SOUTHWEST RESEARCH INSTITUTE®

FALL 2020

TECHNOLOGY TODAY®

HYPERSONICS

Antenna Technology

Southwest Research Institute recently received a $2,091,865 award as part of a $25 million, five-year indefinite delivery/indefinite quantity (IDIQ) contract to provide engineering services and equipment to the U.S. Department of Defense. Under the current IDIQ contract, SwRI's Defense and Intelligence Solutions Division has provided $10 million in services. The preceding contract has delivered $17 million in engineering services and specialized equipment since 2010.

The division has sustained a 35-year relationship with DOD entities. SwRI designs, develops and delivers tactical communications intelligence (COMINT) products and engineering services for the detection, acquisition and geolocation of radiofrequency signals of interest. Certified to NASA standards, SwRI's technical staff build, test, troubleshoot and sustain specialized intelligence equipment, including evaluating the performance of COMINT technology at SwRI's 200-acre test site.

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To be placed on the mailing list or to make address changes, call 210.522.2257 or visit **update.swri.org**.

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

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ON THE COVER

As part of its extensive hypersonics research and development activities, SwRI conducts high-fidelity computational fluid dynamics simulations of a cone in flight at Mach 15.9 (12,200 mph) using the SwRI-developed CULEBRA code.

CONTENTS

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.

SwRI is always looking for talented technical staff for its San Antonio facilities and for locations elsewhere in the United States. We welcome your referrals. Check our employment opportunities at **swri.jobs**.

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RAW SPEED

The Extreme Conditions of Hypersonic Flight

By Nicholas Mueschke, Ph.D., and James Walker, Ph.D.

D024498

Ever since the Wright brothers flew the first motor-powered airplane in 1903, humanity has been trying, and succeeding, to fly faster and faster.

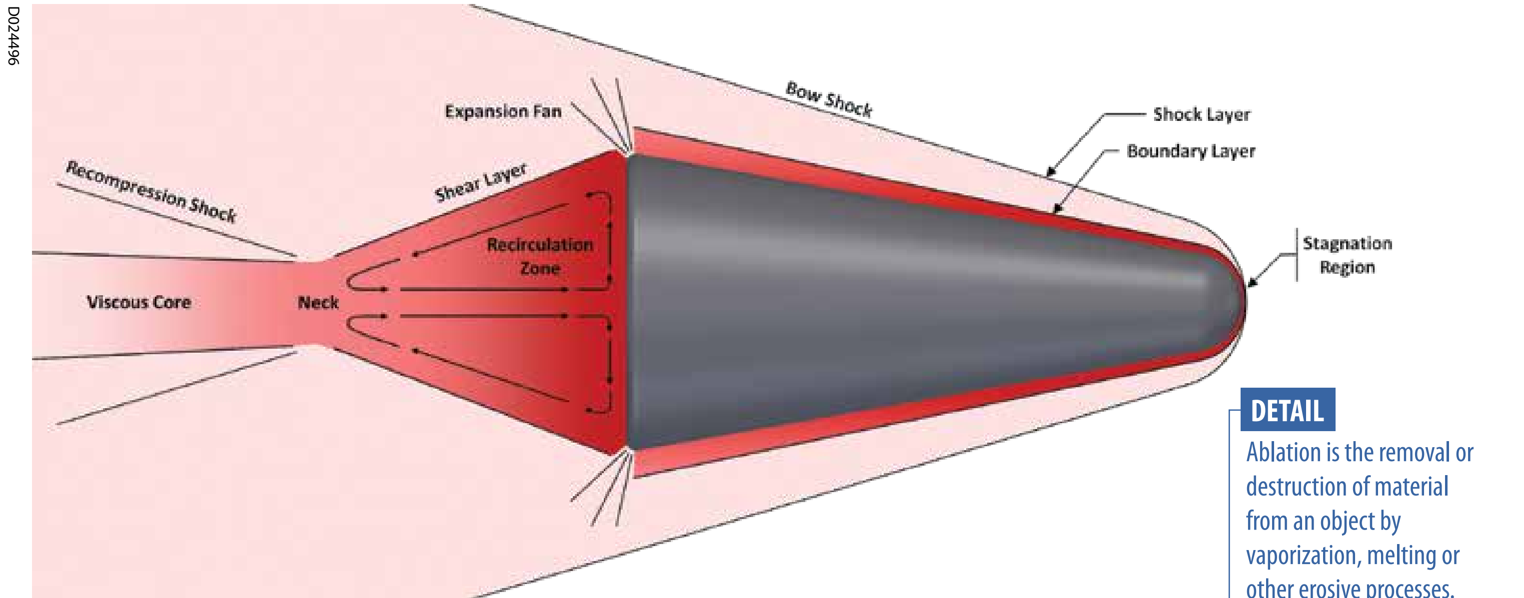
However, as aircraft speeds increase, the physics of high-speed flight imposes challenges that must be overcome. Breaking the sound barrier, or flying faster than the speed of sound, is one example. The speed of sound is a critical measure that affects a vehicle in flight, which is specifically associated with the physical properties of air.

The speed of sound in air is roughly 740 miles per hour, referred to as Mach 1, though it changes depending on the specific composition and temperature of the air. In the early years of human flight, clocked speeds were well below Mach 1. It took nearly half a century of engineering development before an aircraft was able to breach the sound barrier. This metaphorical hurdle refers to sudden increases in aerodynamic drag and other undesirable effects aircraft experience as their speed in air approaches the speed of sound.

In 1947, the Bell X-1 was the first official aircraft to break the sound barrier during level, controlled flight. This pioneering event demonstrated an understanding about supersonic flight and shock waves that form in the air when the aircraft exceeds the speed of sound as well as how compressed air behind the shock waves affects vehicle dynamics. The next two decades witnessed continued progression of supersonic aircraft through the SR-71, which could fly at Mach 3, and the X-15, which used rocket propulsion to reach sustained flight at Mach 6. More recent unmanned test vehicles, such as the X-43 (1997–2004) and X-51 (2004–2013), have demonstrated the feasibility of non-rocket-based propulsion methods, including scramjets (supersonic combustion ramjets). A scramjet has a novel combustion chamber — where the air is mixed with fuel and ignited — designed to operate with supersonic airflow.

While earlier test programs demonstrated the possibility of hypersonic aircraft operating in excess of Mach 5, the U.S., China, Russia and other countries are all striving to develop the first operational hypersonic systems. Aircraft and missiles that can cruise and maneuver at five times the speed of sound or faster will offer significant military advantages. In the commercial arena, a hypersonic flight could travel from New York to Los Angeles in less than 30 minutes, blowing away today’s subsonic airliners covering the same distance in 5 hours. The demand is there, and the technology is coming.

Southwest Research Institute is using its unique facilities and capabilities to explore how hypersonic flight in excess of



This figure illustrates the aerodynamics of a hypersonic body in flight.

DETAIL

Ablation is the removal or destruction of material from an object by vaporization, melting or other erosive processes.

Mach 5 differs from supersonic flight at lower Mach numbers. The complexity of the engineering challenges associated with hypersonic flight requires creative problem-solving as well as advanced modeling and testing.

ENVIRONMENTAL EXTREMES

As an aircraft travels faster and faster, the air around its nose cone, wing leading edges and air intakes can easily heat to temperatures hotter than the surface of the Sun (approximately 5,800 K or 10,000° F). As temperatures increase, air molecules can dissociate or ionize. These hot atoms and ions are prone to chemically react with anything, including the vehicle surface they surround.

Friction heats the air around an aircraft to the point that its outer surface begins to melt, vaporize, oxidize, erode or ablate away. This is not the only problem encountered at hypersonic speeds. It does, however, embody the grand challenge of hypersonic flight: How do you design a vehicle to survive an environment so harsh that the vehicle can literally disintegrate during flight? Because of these high temperatures, all hypersonic vehicles are outfitted with "thermal protection systems." These special materials or coatings protect vehicles from high temperatures and include silica thermal tiles on the space shuttle and X-51, titanium alloys on the X-15 or carbon-carbon composites on the X-43. For example, Apollo capsules were coated with an ablative material that vaporized during reentry, absorbing the heat from the air, like evaporative water in swamp coolers, protecting the capsule from

SwRI offers a 7,050-square-foot facility for launching projectiles at high speeds. The centerpiece of the facility is a two-stage light-gas launcher that can achieve velocities approaching 15,660 miles per hour.

D023365

rising temperatures. The hottest parts of the space shuttle, the nose cone and the leading edges of the wings, were made with specially coated carbon-carbon composites that can withstand extremely high temperatures without melting or ablating.

Surfaces and structures must deal with extreme aerodynamic pressures and external temperatures while keeping internal structures and electronics cool. Aerodynamic and thermal protection systems must tolerate aerodynamic forces and thermal expansion of materials so extreme that they can actually change the shape of the aircraft during flight. Propulsion systems must survive extreme thermal and shock conditions while maintaining combustion stability. Communication and guidance systems must negotiate a potential sheath of charged particles engulfing the vehicle in flight. These issues all affect and complicate the vehicle design.

Ultimately, for aircraft to fly at hypersonic speeds for sustained durations, it is necessary to understand the heating that occurs and how it affects the performance of engineered materials and structures. Airbreathing propulsion systems at hypersonic speeds (such as scramjet propulsion systems) complicate matters even more. SwRI has been developing tools to understand the shock waves, flows and chemistry of hypersonic flight and the material systems needed to survive those conditions.

HYPERSONIC FLIGHT IN THE LAB

Reproducing the extreme velocities, temperatures and chemistries of hypersonic flight is extremely difficult. Flight tests are the only means of replicating such an environment — but are cost-prohibitive. Hypersonics researchers must use ground test facilities to recreate critical aspects of flight conditions. Ground-based facilities, such as wind tunnels, can selectively match some flight conditions, but only for milliseconds to seconds at a time. Currently, no single test facility can replicate all aspects of hypersonic flight.

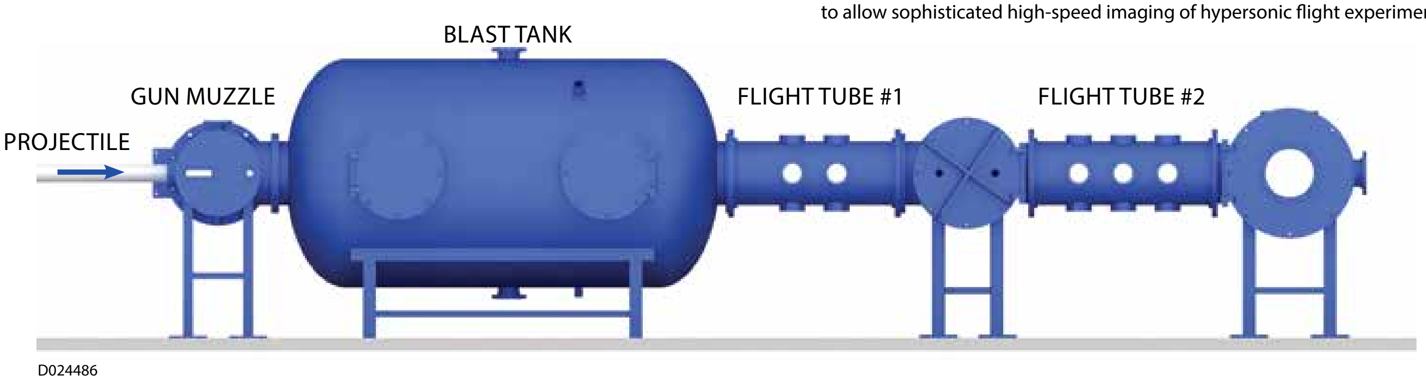
At SwRI, researchers are using a large two-stage light-gas gun to explore how to replicate hypersonic flight. This facility can launch scale-model flight vehicles at speeds from Mach 5 (1.7 km/s) to Mach 20 (7 km/s) into controlled atmospheres that are quiescent or “quiet,” meaning gas is at rest, with no acoustic noise present to inadvertently introduce turbulence. The constraint with this approach is that flight vehicles are small-scale models. They traverse the flight range in only a few milliseconds and are not recovered.

For light-gas gun testing, SwRI encases spherically blunted conical test projectiles in a sabot, a structural device used to keep smaller projectiles in the center of the barrel when fired. The sabot separates from the projectile and is stripped away when it hits an impact plate.

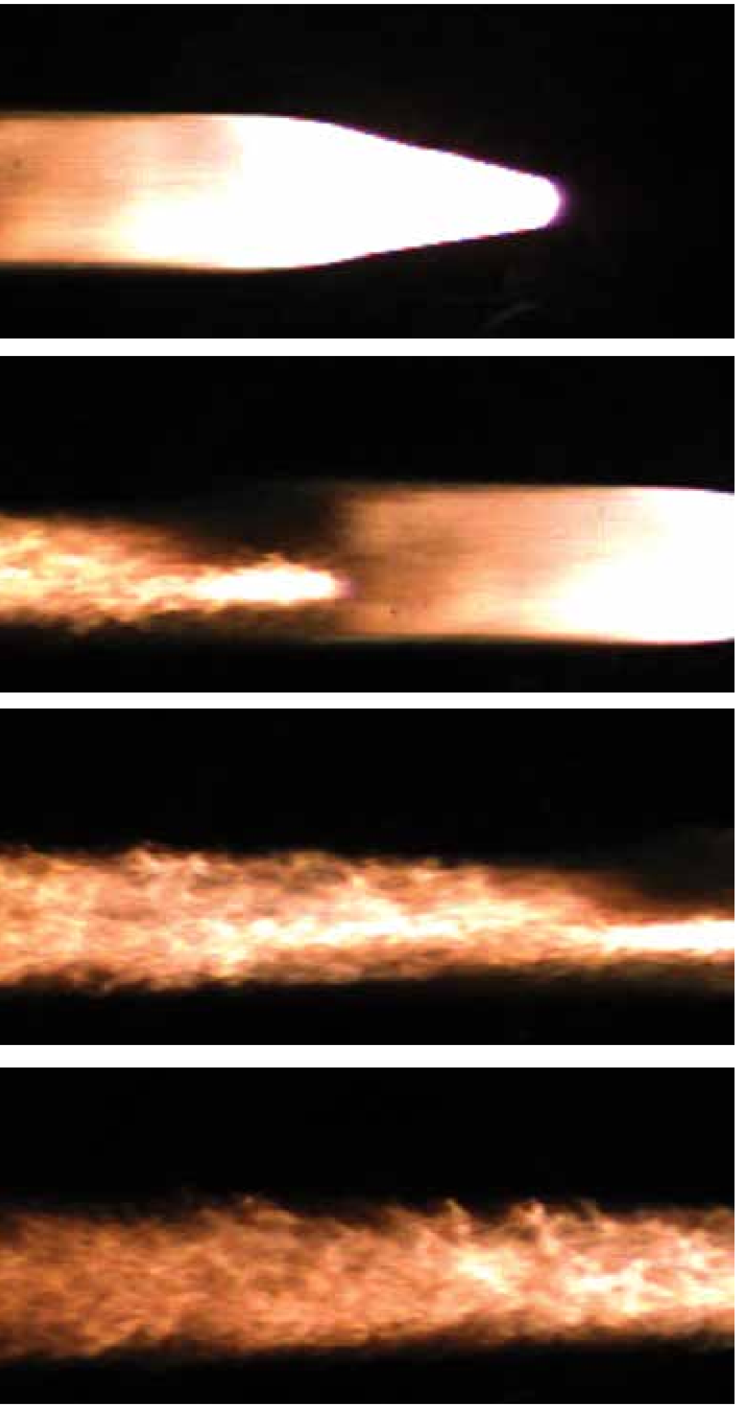
DETAIL

An airbreathing engine such as a jet engine or scramjet engine sucks air in the front and pushes it out the back very quickly.

SwRI’s light-gas gun flight range includes multiple portals in the flight tubes to allow sophisticated high-speed imaging of hypersonic flight experiments.



One advantage of testing in the SwRI light-gas gun is the atmospherically controlled environment. Flight range pressure and gas composition can be controlled to mimic atmospheric conditions equivalent to up to 27 miles in altitude. This allows SwRI to replicate flight conditions for a range of different flight systems, including the space shuttle to ballistic missiles and everything in between.



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This high-speed video sequence shows a spherically blunted conical test article in flight at Mach 14.8 (11,400 mph), illustrating hardbody and wake signatures. The flow around the vehicle and in the wake in these images is self-luminous due to the high temperatures created by the hypersonic flight. No external lighting was added to take these pictures.

SMALL-SCALE FLIGHT TESTING

Launched projectile experiments explore different aspects of hypersonic flight physics, such as the shock wave geometries around and within the vehicle and the chemical reactions resulting from extreme temperatures. Multiple viewports along the flight path allow high-speed flash X-ray, high-speed video, schlieren imaging and photonic Doppler velocimetry, which measures velocities in dynamic experiments with high temporal precision. SwRI is also developing new diagnostic tools to study light emitted by different chemical species created in the high-temperature flight environments, including emission and absorption spectroscopy, and additional laser diagnostic techniques.

DETAIL

Schlieren photography (from German for streak) is a visual process used to photograph the flow of fluids of varying density. Invented in 1864 to study supersonic motion, the technique is widely used in aeronautical engineering to photograph the flow of air around objects.

Some experiments examine how to use the flight range to observe the aerodynamics of different geometries in flight at very high Mach numbers. Understanding the chemistry of the local gas around the vehicle is paramount in the selection of materials that can survive this thermal and chemical environment, understanding vehicle aerodynamics and control, and the design of any airbreathing propulsion system and communication systems. Another goal of these experiments is to understand how the chemical environment interacts with material shed from the vehicle to produce a visible and infrared light-emitting shroud of gas around and in the wake of the aircraft.

Observing the object in flight requires non-contact optical diagnostics, so every test is recorded using high-speed video. This provides raw images of the test article in flight and records the observed chemical luminescence. If gas temperatures are sufficiently hot, ablated material shed by the test article is sometimes visible. However, certain features of the flow field are not easily visible, such as shock waves and density fluctuations in the air around the flight body. Using specialized collimated light sources, SwRI amplifies and visualizes diffraction caused by light rays passing through changes in air density. These shadowgraph or schlieren images, depending upon the exact method used, directly image the test article, shock waves and turbulent zones and can, at times, allow quantitative analysis.

SwRI is also using internal research funding to develop advanced optical diagnostics based on the light emitted by excited chemicals around a flight body. Engineers use this emission spectroscopy method to identify and quantify the specific chemical species present in the flow field. SwRI engineers are developing advanced diagnostic tools with Professor Chris Combs at the University of Texas at San Antonio (see related article on p. 16). These laser-based methods use a specific wavelength to selectively excite different molecules, which subsequently fluoresce in predefined colors as they release the energy absorbed from the laser. Lighting a small packet of gas in this way allows engineers to track its movement around the flying object. These techniques can provide detailed measurements of velocity, density, temperature and chemical species concentration.

One challenge with using a ballistic system to launch and study hypersonic flight is the intrinsic limitation on the scale of the test article that can be flown. SwRI is researching how to manipulate the gas pressure and chemical composition of the flight range to better correlate the small-scale tests with full-scale hypersonic aircraft flight conditions. To design these experiments and understand the physics of the flow where measurements cannot be made, engineers leverage computational fluid dynamics tools. High-fidelity simulations run on hundreds of central processing units performing advanced calculations to predict shock wave locations, local gas temperatures and how air components break down in the highly energetic environment around the test article. This information guides the development of optical diagnostics and test analyses.

