

TECHNOLOGY TODAY®

ADDITIVE MANUFACTURING

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COVID-19

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EMISSIONS
SOLUTION



TURBO TECH

Southwest Research Institute is a leader in advanced power systems, including the design, analysis, prototype fabrication and testing of turbomachinery. We specialize in gas turbines, compressors, pumps, wind turbines and motors from kilowatt-scale to utility-scale. With more than 50 years of experience assessing and improving power generation equipment, SwRI is also a leading developer of cutting-edge power cycle technology.

SwRI designed and fabricated this small-scale impeller to evaluate how inlet flows associated with pipe elbows affect the performance of centrifugal compressors, such as those found in natural gas compressor stations.

We also apply our turbomachinery expertise to advanced energy research applications including:

- Supercritical carbon dioxide power cycles
- Thermal, mechanical and chemical energy storage (TMCES)
- Coal- and natural gas-powered oxy-fuel combustion
- Hydrogen combustion, compression and storage
- Fuel cell research
- Waste heat recovery

TECHNOLOGY TODAY®

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ABOUT THE INSTITUTE

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ON THE COVER

To investigate using additive manufacturing (AM) to bond metal and ceramic materials, the project team ran a metal-to-metal control sample to verify that a fixture installed in the AM 3D printer worked properly. Project engineers printed titanium tubes onto machined titanium pucks and verified that the bond between the AM part and the conventionally manufactured puck was structurally sound and airtight.

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EMPLOYMENT

Southwest Research Institute is an independent, nonprofit, applied research and development organization. The staff of more than 2,700 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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Additive manufacturing (AM) of metals is an advanced 3D printing process that offers unique and exciting capabilities for producing metal parts and components. While many traditional methods of fabrication selectively remove materials to produce a part, AM involves the selective “addition” of material, often in a layer-by-layer manner, to build or “grow” a part. AM revolutionizes the design space, allowing the fabrication of complex parts that are difficult, if not impossible, to produce using conventional machining and fabrication methods.

Currently, the metals AM marketplace exceeds \$4 billion, and it is expected to reach \$30 billion by 2025. AM is infiltrating a range of industries and applications, including the oil and gas, automotive, power generation, biomedical, aerospace and space industries.

In 2018, Southwest Research Institute added its first additive manufacturing capability for metals — a selective laser melting (SLM) machine. SLM is a novel AM process that involves dividing a computer-based rendering of the component geometry into a series of horizontal slices. Each slice represents an individual layer of the part, which is built using a fine metallic powder distributed across the build area. Software then drives a laser

that selectively melts and fuses regions of the powder to the previous layer. The process is repeated, building up a three-dimensional component layer-by-layer.

While AM has distinct advantages in creating parts with complex configurations, adoption of AM parts is hindered by the qualification of high-consequence parts fabricated using the new and unproven process. Unlike conventional subtractive fabrication processes where the properties of the excised part are those of a well-characterized wrought material, the AM build process produces both the part and the material simultaneously. As such, the part and material are inextricably related to the AM build process. Full realization of these advantages requires AM processes that reliably create parts with proper

geometric form while at the same time producing material with appropriate performance properties.

Research and development are critical to understanding and ensuring that AM parts and their material properties meet both form and functional performance requirements. Because AM could impact many research areas across SwRI, materials engineers proposed a Metals Additive Kickoff Emphasizing Research Synergy focused internal research program. MAKERS was launched to advance the collective understanding of this emerging technology and foster collaboration Institute-wide.

Out of 22 concepts across multiple disciplines, the MAKERS advisory committee



Metals Additive Kickoff
Emphasizing Research
Synergy Program

7 MAKERS BREAKTHROUGHS

D024193_9441

recommended 11 be developed into formal proposals, with the plan to fund five projects. In the end, the proposals proved so compelling that the advisory committee requested \$1.4 million in internal research funding to support seven projects.

The projects were selected to advance SwRI knowledge in key aspects of metals AM and develop new capabilities to strengthen understanding of the AM process. The selected projects strategically spanned key elements of metals AM, from thermal load assessments to mechanical and corrosion characterization to nondestructive evaluation. Keep reading for a snapshot of each project, and consider the promises, challenges and advances of AM.

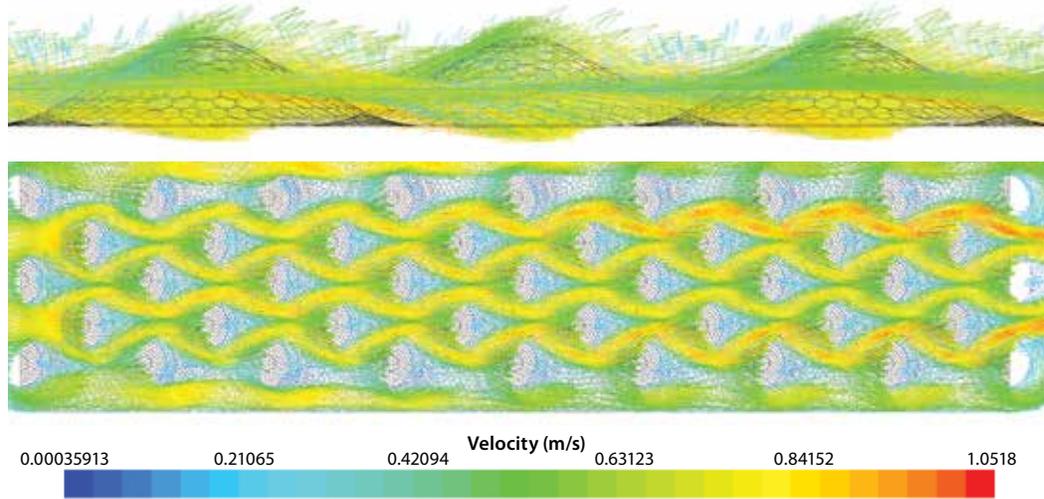
Dr. Carl Popelar, a staff engineer and one of the leaders of the MAKERS program, shows a demonstration build of the SwRI logo. Thin slices of the intricate logo (above) can be machined off the titanium build plate.



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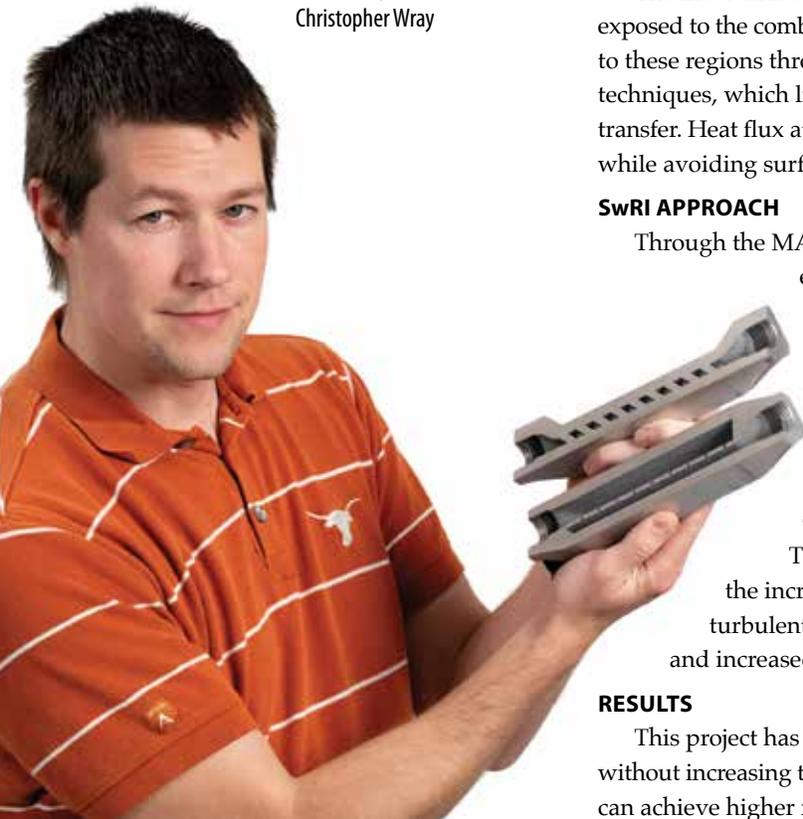
Dimpled geometry inside engine cooling jackets improved heat transfer by increasing local velocities and mixing. These figures show how the dimples create high-velocity flows weaving between the dimples.

D024247/ D024248



1 COOLING COMPLEX CASTINGS

Matthew Hoffmeyer,
Kevin Hoag and
Christopher Wray



D024140_0026

Matthew Hoffmeyer, a powertrain engineer, shows cross sections of two AM-produced cooling passages with complex internal geometries designed to enhance heat transfer in automotive engines.

INDUSTRY PROBLEM

The automotive engine industry faces conflicting development challenges driven by simultaneous requirements to reduce its carbon footprint while producing near-zero harmful exhaust emissions. Engines designed for increased power and reduced engine operating speed, weight and volume face increasing challenges for engine cooling and temperature control.

The most critical regions for engine temperature control are the cylinder head surface exposed to the combustion chamber and the upper cylinder wall. Today, coolant is delivered to these regions through channels produced with conventional casting and/or machining techniques, which limit the design options and mechanisms available to enhance heat transfer. Heat flux at any location is limited by the combination of available coolant velocity while avoiding surface temperatures so hot that all liquid in the vicinity vaporizes.

SwRI APPROACH

Through the MAKERS program, SwRI engineers studied possible AM approaches to enhance heat transfer and minimize coolant pumping work. The team created five alternative cooling jacket geometries using AM in otherwise identical test scenarios and compared their performance to a rectangular baseline coolant passage. The team also developed new fluid flow models that can be scaled up and applied to simulations on entire cylinder head water jackets to improve analysis of existing water jacket designs while ensuring that new designs that incorporate complex features will be modeled accurately.

The 3D modeling also provided insights into the mechanistic sources of the increased heat transfer. More complex internal features lead to more turbulent, higher velocity flows that generate higher heat transfer coefficients and increased mixing of the fluid, which causes it to absorb more heat.

RESULTS

This project has demonstrated that complex geometries can double heat transfer without increasing the pumping work. Using these features within engine cooling systems can achieve higher rates of heat transfer in localized spots, such as the cylinder head fire deck, potentially allowing for more efficient cooling strategies. More effective heat transfer could improve overall engine efficiency by requiring smaller water pumps.

The team also considered using AM to construct a portion of the component, to integrate the AM enhanced cooling section into a larger, conventionally cast component. This option is an important consideration recognizing that the size of engine components probably precludes producing the entire component using AM.

2 INTERNALLY COOLED TURBINE

Grant Musgrove, January Smith, Ellen Smith, Steve White, Charles Krouse and Nathan Andrews

INDUSTRY PROBLEM

In the next five years, the utility industry will need internally cooled radial turbines for next-generation, distributed power generation. A cooled radial turbine is necessary for high-efficiency supercritical carbon dioxide (sCO₂), direct-fired oxy-combustion and conventional power cycles. While the industry has developed cost-effective techniques for producing internally cooled axial turbines, producing radial counterparts using conventional manufacturing methods is cost-prohibitive.

SwRI APPROACH

This project used the SLM-AM process to build a radial turbine with small, internal cooling passages, allowing it to operate at higher cycle temperatures for improved cycle efficiency. SwRI

designed, built and tested internally cooled turbines to overcome conventional manufacturing challenges and reduce production risk. Like traditionally wrought components, the devices needed

DETAIL

A radial turbine is a rotating mechanical device that extracts energy from a fluid flow.

post-processing by hot-isostatic-pressure (HIP) and heat treatment. Over the course of the project, the team learned to overcome challenges in SLM production and post-processing.

RESULTS

The team produced both cooled and uncooled solid turbines using AM. The internally cooled turbine has a diameter of 3.3 inches and rotates at 118,000 rpm for this project. Testing indicated that the properties of the AM material were within 10% of a wrought material of the same alloy and that the cooled turbine decreased temperatures by over 400° F. For the demonstration project, engineers designed simple cooling geometries, allowing ample room for improvement in future builds. For example, engineers could use film cooling and internal turbulators to enhance heat transfer to operate at even higher cycle temperatures. Future studies may also investigate the effect of build parameters on surface roughness to reduce pressure drop through the passages.



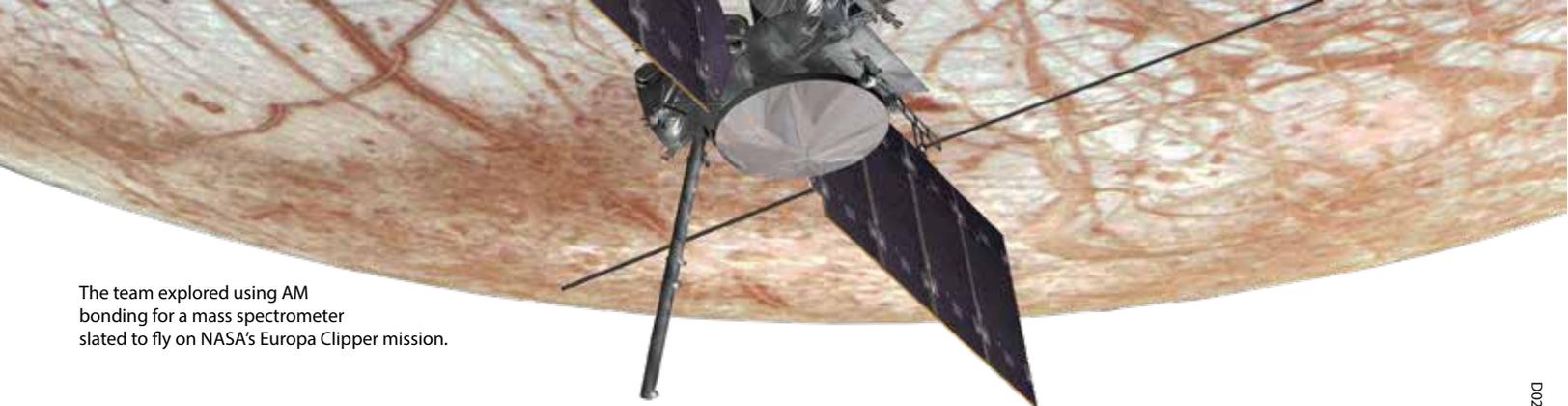
The cooled turbine is sectioned to show a small, internal cooling passage has been successfully manufactured into the turbine arm. Internal cooling channels reduce the operational temperatures by 415° F.

