and tools, streamline project contract administration, and expedite the innovation, development, and production of military ground vehicle systems.

D019357

IMAGE COURTESY NASA/BILL INGALLS

Institute Scientist **Dr. Cathy Olkin** received the Woodie Flowers Award as mentor of the year during the 2018 Idaho Regional FRC Robotics Competition. Olkin teaches students about the engineering process, problem solving and collaboration. She is co-investigator on NASA's New Horizons mission and deputy principal investigator of the Lucy mission to Jupiter's Trojan asteroids.



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Associate Vice President **Dr. Alan Stern** received the 2018 National Award of Nuclear Science & History from the National Museum of Nuclear Science & History. The award recognizes his work in "planetary and near-Earth research with the NASA Hubble Space Telescope and other deep space observations and discoveries in astrophysics and planetary science." Stern is the principal investigator of NASA's New Horizons mission, which flew by Pluto in 2015 and is scheduled to zip past Kuiper Belt object Ultima Thule on Jan. 1, 2019.

TRAINING

SwRI is hosting these short courses.

Introduction to Propulsion Simulations Using NPSS® Software, San Antonio, August 21, 2018

Small Molecule Drug Development: From Concept to IND, San Antonio, October 8, 2018

Fundamentals of Turbomachinery Failure Analysis, San Antonio, October 23, 2018

Gas Turbine & Compressor Training Week, San Antonio, November 12, 2018

CONFERENCES

32nd Annual AIAA/USU Small Satellite Conference, Logan, Utah, August 4-9, 2018, Booth 57 and 58

Texas Groundwater Summit, San Antonio, August 28-30, 2018

Turbine Engine Technology Symposium (TETS), Dayton, Ohio, September 10-18, 2018, Booth 612

American School of Gas Measurement Technology (ASGMT), Houston, September 17-20, 2018

IEEE AUTOTESTCON, National Harbor, Md., September 17-20, 2018, Booth 138

47th Turbomachinery & 34th Pump Symposia, Houston, September 18-20, 2018, Booth 2735

International Refining and Petrochemical Conference (IRPC) Americas, Houston, September 25-26, 2018

ITS 5C Summit, Jacksonville, Fla., October 7-10, 2018, Booth 416

ASNT Annual Conference, Houston, October 29-31, 2018, Booth 932

AAPS PharmSci 360, Washington, D.C., November 4-7, 2018

ITC/USA, Phoenix, November 5-8, 2018, Booth 708

ASIP Conference, San Antonio, November 26-29, 2018, Booth 4

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

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