In addition to using a government-generated aerodynamics code specifically designed for hypersonic aerodynamics, SwRI has developed a computational fluid dynamics code that specializes in solving transient flows with strong shocks and complex, transient chemical reactions between numerous gas species. Known as CULEBRA, this tool is tuned to the complex chemistry and transient flow features that occur behind strong shock waves, like the bow shocks that develop in hypersonic aircraft.

AIRBREATHING HYPERSONIC FLIGHT

The hypersonics research community is particularly interested in airbreathing engine-powered flight, such as that provided by scramjet propulsion systems. Conceptually, these engines are very simple. With no moving parts, air is forced through an engine duct at supersonic speeds where the fuel is injected and ignited, and the exhaust products expand to generate thrust. However, the complex shock wave structure and shock wave-boundary layer interaction, combined with the supersonic combustion, require immense structural cooling. SwRI test techniques examine the shock waves as they interact with complicated shapes. Quantitative details of how a series of shock waves form inside a flight body are very important for scramjet engines. Researchers are investigating ways to build scale models of transparent flight bodies with inlets and internal ducts and using imaging techniques to see the details of the internal shock structure. Though these transparent materials do not survive an extended flight test (because they melt and ablate), they maintain their shapes for the few milliseconds of flight in the light-gas gun flight range, allowing researchers to image the shocks inside the body to understand where they are and how they interact. Engineers then use a variety of aerodynamic, reactive flow and shock/impact physics codes to better understand these complex interactions.

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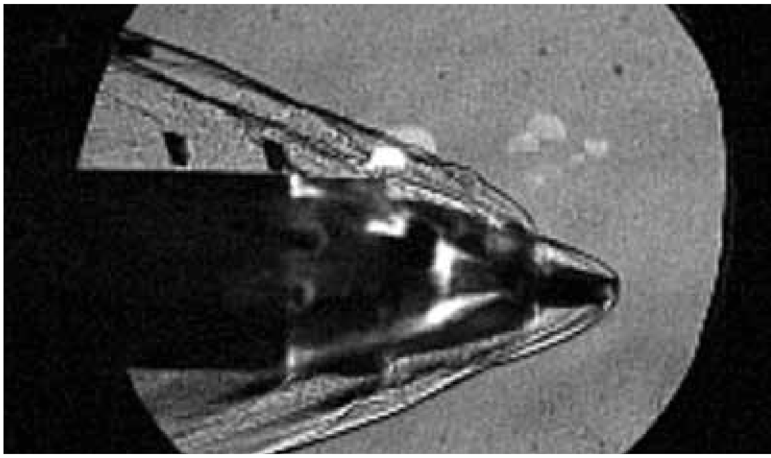
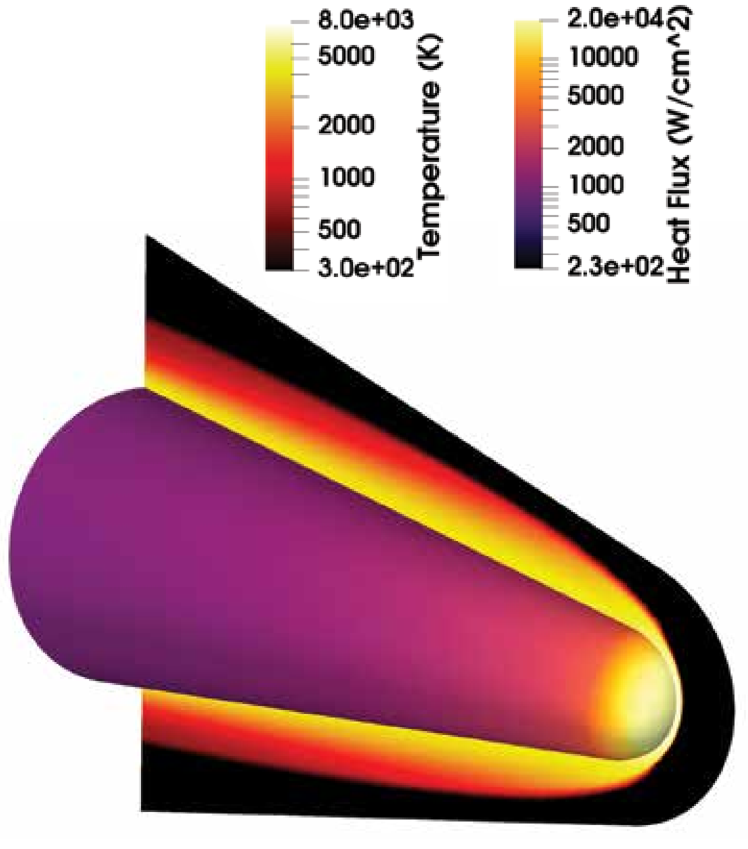


This schlieren image of an additively manufactured test article with internal ducted ports for air flow shows an experiment conducted at Mach 9.6 (7,400 mph).



High-fidelity computational fluid dynamics simulations of a small-scale test article flying at Mach 14.8 (11,400 mph) predicts gas temperatures behind the shock wave reach temperatures in excess of 5,000 K (8,540° F). At these temperatures, air molecules break down and form new chemical compounds, such as nitric oxide.

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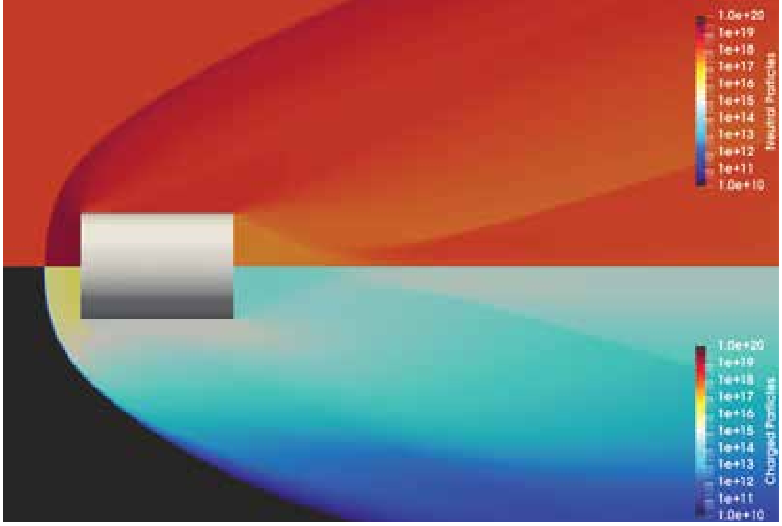

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SwRI-developed CULEBRA models of a cylinder in flight at MACH 16 predict that extreme temperatures strip electrons off molecules and a sheath of plasma forms around the flight body.

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As part of its hypersonics research, SwRI is conducting high-temperature materials testing of carbon-carbon composites, shown glowing at 2,000° F.

Tomorrow's extended hypersonic flight goals are substantially different from current atmospheric reentry vehicles, which experience hypersonic flight environments for a relatively short period of time. Hypersonic airbreathing vehicles intended for civilian air transport and military applications need to maintain hypersonic flight for minutes to several hours. Achieving this performance requires detailed understanding of the thermal environment the materials need to survive as well as a complete understanding of fuel efficiency and scramjet effectiveness.

HIGH-TEMPERATURE MATERIALS TESTING

SwRI is also exploring other avenues of hypersonics research and development, particularly the response of advanced materials to extreme temperatures and loading rates. As new material systems are developed to withstand extreme flight environments, engineering design tools require information on how these systems behave at different temperatures and under varying load configurations and rates. SwRI has a long history of developing test methods to acquire the data as well as the subsequent material models that use the data.

In recent years, SwRI has expanded the range of strain rates and temperatures that can be achieved in various mechanical and impact tests. SwRI uses induction heating techniques to heat carbon-carbon composite materials to 2,670 K (4,350° F) and laser-based heating to rapidly heat test specimens to above 2,600 K (4,220° F).

New materials, and especially high-temperature ceramics and composites, will play critical roles in the functionality of hypersonic vehicles. Extreme temperatures represent only half of the equation for hypersonics materials testing. Mechanical, impact and high strain rate failure testing must incorporate the effects of materials in thermally excited states. Hypersonic designs must incorporate the material expansion, changes in strength and heat conduction as a function of temperature or face the risk of failing in flight testing, an expensive possibility.

An international race to develop operational hypersonic systems is underway with a focus on both airbreathing and boost-glide systems. SwRI's broad hypersonics research and development activities are improving the understanding of this unique flight environment, how materials and structures respond to it and how those insights can be leveraged to advance current flight system capabilities and reliability.

Questions about this article? Contact Walker at james.walker@swri.org or call 210.522.2051 or contact Mueschke at nicholas.mueschke@swri.org or call 210.522.5128.

DETAIL

Engineers named its CFD code CULEBRA, which means snake in Spanish, in homage to SwRI's location on Culebra Road in San Antonio.

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ABOUT THE AUTHORS
Dr. Nicholas Mueschke (left) is a principal engineer in SwRI's Engineering Dynamics Department. He has extensive experience in fluid dynamics, turbulent flows, computational fluid dynamics (CFD) and is the author of SwRI's CULEBRA CFD code, which includes chemistry for modeling blast effects and hypersonic aerothermodynamics. Dr. James Walker is director of the Engineering Dynamics Department and an Institute scientist. Walker is an expert in impact and penetration mechanics and material response under extreme conditions. A large team of SwRI scientists and engineers are involved in new hypersonics initiatives.

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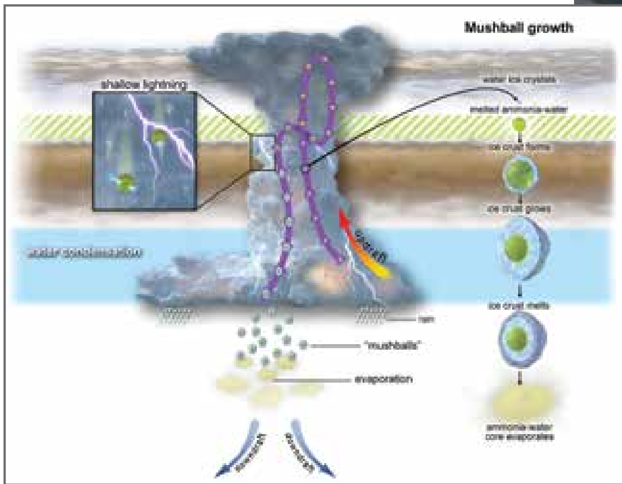


The graphic above depicts the evolutionary process of "shallow lightning" and "mushballs" on Jupiter. The illustration at right uses data obtained by NASA's Juno mission to depict high-altitude electrical storms on Jupiter. Juno's sensitive Stellar Reference Unit camera detected unusual lightning flashes on Jupiter's dark side during the spacecraft's close flybys of the planet.

D024520

SHALLOW LIGHTNING, MUSHBALLS AT JUPITER

New results from the Juno mission at Jupiter suggest our Solar System's largest planet is home to "shallow lightning." The unexpected shallow depth of the electrical discharges indicates an origin from clouds containing an ammonia-water solution, rather than water clouds that drive Earth's lightning. The findings are coupled to a new theory explaining why Juno found so little ammonia in the gas giant's upper atmosphere. Scientists suggest that ammonia-rich hailstones, called "mushballs," are produced by Jupiter's violent thunderstorms, which essentially kidnap ammonia and water in the upper atmosphere and carry them down into the deep atmosphere.

These findings coupled with new analysis from Juno's microwave radiometer suggest the gas giant's violent thunderstorms may produce slushy ammonia-rich hailstones the team calls "mushballs." The scientists theorize that these mushballs essentially kidnap ammonia and water in the upper atmosphere and carry them down to Jupiter's depths. Since NASA's Voyager mission first saw Jovian lightning flashes in 1979, most scientists thought the planet's lightning was similar to Earth's, occurring only in thunderstorms where water exists in all its phases — ice, liquid and gas. Voyager saw lightning as bright spots on Jupiter's cloud tops, suggesting that the flashes originated in deep water clouds. But lightning flashes observed on Jupiter's dark side by Juno's Stellar Reference Unit tell a different story.

"Juno's close flybys of the cloud tops allowed us to see something surprising — smaller, shallower flashes originating at much higher altitudes in Jupiter's atmosphere than previously assumed possible," said Dr. Heidi Becker, Juno's Radiation Monitoring Investigation lead at NASA's Jet Propulsion Laboratory and the lead author of a Nature paper outlining these results.

The findings suggest that Jupiter's powerful thunderstorms fling water-ice crystals high into the planet's atmosphere, where they encounter atmospheric ammonia vapor that melts the ice, forming an ammonia-water cloud, with the ammonia acting as antifreeze. Falling droplets of ammonia-water liquid collide with the upgoing water-ice crystals and electrify the clouds, creating shallow lightning.

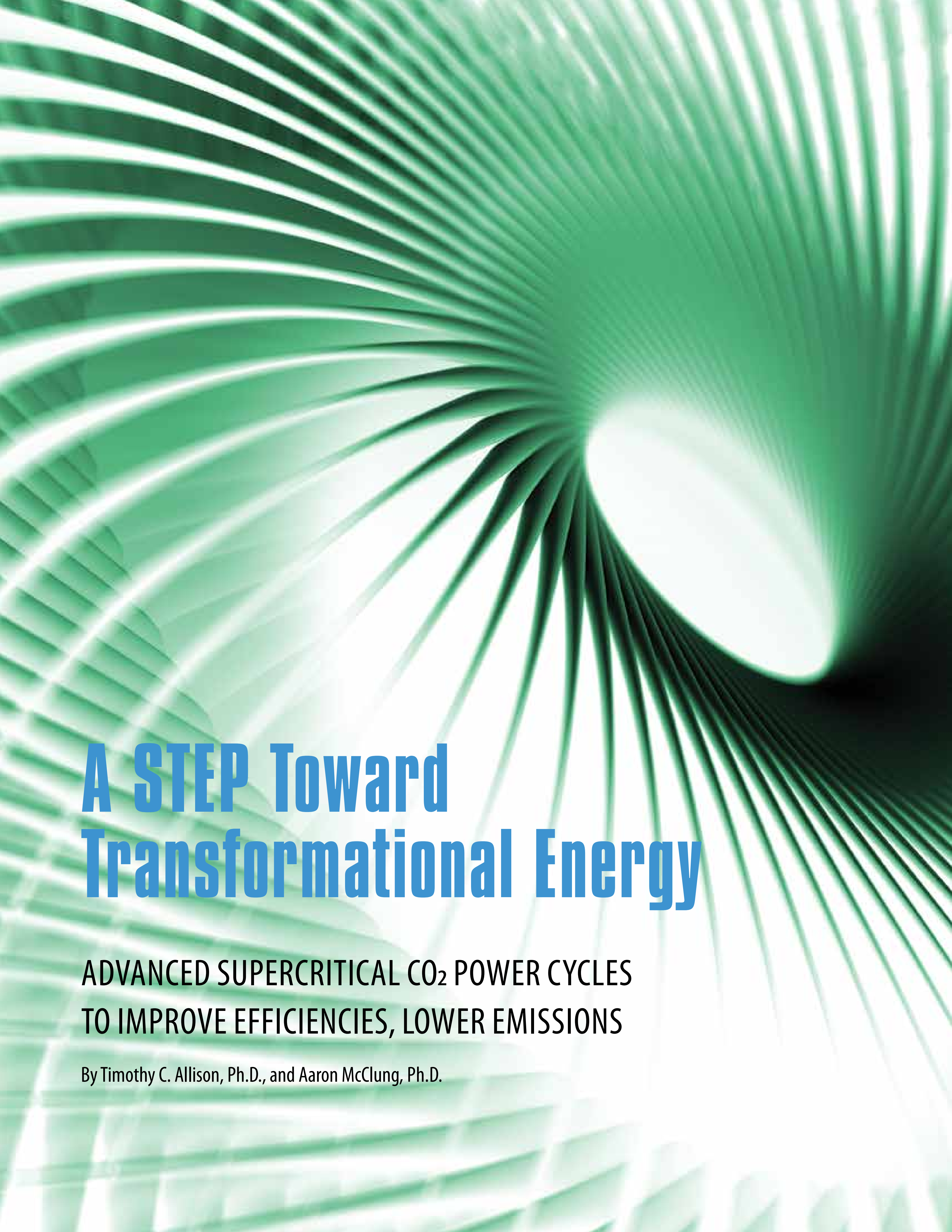
The phenomena provide clues that solve another mystery about the workings of Jupiter's deep atmosphere. Juno's microwave radiometer instrument found large-scale depletion of ammonia in Jupiter's atmosphere, and, even more puzzling, the amount of ammonia varies at deep depths from place to place around the planet.

"Previously, scientists realized there were small pockets of 'missing' ammonia, but no one realized how deep these pockets went or that the depletion covered most of Jupiter," said SwRI's Dr. Scott Bolton, Juno's principal investigator. "We were struggling to explain the depth of the ammonia depletion by rain-out when I realized a solid piece of hail might go much deeper and take up more ammonia. When Heidi discovered shallow lightning, I realized we had evidence that ammonia must be mixing with water high in the atmosphere."

A strange brew of two-thirds water and one-third ammonia gas is the likely seed for the Jovian mushballs. Consisting of layers of water-ammonia slush and ice covered by a thicker water-ice crust, mushballs are generated in a similar manner as hail is formed on Earth — by growing larger as they move up and down through the atmosphere. Once mushballs reach a certain size, they fall deep into the atmosphere, dragging ammonia and water deep into the planet's atmosphere.

"Combining these two results was critical to solving the mystery of Jupiter's missing ammonia," said Bolton. "As it turned out, the ammonia isn't actually missing; it is just transported down while in disguise, having cloaked itself by mixing with water. The theory is very simple and elegant: When the water and ammonia are in a liquid state, they are invisible to us until they reach a depth where they evaporate — and that is quite deep."

The shallow-lightning findings were published in the Aug. 6 issue of the journal Nature, while the mushballs research is available online in the Journal of Geophysical Research: Planets.



A STEP Toward Transformational Energy

ADVANCED SUPERCRITICAL CO_2 POWER CYCLES TO IMPROVE EFFICIENCIES, LOWER EMISSIONS

By Timothy C. Allison, Ph.D., and Aaron McClung, Ph.D.

From 1752, when Ben Franklin used a key attached to a kite to collect electricity from lightning, to 1882 when Thomas Edison opened the first central electric power plant more than 100 years later, tremendous progress was made in the field of electricity. Edison's Pearl Street Station in lower Manhattan used boilers to heat water for the high-speed steam engines that powered electricity-generating dynamos. There have been many, many advances since, but one thing has remained largely the same: Most electrical power is generated with steam.

DETAIL

A watt is a unit of power that quantifies the rate of energy transfer. A megawatt (MW) is equal to one million watts.