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Grant Musgrove, manager of SwRI's Propulsion and Energy Section, led a MAKERS project that successfully demonstrated the ability to design, build and test internally cooled, AM-produced turbines.

D024138_0713



The team explored using AM bonding for a mass spectrometer slated to fly on NASA's Europa Clipper mission.

3 AM SPACE BONDING

James Noll, Kenneth Domingue and John Roberts

INDUSTRY PROBLEM

Space science instruments are typically assembled from metallic and ceramic parts. These dissimilar materials can be bonded into a hermetic assembly by brazing. Brazing is a metal-joining process that fuses two or more metal items by melting and inserting a filler metal into the joint. The filler typically has a lower melting point than the adjoining metals, or in this case, a metal coating on a ceramic subcomponent. One of the challenges in brazing metals to ceramics is managing joint interface stresses arising from mismatched thermal expansion between metals and ceramics during the brazing process.

SwRI APPROACH

The team is considering using AM bonding for a family of spaceflight mass spectrometers. The latest instrument, slated to fly on NASA's Europa Clipper mission, uses a bolted construction to attach and align numerous ceramic-metal joints. The instrument's hard vacuum operations environment requires a separate vacuum cover assembly. The novel ceramic-to-metal bonding method is directly applicable to the next generation of spaceflight instruments, for example, by allowing a mass spectrometer to serve as its own vacuum chamber, which could significantly reduce the instrument's mass.

For the MAKERS program, engineers explored AM technology as an alternative to brazing to bond metals and ceramics for space and other high-vacuum applications. Using AM, SwRI fabricated and tested specimens and assemblies of increasing complexity to evaluate the leak tightness and structural integrity of joints as well as vacuum outgassing and quantification of virtual leaks. Engineers also investigated any issues with adapting AM parts for space applications.

RESULTS

The team tried different parameters in design, materials, tools and coatings, making incremental improvements during the process. They eventually were able to create a metal-ceramic bond, but it lacked the necessary structural integrity. The research showed great promise, however, for future applications for spaceflight instruments with additional process changes. For example, heating the build plate or thickening metals plating on the ceramic part could improve joint integrity.

At right, James Noll, a principal engineer in the Space Science and Engineering Division, shows the titanium tube described above left.



Through the MAKERS program, the team explored different materials and AM techniques for fusing ceramic and metal components. They used AM to affix a titanium tube to a nickel-plated ceramic puck (left), studying how different footing designs and plating thicknesses affected the overall integrity of the bond. They also evaluated how AM titanium adhered to a gold-plated ceramic puck (right).



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INDUSTRY PROBLEM

The quality of the products made by SLM-AM is influenced by many factors, including the properties of metal powders that serve as the raw materials. The shape, size distribution, grain size, impurities, density, surface chemistry and roughness of the particles affect the composition and configuration of a final component. SwRI engineers are concerned that existing material sources will not meet the needs of future applications.

SwRI APPROACH

In this project, engineers investigated novel approaches for developing the next generation of AM source materials. Specifically, the team used a vacuum roll coating process to create engineered metal platelets. Engineers customized materials to increase powder density, layer and /or coat particles, control size and shape morphology, and tailor properties including surface textures and chemistries. The team characterized the structural and chemical properties of commercial powders and the prototype SwRI platelets using scanning electron microscopy, energy-dispersive X-ray spectroscopy and laser light diffraction to measure particle size distribution.

RESULTS

The team synthesized titanium alloy 10-micron hexagonal platelets using a vacuum roll coating process. The goal was to manufacture SLM-AM parts using the engineered platelets and control SLM-AM parts made with commercially available powder to compare the structural, corrosion and mechanical properties of the parts. SLM-AM experiments and builds with the engineered platelets using manual powder distribution and standard build parameters revealed successful platelet powder fusion. However, powder dampness caused by the aqueous release method used to remove the platelets from the substrate resulted in poor flowability that inhibited the manufacture of SLM-AM test parts.

To address this issue, the team is considering changing to an organic release technique to remove the platelets from the roll. They are also considering improved post-processing steps to dry the powders. Otherwise, the project showed promise and has already resulted in a patent application and two conference presentations.

4 PLATELET POWDER

Dr. Vicky Poenitzsch,
John Macha, Dr. Carl Popelar
and Dr. Kent Coulter

Dr. Vicky Poenitzsch, a manager specializing in thin films technology, investigated developing the next generation of AM metal powders that could play a role in solving today's quality issues. Using a vacuum roll coating process as the source material for SLM-AM metal parts production, her team synthesized these titanium alloy 10-micron hexagonal platelets.



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5 QUALIFYING AM PARTS

Dr. Adam Cobb, Dr. Jay Fisher, Albert Parvin, Dr. Teodor Dogaru, Dr. Carl Popelar and John Macha

Dr. Jay Fisher, a program director in the Mechanical Engineering Division, was part of the MAKERS team investigating how to apply nondestructive evaluation techniques for AM materials and components.

D024216_0222



INDUSTRY PROBLEM

Using AM in fatigue-critical applications — where cyclic loading can cause progressive localized structural damage — is tricky. Nondestructive evaluation (NDE) techniques evaluate conventionally manufactured fatigue-critical components both during fabrication and throughout their service life but are not directly applicable for AM components. Because AM produces the component and the material concurrently, the properties of materials cannot be qualified in advance, and the AM process can produce flaws such as porosity, lack of fusion, warping and delamination. Additionally, the surface finish of AM components is significantly rougher than conventionally manufactured components, which can not only affect fatigue life but also reduce NDE performance.

SwRI APPROACH

SwRI investigated the performance of two NDE techniques on AM materials, eddy current testing (ECT) as a function of surface roughness and precision ultrasonic

testing (UT) measurements to understand microstructural properties. Initially, the team produced AM test coupons with various surface and microstructural characteristics.

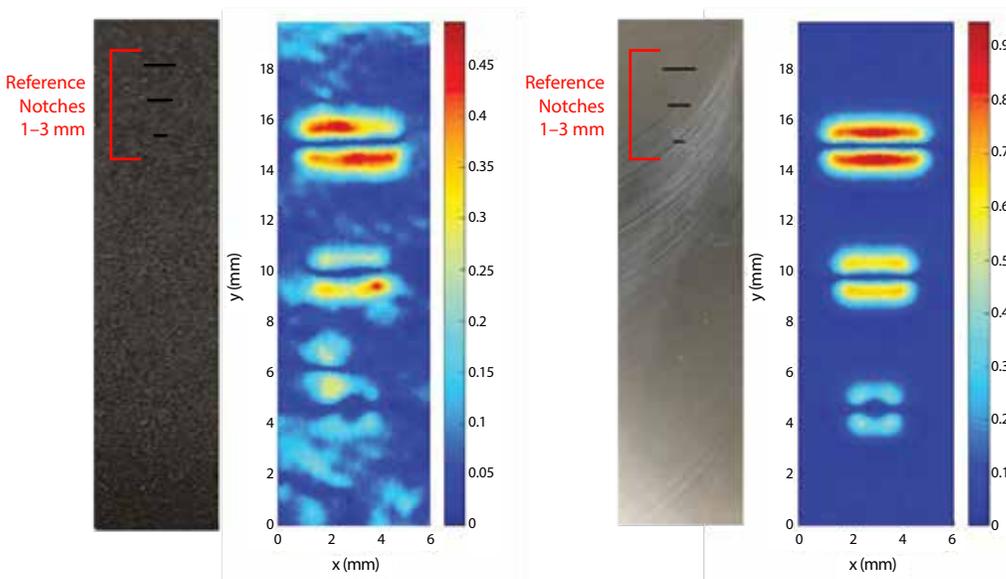
To determine how surface roughness influenced ECT inspection, engineers added notches to test articles to use as reference features for detection. The team used established ECT procedures to assess the signal-to-noise ratio (SNR) to understand how roughness affected the data and determined that the main effect was to cause sensor liftoff during inspections. This gap reduced signal amplitudes overall but did not increase the ECT noise. Based on this result, the team developed a simple ECT probe lift-off signal model to correlate ECT performance to surface roughness.

The UT study sought to estimate material characteristics such as porosity using a combination of longitudinal and transverse acoustic wave velocity measurements. Engineers used a novel, SwRI-developed UT sensor and approach to measure acoustic wave speeds precisely.

The team then developed a multimodal regression model to accurately estimate material porosity. Furthermore, using the combination measurements allowed engineers to compute the elastic properties of the material accurately.

RESULTS

Through the MAKERS program, SwRI determined how AM production of parts affects both UT and ECT NDE techniques necessary to qualify components for fatigue critical applications. The intellectual property developed for the ultrasonic measurement technique positions the Institute to support the AM industry both by manufacturing NDE systems for production use and by providing qualification services for AM service providers.



DETAIL

A coupon is a small sample of the material under test that has been prepared in such a way that its failure mechanism will be representative of the larger production pieces.

These AM coupons were machine-smoothed on one side and notched on both sides to compare ECT data. As expected, AM surface roughness greatly reduced ECT performance by essentially creating a gap between the probe and the solid surface of the part.

D024240

6 AM MODELING

Dr. James Sobotka, Matthew Kirby, Dr. Shengyen Li, David Wieland and Isaac Grothe

INDUSTRY PROBLEM

Predicting the strength and durability of components produced with AM processes is a complex problem. The layer-by-layer deposition of material during AM produces residual stresses severe enough to distort components. Furthermore, the AM process introduces nonhomogeneous microstructures that alter material properties typical of corresponding wrought condition. Potentially, these and other qualities may be tailored in the AM process based on performance requirements.

SwRI APPROACH

To understand how to meet performance goals, SwRI needed to predict them

accurately, which requires a credible AM process model.

Through MAKERS, SwRI developed a viable, computationally tractable, AM process framework to compute thermal profiles, residual stress, distortion, microstructure and material properties. Targeted to Ti-6Al-4V material and SwRI's powder-bed fusion machine, the model can be extended to other AM alloys and similar powder-bed fusion systems. Predictions from this framework have been validated against SwRI-built sample "coupons" (made to NIST specs) and have been demonstrated using a real-world application, a redesigned T-38 dorsal cover.

The AM process framework represents a foundational building block needed to support process-structure-property-performance work and provides a platform for future integrated computational materials engineering studies. Predicting residual stress could reduce the

cost of AM builds and the number of failed builds due to part distortion and cracking. Predicting grain size will help to demonstrate "equivalent or better" yield stress properties.

RESULTS

Potential applications for the model include supporting sustainment efforts on the large fleet of aging aircraft owned by the U.S. Air Force. Replacement parts for damaged structural components can be hard to find because an original manufacturer is out of business or fabrication processes are no longer available. This sustainment problem may be mitigated by using AM processes to quickly produce one-off components. However, these components must meet high quality standards for flight applications, efforts that can be accelerated and optimized by tractable computational models of the AM process.



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NOMINAL DISTORTION PREDICTIONS

POST-SECTIONED DISTORTION



Engineers built a coupon specimen using SwRI's AM machine, sliced its "legs" off the build plate and then measured specimen distortion. Distortion measurements show good agreement with predictions made with the AM process modeling framework.

Dr. James Sobotka, a specialist in computational materials, developed a computational model to predict the material properties, strength and durability of components produced with AM processes. The model has been validated against open-literature coupons and demonstrated using a real-world application.

D024145_9857

7 SPRINGING BACK INTO SHAPE

Cole Buss, Nathan Weyandt and Dr. Carl Popelar

INDUSTRY PROBLEM

Nickel titanium, or nitinol, has unique shape memory and elasticity properties attractive for applications ranging from biomedical to aerospace components. The material deforms at one temperature, then recovers its original shape upon heating above a “transformation temperature.” The material exhibits enormous elasticity, some 10 to 30 times that of ordinary metal. However, it is expensive, difficult to manufacture and challenging to machine and form into complex shapes.

SwRI APPROACH

SwRI engineers were curious about using additive manufacturing to print shape memory alloy (SMA) components from nitinol. Initial research focused on developing parameters using SLM to create components from NiTi powder to overcome challenges associated with standard nitinol materials.

Small-scale test builds helped establish build parameters for shape memory springs using NiTi powder, with initial failures paving the way for more promising results. Engineers tested the tensile specimens to investigate the mechanical and shape memory properties of the printed NiTi materials and compared them to NiTi specimens fabricated from stock material. The AM specimen performed somewhat favorably, although the process requires more development and evaluation.

RESULTS

While using AM from NiTi proved challenging, the project illustrated the complexity possible with the AM process while reducing waste material and tooling costs of traditional fabrication. Using stock material to fabricate something of similar size and complexity would be prohibitively expensive. This research is helping establish SwRI as a leader in nitinol technology, a growing enterprise that remains underdeveloped due to manufacturing and cost limitations.



The dual-spring assemblies experienced cracking and delamination in the AM build process. However, these results, even with flaws, may be adequate for some applications. Shape memory testing of the partial bent plate was successful.