For the past decade, Southwest Research Institute has been at the forefront of researching new power cycles to replace steam with supercritical carbon dioxide (sCO_2) as the working fluid. Component development efforts for commercializing these power cycles have progressed rapidly in recent years, and the technology is poised for demonstration at a 10 MWe scale at the Supercritical Transformational Electric Power (STEP) pilot plant at SwRI. These power cycles could revolutionize power generation, improving the cost, efficiency and responsiveness of electricity production to changes in demand.

sCO_2 POWER CYCLES

Most power plants in the United States today are more than 30 years old and operate below 35% efficiency. About 60% of all power in North America comes from fossil fuels, so these inefficient plants burn huge quantities of expensive hydrocarbon fuels and emit significant amounts of greenhouse gases. Alternative energy sources such as wind, solar and hydropower are making impressive inroads in

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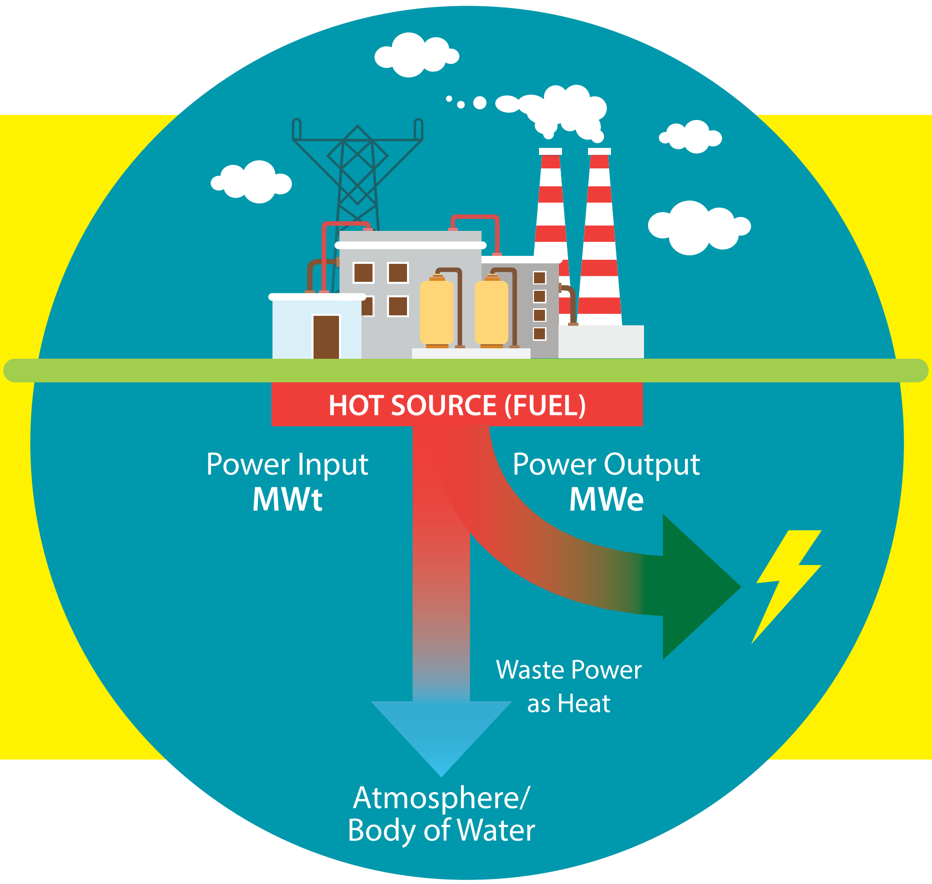
ABOUT THE AUTHORS

Dr. Aaron McClung (left) manages SwRI's Power Cycles Machinery Section and is the principal investigator and technical lead of the STEP demonstration pilot plant, pictured in the background. He's holding a model of a revolutionary desk-sized 10 MWe sCO_2 turbine that could power 10,000 homes. Dr. Tim Allison directs the Machinery Department in SwRI's Mechanical Engineering Division. His development and test experience includes new turbomachinery technologies, such as novel sCO_2 turbines and compressors, a high-pressure oxy-fuel combustor and a high-temperature gas turbine recuperator.



Powerplants are assigned two values: megawatts electric (MWe) and megawatts thermal (MWt). The former refers to the output capacity of a power plant, while the latter refers to the input thermal energy required. For example, a coal-fired power plant rated at 1,000 MWe and 3,000 MWt will require 3,000 MW of heat from burning coal for every 1,000 MW of electricity produced. Typical older power plants are rated 1,000 MWe/3,000 MWt, which translates to an efficiency of 33%. The closer a power plant's MWt and MWe ratings are, the more efficient it is.

the power generation spectrum but face challenges associated with variable production and storage. Even with continued improvements in alternative energy technology, a diverse portfolio of electricity-generating plants, with many utilizing fossil fuels, will almost certainly be required for many years. If the U.S. continues to rely on fossil fuels, it is imperative to increase plant efficiency while also decreasing emissions produced.

Supercritical carbon dioxide power cycle technologies that use high pressure CO_2 as a working fluid can increase power plant efficiency by as much as 10% relative to steam cycles. Carbon dioxide typically behaves as a gas at ambient temperatures and pressures, or as a solid — dry ice — when frozen. When held at temperature and pressure above its critical point (1,070 psi, 88° F), CO_2 acts like a gas while having density near that of a liquid. It's also nontoxic and nonflammable.

The anticipated economic and environmental benefits of sCO_2 power plants include higher efficiency, reduced fuel consumption and lower emissions with decreased cooling water consumption. Additionally, the compact design and small footprint of sCO_2 turbomachinery technology would lower capital costs and improve ramp rate capabilities that are becoming more important as additional renewable energy resources are brought online. Power plants can be designed using sCO_2 cycle technology to use heat from gas turbine exhaust, fossil fuel combustion, solar thermal, geothermal or even nuclear sources. Some direct-fired variations are directly heated through high-pressure oxy-combustion of natural gas.

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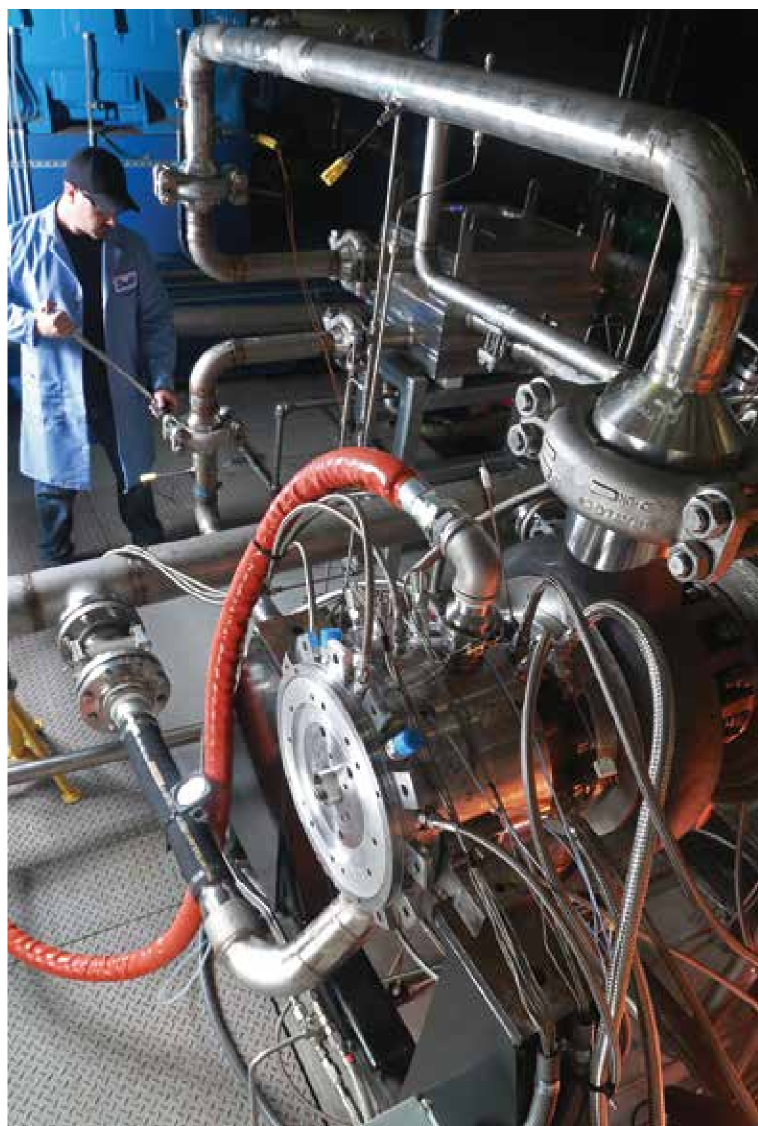

SwRI successfully operated this 10 MWe scale sCO_2 expander at up to 1,320° F and 3,600 psi, proving its ability to withstand the sCO_2 operating environment.

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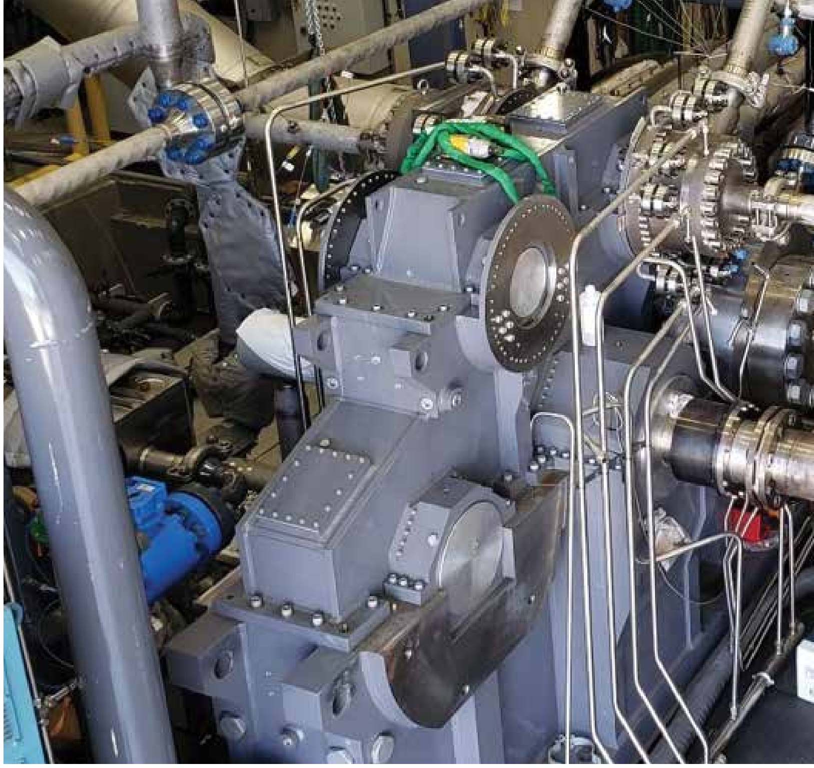


Engineers are testing an integrally geared compressor-expander prototype for its performance and durability.

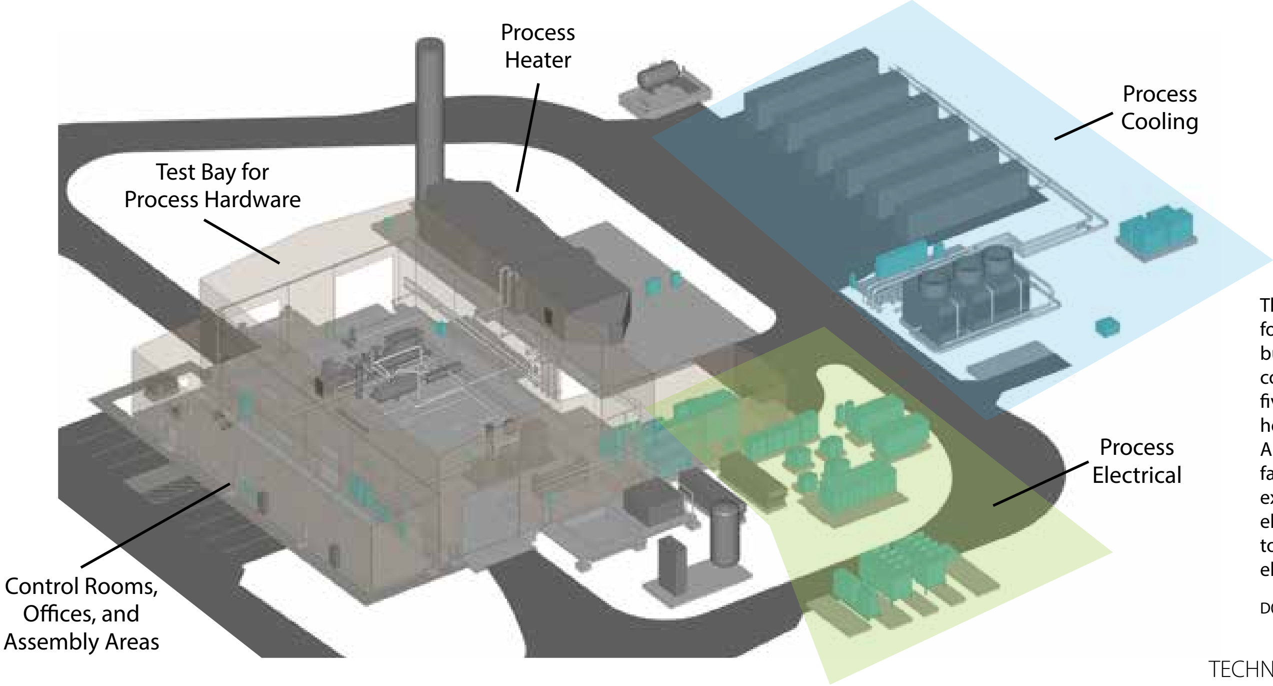
While concepts for sCO_2 cycles date back to the 1960s, recent advancements in heat exchangers and turbomachinery components are now bringing the promise of its potential to fruition. These sCO_2 systems operate at high fluid density at turbomachinery inlet and exit conditions, enabling efficient compression and extremely power-dense turbomachinery and heat exchangers. The thermodynamic properties of sCO_2 offer better cycle efficiency than steam cycles, particularly at low ambient temperatures and at turbine inlet temperatures exceeding 1,000–1,100° F. The compact system packaging, fast startup capability and high-power density of sCO_2 allow for modular and efficient power generation, all with an inert fluid.

DETAIL

Closed power cycles use a fixed mass or "charge" of working fluid in the system to drive a turbine and create energy, recirculating the fluid from the turbine exit instead of emitting it into the atmosphere. The working fluid is cooled and recirculated for continuous operation of the system. A recuperated power cycle adds a heat exchanger between the turbine and the cooler to transfer thermal energy to the cold, high-pressure stream entering the primary heater, minimizing heat input into the cycle and increasing thermodynamic efficiency.

In recent years, sCO_2 research programs have targeted specific component- and system-level technology gaps motivating the development, construction and operation of multiple MW-scale test loops. SwRI and our collaborators have developed, prototyped and validated multiple compressor and turbine designs. Notable recent successes include operating a 10 MWe axial expander prototype up to 1,320° F and 3,600 psi. This axial-flow turbine expands high-pressure gas to drive a compressor or generator. SwRI is also testing an integrally geared compressor-expander prototype. This relatively low-cost, multi-shaft turbomachine enables compressor impellers and turbine wheels to operate at the optimum speed for every stage, resulting in higher efficiency than most turbomachinery.

Research projects targeted specifically at gas turbine waste heat recovery (WHR) systems are underway. These systems use a heat exchanger to extract high-temperature waste heat from a gas turbine exhaust stream and convert this thermal energy to power using an sCO_2 cycle, increasing the overall system efficiency as a combined cycle. The team is adapting high-temperature machinery designs to lower-temperature WHR operations while developing mature technoeconomic models for designs that operate over a range of ambient temperatures and load profiles. Combined



The 22,000-square-foot pilot plant building was recently completed on a five-acre site at SwRI's headquarters in San Antonio. The overall facility includes external heating elements, a cooling tower and a separate electronics room.

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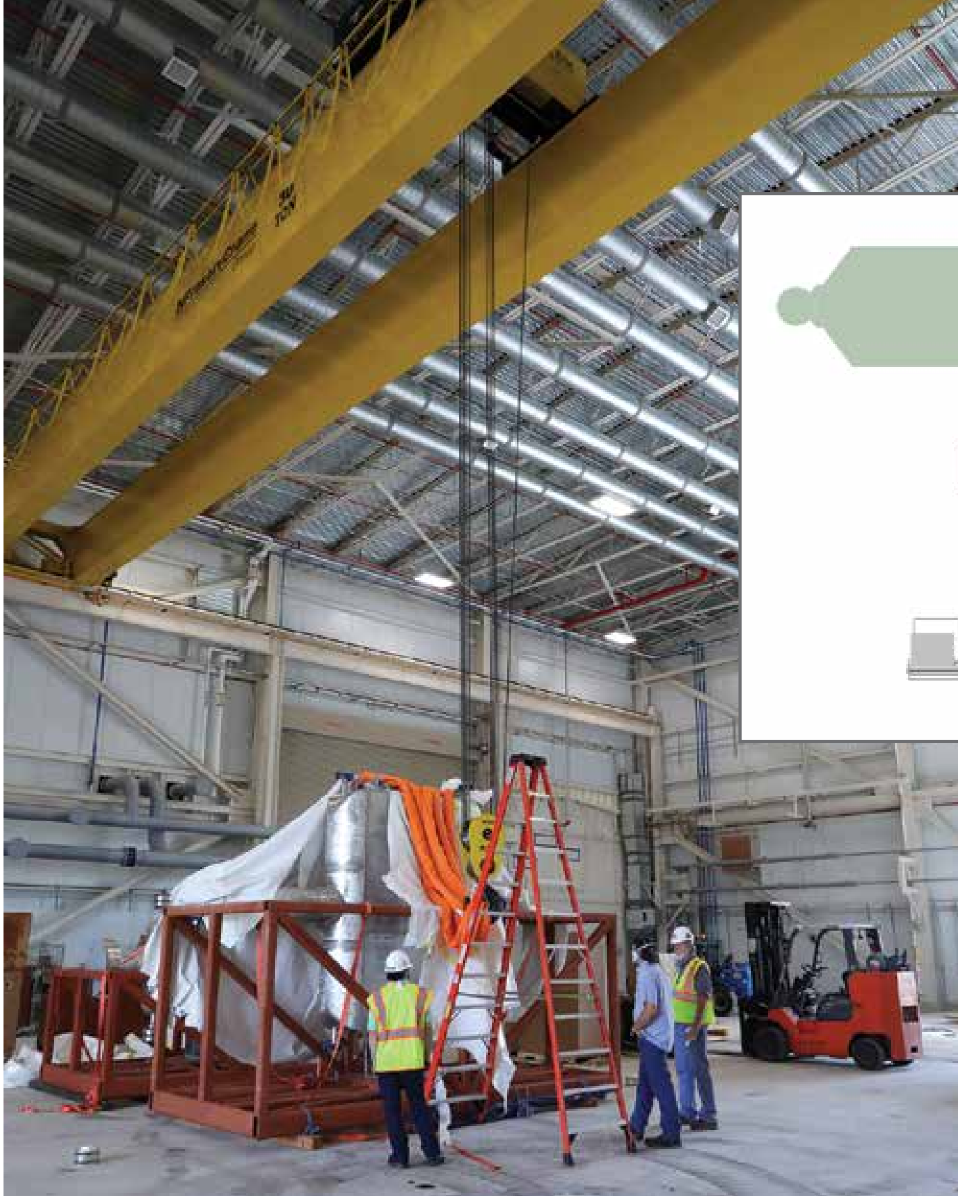

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Component manufacturing and equipment installation begins in the STEP facility, aided by a ceiling-mounted 30-ton crane.