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DETAIL

Nitinol is a nickel-titanium shape memory alloy with a name derived from its composition — Ni and Ti — and its place of discovery, the Naval Ordnance Laboratory (NOL).

Cole Buss, a senior research engineer in the Applied Power Division, was part of a team investigating using AM to produce innovative nitinol shape memory actuators.

D024193_9667

Questions about the MAKERS program? Contact Popelar at carl.popelar@swri.org or 210.522.4213.



SOLAR WIND STUDIES

Particles near Sun point to distant solar wind structures

Using data from NASA's Parker Solar Probe (PSP), an SwRI-led team identified low-energy particles lurking near the Sun that likely originated from solar wind interactions well beyond Earth orbit. The discovery explains the origin of mysterious particles accelerated by interactions between slow- and fast-moving regions of the solar wind.

PSP is venturing closer to the Sun than any previous probe, carrying hardware SwRI helped develop. Scientists are probing the enigmatic features of the Sun to answer many questions, including how to protect space travelers and technology from the radiation associated with solar events.

"Our main goal is to determine the acceleration mechanisms that create and transport dangerous high-energy particles from the solar atmosphere into the solar system, including the near-Earth environment," said Dr. Mihir Desai, a mission co-investigator on the Integrated Science Investigation of the Sun (ISOS) instrument suite. ISOS consists of two instruments, Energetic Particle Instrument-High (EPI-Hi) and Energetic Particle Instrument-Low (EPI-Lo). "With EPI-Lo, we were able to measure extremely low-energy particles unexpectedly close to the solar environment."

Roughly every 11 years, when solar activity reaches a lull, the Sun's equatorial regions emit slower solar wind streams, traveling around 1 million miles per hour, while the poles spew faster streams, traveling twice as fast. When the fast-moving streams overtake slower streams, turbulent corotating interaction regions are formed, producing shock waves and accelerated particles.

"The presence of low-energy particles near the Sun are the smoking gun pointing to interactions between slow- and fast-moving regions of the solar wind that accelerate high-energy particles from beyond the orbit of Earth," Desai said. "Some of those travel back toward the Sun, slowing against the tide of the outpouring solar wind but still retaining surprisingly high energies."

For more information, go to: <https://www.swri.org/heliophysics>.

Supersonic stream slows with distance

NASA's New Horizons spacecraft is providing important new insights about some of the farthest reaches of space ever explored. In a paper recently published in *The Astrophysical Journal*, an SwRI-led team detailed how the solar wind — the supersonic stream of charged particles blown out by the Sun — slows at increasing distances from the Sun.

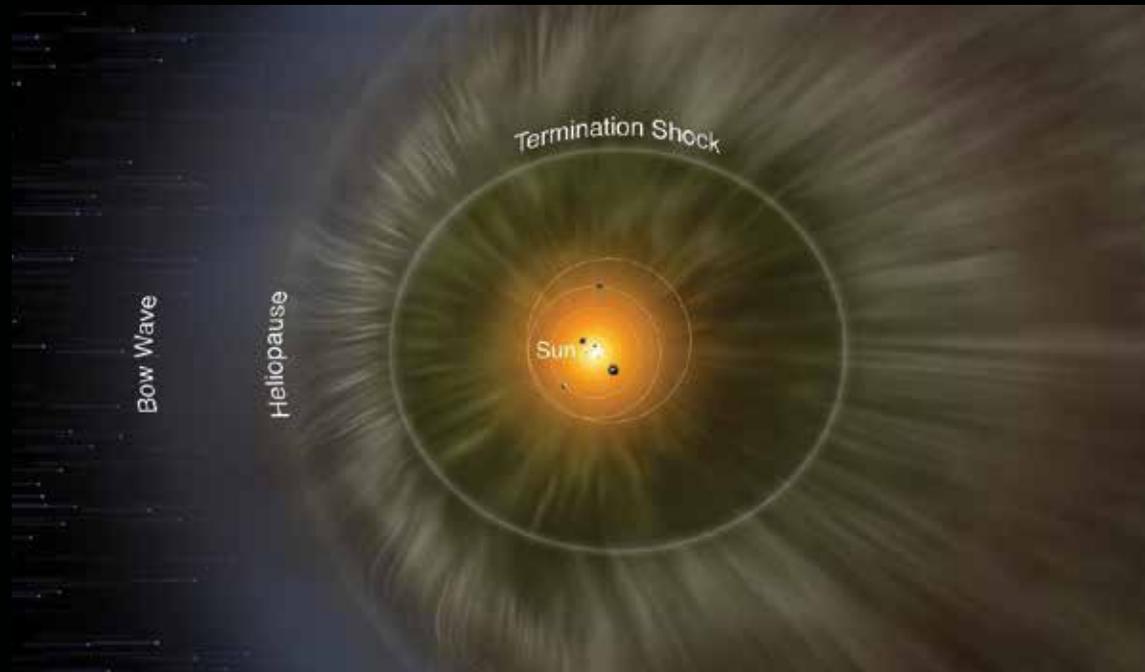
"Previously, only the Pioneer and Voyager missions had explored the outer solar system," said SwRI's Dr. Heather Elliott, deputy principal investigator of the Solar Wind Around Pluto (SWAP) instrument and lead author of the paper. "Now, New Horizons is looking at the outer reaches with more modern technology, such as the SWAP instrument. Our Sun's influence on the space environment extends well beyond the outer planets, and SWAP is revealing how that environment changes with distance."

The solar wind fills a bubble-like region of space encompassing our solar system, known as the heliosphere. From aboard New Horizons, SWAP collects detailed, daily measurements of the solar wind as well as other key components called "interstellar pickup ions" in the outer heliosphere. Interstellar pickup ions are created when neutral material from interstellar space enters the solar system and becomes ionized by sunlight or by solar wind ion interactions.

The SWAP team measured solar wind speeds at 21 to 42 astronomical units (one AU equals the distance between the Sun and the Earth). These measurements were compared to those made by spacecraft at 1 AU. By 21 AU, SWAP detected an apparent slowing of the solar wind in response to interstellar material pickup. When New Horizons traveled beyond Pluto, between 33 and 42 AU, the solar wind measured 6-7% slower than at the 1 AU distance, confirming the effect.

For more information, go to: <http://pluto.jhuapl.edu/>.

New SWAP research shows the solar wind begins to slow as it approaches Jupiter orbit and continues to slow as it moves through the solar system and picks up interstellar material. The solar wind becomes slower than the speed of sound at the termination shock and continues to slow until it reaches the heliopause, where the interstellar medium and solar wind pressures balance. This is the boundary of the heliosphere, or the sphere of the Sun's influence.



SwRI WINS TWO R&D 100 AWARDS

Two SwRI-developed technologies were selected as winners of prestigious R&D 100 Awards. R&D World magazine recognized SwRI's Lotus Superhydrophobic Compositions and Coating Process (LotusFlo™) and AF-369 VHF/UHF Terrestrial Direction-Finding Antenna as being among the 100 most significant innovations for 2019.



SwRI applies the LotusFlo superhydrophobic coating, which prevents materials from occluding the flow of oil, to a series of offshore drilling pipes.

D024251

LOTUS SUPERHYDROPHOBIC COMPOSITIONS AND COATING PROCESS (LOTUSFLO™)

Substances found in crude oil can clog offshore drilling pipes and require costly chemicals to clear the blockage, which can then pollute the surrounding ocean.

"Offshore oil drilling faces a number of challenges in extracting petroleum from beneath the ocean floor," said Institute Scientist Dr. Michael Miller, one of LotusFlo's principal developers. "Pipes are frequently clogged by sticky, tar-like molecular substances derived from petroleum and inorganic scales, mineral deposits that form when water mixes with different types of salty liquids."

LotusFlo coating technology is superhydrophobic, designed specifically to repel substances that often clog drilling pipes. The coating is applied to pipes under vacuum conditions through a unique process that involves linking several 40-foot sections of pipe together in very

low atmospheric pressures. The coupled pipes essentially act as a vacuum chamber, with an end unit on either side of the pipe providing the vacuum source. An electrode is strung through the pipe from one end to the other and suspended in the middle of the pipe.

Volatile molecules introduced into the evacuated pipe are electrically stimulated to produce highly ionized gas molecules, or plasma, along the length of the pipe structure. This causes chemical precursor molecules to form other ions in the plasma, which are then accelerated very rapidly onto the interior surface of the pipe. When the ions collide on the interior surface, they undergo a polymerization reaction that creates a partially inorganic coating. This glass-like coating is what keeps materials from adhering to pipe surfaces.

“SwRI seeks solutions for the world’s most complex problems,” said President and CEO Adam L. Hamilton, P.E. “We are committed to continuously improving the world around us through innovation, and it’s an honor to see the Institute recognized for those efforts at what is widely known as the ‘Oscars of Innovation.’ Since 1963, SwRI has won 45 R&D 100 Awards.”



AF-369 VHF/UHF TERRESTRIAL DIRECTION-FINDING ANTENNA

Mitigating ongoing threats to national security requires timely intelligence data, including signals intelligence obtained through electronic surveillance. The military uses modern signals intelligence systems to collect this information by monitoring electronic communications transmitted over the air.

“To cover so much bandwidth, most DF antenna products need three separate arrays. The patent-pending sleeved electric dipoles we developed cover 80% more bandwidth than conventional dipoles,” said Brandon Nance, a manager in the Defense & Intelligence Solutions Division and the principal developer of the AF-369 antenna. “This improves direction-finding sensitivity tenfold over a significant part of their frequency coverage. That is, we can get the same performance with 10-times weaker signals. And because we are doing more with fewer antennas, the complexity and the overall costs of the antenna system are reduced.”

Direction finding is performed using antenna arrays made up of

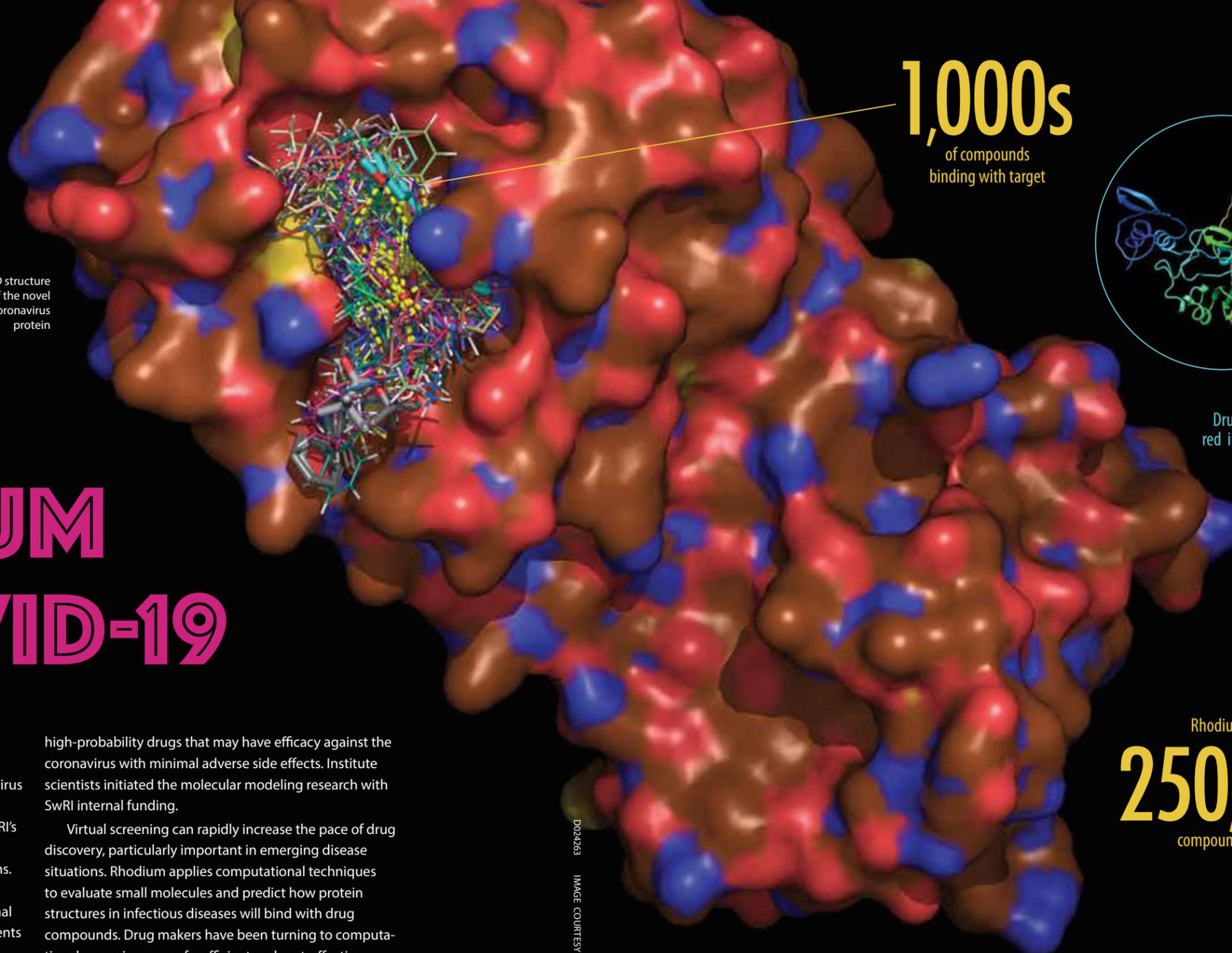
multiple antenna array elements to sample the incoming wave field. Frequencies typically used for line-of-sight communications are spread across the 20 MHz to 3 GHz RF spectrum, a tremendous amount of bandwidth to monitor.

To monitor this broad spectrum requires multiple arrays, each with elements designed to cover a smaller sub-band of frequencies. Each sub-band typically uses between five and nine antenna elements, with the total number required to cover the full frequency range increasing with the addition of each sub-band. The cost of each DF antenna array, as well as the complexity of the RF receiving system connected to it, drives up costs for both the antenna itself and the system as a whole. SwRI’s innovative sleeved electric dipoles for the AF-369 antenna reduce the number of arrays necessary to monitor a similar amount of bandwidth, thereby lowering the cost of the entire system and simultaneously improving its performance.



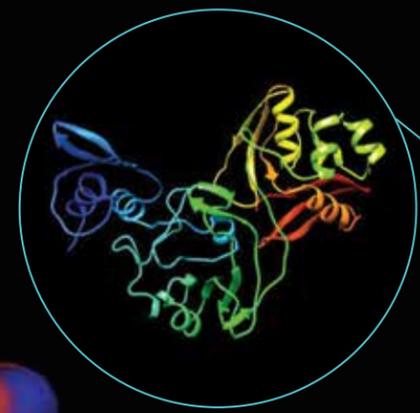
SwRI’s award-winning AF-369 VHF/UHF Terrestrial Direction-Finding Antenna provides accurate direction finding of radio frequency transmissions from 20 MHz to 3 GHz.

DM24005_2945



3D structure of the novel coronavirus protein

1,000s
of compounds
binding with target

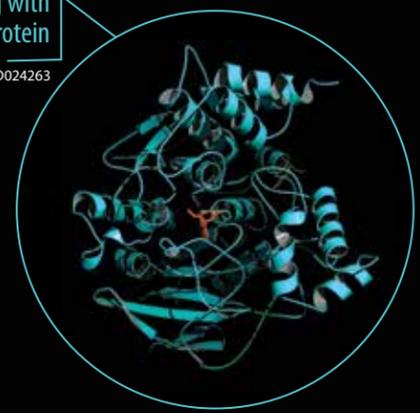


Crystal structure of the novel coronavirus

D024262

Drug compound in red interacting with a virus protein

D024263



RHODIUM VS COVID-19

Southwest Research Institute scientists use drug discovery software to virtually screen millions of drug compounds for possible treatment of the novel coronavirus and other infectious diseases. Rhodium™ is a novel structure-based virtual screening tool developed by SwRI's chemical engineers and computer scientists. Rhodium speeds up the preliminary efficacy and safety evaluations. SwRI works with commercial and government organizations to select and develop the best candidates for animal testing and eventually clinical trials. Developing treatments and vaccines takes a minimum of 12 to 18 months.

Prior to the recent coronavirus outbreak, SwRI had increased the capacity of its Rhodium software to scan 250,000 drug compounds per day, up from its prior limit of 25,000. Researchers enhanced the capability with new graphical processing, software updates and machine learning techniques. A 3D model of the coronavirus was used to evaluate potential drugs from a vast library of compounds.

Using the 3D structure of the viral protein, Rhodium screens drug compounds in a few days, hoping to identify

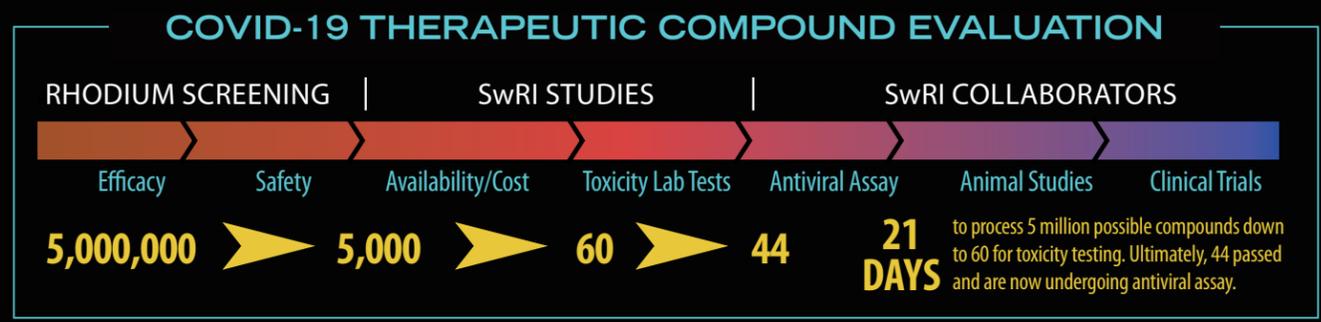
high-probability drugs that may have efficacy against the coronavirus with minimal adverse side effects. Institute scientists initiated the molecular modeling research with SwRI internal funding.

Virtual screening can rapidly increase the pace of drug discovery, particularly important in emerging disease situations. Rhodium applies computational techniques to evaluate small molecules and predict how protein structures in infectious diseases will bind with drug compounds. Drug makers have been turning to computational screening as a safe, efficient and cost-effective alternative to evaluating physical samples in a laboratory in the early stages of drug development.

Rhodium uses drug compound libraries to predict how protein structures in infectious diseases will bind with compounds or a series of compounds known as ligands. Rhodium's high throughput 3D analysis of protein docking efficiently selects ligands to predict how a compound interacts with a virus' protein structure. Its machine learning tools interpret data analysis for faster results.

D024263 IMAGE COURTESY SWRI/PROTEIN DATABASE (RCSB.ORG), ENTRY 6LU7

Rhodium scans
250,000
compounds per day



SYSTEMS SOLUTION for DIESEL EMISSIONS

By Bryan Zavala and Chris Sharp

DETAIL

Aftertreatment systems are a series of components that clean diesel exhaust before it's emitted by the tailpipe. They reduce the amount of harmful pollutants released into the environment.

In the United States, trucks transport about 11 billion tons of goods worth more than \$32 billion every day. Diesel powers 98% of the large over-the-road Class 8 trucks hauling these goods. Over the last 30 years, the industry has reduced emissions from heavy-duty diesel trucks, buses and other vehicles by 95% for nitrogen oxides (NOx) and 90 percent for particulate emissions. Today, it takes 60 new trucks to generate the same emissions as a single truck manufactured in 1988.

In 1985, the Environmental Protection Agency (EPA) established the first emissions standard for heavy-duty diesel trucks and buses to address the growing impact of air pollution on human health and the environment. Even before the EPA was established in 1970, Southwest Research Institute was measuring exhaust emissions, eventually conducting the research and development needed to create techniques and technologies to reduce tailpipe emissions and improve fuel efficiency. Despite significant advancements in technology since, several regions in the U.S. still struggle to meet ambient air quality standards set by the federal government. These challenges highlight the continued need for innovative approaches.

THE CO₂, NOx PARADOX

To address air pollution challenges, SwRI worked with regulatory agencies, vehicle manufacturers and suppliers to evaluate the feasibility of a new ultra-low NOx standard. During the combustion cycle of a diesel engine, nitrogen binds with oxygen atoms to create nitric oxide (NO) and then combines with oxygen to create nitrogen dioxide (NO₂), an irritant gas that causes inflammation of the airways in the lungs at high concentrations. Together, nitrogen dioxide and nitric oxide are referred to as oxides of nitrogen or NOx. These pollutants are precursors to the formation of smog, acid rain, fine particles and ground-level ozone, all associated with adverse health effects. These new standards would also aim to lower carbon dioxide emissions. The need to simultaneously reduce NOx and CO₂ emissions compounds the challenge and limits potential solutions. SwRI engineers proposed a systematic, holistic approach combining engine, aftertreatment and controls expertise to develop and integrate a pragmatic solution.

A systems approach to create an efficient engine with ultra-low NOx emissions required multidisciplinary expertise. The SwRI team included (left to right) Institute Engineer and co-author Chris Sharp, Principal Engineer Gary Neely, Research Engineer Sandesh Rao, Research Engineer and co-author Bryan Zavala and Group Leader Sankar Rengarajan. Not pictured is Senior Research Engineer Shekhar Vats.

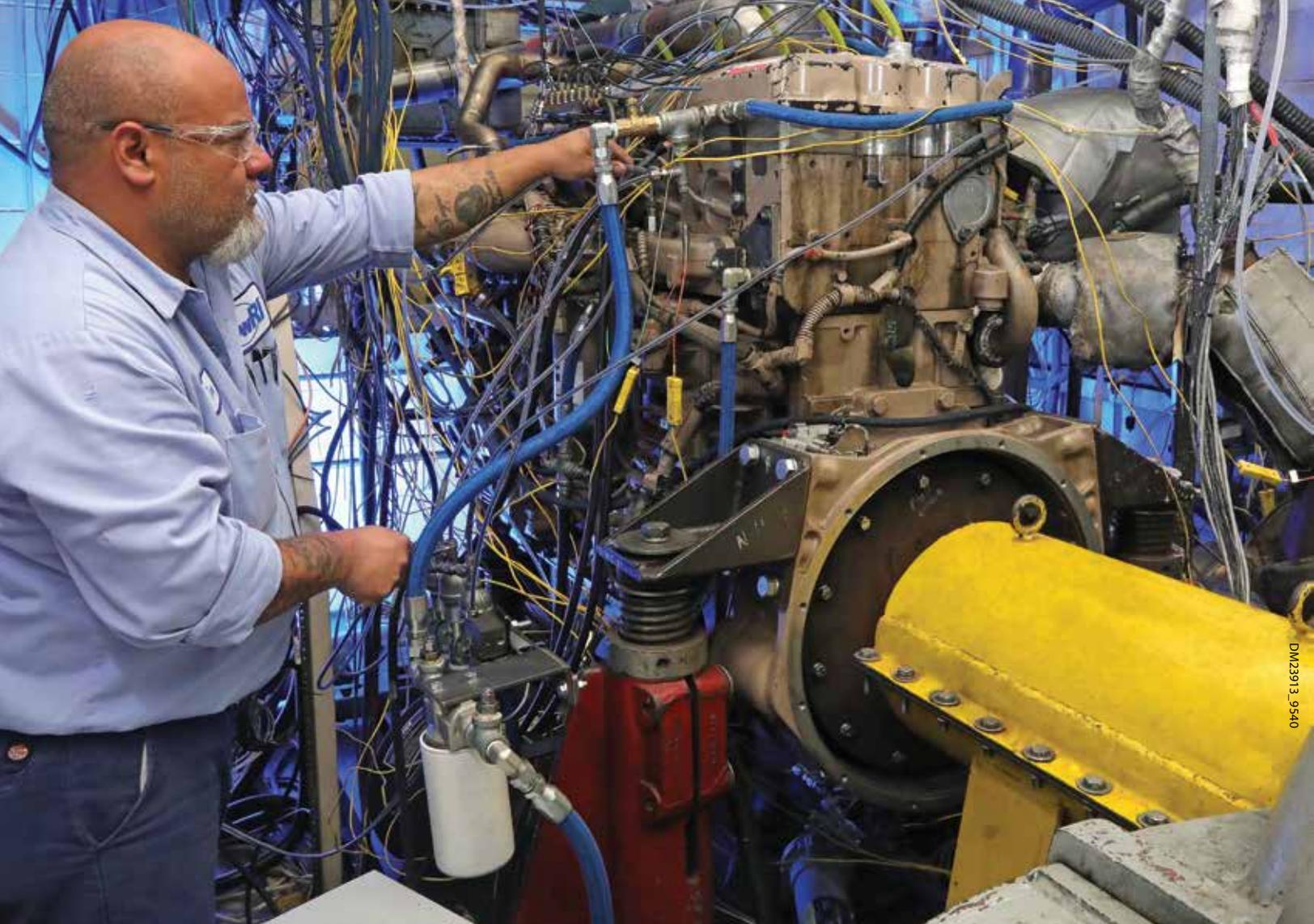
ABOUT THE AUTHORS

Zavala has been one of the primary aftertreatment calibration leads for the CARB Low NOx demonstration program and for similar client-driven efforts. Sharp specializes in emission research and development programs for heavy-duty and nonroad engine applications with a focus on integrating and evaluating aftertreatment systems for large diesel engines.



D024008_2371





Using a systems approach, SwRI has developed a fuel-efficient heavy-duty engine that achieves 90% NOx emission reduction over real-world driving conditions, where catalyst temperatures are typically below the optimum level.

In 2013, the California Air Resources Board (CARB) contracted SwRI to investigate potential approaches for achieving an ultra-low NOx target. This high-visibility effort provided the heavy-duty industry a preview of the next generation of technologies. Specifically, the initiative focused on evaluating multiple after-treatment technology pathways, low NOx engine calibration work, and model-based aftertreatment controller development. The final demonstration solution emphasized a practical approach, addressing impacts on fuel economy and tailpipe emissions. In the end, the solutions proved that new ultra-low NOx targets are feasible but revealed a need for continued exploratory efforts.

The program's success set the stage for continuing efforts to improve and understand emissions technologies. The culmination of these activities led to the CARB low NOx Stage 3 program, which utilizes a new engine architecture to meet the EPA's broader Phase 2 greenhouse gas targets while simplifying low NOx aftertreatment solutions. Through the continued efforts of a multidisciplinary team, SwRI has developed one of the most fuel-efficient, low-emission diesel engines in the world.