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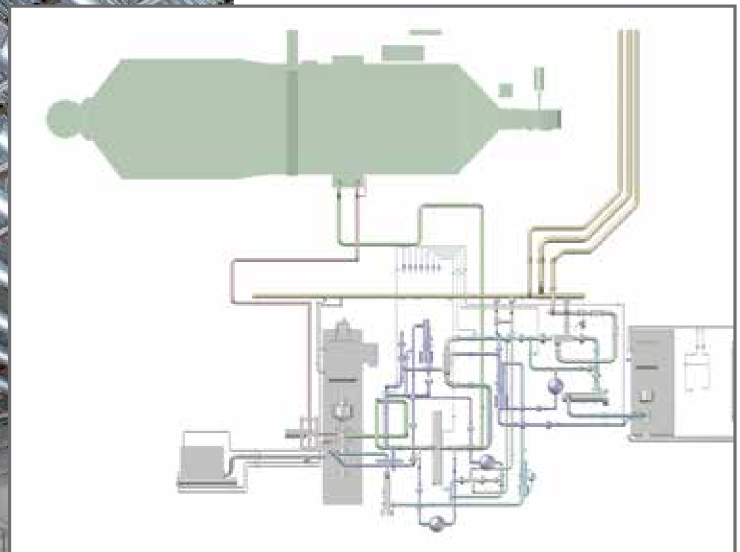

SwRI has entered the equipment installation phase for the STEP pilot plant, shown in this layout with the turbine skid at left and the compressor skid at right. The sCO_2 heater is the large green element at top.

cycle analysis results show that plant efficiencies near 50% are achievable even for small-scale 20 MWe systems with no changes to the gas turbine — efficiencies well above conventional open-cycle gas turbines. This increase in power output by converting waste heat to power inherently lowers emissions and increases system efficiency.

ADVANCED COMPONENTS, TECHNOLOGIES

SwRI, the Gas Technology Institute and General Electric are advancing sCO_2 technology, designing, constructing and operating a pilot plant test facility to demonstrate sCO_2 power cycle technologies at a commercially relevant scale. STEP is a state-of-the-art facility valued at $124 million with primary funding provided by the Department of Energy along with cost sharing from industry partners and the state of Texas. This pilot plant will advance sCO_2 technologies to near-commercial readiness, demonstrate their operability and performance, and serve as a reconfigurable test facility for component development and validation now and in the future.

The STEP pilot plant is a significant scale-up from existing sCO_2 test loops. Designed as a fully integrated and functional electric power plant, the 10 MWe facility supports operation at sCO_2 turbine inlet temperatures up to 1,320° F. This demonstration project mitigates technical risks and challenges for key components including the turbomachinery, recuperators and materials. The facility will demonstrate the aerodynamics, sealing performance and durability of full-sized turbomachinery for sCO_2 power cycles scalable to 100s of MW. The pilot plant will also prove the performance, fabrication and durability of compact heat exchanger designs. The project sources materials for large-scale hardware to verify the corrosion, creep and fatigue characteristics of these materials in high-temperature CO_2. Finally, the project will demonstrate successful integration and operability of all system

DETAIL

Recuperators recover thermal energy from the turbine exhaust and use it to preheat the working fluid entering the primary CO_2 heater, minimizing heat rejection and improving thermal efficiency.

components through many ambient conditions and operating states, including startup, transient and shutdown.

NEXT STEPS

The 22,000-square-foot laboratory building housing the pilot plant was recently completed on a five-acre site at SwRI's headquarters in San Antonio. The facility will feature skid-mounted components that provide flexibility and a unique reconfigurable design, which allows it to evolve over time to keep pace with industry advancements. The plant is also home to external heating elements and a cooling tower, a separate electronics room and a 30-ton crane that will support the project operation and construction of the sCO_2 power block.

Now that the building is completed, component manufacturing and equipment installation is progressing, with the aim of starting operations in 2021. Comprehensive testing to evaluate the advancement of sCO_2 technology will follow. State-of-the-art equipment is being developed by STEP partners, including a revolutionary desk-sized 10 MW sCO_2 turbine that could power 10,000 homes.

Optimus Industries LLC is providing the primary process heater, incorporating a ~80 MWt gas-fired burner and heat recovery steam-generator-style CO_2 heater fabricated from superalloys for operation up to 1,320° F. The 16 MW (gross) axial turbine, developed jointly by SwRI and GE, has a 100,000-hour commercial product design life at inlet conditions of 1,320° F and 3,626 psi. The team is also procuring rotor and casing materials and initiating fabrication.

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High- and low-temperature recuperators include compact printed circuit heat exchangers. Photochemically etched fluid channels provide numerous microchannels with exceptionally high thermal performance, while diffusion bonding produces a solid core packed within a heat transfer area. The combined result is maximum efficiency and minimum footprint, ensuring the lowest total life cycle cost.

Collaborator Baker Hughes is providing a pair of 3 MW gas compressors. GE has developed the turbine control/stop valve based on its existing commercial product line of steam valves. However, the STEP valves were modified from a design for advanced ultrasupercritical steam power plants to accommodate high operating temperatures and pressures for the sCO_2 system.

The facility includes high-temperature piping designed to ASME B31.1 code and fabricated with corrosion-resistant alloys well suited for service in extreme environments. Additional plant equipment includes low-temperature piping, cooling towers, coolers and valves as well as CO_2 supply and inventory control systems.

STEP DEMO

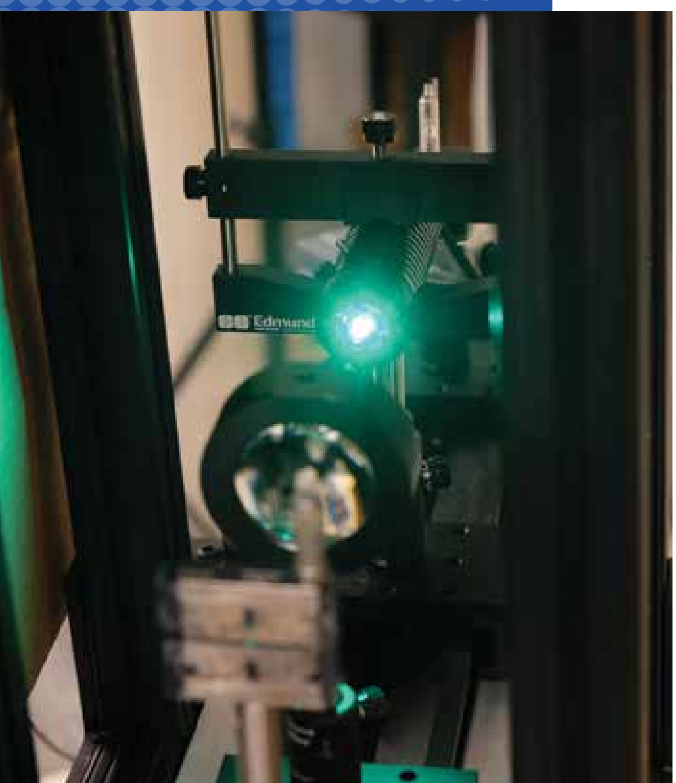
The team will initially test a simple recuperated cycle architecture. A second round of testing for a higher-temperature recompression cycle configuration will follow. Once these initial phases are complete, the reconfigurable facility can be adapted to perform validation testing of alternative component designs, cycle layouts or control logic. The system may also be extended to include additional components (such as thermal energy storage, oxy-combustion hardware) or to perform validation/qualification testing of full-scale waste heat recovery systems.

The STEP plant will demonstrate technology that could revolutionize the power plant industry. The high overall density of sCO_2 as a working fluid allows turbomachinery to be approximately one-tenth the size of conventional power plant components, providing the opportunity to shrink the environmental footprint and construction costs of new facilities. The technology can also use industrial waste heat, concentrating solar power or practically any other heat input to generate electricity. Like Franklin and Edison in their time, the STEP team is working toward the next generation of higher-efficiency, lower-cost electric power technology.

Questions about this article? Contact Allison at tim.allison@swri.org or call 210.522.3561 or contact McClung at aaron.mcclung@swri.org or call 210.522.2677.

Team leaders for the construction of the Supercritical Transformational Electric Power pilot plant building include C.J. Nolen, Katie McLoud, Eric Thompson, Dr. Tim Allison, Dr. Jeff Moore, Brittany Tom, Josh Neveu, Danny Deffenbaugh, Stefan Cich, Scott MacAdam of GTI, Jon Wade, Al Steiner, Dr. Aaron McClung and Trenton Cook. The 22,000-square-foot building was completed in June after 18 months of construction. The pilot plant facility is expected to be operational in the fall of 2021.

SwRI, UTSA CONNECT Through Research



DSCF8810

SwRI and UTSA are developing new laser-based techniques to study the extreme environment around a hypersonic flight body.

The University of Texas at San Antonio and SwRI are collaborating to understand hypersonic flight environments and reduce the costs of malaria treatments. The two research projects are supported by $125,000 grants from the SwRI-UTSA Connecting through Research Partnerships (CONNECT) Program.

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

HYPERSONIC FLIGHT

Dr. Nicholas J. Mueschke of SwRI's Mechanical Engineering Division and Dr. Christopher Combs of UTSA's College of Engineering are leading the project to develop unobtrusive diagnostics for hypersonic flight testing.

"The goal is to ultimately make full aerodynamic measurements in a truly representative hypersonic environment," Mueschke said. "These measurements will directly contribute to the design of next-generation hypersonic vehicles."

Hypersonic speed is defined as faster than five times the speed of sound, or greater than Mach 5. When something is flying that fast, the air moving around the object will chemically decompose. Some points behind the shockwave created by the vehicle are hotter than the surface of the sun. This strange environment causes whatever is traveling through it to heat up, and even melt and chemically react with the air.

Mueschke has researched the hypersonic environment extensively at SwRI using the Institute's two-stage light-gas gun system, which simulates hypersonic flight conditions and allows researchers to image objects in hypersonic flight.

By pointing a laser at just the right wavelength at the airflow around a hypersonic vehicle, certain molecules absorb the light briefly and then emit it in different colors, a process known as laser-induced fluorescence. Engineers determine how fast the molecules are moving by taking image after image of the emitted light as it moves.

This technique is significant, because intrusive velocity sensors would interfere with the airflow and flight environment. For the scale of the objects under test, the most relevant action is happening within a millimeter of the surface of the object in motion. Mueschke and Combs hope to determine the environment's pressure, temperature and density, to create a representative picture of the mysterious hypersonic flight environment.

"Hypersonic flight generally refers to speeds faster than five times the speed of sound, which is roughly 4,000 mph," Combs said. "At this speed it would take less than an hour to fly from New York to Los Angeles, and you could get from San Antonio to just about anywhere in the continental U.S., in less than 30 minutes. There's potential to truly revolutionize how we get from place to place. Add in the fact that all spacecraft return to

Earth at hypersonic speeds, along with the obvious defense applications, and you can see why hypersonics is a particularly hot topic right now."

Mueschke and Combs will make their initial measurements at Combs' laboratory at UTSA, which will soon include a Mach 7 Ludwieg Tube, a facility that can mimic some conditions of hypersonic flight. In later stages, the experiments will move to SwRI's two-stage light-gas gun system, which more closely simulates the hypersonic flight environment.*

MALARIA DRUGS

Shawn Blumberg of SwRI's Chemistry and Chemical Engineering Division and Dr. Doug Frantz of the Department of Chemistry within UTSA's College of Sciences are leading the second CONNECT project. They are developing techniques to synthesize highly potent derivatives of the antimalarial drug artemisinin to create a more powerful, cost-effective malaria treatment.

In 2018, Blumberg and Frantz collaborated in a project funded by the Bill & Melinda Gates Foundation to create a more efficient way to synthesize artemisinin, a drug derived from the sweet wormwood plant, Artemisia annua. While artemisinin is considered the most effective treatment for malaria, the mosquito-borne parasitic infection is becoming harder to battle as it becomes increasingly resistant to drugs like artemisinin.

"Malaria affects 200 million people every year and kills close to 400 thousand people, making it one of the world's deadliest infectious diseases," Blumberg said. "Unfortunately, the countries that have the highest incidence of malaria also tend to have lower resources and are significantly burdened by the cost of current and newer treatments."

Most artemisinin is still made from Artemisia annua, but this process is time-consuming, and crop yields are susceptible to weather patterns, insects and other factors. A newer semisynthetic development method involves inserting the plant's genes into a microorganism to produce an intermediate compound used to make artemisinin.

"Dr. Frantz and I were able to create artemisinic acid, which is the direct precursor to artemisinin," Blumberg said. Now, the two researchers are following up on their previous work by revisiting the pioneering work of Dr. Mitchell Avery at The University of Mississippi in the 1990s.

"Using the chemical technology that we developed, we can pivot the artemisinin synthesis to produce the same highly potent artemisinin derivatives that had previously been studied by Dr. Avery nearly 30 years ago," Blumberg said. "He was able to make several ultra-potent derivatives from various compounds, but it took multiple complex steps to accomplish that."

Using the much simpler synthesis technique created by Blumberg and Frantz, they plan to revisit these potent artemisinin derivatives to address the growing drug resistance in a cost-effective manner.

"Our combined expertise in synthetic chemistry and drug discovery will allow us to accelerate our discoveries at the bench into tangible bedside treatments for this devastating disease," Frantz said.

UTSA and SwRI are collaborating to synthesize a less expensive and more potent drug to treat malaria, one of the world's deadliest mosquito-borne diseases.

* See p. 2 for Hypersonics feature story.

10 COOL DISCOVERIES ABOUT PLUTO

Five years ago, after an epic 10-year voyage of more than 3 billion miles, the SwRI-led New Horizons mission made history. NASA's piano-sized spacecraft flew within 7,800 miles of Pluto revealing a surprisingly complex, geologically active surface. Scientists continue using New Horizons data to gain new insights about Pluto and Charon and to understand other Kuiper Belt objects.

1 For the first time ever, the surface of this distant planet was revealed in spectacular, colored detail. Pluto's surface includes towering mountains, giant ice sheets, pits, scarps, valleys and terrains seen nowhere else in the Solar System.

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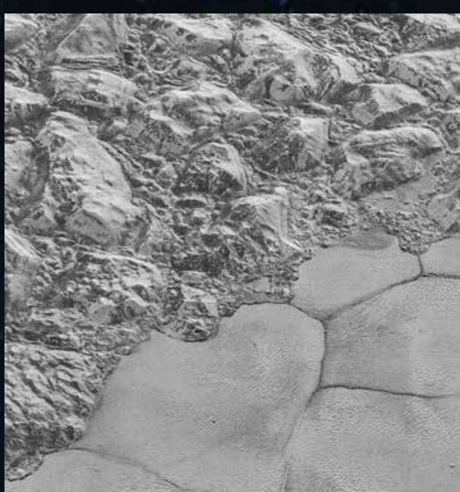
2 Like Earth, Mars and a handful of moons, Pluto hosts active, flowing glaciers. This 50-mile section of the Sputnik Planitia glacier is covered with thousands of pits and larger circular patterns on the nitrogen ice surface.



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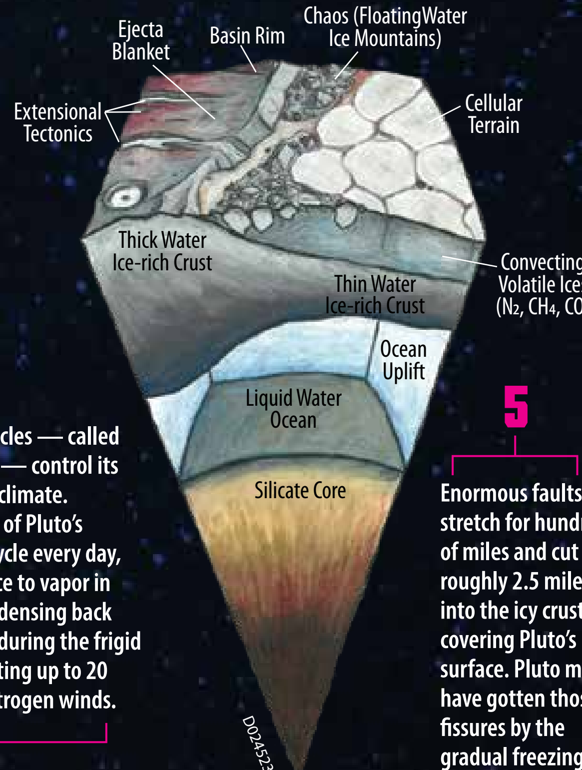
3 Pluto's winds explain the thousands of dunes that stretch 45 miles on the western edge of Sputnik Planitia. Dunes require small particles and sustained, driving winds to lift and blow specks of materials.



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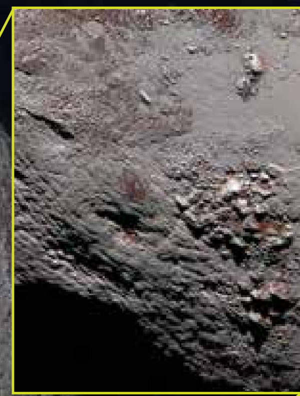
4 Pluto's climate cycles — called its beating heart — control its atmosphere and climate. The nitrogen ices of Pluto's Sputnik glacier cycle every day, subliming from ice to vapor in the sunlight, condensing back onto the surface during the frigid night and circulating up to 20 mile-per-hour nitrogen winds.

5 Enormous faults stretch for hundreds of miles and cut roughly 2.5 miles into the icy crust covering Pluto's surface. Pluto may have gotten those fissures by the gradual freezing of an ocean beneath its surface.

D024527

“IT’S CLEAR TO ME THAT THE SOLAR SYSTEM SAVED THE BEST FOR LAST. WE COULD NOT HAVE EXPLORED A MORE FASCINATING OR SCIENTIFICALLY IMPORTANT PLANET AT THE EDGE OF OUR SOLAR SYSTEM.”

— SwRI’s Dr. Alan Stern, New Horizons principal investigator



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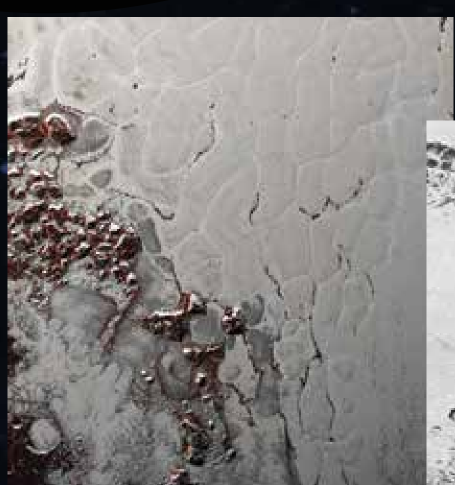
6 This close-up of Wright Mons, one of many potential cryovolcanoes spotted on the surface of Pluto, indicates the dwarf planet was, and may still be, volcanically active. West of Sputnik Planitia, scientists think ammonia-rich cryolava erupted and coated several thousand square kilometers in red-colored organic molecules.

D024529

7 Pluto’s largest moon Charon also features surprising geological features, indicating a geologically active past. An immense southern plain the size of California gives way to rugged terrain to the north, likely the result of freezing and expansion of an ancient ocean beneath Charon’s crust.

8 Zoom in on the surface of Sputnik Planitia and you will see a novel network of strange shapes churning the surface of the glacier. These six-mile polygons are evidence of Pluto’s internal heat trying to escape from beneath the glacier, creating bubbles of upwelling and down-welling nitrogen ice.



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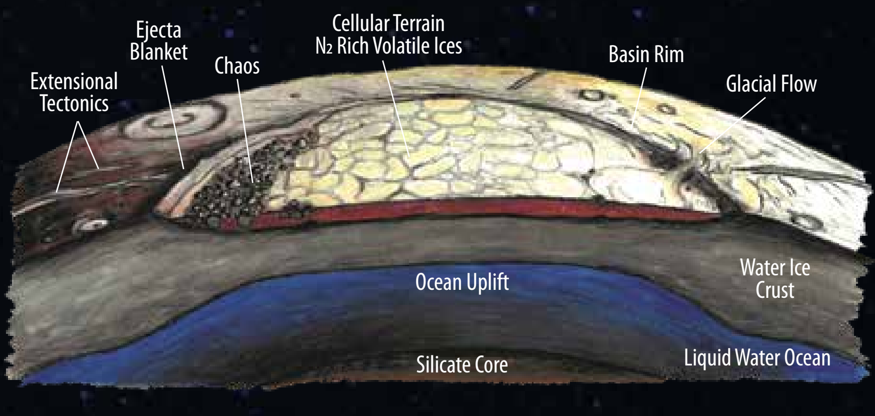
9 Small craters that are common to most planets are a rarity on Pluto. The dwarf planet features mostly large craters, indicating that the Kuiper Belt is home to few small objects, the building blocks for planets.



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10 A vast, liquid, water ocean may be sloshing beneath Pluto’s surface. Models indicate that the ocean may date back to the rapid, violent formation of the dwarf planet.

IMAGE COURTESY NASA/JHUAPL/SWRI/JAMES TUTTLE KEANE

S•P•A•R•T•A
Software Solution

Assessing Electronic Countermeasures to Help Save Lives

By Finley Hicks and Jarrett Holcomb

D024476

Imagine a battlefield scenario where a United States infantry squad is pinned down by enemy units. A couple of A-10 Warthogs quickly swoop in to provide air coverage and allow the soldiers to escape. American lives are saved, but what about the aircrew? Can they elude enemy forces and escape? A critical part of their air defenses is something known as electronic countermeasures (ECMs) or jammers. ECMs trick enemy radar, sending fake signals to confuse or deceive missile guidance systems.

Electronic countermeasures fall within the field of electronic warfare (EW), which includes techniques and technology to control the electromagnetic (EM) spectrum. Electronic warfare seeks to deny advantages to an opponent while ensuring friendly dominance in the EM spectrum. Critical aircraft defense systems use ECMs that emit electronic smoke screens to thwart radar or other detection systems, denying accurate targeting information to an enemy. Depending on the scenario, ECMs will create the illusion of multiple targets or make the real target disappear or move about randomly to protect aircraft from guided missiles. Jamming also creates radio signals to disrupt communications, creating electronic noise that degrades or denies targeting capabilities.

Fighter planes can be outfitted with underwing electronic attack pods, integrated systems, or can depend on standoff jammers, aircraft that patrol the air space to jam radar acquisition and tracking devices. As EW techniques become more complex, the time and cost of verifying system performance increases exponentially.
The most advanced commercially available test equipment has many limitations. Additionally, advanced test equipment cannot perform automated testing for the array of complex ECM patterns that must be analyzed to validate EW system requirements.

Southwest Research Institute has developed an advanced electronic warfare measurement and analysis system to cost-effectively address these shortcomings. The System Performance and Real Time Analysis (SPARTA) software tool is designed to evaluate systems to ensure that ECM technologies send the correct countersignal for a given radar cue to help ensure aircrew survivability during operations.

SPARTA SAVES LIVES

Current EW test systems struggle to achieve absolute certainty that jammer anti-radar systems are giving the correct ECM response for any given radar stimulus. With over three decades supporting electronic attack pod systems used to counter radars, SwRI found, in one typical example, that of 61 ECM parameters, only 24 were measurable using conventional testers. The team knew it must do better — the lives of U.S. aircrews were at stake, in addition to the ground forces they support. With that in mind, SwRI leadership invested nearly $4 million in internal funding to develop SPARTA.

This F-16 aircraft is outfitted with an ALQ-131 electronic attack pod to provide electronic warfare protection. Institute staff members have comprehensive background and expertise in active and passive electronic warfare systems.

SwRI developed techniques to measure every parameter — even in a highly congested and noisy electromagnetic spectrum — which is visualized and displayed via interactive videographs. SPARTA separates signal(s) of interest and multiple false targets (MFTs) in the spectrum, allowing MFTs to be analyzed together or individually. In one example, SwRI researchers demonstrated SPARTA for an Air Force customer, analyzing four complex ECM techniques to assess combined range, velocity and amplitude modulation characteristics. AF technicians measured parameters using SPARTA and then compared the results to parameters that could be measured using their existing test equipment. All parameters were accurately measured using SPARTA, while only 43% were measurable using existing test equipment.

SPARTA's software system is hardware agnostic, allowing it to ingest radio frequency data collected by existing test equipment. The system flags out-of-limit parameters, identifying problems for engineers to resolve. In addition, SPARTA extracts, isolates and analyzes signals of interest within highly congested spectra, achieving greater than 99% pulse detection rate with better than 10 nanoseconds time accuracy.

SPARTA EVOLUTION

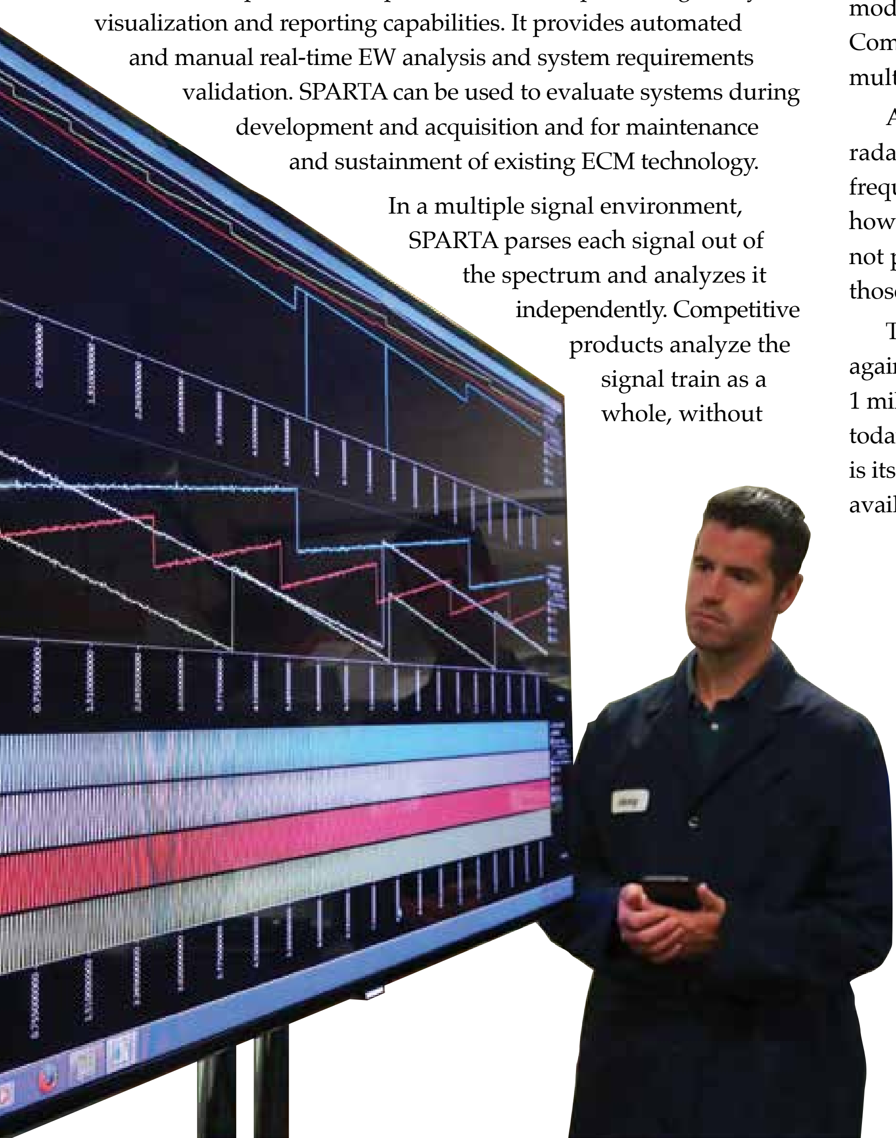
SPARTA represents a leap forward in ECM processing, analysis, visualization and reporting capabilities. It provides automated and manual real-time EW analysis and system requirements validation. SPARTA can be used to evaluate systems during development and acquisition and for maintenance and sustainment of existing ECM technology.

In a multiple signal environment, SPARTA parses each signal out of the spectrum and analyzes it independently. Competitive products analyze the signal train as a whole, without the capability to identify and analyze individual signals within the train. For each signal within the radio frequency (RF) spectrum, SPARTA can isolate and analyze range, velocity, amplitude modulation (AM), percent jamming and intra-pulse modulation. Competitive products are unable to provide these data from multiple signal environments.

A typical real-world EW analysis scenario contains multiple radar signals and multiple ECM false targets. SPARTA measures frequency on a pulse-by-pulse basis. Competing products, however, measure frequency on an interval basis. As a result, it is not possible to determine the frequency of individual pulses using those products.

To meet complex test needs, SPARTA has been thoroughly tested against many realistic environments, such as 50 emitters with over 1 million pulses per second within a 500 MHz span, to replicate today's congested electromagnetic environments. A key advantage is its ability to harness "big data," assessing large amounts of available data for relevance. The faster the information is generated,

IMAGE COURTESY U.S. AIR FORCE



SPARTA automatically validates signal requirements for radar and electronic countermeasure systems. The system is capable of discovering possible problems in aircraft attack pods that could not be detected with previous test systems.

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The Air Force's F-16 Fighting Falcon relies on airborne electronics countermeasure pods to defeat anti-aircraft defense systems. SPARTA helps resolve software issues associated with these pods, such as the ALQ-184 pod shown here.

D015341_9

the faster it must be collected and processed. SPARTA provides the user with out-of-limit notifications, error tables and visualization presented through interactive videographs.

SPARTA measures parameters that competing products cannot while providing better visualization, allowing less experienced personnel to perform analyses. In addition, the system provides more than just an automated pass or fail of individual parameters; it also allows engineers to determine the cause of ECM failures. This allows a quick diagnosis of failures early in the acquisition or sustainment processes, saving total costs while accelerating deployment in military aircraft. SPARTA is more than just a testing tool — it also functions as a visualization platform for customized evaluations, simulation and reporting.

SPARTA's analysis package can run on any standard personal computer with a Windows operating system. The tool ingests radar and ECM sample data and automatically extracts pulse and signal information. It then separates the signals, isolating those of interest. SPARTA is capable of either displaying these ECM patterns along with the user-defined limits or performing automated testing and providing summary information at the end of a series of tests. Other commercially available test equipment cannot extract and isolate radar and ECM signals.

CURRENT, FUTURE APPLICATIONS

SPARTA currently serves as a key evaluation tool for four different U.S. Air Force systems at four different Department of

ECMs emit electronic smoke screens to impede radar and other detection systems, denying accurate targeting information to an enemy. Jamming creates radio signals to disrupt communications, creating electronic noise that degrades or denies targeting capabilities.

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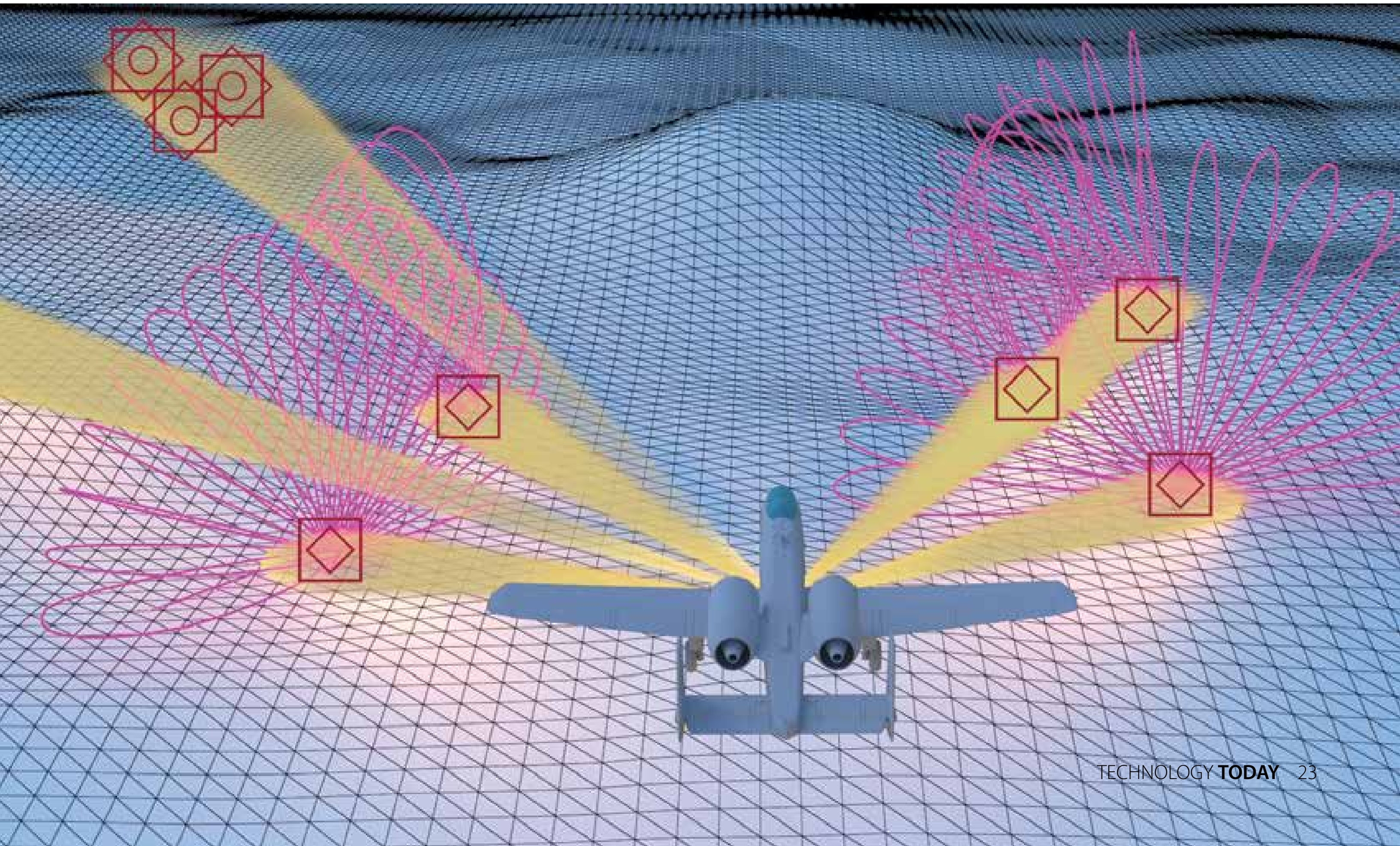


Defense locations. In addition, the Air Force is considering its use to inform the ECM acquisitions process. Jammer manufacturers also have interest in using SPARTA to speed development of their products. SwRI recently demonstrated SPARTA in a Navy facility and is discussing using the measurement capability for several advanced EW labs, chambers and test ranges.

SPARTA's modular architecture supports expanding capabilities beyond just testing. As an example, SPARTA's Pulse Descriptor Word (PDW) Streaming Module, which describes the characteristics of a radar signal, is currently being ported to two different multifunction AF EW systems. Because the module extracts high-fidelity pulse characteristics from complex, congested spectra so effectively, it is being integrated as an open architecture wideband receiver to perform radar warning and signals intelligence applications.

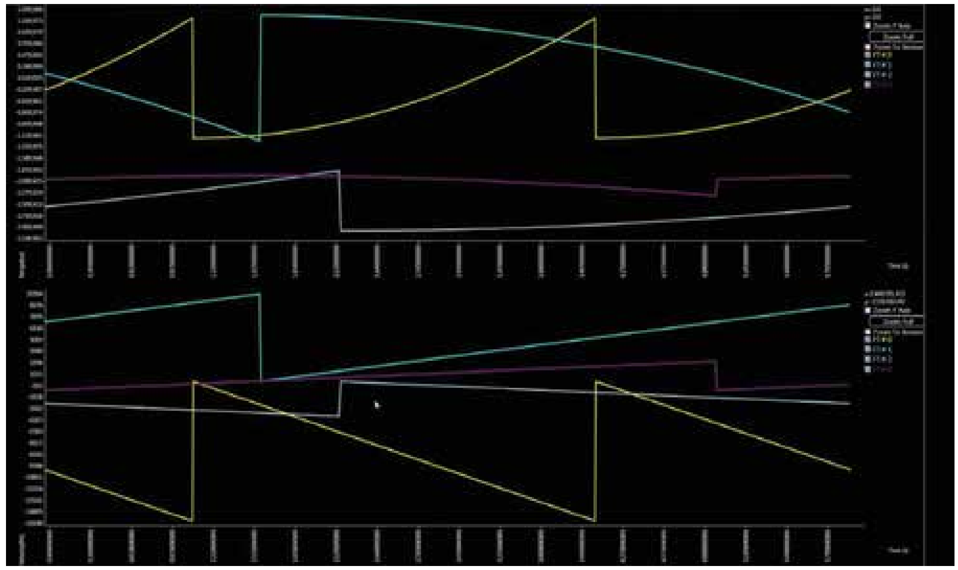
Some customers want on-site analyses in real time. SwRI is investigating moving from near real-time to real-time processing by using firmware to support the software analyses. Software processing is limited by current PC speeds. SwRI engineers are working on upgrades to decrease the processing time required for all analyses to expand it into the realm of real-time operations.

SwRI's EW specialists are continuing to advance SPARTA technology for new applications to help protect warfighters in evolving situations.

Questions about this article? Contact Hicks at finley.hicks@swri.org or Holcomb at jarrett.holcomb@swri.org or call 478.328.7974.

As Technology Today was going to press, the SPARTA system received a 2020 R&D 100 award. R&D World magazine recognizes the 100 most significant innovations every year with these awards.

2020 R&D 100 WINNER



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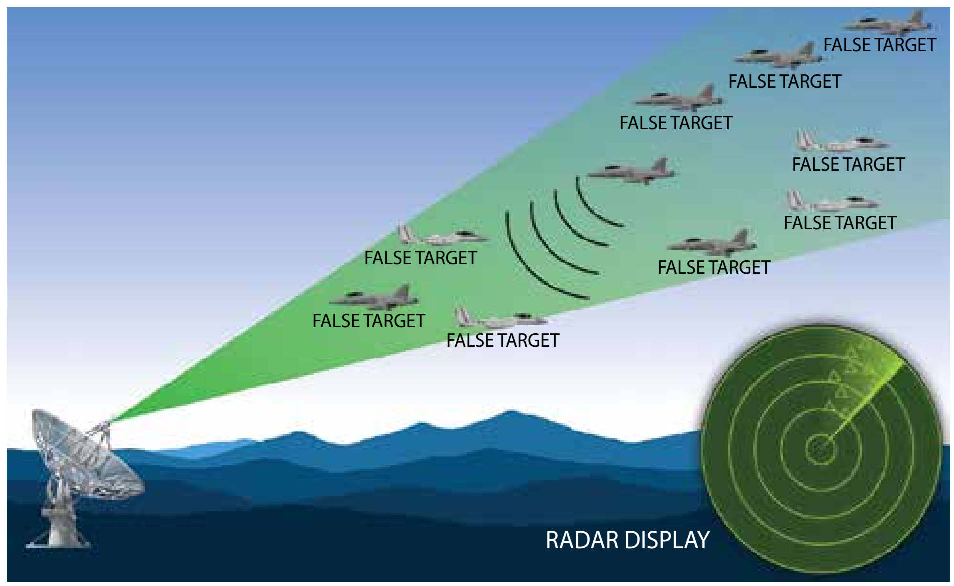
SPARTA analyzes multiple false target EW signals independently and displays them in different colors.