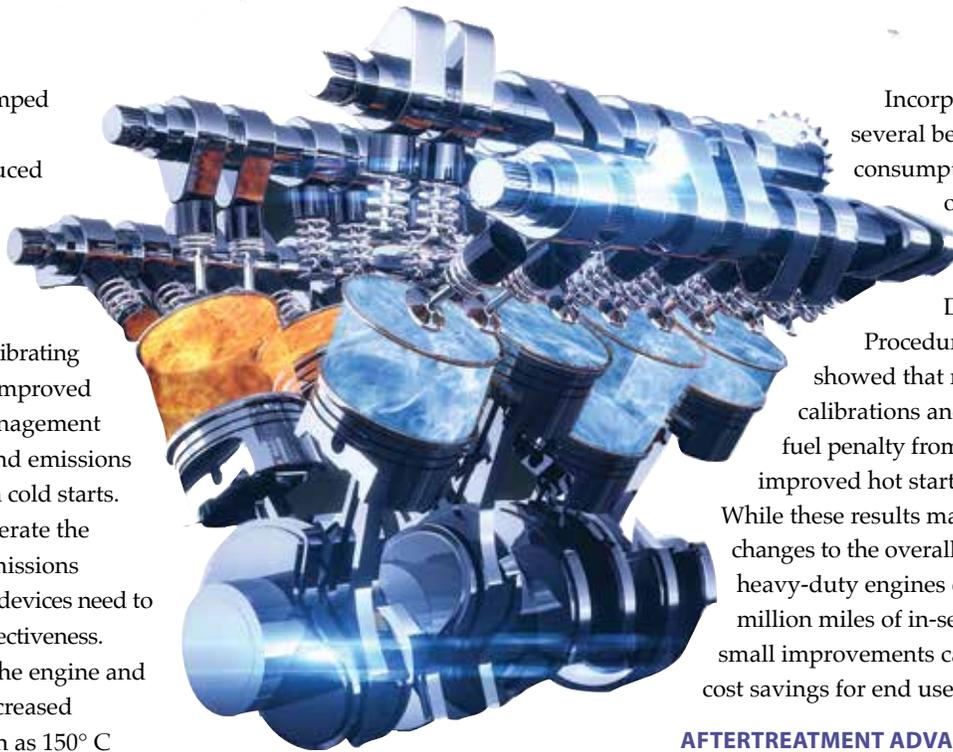
ENGINE EQUIPMENT

Many people think the most fuel-efficient engines are also the least polluting. While that may be true for CO₂ emissions, reducing emissions such as hydrocarbons, carbon monoxide, particulate matter and NOx involves using abatement devices that typically incur a fuel penalty. This fuel economy and emissions reduction tradeoff required engineers to consider several solutions to find a balanced approach. Proper engine architecture is critical to employing low-emission technologies while avoiding a substantial fuel penalty.

For the program, SwRI selected a production 2017 Cummins X15 engine certified to U.S. 2010 on-road heavy-duty emissions regulations. Engineers modified the engine to include an exhaust gas recirculation (EGR) cooler bypass and a cylinder deactivation (CDA) system. EGR recirculates a portion of engine exhaust back into the cylinders to significantly reduce NOx, particularly from diesel engines. CDA reduces engine fuel consumption and emissions during light-load operations by shutting down some of the cylinders. Between reducing the pumping losses, which increases pressure in each operating cylinder, and decreasing the

amount of fuel being pumped into the cylinders, fuel consumption can be reduced by 8% to 25% for highway conditions, particularly for large displacement engines.

By integrating and calibrating these systems, the team improved the engine's thermal management and mitigated the fuel and emissions penalties associated with cold starts. Typically, cold starts generate the highest levels of NOx emissions because exhaust catalyst devices need to heat up for maximum effectiveness. However, recalibrating the engine and using CDA hardware increased temperatures by as much as 150° C to improve catalyst performance. The engine-out NOx mass rate is also reduced during the warm-up phase, decreasing the overall burden on the aftertreatment system.

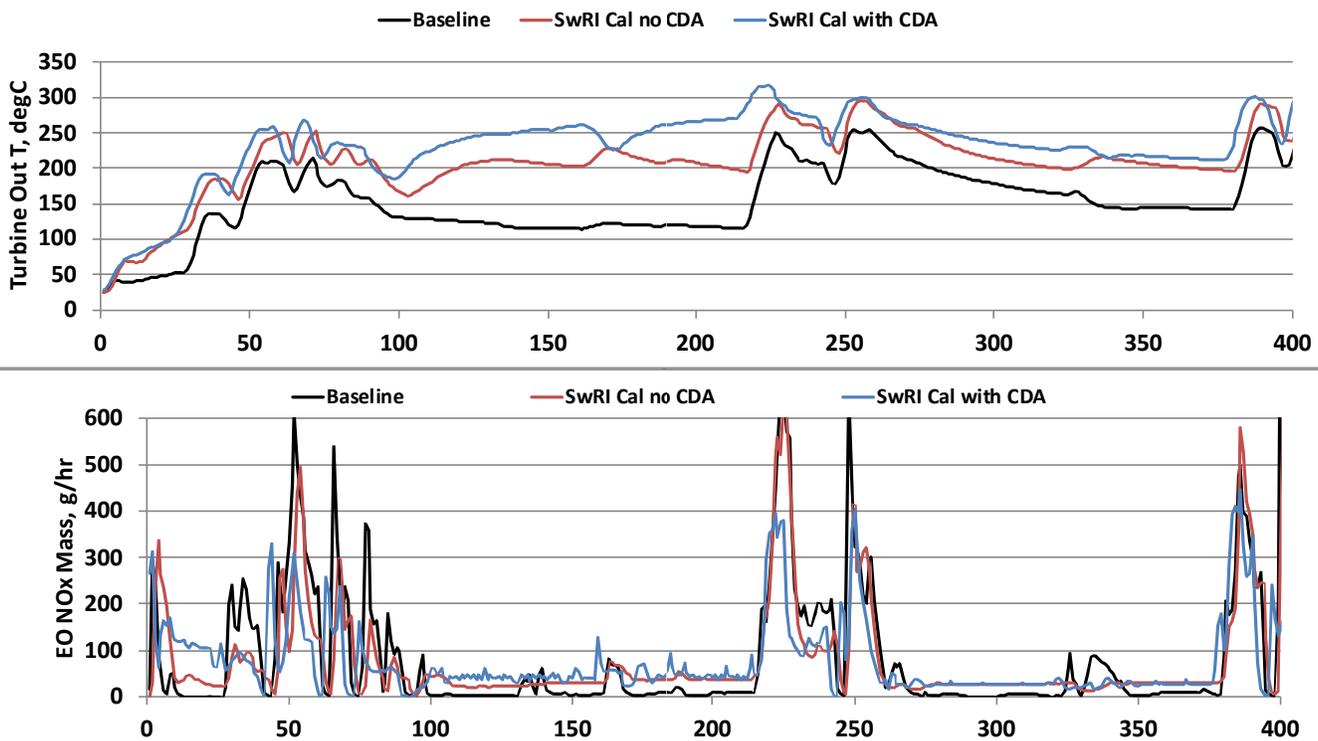


CDA reduces fuel consumption and emissions during light-load operations by shutting down some of the cylinders. In heavy-duty diesel engines, this can reduce fuel consumption by 8–25% for highway conditions.

Incorporating CDA provides several benefits, decreasing fuel consumption while simultaneously reducing NOx and CO₂. Using the cold start Heavy Duty Federal Test Procedure (HD-FTP), engineers showed that modified engine calibrations and CDA decreased the fuel penalty from 4% to 1.3%. CDA also improved hot start fuel economy by 2%. While these results may seem like small changes to the overall fuel economy, current heavy-duty engines can accumulate a million miles of in-service use, so even small improvements can lead to substantial cost savings for end users and their clients.

AFTERTREATMENT ADVANCES

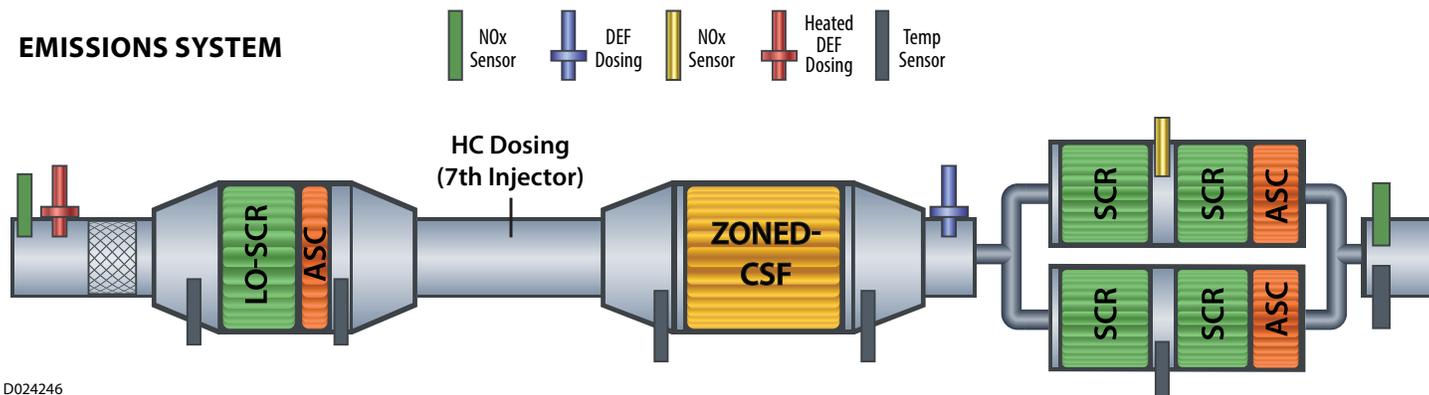
Diesel engine aftertreatment systems remove harmful particulate matter and chemicals from exhaust emissions. A combination of diesel oxidation catalyst (DOC), diesel particulate filter (DPF) and selective catalytic reduction (SCR)



D024243

These graphs illustrate cold-start exhaust temperature data for the SwRI engine. The turbine outlet temperature and NOx mass rate are compared for baseline, calibration and CDA configurations.

EMISSIONS SYSTEM



D024246

To reduce NOx in low temperature scenarios, SwRI placed an extra SCR next to the engine, in front of the diesel particulate reduction system. The backend of the aftertreatment systems includes zoned CSF that combines DOC and DPF systems integrated with additional SCR technology.



For the ultra-low NOx demonstration test cell, engineers placed a relatively simple, low-cost LO-SCR device (upper left) next to the engine. As the first aftertreatment device in the exhaust stream, LO-SCR takes advantage of engine heat to improve its performance and minimize NOx emissions during low-temperature operations.

D024008_2450

systems convert the toxic cocktail of gases and soot in untreated diesel exhaust to harmless substances including oxygen and water. The combination of physical mechanisms and chemical reactions can, under the right conditions, achieve nearly complete removal of particulates and harmful gases. Typically, 70% of all harmful emissions are released immediately after start-up when catalysts are cold and less effective. Finding ways to increase catalyst temperatures more quickly is a key to decreasing NOx emissions.

For this application, engineers used light-off SCR (LO-SCR) technology — a relatively simple, low-cost solution — as the first aftertreatment device in the exhaust stream. Placing the catalyst near the engine takes advantage of elevated exhaust temperatures to better reduce NOx during cold-start and low-temperature scenarios. Then, SwRI used a zoned-catalyzed soot filter (CSF) that incorporates DOC and DPF technology into one component as the next aftertreatment system in the exhaust stream. This configuration decreases emission particulates with less heat loss to the exhaust delivered to the final aftertreatment device, an SCR system. These advanced active emission control systems inject diesel exhaust fluid, which reacts with a special catalyst to create the ammonia (NH₃) needed to effectively remove NOx from the exhaust stream of a diesel engine.

Utilizing LO-SCR and a heated diesel exhaust fluid dosing option improves performance at low temperatures. Combining dual-path SCR and ammonia slip catalyst (ASC) configurations also provides backpressure savings, reducing the amount of work required to pump exhaust. This ultimately translates into a fuel economy benefit during higher engine load conditions.

DETAIL

In addition to cold start scenarios, delivery trucks often operate in low-temperature modes as vehicle systems cool during the multiple stops along a route. This SwRI strategy could minimize NOx emissions in these common scenarios.



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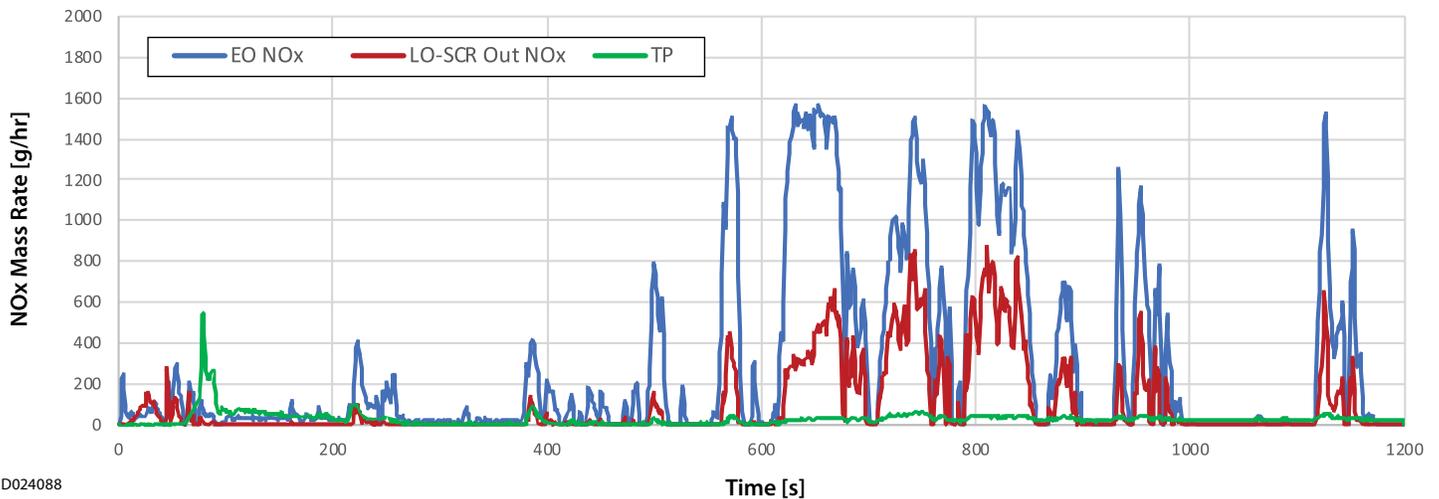
The SwRI configuration reduced NO_x by up to 99% in the first 400 seconds after ignition, while today's systems can only achieve 30% for the same period. The 1.3% fuel penalty is a small price to pay for the substantial improvement in NO_x reduction. SwRI achieved this performance with a system-level approach to improve fuel economy and NO_x emissions without compromising either one.

CONTROL STRATEGIES

One of the key challenges to decreasing NO_x emissions is maintaining reduction efficiencies in excess of 99.5% across the full range of engine operating loads and temperatures. Commercial SCR technologies can achieve high performance within a narrow band of conditions, but struggle to do so outside that range. To address this problem, SwRI engineers conducted internal research to develop and deploy a model-based controller for SCR systems. This high-fidelity controller models the catalyst state, predicting the amount of NH₃ absorbed by the catalyst surface as it is constantly consumed and reintroduced into the catalyst via an injection system. During a duty cycle, dynamic SCR temperatures change the maximum NH₃ storage. Ensuring that enough NH₃ is adsorbed without NO_x breakthrough or NH₃ saturation requires prediction accuracy and high-speed feedback.

Engineers calibrated the controller using established testing protocols and SwRI's universal

SwRI used integrated emissions aftertreatment technology in its ultra-low NO_x test cell. This package incorporates zoned-CSF technology to decrease particulates with SCR technology to reduce NO_x.



D024088

This graph compares the NO_x in untreated engine-out emissions (blue) with the LO-SCR emissions (red) and tailpipe emissions (green) during cold-start testing. The NO_x mass rate measurements in the first 1,200 seconds after ignition show how the SwRI system effectively minimizes these emissions during this critical period of operation.



D022671_1077

SwRI's unique universal synthetic gas reactor can monitor the overall performance of vehicle emissions systems under a wide range of operating conditions.

DETAIL

SwRI offers a state-of-the-art universal synthetic gas reactor (USGR[®]) to characterize aftertreatment catalyst materials. Preconditioned core samples are run through specialized tests with specific gas mixtures, temperatures and durations. Characterizations include steady-state and perturbed performance, temperature ramps, stepped light-off tests, thermal and chemical aging, accelerated thermal aging and accelerated poisoning.

synthetic gas reactor. The controller also relies on a network of temperature, NO_x and NH₃ sensors that support different strategies for the various catalyst systems available.

To achieve proposed ultra-low NO_x emission levels at minimal fuel penalty, SwRI has validated a combination of diesel engine hardware and aftertreatment technologies that can meet or beat the target. SwRI is continuing to evaluate the system and its NO_x reduction performance under realistic operating conditions such as hydrothermal stress and catalyst contamination to validate real-world performance of tomorrow's ultra-low NO_x heavy-duty emissions technology.

Questions about this article? Contact Zavala at bryan.zavala@swri.org or 210.522.3840.



SwRI collects emissions data associated with changes in speed and torque during low-load cycles.

LOW LOADS = HIGHER EMISSIONS

SwRI engineers developed a new certification cycle, the Low-Load Cycle (LLC), to gauge the performance of heavy-duty diesel engine emissions systems in low-load conditions. The new test could help develop cleaner technology that could potentially improve emission control tenfold.

Emissions aftertreatment systems filter exhaust emissions and reduce pollutants escaping into the environment. The new cycle challenges aftertreatment systems by analyzing them in common, but unfavorable, low-load conditions, such as idling or speeds less than 25 miles per hour, when exhaust temperatures are low. Current regulatory certification cycles simulate urban and highway driving only.

"The Low-Load Cycle is uncovering weaknesses in current tests used to certify engine emissions technology," said SwRI Research Engineer Bryan Zavala, who was part of the development team. "When we operate heavy-duty engines at low-load conditions, the aftertreatment systems do not perform well. This tells us heavy-duty diesel engines are routinely emitting emissions above the regulated standard."

SwRI developed the Low-Load Cycle for the California Air Resources Board (CARB), a state organization charged with combatting air pollution, using real-world service logs to characterize the full range of operating conditions. California is projected to be the first state to implement the stricter engine test when new emissions standards are scheduled to take effect in 2024.

During LLC, a technician connects the engine to a dynamometer, adjusting the speed and torque to reflect a low load. Aftertreatment technology exposed to the stringent cycle consistently shows deficiencies.

"If the Low-Load Cycle is widely adopted as a standard test, we would expect manufacturers to develop technology that can pass these challenges, leading to less pollution and cleaner heavy-duty engines on the road," said SwRI Senior Research Engineer Shekhar Vats.

D023913_9596

SWRI DEVICE TESTED ONBOARD BLUE ORIGIN VEHICLE

SwRI recently tested a device designed to deliver liquid propellant to a rocket engine on a suborbital flight aboard Blue Origin's New Shepard vehicle. SwRI engineers and NASA's Glenn Research Center developed the tapered liquid acquisition device (LAD) to prevent potentially dangerous vapor bubbles from being transferred from the fuel tank to the engine. NASA has provided an additional \$500,000 in funding for two additional launch evaluations.

"On a long space mission, large amounts of fuel must be stored at low temperatures for transfer to the rocket engine as needed," said Kevin Supak, a senior research engineer at SwRI and the project's principal investigator. "Current LADs have straight channels that cannot manage internal vapor bubbles."

Through propellant boil-off, vapor bubbles can hinder liquid propellant from transferring to other tanks or damage rocket engines during ignition. Supak, along with SwRI engineers Dr. Amy McCleney and Steve Green, are evaluating the device, which has a tapered channel that passively removes bubbles through surface tension. The idea originated with a joint research effort between SwRI and NASA in the late 1990s and early 2000s to develop cryogenic fluid management capabilities.

"The device had never been tested in long-duration microgravity because it has historically been too expensive," Supak said. "Blue Origin is providing access to inexpensive, high-quality microgravity for research."

New Shepard launches from Blue Origin's test site near Van Horn, Texas. Future flight evaluations will focus on larger, more realistic versions of the bubble-free LAD.





D019245_9653

SwRI conducts emissions characterization and technology assessments, developing test procedures and equipment to evaluate regulated and unregulated emissions for virtually any propulsion system, from lawnmowers to locomotives.

\$25 MILLION FOR EPA VEHICLE FUEL, EMISSIONS STUDIES

SwRI has received a five-year, \$25 million contract from the U.S. Environmental Protection Agency (EPA) to provide testing and analytical services related to vehicle emissions and fuel efficiency.

Emissions characterization and technology assessment includes developing test procedures and equipment for regulated and unregulated emissions in light- and heavy-duty vehicles and components as well as for marine, railway, aircraft, small engine and other non-highway propulsion systems.

"We develop advanced technology to minimize emissions while increasing the efficiency and reliability of cars and heavy-duty vehicles," said Patrick Merritt, a program manager in SwRI's Powertrain Engineering Division. "Our work provides the agency the data needed to formulate industry standards. SwRI supports clean air not just in the United States but around the world as other countries adapt emission standards based on EPA standards."

Under the contract, SwRI will evaluate all types of fuels and additives, including conventional and reformulated gasoline and diesel fuels. Engineers will study alternative fuels such as methanol, ethanol, compressed natural gas, liquefied natural gas, liquefied petroleum gas, hydrogen and blends of hydrocarbon fuels. The team will also assess electrified powertrains for passenger cars, heavy-duty trucks and off-road vehicles.

Structured as a series of task orders, the contract follows previous emissions research for the EPA, which conducts environmental assessment, research and education efforts to maintain and enforce national standards under a variety of environmental statutes. In 2015, SwRI won a similar five-year, \$20 million contract.

"The scope of this contract is quite broad, touching nearly all aspects of powertrain and vehicle research here at the Institute," Merritt said. "In addition to extensive emissions research facilities in our San Antonio headquarters, we also provide support to the EPA's National Vehicle and Emissions Laboratory in Ann Arbor, Michigan, through our Ann Arbor Technical Center."

Our specialized facilities support a range of clean air initiatives, including ultra-low NOx, aftertreatment and control technologies (see Systems Solution for Diesel Emissions feature on p. 16). SwRI is an industry leader in characterizing fine particle emissions.

"SwRI's diverse expertise enables us to perform science, engineering and support functions in one location rather than having to rely on external laboratories," Merritt said. "Our long history and extensive expertise in engines, powertrains, fuels, lubricants and electrification provides the full range of emissions research, development and testing."

In addition, SwRI offers a local resource to the Detroit-area auto industry at our Ann Arbor Technical Center, which specializes in control systems. Using our Rapid Prototyping Electronic Control System (RPECS®), SwRI supports benchmarking, modeling, and development of combustion systems, engines, transmissions, batteries and electrified powertrains.

The EPA Office of Transportation and Air Quality (OTAQ) contract draws on SwRI's expertise in all facets of the automotive industry. The Institute has supported federal environmental endeavors since before the EPA came into existence in 1970.



RESTRAINING “RABBIT FEVER”

SwRI, The University of Texas at San Antonio (UTSA) and Lovelace Respiratory Research Institute received an \$18 million contract from the U.S. Department of Defense’s Defense Threat Reduction Agency to develop a vaccine against tularemia, a potential biothreat caused by the bacterium *Francisella tularensis*.

To support human clinical trials, SwRI’s pharmaceutical testing laboratories will formulate UTSA’s previously modified bacterium for an intradermal injection. The goal is to develop a vaccine formulation that protects humans from tularemia, also known as rabbit fever, for up to a year.

SwRI, the principal investigator organization, will help improve vaccine stability through chemical manufacturing controls and encapsulation with nanoparticles to extend immunity with a slow release formulation.

“There is an urgent need to develop a tularemia vaccine that is safe, effective and supported by sufficient data for Food and Drug Administration approval,” said Dr. Joe McDonough, SwRI’s director of Pharmaceuticals and Bioengineering.

The contract will expand on UTSA researcher Dr. Karl Klose’s development of a genetically modified strain of *Francisella novicida*, a relative of the bacterium that causes tularemia. Klose and

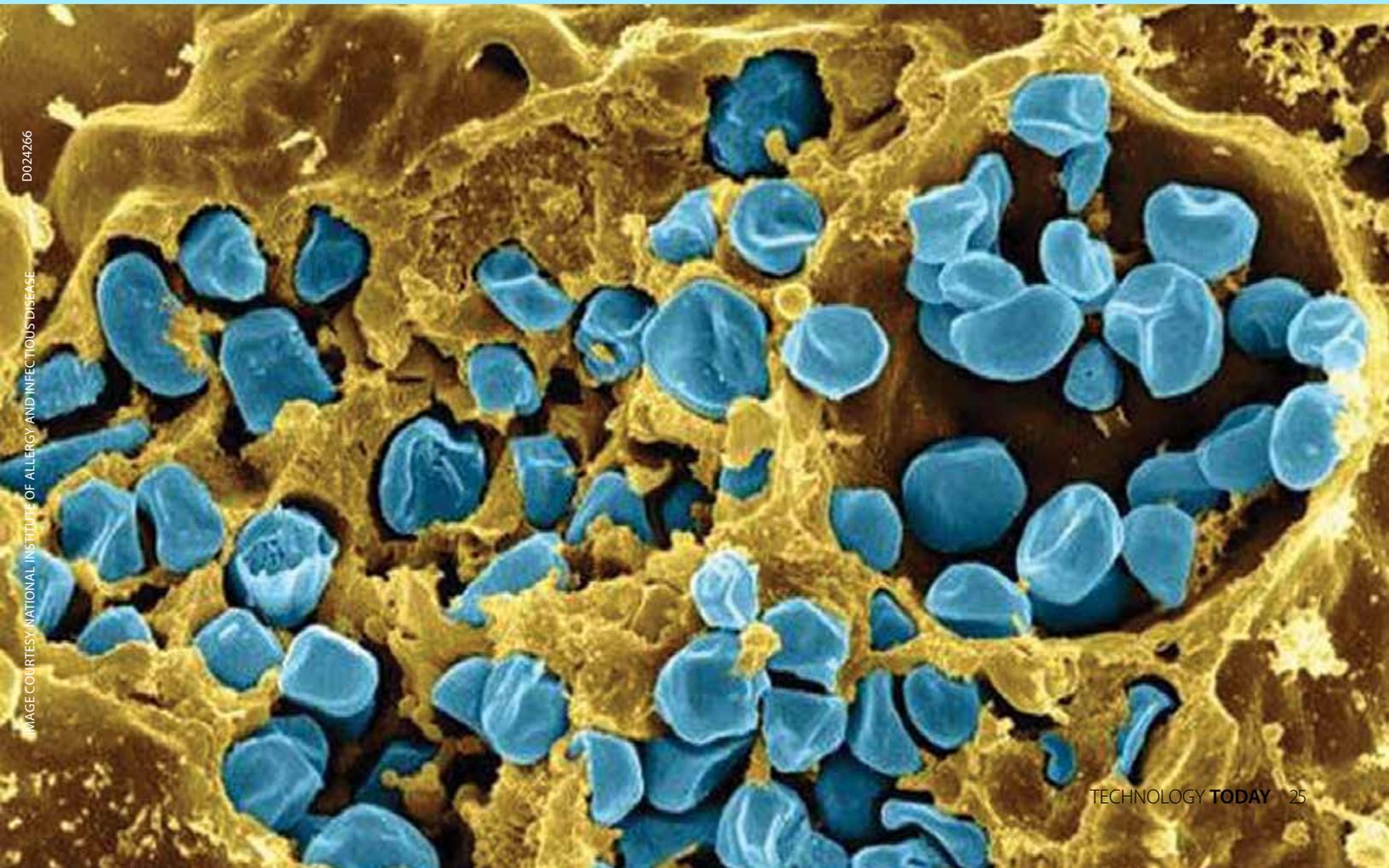
his colleagues previously demonstrated that, in vaccine form, it can protect against airborne exposure in animal models.