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Electronic countermeasures are designed to thwart radar and other detection systems and deny accurate targeting information to an enemy. This scenario shows how EW signals can create the illusion of multiple false targets.

ABOUT THE AUTHORS

Finley Hicks (left) is a staff engineer in the Defense and Intelligence Solutions Division, assigned to SwRI's Warner Robins office in Georgia. He is a specialist in radio frequency communications, automatic test systems and electronic warfare. Jarrett Holcomb is a research engineer also working in SwRI's Georgia office. He develops radar processing hardware and software for RF countermeasures systems and radar electronic support receivers.

D024477

LASER COATING REMOVAL ROBOT WINS R&D 100 AWARD

Stripping paint and other coatings from full-body aircraft is required multiple times over the course of an aircraft's lifespan. Traditional coating removal processes are costly, time-consuming and potentially hazardous to workers and the environment. An efficient, robot-guided laser developed by Southwest Research Institute and XYREC is revolutionizing that.

The laser coating removal (LCR) robot, recognized by R&D World magazine as one of the 100 most significant innovations of 2020, is the only robotic aircraft coating removal process that can cover the full range of aircraft sizes, coatings, colors and substrates on a broad range of defense and commercial aircraft, from fighter jets and helicopters to cargo planes.

"The technology is unique, fast and more environmentally friendly than traditional processes," said Paul Evans, Director of SwRI's Manufacturing and Robotics Technologies Department. "LCR uses the largest specialized commercially available CO_2 laser on the largest mobile manipulator to accurately control the coating removal process."

Controlled by a proprietary computer vision system with a patented polygon scanner, the robot uses a CO_2 laser to combust and ablate paint. Effluent is immediately vacuumed from the surface and filtered.

A built-in, closed-loop, color recognition and control system allows it to strip both metal and composite surfaces accurately, making selective stripping possible. Software guides the robot, allowing LCR to closely follow the three-dimensional contour of an aircraft. The fully autonomous system can be managed by a single operator and can work independently or in tandem with another LCR.

"Coating removal is a critical and necessary operation needed for all aircraft at multiple times over their service life," said Steve Dellenback, vice president of SwRI's Intelligent Systems Division. "We worked closely with XYREC engineers to develop this innovative system."

The LCR system is faster than traditional processes, and testing has shown a drastic reduction in costs per aircraft, while minimizing reliance on support facilities and reducing aircraft downtime. It is compatible with all types of aircraft and helicopters and can also remove coatings from a range of off-airframe parts.

"We are committed to continuously improving the world around us through innovation," said SwRI President and CEO Adam L. Hamilton, P.E. "It's an honor to see the Institute recognized for those efforts at what's widely known as the 'Oscars of Innovation.'"

The R&D 100 Awards are among the most prestigious innovation awards programs, honoring the top 100 revolutionary technologies each year since 1963. Recipients hail from research institutions, academic and government laboratories, Fortune 500 companies and smaller organizations. Since 1971, SwRI has won 47 R&D 100 Awards, including another 2020 award for the SPARTA system (see feature story, p. 20).

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SLED Tackles New Challenges

SwRI engineers added two types of oil to tanks of water to train machine learning algorithms to detect oil under various lighting and environmental conditions.

SwRI is continuing to develop new applications for its Smart Leak Detection system (SLED), which autonomously finds liquid and gaseous leaks of hazardous materials. The award-winning SLED technology collects inputs from low-cost optical sensors and applies machine learning techniques to reliably detect the chemical "fingerprint" of methane gas escaping from pipelines as well as liquid leaks on solid surfaces such as soil, gravel, sand and now water.

QUANTIFYING METHANE LEAKS

SwRI is continuing the development of SLED/M technology to quantify fugitive methane emissions through a project funded by DOE's Office of Fossil Energy and managed at the National Energy Technology Laboratory (NETL).

SwRI developed SLED/M to accurately detect small methane leaks that typically go unnoticed along natural gas pipelines and in compressor stations. Over the next year, SwRI will enhance the algorithms to quantify these leaks, adding a low-cost longwave infrared thermal imager and a lightweight lidar (light detection and ranging) system to the existing midwave infrared thermal imager. Natural gas leaks are typically measured from a single point using a diode laser absorption spectroscopy instrument, which must be moved to several positions to gather data.

"Conventional methods can be costly and time-consuming, and they often fail to pinpoint leak sources," said Heath Spidle, SwRI project lead. "This new technology will enhance SLED/M's proven methane detection algorithms with a physics model using 3D visuals to measure the volume of fugitive methane emissions."

The DOE is particularly interested in developing scalable quantification technologies, partly in response to a recent Stanford study that found only one in nine methane detection technologies are reliable.

"This newly added task will continue the important research being done at SwRI," said Joe Renk, the DOE NETL senior federal project manager overseeing the work. "The use of gas imagers and lidar with machine learning presents an opportunity to develop cost-effective solutions to accurately quantify natural gas flow rates."

SLED/W FINDS OIL ON WATER

SwRI is using internal funding to expand SLED to find leaks on water. With over 80,000 miles of oil pipelines across the United States, many waterways are at risk for environmental damage from incidents such as the 2010 Kalamazoo Spill, which cost more than $1.2 billion and took three years to clean up. Monitoring waterways near oil pipelines is costly and time-consuming using conventional solutions that rely on satellite remote sensing or laser spectroscopy.

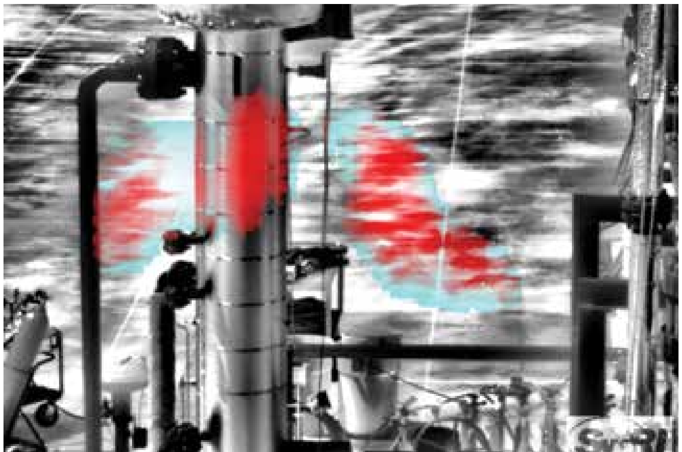
SwRI addresses these challenges with a SLED/Water system, which uses algorithms to process data from visual and thermal cameras affixed to aircraft, stationary devices or watercraft. This machine learning-based solution can detect and monitor oil leaks before they become major threats to lakes, rivers and coastal areas.

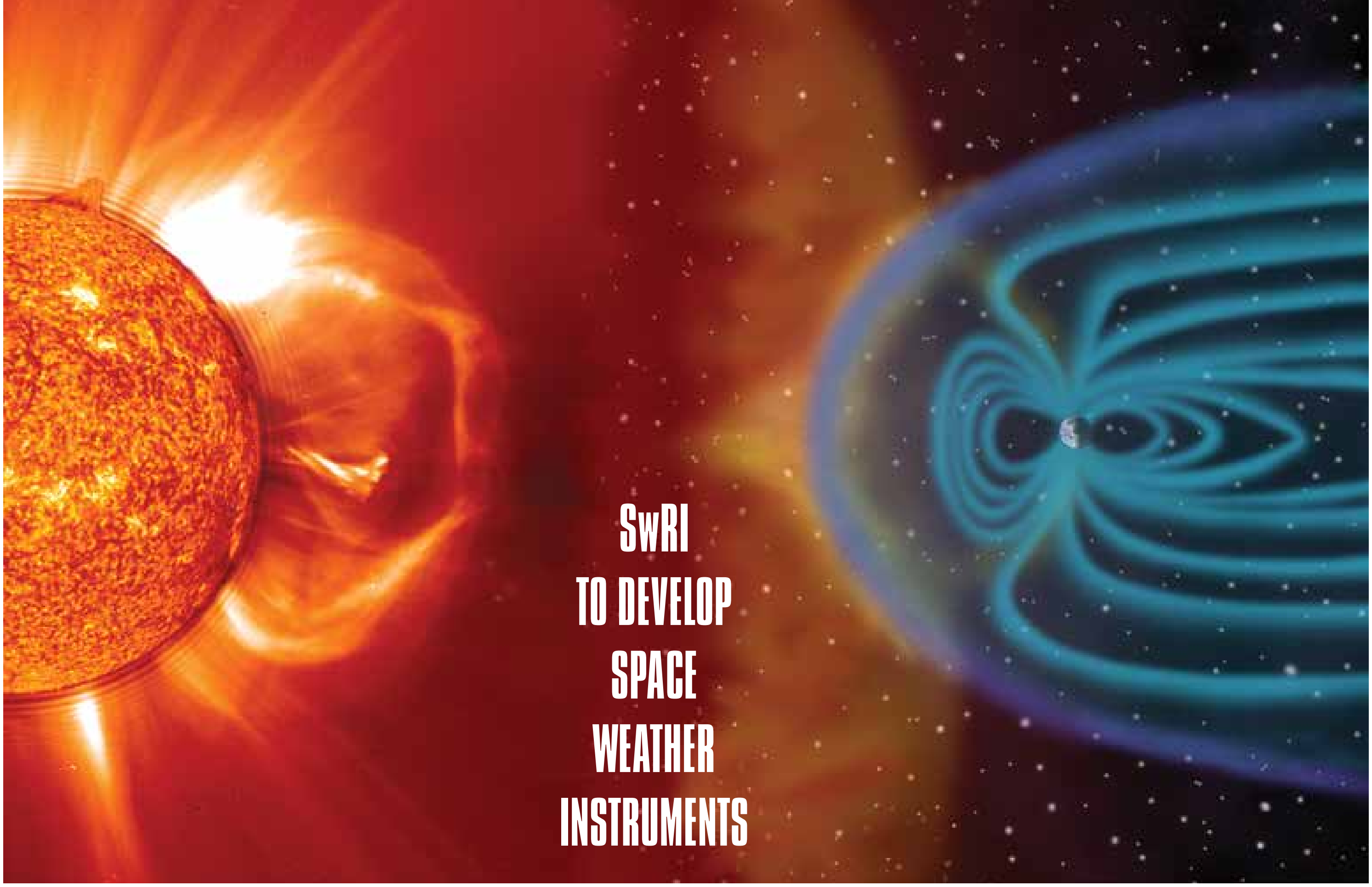
"SLED/W was able to detect two different types of oil with unique thermal and visible properties," said Ryan McBee, who led the project. "SLED/W showed positive initial results, and with further data collection, the algorithm will handle more varied external conditions."

SwRI applied a multidisciplinary approach to develop SLED/W. Computer scientists teamed with oil and gas experts from the Institute's Mechanical Engineering Division to train algorithms to recognize the unique characteristics of oil on water. For example, oil can spread over water or blend with it, making it difficult for sensors to discern under various lighting and environmental conditions.

By combining thermal and visible cameras, SLED/W analyzes scenes from different perspectives. Visible cameras are limited by glare and have difficulty capturing transparent thin oils that blend with water. Thermal vision requires heat differences to discern features, which lead to false positives near animals and other warm objects. By combining thermal and visual images into the machine learning system, algorithms can choose the most relevant information, mitigating the weaknesses of each sensor.

SwRI will quantify fugitive methane flow rates using machine learning, thermal imaging and lidar technology. A midwave infrared imager captured this methane plume (red and blue).





D024516

IMAGE COURTESY NASA

SwRI TO DEVELOP SPACE WEATHER INSTRUMENTS

NASA, on behalf of the National Oceanic and Atmospheric Administration (NOAA), recently awarded SwRI two contracts to develop a magnetometer and a solar wind plasma sensor for a satellite mission dedicated to tracking space weather. Both instruments are part of the satellite's solar wind instrument suite, which measures the characteristics of the solar wind plasma that interacts with the Earth's geomagnetic environment.

"The satellite will collect solar wind data and coronal imagery to support NOAA's mission to monitor and forecast space weather events," said Dr. Roy Torbert, a program director in SwRI's Earth, Oceans and Space Department at the University of New Hampshire in Durham and principal investigator of the magnetometer. "Space weather refers to the variable conditions on the Sun and in space that can influence the performance of technology we use on Earth, such as electrical power grids, and disrupt satellite-based communication and navigation systems."

Scheduled to launch in 2024, the Space Weather Follow-On Lagrange 1 (SWFO-L1) satellite will orbit the Sun at approximately 1.5 million kilometers from Earth, a point known as L1. Instruments onboard the satellite will make local measurements of the solar wind thermal plasma and magnetic field. It also carries a compact coronagraph instrument to detect coronal mass ejections and an instrument to measure high-energy particles.

SWFO-MAG

"The magnetometer instrument, known as SWFO-MAG, provides key data about the solar wind as it approaches Earth," Torbert said. "The data will be available to the science community but are targeted to the Space Weather Prediction Center."

SwRI will work with UNH to design, develop, fabricate, integrate, calibrate and evaluate the magnetometer. The team will also support launch and on-orbit check-out of the instrument, supply and maintain the instrument's ground support equipment and support NOAA's mission operations center as needed. SWFO-MAG includes two three-axis magnetometers and associated electronics to measure the vector interplanetary magnetic field.

SWiPS

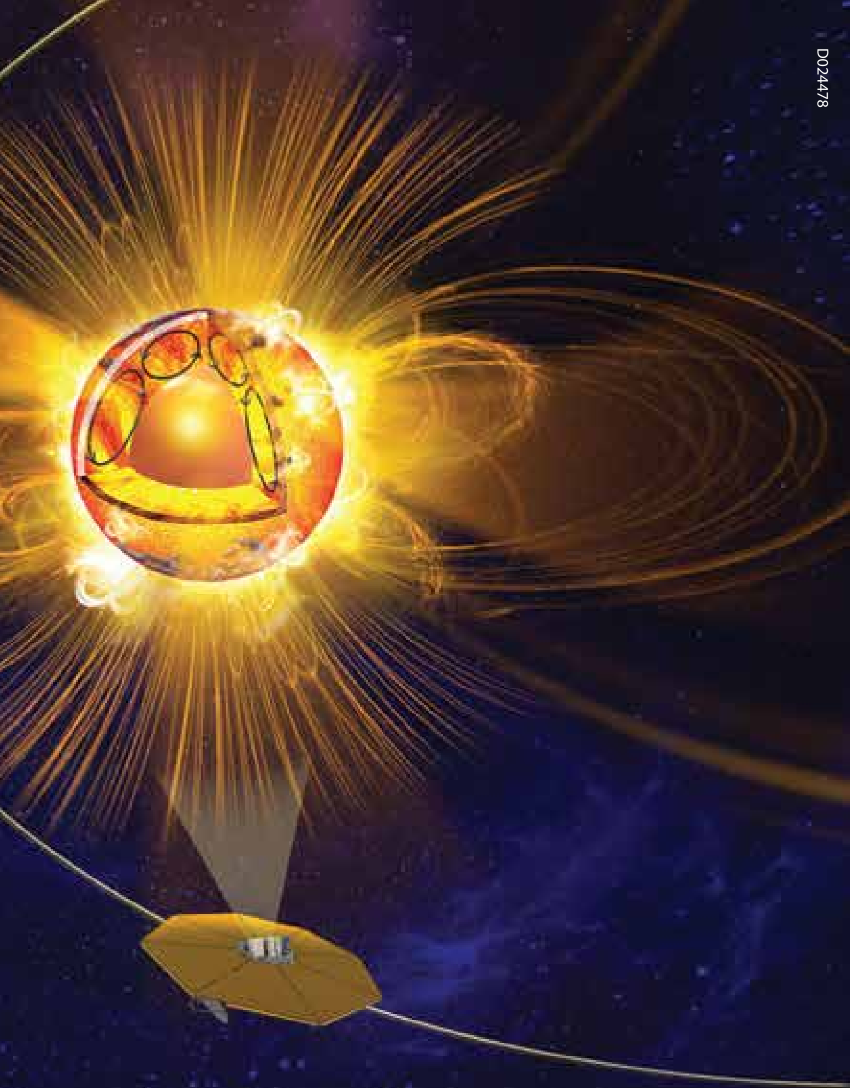
"The Solar Wind Plasma Sensor (SWiPS) is based on the Ion and Electron Sensor flown on ESA's comet mission, Rosetta," said Dr. Robert Ebert, an SwRI principal scientist and SWiPS principal investigator. "The compact design, low resource requirements and ideal data production make this a well-suited instrument for the SWFO-L1 mission."

A traditional strength of SwRI's Space Science and Engineering Division is the design and fabrication of instruments for the in-situ measurement of space plasmas. These dilute ionized gases populate the immediate space environments of the Earth and other Solar System bodies as well as interplanetary space.

NASA is planning to launch SWFO-L1 in 2024 as a rideshare with the Interstellar Mapping and Acceleration Probe (IMAP) mission. SwRI also plays a key role in that mission, managing the payload and providing scientific instruments to help analyze and map particles streaming from the edge of interstellar space and to help understand particle acceleration near Earth.

Developing High-Latitude Mission to the Sun's Poles

SwRI also contributing to two additional mission concept design studies



An SwRI proposal to study the Sun's poles — considered among the last unexplored regions of the Solar System —is one of five science investigations selected as a possible future NASA mission.

Dr. Don Hassler, a program director at SwRI's Boulder office, is the principal investigator for Solaris. This proposed solar polar Medium-Class Explorers (MIDEX) mission could revolutionize our understanding of the Sun by addressing fundamental questions that can only be answered from a polar vantage point. NASA has approved a $1.25 million, nine-month contract for Phase A concept design studies and analyses to develop the mission that would visit this region for the first time since the 1990s.

"Solaris would explore one of the last unseen places in the Solar System, the poles of the Sun," Hassler said. "The Ulysses spacecraft visited the region but did not have remote sensing instruments onboard to probe the Sun's polar magnetic field or surface/subsurface flows."

To get to the Sun's poles, Solaris would first travel to Jupiter and use Jupiter's gravity to slingshot out of the ecliptic plane and fly over the Sun's poles at 75 degrees latitude. Imaging the poles of the Sun from such high latitude promises to reveal clues to understanding how the Sun's polar magnetic fields and flows shape the solar activity cycle.

"Solaris would spend more than three months over each pole of the Sun, obtaining the first continuous, high-latitude, months-long studies of the Sun's polar regions," said Hassler. "With focused science and a simple, elegant mission design, Solaris would also provide enabling observations for space weather research, such as the first polar views of coronal mass ejections, energetic events that spew highly magnetized plasma from the solar corona into space, causing radio and magnetic disturbances on the Earth."

The proposed spacecraft would be provided by Ball Aerospace, and the payload is expected to include a compact Doppler magnetograph to study the polar magnetic fields and subsurface flows, a white light coronagraph to image the solar corona from the poles, and an extreme ultraviolet instrument to image the million degree solar surface of the poles.

SwRI also supports two other missions funded for Phase A concept design studies, the Auroral Reconstruction CubeSwarm (ARCS) and the Solar-Terrestrial Observer for the Response of the Magnetosphere (STORM) mission proposals. SwRI would manage the ARCS mission for the principal investigator, Dartmouth Professor Kristina Lynch, and provide a solar wind instrument for the STORM mission, led by David Sibec of the Goddard Space Flight Center.