Typically a tick-borne disease found in animals such as rabbits, tularemia is rare in humans. However, when aerosolized, the bacterium is highly infectious and can cause a potentially fatal infection in the lungs. Classified by the Centers for Disease Control and Prevention as a Category A biothreat agent, it has been developed as an aerosolized bioweapon, posing a threat to national security.

The \$18 million contract is a significant accomplishment for the Vaccine Development Center of San Antonio. Founded in 2012 by UTSA, SwRI, Texas Biomedical Research Institute and UT Health San Antonio, the center leverages the strength, expertise and assets of San Antonio’s four leading research institutions to identify and develop promising vaccine candidates to promote public health.

“This program exemplifies the progress that happens when institutions are brought together through partnerships like the Vaccine Development Center of San Antonio,” added McDonough, the center’s scientific co-director. “By combining SwRI’s medical countermeasure development and formulation development experience with Dr. Klose’s and UTSA’s innovation, we will provide a much-needed solution to a critical problem.”

This scanning electron micrograph shows a mouse immune cell (yellow) infected with *Francisella tularensis* bacteria (blue).



D024266

IMAGE COURTESY NATIONAL INSTITUTE OF ALLERGY AND INFECTIOUS DISEASE



SwRI-LED LUCY MISSION HAS A NEW DESTINATION

Less than two years before launch, scientists associated with NASA's Lucy mission have discovered an additional small asteroid that will be visited by the spacecraft. The SwRI-led mission is an ambitious 12-year, 4-billion-mile odyssey to explore the Trojan asteroids, a population of ancient small bodies that share an orbit with Jupiter.

Set to launch in 2021, the first spacecraft to visit the Trojans was already set to break records by visiting seven asteroids during a single mission. Now, using data from the Hubble Space Telescope (HST), the Lucy team discovered that Eurybates, the first Trojan target, has a satellite, providing an additional object for Lucy to study.

"If I had to bet that one of our destinations had a satellite, it would have been this one," said SwRI's Hal Levison, principal investigator of the mission. "Eurybates is considered the largest remnant of a giant collision that occurred billions of years ago. Simulations show that

asteroid collisions like the one that made Eurybates and its family often produce small satellites."

Science team members spied a faint spot in a Hubble image of Eurybates. The spot was also in the next set of data, but had moved, just as a satellite would. Although the object was difficult to discern, in part because Eurybates is 6,000 times brighter than its satellite, HST confirmed its existence.

"We then used computer simulations to demonstrate many possible satellite orbits that match both the observations where we can see the satellite, as well as the times when we don't," said SwRI's Cathy Olkin, deputy principal investigator of the Lucy mission.

For more information go to: <http://lucy.swri.edu>

To see a video about the Lucy mission, visit: <https://youtu.be/4ZHCwSaBzd8>.



D023997_1354

SwRI acquired a VASE tool to develop efficient techniques for measuring deposits in fuel injectors at nanoscales. We plan to adapt VASE technology for other component tests.

EVALUATING INJECTOR DEPOSITS AT NANOSCALES

SwRI has adapted a procedure that significantly reduces the time and fuel needed to evaluate the formation of internal deposits on diesel engine fuel injectors. The custom-built injector rig generates deposits that are measured using a variable angle spectroscopic ellipsometer (VASE), a tool typically used by computer engineers to examine film layers in microchips.

SwRI began offering its new, highly accurate internal diesel injector deposit tests in November 2019. For several decades, engineers have used internal diesel injector deposit (IDID) tests to study deposits associated with fuels, additives and contaminants.

"Deposits can slow down or even plug an injector, which can stop the engine from working," said Doug Yost, staff engineer in SwRI's Fuels and Lubricants Division. "For many years, the most common IDID test methods involved some combination of full-size engines and test fuels, perhaps doped with excessive levels of additives or contaminants to create deposits that could be characterized with the naked eye. These test conditions did not represent typical engine operations."

The VASE instrument can detect deposits as thin as 10 nanometers, invisible to the naked eye. The enhanced analytical sensitivity of VASE allows for meaningful deposit data from an IDID rig test run for just seven hours, instead of the hundreds of hours required by the previous methodologies to generate visible deposits, which also saves fuel costs.

MARS' WILD HISTORY

Amid the chaos of the early solar system, Mars was likely struck by small protoplanets up to 1,200 miles in diameter as it formed. SwRI scientists modeled the mixing of materials associated with these impacts, revealing that the Red Planet may have formed over a longer timescale than previously thought.

"To fully understand Mars, we need to understand the role the earliest and most energetic collisions played in its evolution and composition," said SwRI's Dr. Simone Marchi, lead author of a Science Advances paper outlining these results.

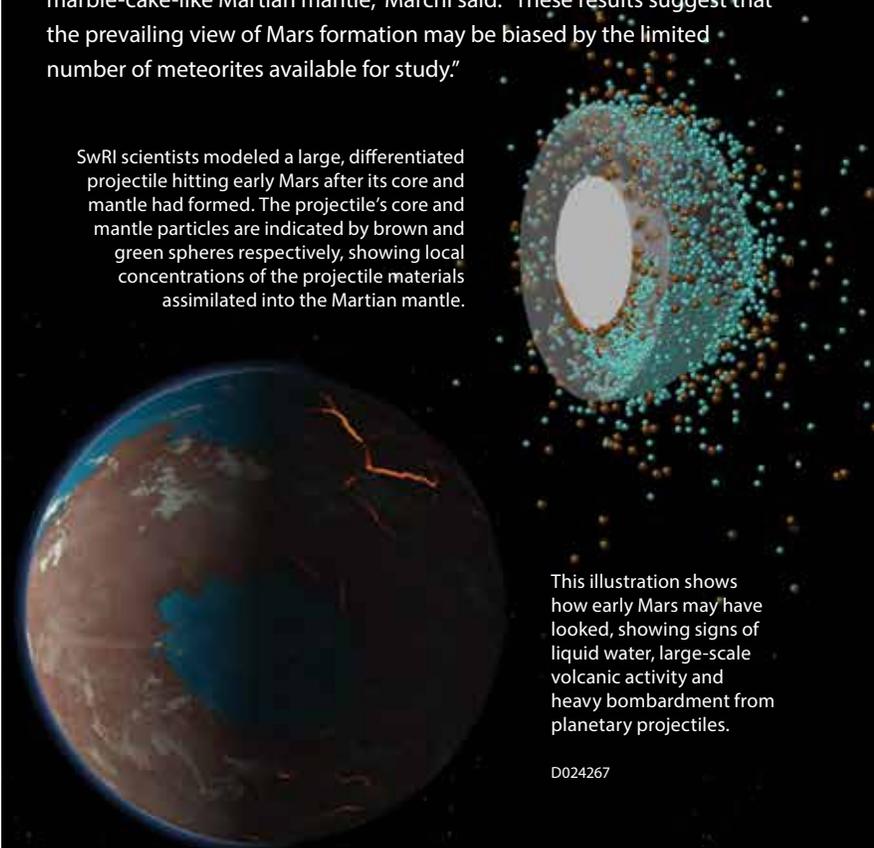
Billions of years of history have steadily erased evidence of early impact events. Luckily, some of this evolution is recorded in Martian meteorites. These meteorites exhibit large variations in iron-loving elements, which tend to migrate from a planet's mantle into its central iron core during formation. Evidence of these elements in the Martian mantle are important because they indicate that Mars was bombarded by planetesimals sometime after its primary core formation ended.

"Collisions by projectiles large enough to have their own cores and mantles could result in a heterogeneous mixture of those materials in the early Martian mantle," said co-author Dr. Robin Canup, assistant vice president of SwRI's Space Science and Engineering Division.

Based on the ratio of certain materials in Martian meteorites, it has been argued that Mars grew rapidly within about 2 to 4 million years after the Solar System began to form. However, large early collisions could have altered the ratio, which could support a Mars formation timescale of up to 20 million years, as shown by the new model.

"Based on our model, early collisions produce a heterogeneous, marble-cake-like Martian mantle," Marchi said. "These results suggest that the prevailing view of Mars formation may be biased by the limited number of meteorites available for study."

SwRI scientists modeled a large, differentiated projectile hitting early Mars after its core and mantle had formed. The projectile's core and mantle particles are indicated by brown and green spheres respectively, showing local concentrations of the projectile materials assimilated into the Martian mantle.



This illustration shows how early Mars may have looked, showing signs of liquid water, large-scale volcanic activity and heavy bombardment from planetary projectiles.

D024267



D024106-2998

FLOW LOOP SIMULATES PIPELINE ENVIRONMENT

SwRI now offers a reciprocating compressor flow loop capable of recreating real-life gas pipeline pressures, temperatures and horsepower levels. The flow loop is one of only a handful of its kind available for industry research, development and testing and will play a central role in an ongoing SwRI project to reduce methane emissions.

“Most people don’t realize the role compressors play in their everyday lives,” said Dr. Tim Allison, director of SwRI’s Machinery Department. “Natural gas travels through pipelines, meeting a series of compressors every few miles. These devices push gas farther down the pipeline network to its eventual destination, which could be a hot water heater or gas stove at your house.”

The SwRI facility recreates real-world conditions, providing realistic data to evaluate innovations designed to make reciprocating compressors more efficient, reliable and environmentally friendly. While other compressor flow loops exist, SwRI’s is the only one available to anyone in the industry.

Initial research includes efforts to reduce fugitive emissions escaping from natural gas pipelines. Available for client testing since February 2020, future research could include compressor valve testing, advanced pulsation control, drivetrain dynamics studies and lubrication optimization for reciprocating compressors.

VIRTUAL INSTRUMENT ENHANCES SCIENCE

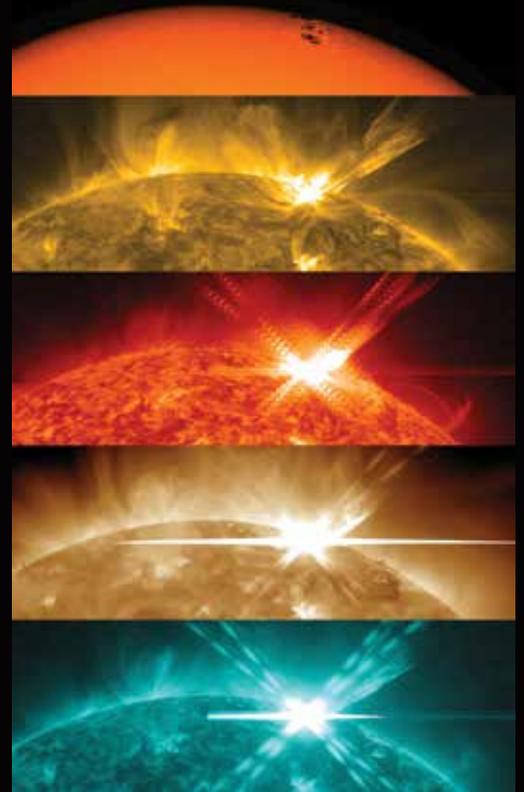
An SwRI scientist participated in a deep learning project that showed it is possible to virtually monitor the Sun’s extreme ultraviolet (EUV) irradiance, a key driver of space weather such as solar flares. These phenomena can affect spacecraft, satellites and even systems on Earth, including GPS navigation, radio communications and the power grid. This virtual “super instrument” can substantially increase the scientific productivity of NASA missions.

“Deep learning is an emerging capability that is revolutionizing the way we interact with data,” said Dr. Andrés Muñoz-Jaramillo, a senior research scientist at SwRI. He is working with collaborators from nine other institutions as part of NASA’s Frontier Development Laboratory, an artificial intelligence research accelerator that applies deep learning and machine learning techniques to challenges in space science and exploration.

The research showed that a deep neural network trained to mimic an instrument on the Solar Dynamics Observatory (SDO) could infer ultraviolet radiation levels based on what the other SDO instruments observed. Muñoz-Jaramillo stressed that these virtual super instruments will not make hardware obsolete. They will always require spacecraft instruments to collect the necessary data for virtualization.

“Deep learning instruments cannot make something out of nothing, but they can significantly enhance the capabilities of existing technology,” he said.

Their virtual super instrument is already in use as part of a Frontier Development Laboratory project to monitor solar sources of space weather. Muñoz-Jaramillo is currently working on a virtual instrument to increase the resolution and sensitivity of historical maps of the solar magnetic field.



An SwRI scientist used a deep neural network trained to mimic an instrument on the Solar Dynamics Observatory that could infer ultraviolet radiation levels based on what the other SDO instruments observed.

IMAGE COURTESY NASA/GSFC/SDO D024268

UVS DELIVERED

An ultraviolet spectrograph (UVS) designed and built by SwRI was the first scientific instrument to be delivered for integration onto the European Space Agency's Jupiter Icy Moon Explorer (JUICE) spacecraft. Scheduled to launch in 2022 and arrive at Jupiter in 2030, JUICE will spend at least three years making detailed observations in the Jovian system before going into orbit around the solar system's largest moon, Ganymede.

From aboard JUICE, UVS will get close-up views of the Galilean moons Europa, Ganymede and Callisto. UVS will record ultraviolet light emitted, transmitted and reflected by these bodies, all thought to host liquid water beneath their icy surfaces. These measurements will reveal the composition of their surfaces and tenuous atmospheres as well as their interactions with Jupiter and its giant magnetosphere.