ARCS proposes to explore the processes that contribute to auroras at size scales that have been rarely studied — at the intermediate scale between the smaller, local phenomena leading directly to the visible aurora and the larger, global dynamics of the space weather system coursing through the Earth's ionosphere and thermosphere. The mission would deploy an innovative, distributed set of sensors via 32 CubeSats and 32 ground-based observatories to provide a comprehensive picture of the drivers and response of the auroral system.

For STORM, SwRI would provide a next generation of the Ion and Electron Sensor that flew on the Rosetta mission. This mission would provide the first-ever global view of our vast space weather system in which the constant flow of particles from the Sun — known as the solar wind — interacts with Earth's magnetosphere and improve our ability to forecast the harmful effects of this interaction on society and technological infrastructure.

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SwRI ROBOTIC SYSTEM INSPECTS TIGHT SPOT

SwRI has been awarded a $1.3 million project from Washington River Protection Solutions (WRPS), a contractor to the U.S. Department of Energy (DOE), to build a robotic system to inspect the bottoms of massive underground double-shell tanks at the Hanford Site. The design phase of the project was completed in 2019.

The site stores chemical and radioactive waste in million-gallon tanks that hold waste in an inner vessel encased in a secondary shell to further protect the surrounding environment. The tanks must be inspected regularly, but there are no commercially available technologies for inspecting the vessel bottoms due to access restrictions.

"The biggest challenge for inspection is the bottom of these vessels," said Dr. Adam Cobb, an SwRI principal engineer. "While WRPS performs visual and ultrasonic inspection of the accessible portions of the vessels, our tool is unique in that it uses ultrasonic guided waves. Our sensor is placed in an accessible location, and we are able to inspect the bottoms of the vessels where there is no direct access."

The guided wave sensor is paired with a robotic delivery system to position the sensor within the harsh environment. The robotic inspection system is designed to identify flaws in the carbon-steel tanks while operating in the 30-inch space between the primary and secondary vessels.

"Our robotic inspection system uses SwRI-developed guided wave inspection technology to nondestructively find defects in the metal so mitigation steps can be taken," Cobb said. "Sound waves travel down the primary wall into the vessel bottom; the inspection system listens for the sound waves to reflect from any damage, such as cracks or corrosion."

The robot housing the system is five feet long but narrow, allowing it to be lowered into the space between the primary and secondary tanks and then expanded to perform the inspection.

Construction of the inspection system is underway, with delivery planned for early 2021.

Characterizing Near-Earth Asteroids

An SwRI scientist is helping NASA observe and characterize near-Earth objects (NEOs) that could pose a threat to Earth or have potential for further exploration. Dr. Tracy Becker is part of an international team of scientists using data from the Arecibo Observatory in Puerto Rico to study nearby asteroids and comets through a $19 million grant managed by the University of Central Florida (UCF).

"We are looking at the trajectory, spin, shape, mass, composition and size of NEOS, which allows us to look forward in time and understand if they pose a future impact risk to Earth," said Becker, a co-investigator on the project. "The idea is that if an impact hazard is discovered far enough in advance, you can potentially avert that risk, perhaps by nudging the asteroid's orbit to a safer distance."

Arecibo is home to one of the most powerful and sensitive radio telescopes in the world. The active radar system emits a radio signal toward its target and receives the reflected radio waves back using spherical dishes to characterize these relatively small objects.

In 2005, Congress prioritized this type of research, directing NASA to find and characterize at least 90 percent of near-Earth objects larger than 150 yards in diameter — about 50 percent larger than a football field — by 2020.

"The data are also significant for identifying asteroids that may be of interest for future exploration," Becker said. "For example, Arecibo did a great job of characterizing asteroid Bennu, data critical to NASA's OSIRIS-REx mission, which will collect a sample from the asteroid's surface this year. There's even interest in mining useful resources available on these objects, but we have to know a lot more about them."

IMAGE COURTESY JUAN ALCAIDE231/CC BY-SA 4.0   D024407_7270c

TARGETING STELLAR PHOSPHORUS FOR LIFE

An SwRI scientist has identified stellar phosphorus as a probable marker in narrowing the search for life in the cosmos. She has developed techniques to identify stars likely to host exoplanets, based on the composition of stars known to have planets, and proposes that upcoming studies target stellar phosphorus to find systems with the greatest probability for hosting life as we know it.

"When searching for exoplanets and trying to see whether they are habitable, it's important that a planet be alive with active cycles, volcanoes and plate tectonics," said SwRI's Dr. Natalie Hinkel, a planetary astrophysicist and lead author of a new paper about this research in the Astrophysical Research Letters. "My coauthor, Dr. Hilairy Hartnett, is an oceanographer and pointed out that phosphorus is vital for all life on Earth."

Current technology cannot measure the composition of exoplanets, but it's generally assumed that their compositions mirror those of their host stars. Scientists can measure the abundance of elements in a star spectroscopically and can infer what a star's orbiting planets are made of using the stellar composition as a proxy. But there's very little stellar phosphorus abundance data because it's detected in a region of the light spectrum not typically observed: at the edge of the optical (or visual) wavelengths of light and infrared light.

"Our Sun has relatively high phosphorus and Earth biology requires a small, but noticeable, amount of the element," Hinkel continued. "So, on rocky planets that form around host stars with less phosphorus, it's likely that the element will not be available for potential life on that planet's surface. Therefore, we urge the stellar abundance community to make phosphorus observations a priority in future studies and telescope designs."

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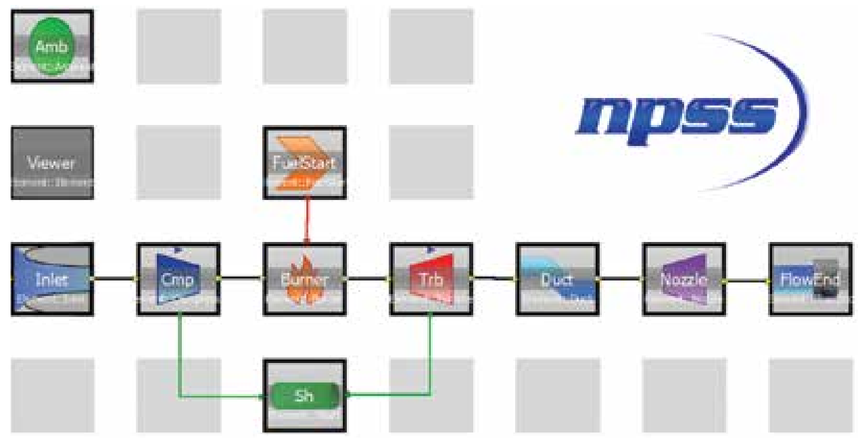
IMAGE COURTESY NASA/JPL-CALTECH



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Major Updates to NPSS Software

SwRI has released a new, updated version of the Numerical Propulsion System Simulation (NPSS®) software. NPSS has a new user-friendly interface that reduces the amount of time needed to learn the software, and new functions streamline the design process.

Engineers use this design and simulation tool to model rocket engines, jet engines, turbomachinery, environmental control systems, advanced power cycles including supercritical carbon dioxide (sCO_2) cycles and other technologies beneficial to the aerospace and energy industries.

"NPSS has always been an excellent tool for engineers and developers," said Charles Krouse, an SwRI group leader. "This new version introduces several new features that improve usability, including an integrated development environment, updated user guides and new example models."

Developed in the 1990s by the NASA Glenn Research Center, NPSS has become the leading aerospace software package for simulating and designing propulsion systems. SwRI has managed the NPSS Consortium since 2013, supporting the NPSS user community with new software capabilities, improved usability and technical support. Key features of NPSS include a standard library of thermodynamic databases, standard elements for engine cycle models, example engine models, interfacing examples, completely customizable elements and a robust solver.

"We also updated the NPSS library of element, model and interface examples," Krouse said.

The updated software is licensed through SwRI and available on its NPSS webpage. The new NPSS integrated development environment, NPSS IDE, provides an intuitive modeling environment without sacrificing the versatility of NPSS. IDE helps users develop, interrogate and run models, as well as view results.

D024513

CHARACTERIZING A TRANS-NEPTUNIAN BINARY LOCKED IN A TIGHT ORBIT

SwRI scientists collaborated with a network of citizen scientists to characterize the close binary nature of a trans-Neptunian object (TNO). This population of small icy bodies — which includes Kuiper Belt, scattered disc and detached objects — orbit the Sun at a greater average distance than Neptune.

Binary TNOs occur when two of these objects orbit each other as they circle the Sun. Rodrigo Leiva and Marc Buie discovered this TNO in a particularly close gravitational configuration using stellar occultation. When an object passes between Earth and a distant star, it hides, or "occults," the star from view. Observers located in the path of the object's shadow can record the star blinking out and reappearing.

"In this instance, the occulted star also turned out to be a binary system. Binary stars are not unusual and binary objects are not unusual," Buie said. "But it is unusual that we had a binary TNO occulting a binary star."

The discovery of the new TNO was made possible by the Research and Education Collaborative Occultation Network (RECON), a collection of 56 observation stations stretching from Yuma, Arizona, to Orville, Washington. The NSF-funded project provides each station with an array of observation equipment, including 11-inch telescopes. Trained high school teachers and their students make the observations.

The TNO's two components are only 350 kilometers (217 miles) apart. The majority of observed binary TNOs are separated by 1,000 kilometers or more. Most Solar System models indicate that binaries are very common, particularly close binaries such as this one, but they can be difficult to characterize.

"Our overarching aim is to know how common close binary TNOs are," Buie said. "Is this object one in a million or just like 90% of them? This is fueling our knowledge for building better models of how the Solar System formed."

SEND IN THE DRONES

SwRI is offering new drone-based, remote-sensing techniques to digitally map and model exposed geologic structures, or outcrops, to better understand subsurface structures associated with petroleum and water reservoirs. Through digital photogrammetry — reconstructing real-world objects in 3D from overlapping digital images — SwRI can extract accurate and reliable geologic information.

"These new techniques allow us to create 'virtual' outcrops or digital outcrop models, a digital 3D representation of the outcrop surface," said Adam Cawood, who recently joined SwRI after receiving his Ph.D. from the University of Aberdeen (United Kingdom). "We are developing new drone-based, remote-sensing techniques to allow cost-effective 3D modeling and analysis of the Earth's surface. The information we extract from these models will help us to better understand conditions below ground."

The technique allows computer-based geological interpretation and data extraction where conventional fieldwork may be impractical or unsafe. Drone-based techniques have the potential to substantially increase the amount of geological data that can be collected from field localities.

By using this data-driven approach, SwRI geologists will be able to capture the statistical properties of fault and fracture networks to study geological settings below ground. This will improve the understanding of hydrocarbon reservoirs, aquifers and potential sites for geological storage.

This effort uses automated feature detection to improve the efficiency, reliability and speed of digital data collection. Digital data are benchmarked and tested against traditional measurements to ensure that automated extraction provides robust results.

"We see this revolutionary technique as a way to supplement rather than replace traditional field-based data collection and analysis," said Dr. David Ferrill, an SwRI geologist and Institute scientist. "This new approach enhances our already robust capabilities for field-based structural geology and quantitative structural analysis."

D024489/ D021916

First Mission to the Trojan Asteroids Reaches Milestones

The SwRI-led Lucy mission continues to move forward, passing two critical mission milestones in August in preparation for its October 2021 launch. This NASA Discovery Program class mission will be the first to explore the Trojans, ancient small bodies that share an orbit with Jupiter and hold important clues to understanding the early Solar System.

During this part of the mission's life cycle, the spacecraft is completed, and the instruments are integrated into the spacecraft and tested. Next summer, the spacecraft will be sent to NASA's Kennedy Space Center in Florida for integration with the launch vehicle.

"Each phase of the mission is more exciting than the last," said Lucy Principal Investigator Dr. Hal Levison of SwRI. "While, of course, Lucy still has several years and a few billion miles to go before we reach our real goal — exploring the never-before-seen Trojan asteroids — seeing this spacecraft come together is just incredible." Assembly, Testing and Launch Operations (ATLO) has begun at Lockheed Martin Space in Littleton, Colorado, in preparation for the launch window opening on October 16, 2021.

"We've had to revise the ATLO schedule to give the components affected by COVID-19 restrictions a bit more time before they will be integrated onto the spacecraft," says Lucy Payload Deputy Project Manager John Andrews of SwRI. "Through a lot of hard work and ingenuity, the Lucy team is on schedule to ship the spacecraft to Kennedy Space Center as planned next July."

After launch, Lucy will still have a long path ahead flying out to the distance of Jupiter to make close flybys past a record-breaking number of asteroids. The spacecraft will encounter the first of its eight targets, a main belt asteroid, in 2025. Lucy will reach the first of seven Trojan asteroids in 2027 and fly past the final binary pair in 2033.

IMAGE COURTESY LOCKHEED MARTIN D024511

Engineers install Lucy's oxidizer tank into the spacecraft structure in the high bay at Lockheed Martin.

ECTO-LAB EXPANDS CAPACITY

D024314_0546

SwRI added two new test stands to its Exhaust Composition Transient Operation Laboratory™ (ECTO-Lab), expanding its capacity to support Environmental Protection Agency and automotive industry initiatives to reduce harmful emissions.

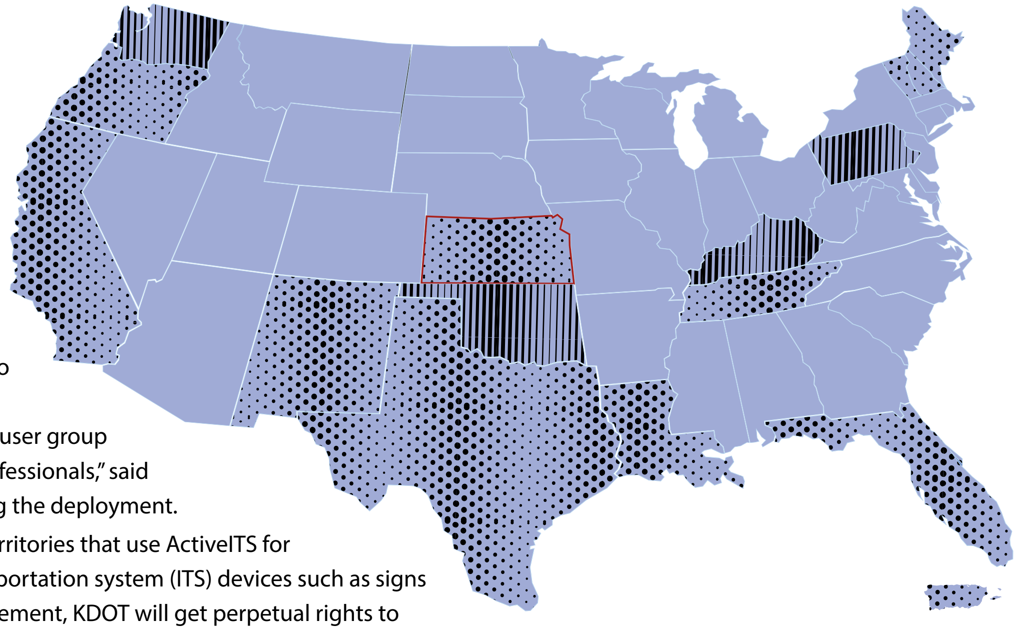
This state-of-the-art, computer-controlled, multi-fueled burner system simulates engine exhaust conditions to conduct steady-state and transient evaluations, including the ability to rapidly "age" a wide range of emission control systems. These systems include a series of components that reduce the pollutants emitted in tailpipe engine exhaust.

"ECTO-Lab data have demonstrated reduced cycle-to-cycle variation compared to engine dynamometer results, and performance data from ECTO-Lab-aged parts correlate well to field-aged parts," said Dr. Cary Henry, an assistant director in SwRI's Powertrain Engineering Division. "The ability to run accelerated aging on a bench stand could save industry millions of dollars, helping develop or improve technology to meet increasingly strict emissions regulations and increased targets for full useful life."

SwRI has made significant technological advancements to ECTO-Lab hardware and software systems. The system is a critical instrument in evaluating the Diesel Aftertreatment Accelerated Aging Cycles (DAAAC) protocol, part of the EPA's 2018 Cleaner Trucks Initiative to reduce NOx emissions from heavy-duty trucks. Once this validation is complete and the EPA grants approval, the DAAAC protocol will allow OEMs to simulate lifetime performance of diesel aftertreatment systems.

"Continued development of our ECTO-Lab technology helps us stay ahead of industry trends to evaluate full-size aftertreatment systems with the latest technologies for light-duty gasoline, heavy-duty diesel and natural gas engines," Henry said. "Our latest generation of ECTO-Lab technology features a host of novel controls and instrumentation to improve the range of operation and controllability of stoichiometric and lean-burn systems."

Kansas DOT Selects ActiveITS



California, Oregon, Kansas, New Mexico, Texas, Louisiana, Tennessee, Florida, Maine, Vermont, New Hampshire and Puerto Rico are running ActiveITS in production.

SwRI supports ATMS systems in Pennsylvania, Kentucky, Washington and Oklahoma.

D024469

The Kansas Department of Transportation (KDOT) has selected SwRI's ActiveITS Advanced Traffic Management System (ATMS) for statewide use under a $1.4 million, three-year contract.

"The unique thing that SwRI's ActiveITS brings to the table is the ability to share the costs of software development with other states and participate in a user group to share knowledge and features with other ITS professionals," said Shari Hilliard, the KDOT project manager overseeing the deployment.

Kansas is now among a dozen states and U.S. territories that use ActiveITS for traffic management and control of intelligent transportation system (ITS) devices such as signs and cameras. Through SwRI's flexible licensing agreement, KDOT will get perpetual rights to freely use the software, providing the agency with more control over how it is deployed and customized, with support from SwRI engineers and knowledge shared from other state agencies.

"We are proud to support KDOT with a reliable and proven ATMS solution," said Tucker Brown, the SwRI principal engineer leading the project. "ActiveITS will help Kansas get traffic information and incident response to the public as quickly as possible with integrated and streamlined data on congestion, event information, travel times and weather."

ActiveITS provides coordinated real-time traffic, safety and weather information to motorists and enables collaboration between traffic managers and other agencies on accidents, construction and traffic flows. ActiveITS, which supports deployment on traditional servers, virtual machines or cloud environments, currently manages more than 13,000 consecutive highway miles in over 50 traffic management center deployments.

"This flexibility to operate in the cloud is especially relevant in the context of the COVID-19 pandemic or natural disasters," added Dr. Steve Dellenback, vice president of SwRI's Intelligent Systems Division. "We develop ITS solutions with the future in mind."

Unexpected Ultraviolet Aurora Discovered at a Comet

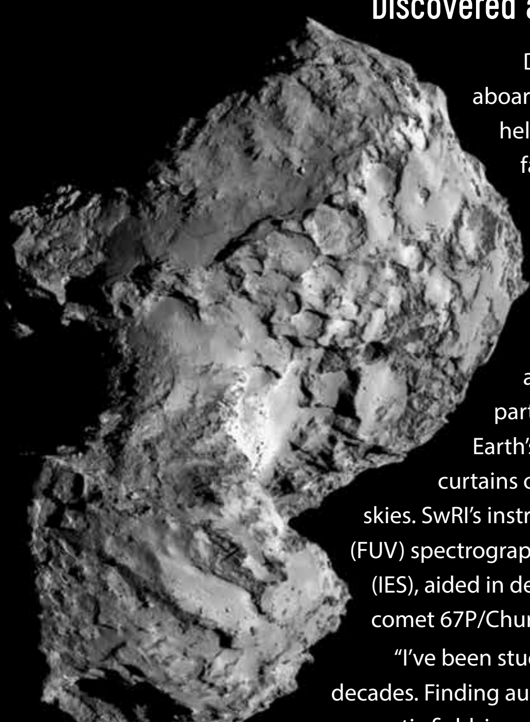


IMAGE COURTESY ESA/ROSETTA/MPS FOR OSIRIS TEAM MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA D024515

Data from SwRI-led instruments aboard ESA's Rosetta spacecraft have helped reveal auroral emissions in the far ultraviolet around a comet for the first time.