"In 2013, NASA selected UVS for the first ESA-led mission to an outer planet," said Steven Persyn, project manager for JUICE-UVS and an assistant director in SwRI's Space Science and Engineering Division. "Meeting both NASA's and ESA's specifications was challenging, but we did it."

UVS will be one of 10 science instruments and 11 investigations for the JUICE mission. The mission has overarching goals of investigating potentially habitable worlds around the gas giant as well as studying the Jupiter system as an archetype for gas giants in our solar system and beyond.

"JUICE-UVS is the fifth in a series of SwRI-built ultraviolet spectrographs, and it benefits greatly from the design experience gained by our team from the Juno-UVS instrument, which is currently operating in Jupiter's harsh radiation environment," Persyn said. "Each successive instrument we build is more capable than its predecessor."



SwRI's human motion prediction system overlays sparse skeletal features on pedestrians to predict movement. Deep learning algorithms predict motion based on pelvic biomechanical movement, as indicated by blue dot.

D024258

PREDICTING PEDESTRIAN PATHS

As a leading innovator of machine learning technologies, SwRI has developed a system to help automated vehicles detect pedestrians. The computer vision tool uses a novel biomechanical deep learning algorithm that predicts a pedestrian's path as indicated by movement of the person's pelvis.

"If a pedestrian is walking west, the system can predict if that person will suddenly turn south," said SwRI's Samuel E. Slocum, a senior research analyst who led the internally funded project. "As the push for automated vehicles accelerates, this research offers several important safety features to help protect pedestrians."

Recent accidents involving automated vehicles have heightened the call for improved detection of pedestrians and other moving obstacles. Although previous technologies could track and predict movements in a straight line, they were unable to anticipate sudden changes.

Motion prediction often uses algorithms based on "optical flow," a type of computer vision that pairs algorithms with cameras to track dynamic objects. Its accuracy diminishes, however, when people move in unexpected directions.

SwRI compared optical flow to other deep learning methods, including temporal convolutional networks (TCNs) and long short-term memory (LSTM). After testing several configurations, researchers optimized a novel TCN that outperformed competing algorithms, predicting sudden changes in motion within milliseconds with a high level of accuracy.

SwRI's research is a small step for autonomous systems to react more like human drivers. "If we see a pedestrian, we might prepare to slow down or change lanes in anticipation of someone crossing the street," said Dr. Douglas Brooks, a manager in SwRI's Applied Sensing Department. "We take it for granted, but it's incredibly complex for a computer to process this scene and predict scenarios."

Applications include human performance, automated vehicles and manufacturing robotics. The algorithms can work with a variety of camera-based systems. Datasets are available to SwRI clients.

D024258



ENCELADUS INSIDE OUT

A new SwRI-developed geochemical model reveals that carbon dioxide (CO₂) from within Enceladus, an ocean-harboring moon of Saturn, may be controlled by chemical reactions at the seafloor of Enceladus. Studying the plume of gases and frozen sea spray released through cracks in the moon's icy surface suggests an interior more complex than previously thought.

"By understanding the composition of the plume, we can learn about what the ocean is like, how it got to be this way and whether it provides environments where life as we know it could survive," said SwRI's Dr. Christopher Glein, lead author of a paper in *Geophysical Research Letters* outlining the research. "We came up with a new technique for analyzing the plume composition to estimate the concentration of dissolved CO₂ in the ocean. This enabled modeling to probe deeper interior processes."

Analysis of mass spectrometry data from NASA's Cassini spacecraft indicates that the abundance of CO₂ is best explained by geochemical reactions between the moon's rocky core and liquid water from its subsurface ocean. Integrating this information with previous discoveries of silica (SiO₂) and molecular hydrogen (H₂) points to a more complex, geochemically diverse core. Another phenomenon that contributes to this complexity is the likely presence of hydrothermal vents inside Enceladus. At Earth's ocean floor, hydrothermal vents emit hot, energy-rich, mineral-laden fluids that allow unique ecosystems teeming with unusual creatures to thrive.

"The dynamic interface of a complex core and seawater could potentially create energy sources that might support life," said SwRI's Dr. Hunter Waite, principal investigator of Cassini's Ion Neutral Mass Spectrometer (INMS). "While we have not found evidence of the presence of microbial life in the ocean of Enceladus, the growing evidence for chemical disequilibrium offers a tantalizing hint that habitable conditions could exist beneath the moon's icy crust."

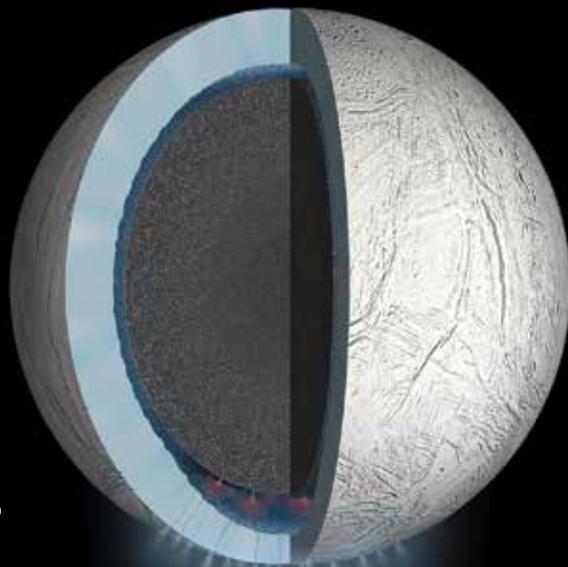


IMAGE COURTESY NASA/JPL-CALTECH
D024264

STRATOSPHERIC SCIENCE PLATFORM

An SwRI team successfully demonstrated the SwRI Solar Instrument Pointing Platform (SSIPP), a miniature solar observatory, on a high-altitude balloon. The reusable, high-precision platform weighs 160 pounds and was carried aloft by a stratospheric balloon, collecting 75 minutes of solar images in the proof-of-concept flight.

"SSIPP is a novel, low-cost observatory prototype," said SwRI's Dr. Craig DeForest, principal investigator of the NASA Flight Opportunities mission. "We are working to provide similar infrastructure and flexibility to a ground-based observatory, delivered to near-space."

SSIPP collects solar data using infrared, ultraviolet or visible light instruments on an optical table, similar to those used in ground-based observatories, but from a near-space environment. SSIPP is an arcsecond-class observatory, which provides optical precision equivalent to imaging a dime from a mile away. The platform supports the development of custom solar instruments. Collecting data from

the edge of space — around 20 miles above the Earth's surface — avoids image distortions caused by looking through the atmosphere.

"SSIPP could support the development of a range of new instruments for the near-space environment at relatively low cost," DeForest said. SSIPP includes an "optical table," a stable platform used to support optics in a laboratory environment. "Using a standard optical table platform increases flexibility, allowing scientists to develop new technologies without designing a custom observatory."

Because existing spaceborne assets are optimized for different science, the wavelength range observed by SSIPP fills a gap in current measurements, highlighting the importance of new instruments to advance knowledge.

"Upon reaching the stratosphere, SSIPP immediately locked onto the solar disk using a novel two-stage pointing system," said SwRI Principal Analyst Dr. Glenn Laurent. "The next step for SSIPP is to partner with outside institutions to extend quick-turnaround solar flights to a range of scientific instrumentation."

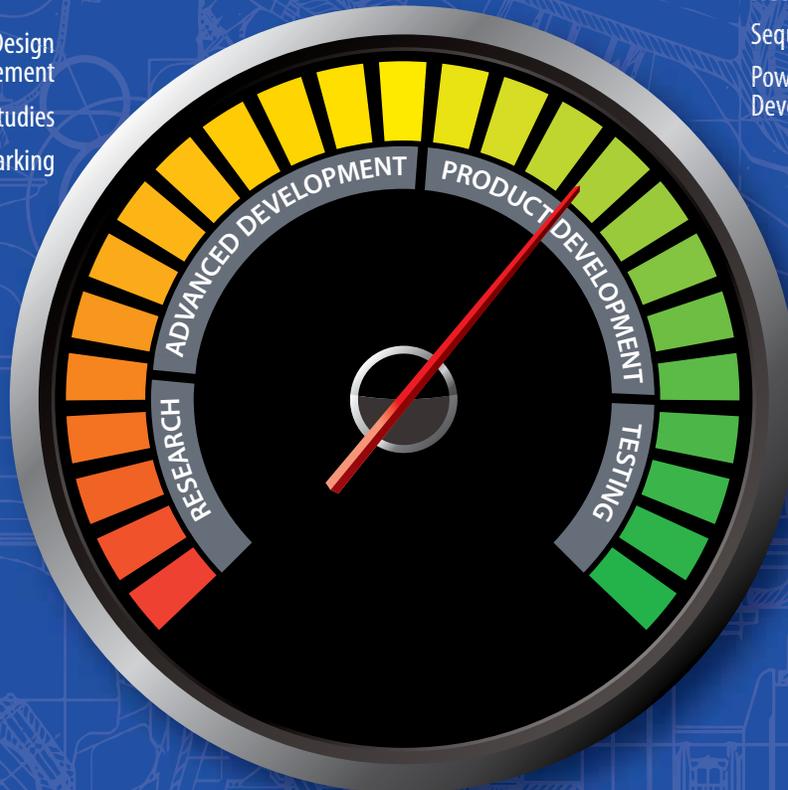


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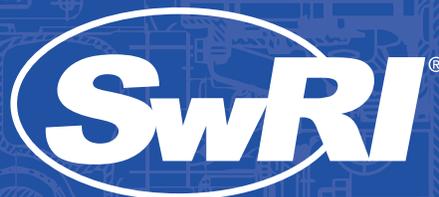
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43
presentations
given in



11
states &



5
countries

22
papers
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11
publications

12
patents
awarded



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SwRI HOSTS ROS-I CONSORTIUM

The ROS-Industrial Consortium Americas held its ninth annual meeting SwRI in March. Paul Evans, director of SwRI's Manufacturing and Robotics Technologies Department, welcomed the diverse mix of manufacturing and technology specialists who came to discuss open-source robotics software applications.

The event featured presentations, panels and demonstrations from industrial robotics and software engineers showcasing the latest manufacturing robotics innovations using cloud computing, collaborative robotics, factory automation, internet of things (IoT), open-source software development, warehouse fulfillment and more. Talks were distributed via video conference live feeds to those who chose not to attend amid international travel concerns related to the coronavirus.

ROS-Industrial leverages the open-source robot operating system (ROS) to develop automation and machine learning solutions for heavy industry and manufacturing robotics used in factories around the world. The ROS-Industrial Consortium is organized by three geographic regions in the Americas, European Union and Asia-Pacific. Member organizations include nonprofit research institutions, universities and a broad spectrum of manufacturers around the world.

SwRI initiated the development of ROS-Industrial in 2012 through an internal research program conducted with industry collaborators. The Institute maintains the ROS-Industrial software repository and manages the ROS-Industrial Consortium.



SwRI and the Lyle School of Engineering at Southern Methodist University announced the Seed Projects Aligning Research, Knowledge, and Skills (SPARKS) joint program, which aims to strengthen and cultivate long-term research collaboration between the organizations. Research topics will vary for the annual funding cycles, with inaugural program selections applying machine learning to solve industry problems.

D024249

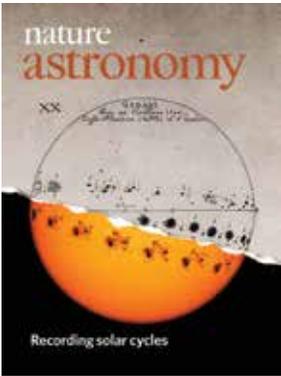


The Association of Old Crows awarded **Henry Sees**, a director leading SwRI's office in Warner Robins, Georgia, the Anton D. "Tony" Brees Lifetime Service Award. The association recognized Sees with its most prestigious award to honor his outstanding contributions to the field of electronic warfare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

D024241



SwRI President and CEO **Adam L. Hamilton, P.E.**, has been named a Fellow of the American Association for the Advancement of Science (AAAS). Honorees are elected by the organization's council to recognize their distinguished efforts to advance science or its applications. In addition to acknowledging his leadership at SwRI, the distinction recognizes his role in establishing Signature Science, LLC, in Austin.



Senior Research Scientist **Dr. Andrés Muñoz-Jaramillo** and Physicist **Dr. José M. Vaquero** (University of Extremadura) received the 2019 cover image of the year award for their March cover illustration for Nature Astronomy featuring an artistic rendering of solar cycles and sunspots. The scientists merged a historic illustration of sunspots with a modern image to create the composite.

D024252



The SwRI-led **New Horizons** mission to Pluto and the Kuiper Belt received the Sir Arthur Clarke Award for International Space Achievement. The mission team and its Principal Investigator **Dr. Alan Stern** were jointly selected for outstanding achievements in space over many years. The Sir Arthur Clarke Awards, presented annually since 2005, recognize contributions to space exploration.

D024245



SwRI and the Commercial Spaceflight Federation (CSF) organized the 2020 Next-generation **Suborbital Researchers Conference (NSRC)** held in Broomfield, Colorado, March 2–4, 2020. Hundreds of suborbital researchers, educators, flight providers, spaceports and government officials discussed the next generation of space vehicles, laying the groundwork for space research and education.



SwRI helped launch the **San Antonio Partnership for Precision Therapeutics (SA PPT)** in collaboration with UT Health San Antonio, Texas Biomedical Research Institute and The University of Texas at San Antonio. The partnership has funded its first project aimed at the specific and diverse medical needs of the city's population.



This location in Technology Today is normally devoted to upcoming trade shows and trainings. As the Spring edition goes to press, most upcoming events are tentative or cancelled, but SwRI wants you to know that together, we have the strength and ingenuity to take on anything.

D024256

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