At Earth, auroras are formed when charged particles from the Sun follow our planet's magnetic field lines to the north and south poles. There, solar particles strike atoms and molecules in Earth's atmosphere, creating shimmering curtains of colorful light in high-latitude skies. SwRI's instruments, the Alice far-ultraviolet (FUV) spectrograph and the Ion and Electron Sensor (IES), aided in detecting these novel phenomena at comet 67P/Churyumov-Gerasimenko (67P/C-G).

"I've been studying the Earth's auroras for five decades. Finding auroras around 67P, which lacks a magnetic field, is surprising and fascinating," said SwRI Vice President Dr. Jim Burch, who leads IES. "The IES instrument detected the electrons that caused the aurora."

"Initially, we thought the ultraviolet emissions at comet 67P were phenomena known as 'dayglow,' a process caused by solar photons interacting with cometary gas," said SwRI's Dr. Joel Parker ,who leads the Alice spectrograph. "We were amazed to discover that the UV emissions are aurora, driven not by photons, but by electrons in the solar wind that break apart water and other molecules in the coma and have been accelerated in the comet's nearby environment. The resulting excited atoms make this distinctive light."

Dr. Marina Galand of Imperial College London led a team that used a physics-based model to integrate measurements made by various instruments aboard Rosetta.

"By doing this, we didn't have to rely upon just a single dataset from one instrument," said Galand, who is the lead author of a Nature Astronomy paper outlining this discovery. "This enabled us to unambiguously identify how 67P/C-G's ultraviolet atomic emissions form, and to reveal their auroral nature."

SIMULATING CATASTROPHIC WELL EVENTS

SwRI's Gas Blowdown Facility has successfully recreated the intense conditions associated with high-pressure gas emergencies on offshore rigs, making it possible to test safety valves designed to withstand these conditions and prevent injury, loss of life and catastrophic oil spills.

"Subsurface safety valves seal the production tubing when an emergency, such as failure of well control equipment, occurs," said SwRI Research Engineer Maria Cortes. "They are installed as part of the upper production tubing and sit below the mouth of the well, beneath the ocean floor."

SwRI has retrofitted its Gas Blowdown Facility to increase flow capacity and allow testing large diameter subsurface safety valves at higher-rate velocities.

"We simulate catastrophic well events," Cortes said. "We want our clients to have more confidence in the capabilities of their safety equipment. This added testing capability could realistically prevent incidents that could cause a major oil spill."

SwRI has been testing subsurface safety valves since 1975. SwRI's Gas Blowdown Facility uses pure nitrogen gas, from a liquid source, to perform high differential pressure flow testing on client test articles. The facility has a gas source volume of 1,125 cubic feet and a maximum pressure of 3,000 pounds psi.

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D024502

SwRI Achieves 20% Improvement in Vehicle Fuel Efficiency

A team led by Southwest Research Institute has applied connectivity and automation to achieve a 20% improvement in efficiency on a 2017 Toyota Prius Prime.

The program met efficiency goals without changing the powertrain or compromising emissions, safety or drivability. Typically, single-digit vehicle efficiency improvements are made by incrementally modifying components and control systems, often at a cost of millions of dollars.

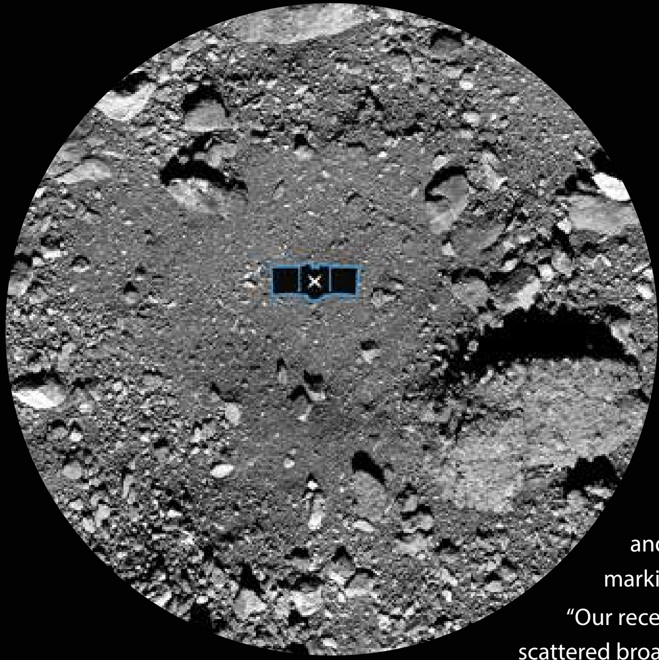
"Vehicle connectivity and automation are already being used to effectively improve vehicle safety and driver convenience," said Sankar Rengarajan, manager of SwRI's Powertrain Controls Section. "For this program, we were able to tap into those existing data streams and put the information to use in a new way."

Onboard sensing combined with data from vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-everything (V2X) technologies provided the information needed to predict driving environments and develop new technologies. The team achieved these benefits by developing next-generation vehicle dynamics and powertrain control software, designed to proactively use "look-ahead" information to anticipate vehicle power demands.

The new tools developed to meet these efficiency goals include eco-routing, eco-driving and power-split optimization. Using a mapping tool like Google Maps, drivers can set their destinations and see routes that may add a couple of minutes to their arrival, but that are more fuel-efficient. While the technology is appealing to the eco-minded consumer, for delivery and service fleets this 5–10% savings in fuel consumption can add up to millions of dollars in savings each year.

Eco-driving uses information from neighboring vehicles to minimize accelerations, while power-split optimization uses knowledge of routes and speeds to optimize battery and engine operations to more efficiently meet power demands.

The team included University of Michigan and Toyota Motor North America, and the project was sponsored by the Advanced Research Projects Agency – Energy (ARPA-E).



SwRI scientists played a role in sample-site selection, including the primary site Nightingale shown here.

D024519

UNDERSTANDING NEAR-EARTH ASTEROID BENNU

WHAT CAN NASA EXPECT TO RETURN FROM THE ASTEROID'S SURFACE?

While NASA's OSIRIS-REx spacecraft made history with a successful Touch-And-Go asteroid sample collection attempt, new research by SwRI scientists helped determine what the spacecraft can expect to return from the near-Earth asteroid Bennu's surface. Three papers published online by Science discuss the color, reflectivity, age, composition, origin and distribution of materials on the asteroid's rough surface.

On October 20, the spacecraft descended to the asteroid's boulder-strewn surface and touched the ground with its robotic arm to collect a sample of rocks and dust — marking the first time NASA has grabbed pieces of an asteroid for return to Earth.

"Our recent studies show that organics and minerals associated with the presence of water are scattered broadly around Bennu's surface, so any sample returned to Earth should contain these compounds and minerals," said SwRI's Dr. Vicky Hamilton, a coauthor on all three papers. "We will compare the sample's relative abundances of minerals to those in meteorites to help determine the scenarios that best explain Bennu's surface composition."

Asteroid Bennu is a dark, rubble pile held together by gravity and thought to be the collisional remnant of a much larger main-belt object. It's had a rough-and-tumble life since being liberated from its much larger parent asteroid millions or even billions of years ago.

"Boulders strewn about near the sample site have bright carbonate veins," Hamilton said. "This suggests that, early in Solar System history, at least some aqueously altered asteroids had considerably larger systems of percolating water than previously recognized." The boulders on Bennu have diverse textures and colors, which may provide information about their variable exposure to micrometeorite bombardment and the solar wind over time. Studying color and reflectance data provides information about the geologic history of planetary surfaces.

"Bennu's diverse surface includes abundant primitive material potentially from different depths in its parent body plus a small proportion of foreign materials from another asteroid family littered about its surface," said SwRI's Dr. Kevin Walsh, a coauthor of one of the papers.

SAND-SIZED METEOROIDS PEPPER BENNU

An SwRI-led study indicates that observed particle ejections off the near-Earth asteroid Bennu are linked to surface impacts by sand-sized meteoroids as the object nears the Sun.

SwRI's Dr. William Bottke led the research team, which used data from NASA's OSIRIS-REx mission. "While in orbit, the spacecraft has been sending images of Bennu back to Earth," Bottke said. "One of the most significant things we've noticed is that the asteroid is frequently ejecting materials into space. Tiny rocks are just flying off its surface, yet there is no evidence that they are propelled by sublimating ice, as one might expect from a comet."

Curiously, centimeter-scale pebbles fly off in the "afternoons" on Bennu. Determined to get to the bottom of these events, Bottke reached out to Althea Moorhead, a member of NASA's Meteoroid Environment Office, which monitors and models meteoroid spacecraft hazards.

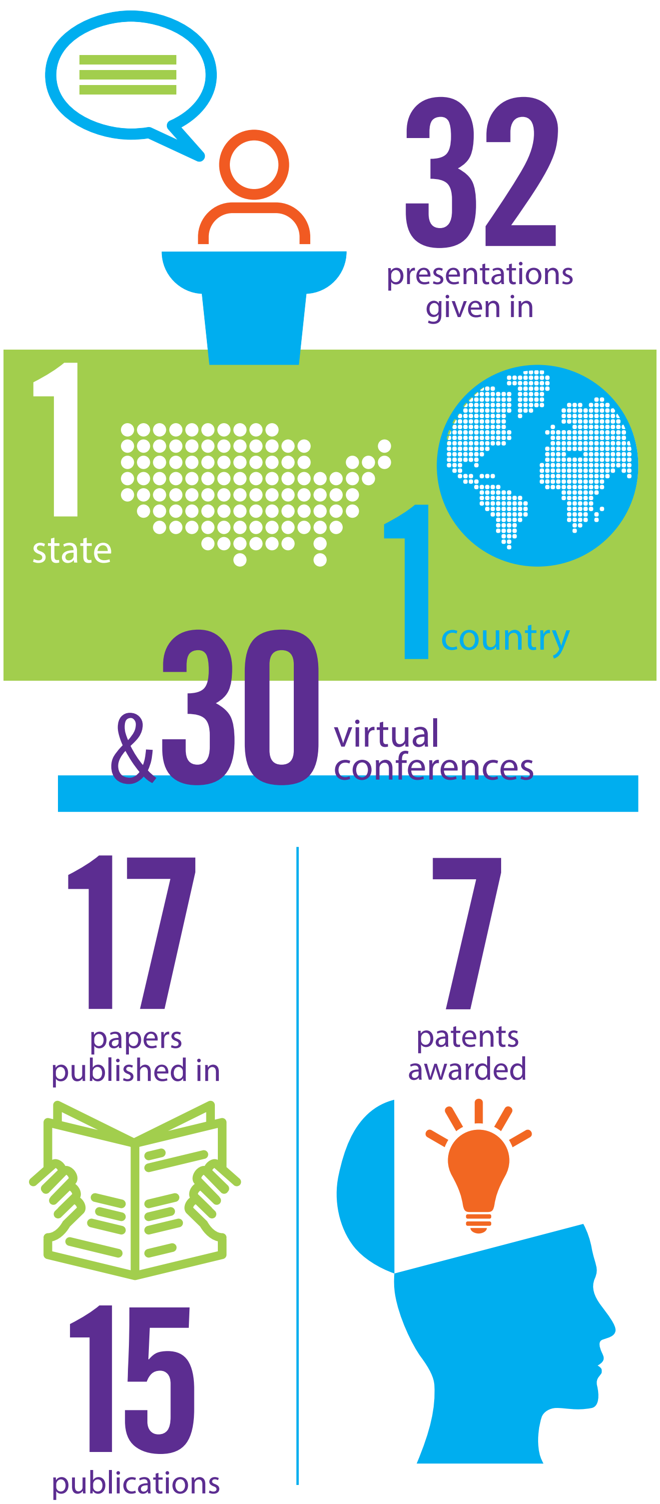
"Over the years, Althea and her team have built a computer model that determines the number of tiny particles impacting spacecraft," Bottke explained. "We used this software to calculate the number of meteoroid impacts Bennu would face in its current orbit."

Many meteoroids originated on comets. As comets approach the Sun, pieces break off and some comets even break apart completely as a consequence of solar heating, potentially providing a major source of meteoroids in the inner Solar System.

Models suggest that as Bennu approaches the Sun, it experiences a higher number of meteoroid impacts. These minuscule meteoroids hit Bennu with the force of a shotgun blast about once every two weeks, expelling significant amounts of pebble-sized debris from what is now thought to be a weak porous surface.

IMAGE COURTESY NASA/GODDARD/UNIVERSITY OF ARIZONA D024512

BY THE NUMBERS SUMMER – FALL 2020



NEW CONTRACT HIGHLIGHTS

ARPA-E

SwRI has received $764,000 in funding from the U.S. Department of Energy's Advanced Research Projects Agency–Energy (ARPA–E) to develop a zero-emission fossil fuel power plant that incorporates a supercritical carbon dioxide (sCO_2) power cycle, renewable energy, oxygen storage and carbon capture.

SwRI is leading one of 12 teams that received an award to conduct Phase 1 of ARPA-E's FLExible Carbon Capture and Storage (FLECCS) competitive program. At the conclusion of Phase 1, a subset of teams will advance to Phase 2 of the program. These teams will receive additional funding to focus on building components, unit operations and prototype systems.

During Phase 1, the SwRI-led team will design, model and optimize plans for the innovative new zero-emission power plant. The proposed plant uses a direct-fired sCO_2 power cycle, which utilizes sCO_2 instead of water as a thermal medium.

RAPID SPACECRAFT CATALOG

NASA has selected SwRI to take part in the $6 billion indefinite delivery/indefinite quantity Rapid Spacecraft Acquisition IV contract. SwRI will be listed in the NASA spacecraft catalog used by the U.S. government to easily contract for proven spacecraft.

Rapid IV contracts serve as a fast and flexible means for the government to acquire spacecraft and related components, equipment and services to support NASA missions and/or other federal government agencies.

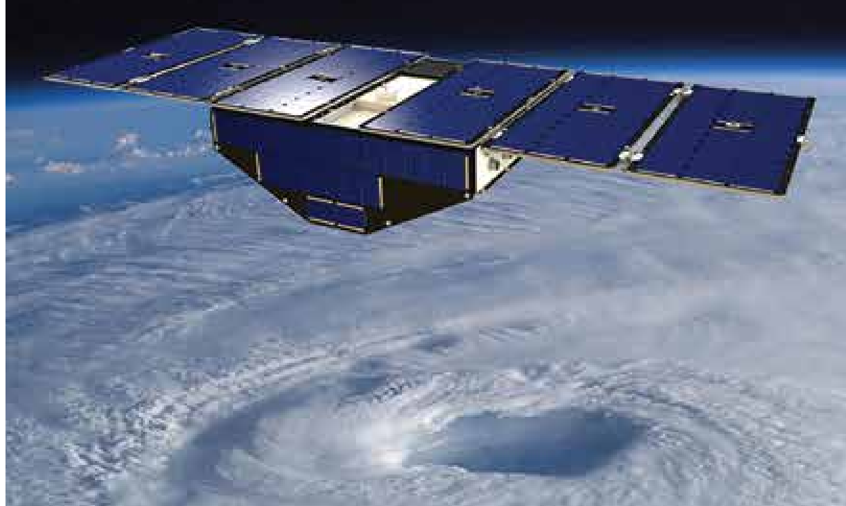
An evolution of SwRI's small satellite platform used for the Cyclone Global Navigation Satellite System (CYGNSS) mission is the specific asset listed. CYGNSS is one of the first small satellite platforms added to the catalog. It provides a solution for a class of spacecraft in the 30–75 kilogram mass range not previously available through the RSDO catalog.

EXTENDING THE LIFE OF AGING AIRCRAFT

SwRI has received a $1 million contract from the U.S. Air Force to continue structural analysis and other maintenance work on a fleet of military aircraft, the Fairchild Republic A-10 Thunderbolt II.

The A-10 came into service in the late 1970s, and the fleet is currently set to continue service until at least 2040. SwRI's structural engineers perform damage tolerance analysis for military and commercial aircraft and provide the information necessary to safely and effectively manage the structural health of their fleets.

An SwRI-developed flight data recording system provides structural stress data associated with various flight maneuvers. Using NASGRO software and controlled testing of aircraft materials, engineers analyze how cracks originate and determine how quickly they grow.



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D022331

Pipeline Research Council International (PRCI) awarded Staff Engineer Terry Grimley of SwRI's Mechanical Engineering Division the PRCI Distinguished Researcher Award. Grimley has worked on dozens of research projects to advance the pipeline industry, often serving as lead investigator. PRCI is a nonprofit corporation of energy pipeline companies that collaboratively deliver relevant and innovative applied research to improve global energy pipeline systems.

D024501

The American Institute of Aeronautics and Astronautics (AIAA) has named SwRI President and CEO Adam L. Hamilton, P.E., to the Class of 2021 Associate Fellows. This designation recognizes individuals who have acheived important engineering or scientific work, contributed original work of outstanding merit or made other outstanding contributions to the arts, sciences or technology of aeronautics or astronautics.

D024506

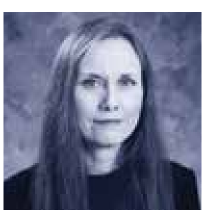
The U.S. Air Force has selected SwRI Manager Jody Little to lead the Department of Defense Joint Base San Antonio 5G NextGen Program and Program Management Office. Little will serve as the executive program manager through the Intergovernmental Personnel Act, which temporarily assigns personnel from an external organization to a government position. 5G, the newest generation of mobile network technology, can offer the DoD and intelligence community long-term economic and military advantages.

D023187

Institute Scientist Dr. Cathy Olkin received the Rock Star Award from Cranbrook Institute of Science "Women Rock Science" event. Olkin is an alumnus of the school at the renowned center for the arts, education, science and culture located in Bloomfield Hills, Michigan. Olkin is a deputy project scientist on NASA's New Horizons team and deputy principal investigator for its Lucy mission.

D021566_2209

Dr. Hunter Waite has been honored with an invitation to present the annual Eugene Shoemaker Lecture at the American Geophysical Union Fall Meeting in December. The lecture will discuss the Cassini-Huygens mission and what it may indicate about the formation of the Saturn system and the possibility that microbial life may exist within it. The lecture recognizes excellence in planetary exploration, in honor of planetary scientist Eugene Merle Shoemaker.



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Principal Scientist Dr. Danielle Wyrick received the 2020 Ronald Greeley Distinguished Service award from the Planetary Geology Division of the Geological Society of America (GSA), recognizing exceptional service to the planetary community. Wyrick was commended for helping early career scientists succeed, for contributing to new GSA Codes of Conduct, and for her efforts to make the field of planetary geosciences become more equitable and inclusive.

NCDMM
NATIONAL CENTER FOR DEFENSE MANUFACTURING AND MACHINING

The National Center for Defense Manufacturing and Machining recognized SwRI with a 2020 Manufacturing Leadership Award for the A5 program, an open-source software framework for adaptive robotic solutions in aerospace manufacturing. The project implemented a next-generation automation solution allowing robot systems to adapt to part variations by using models combined with real-time sensor data to drive the automation process.

WEBINARS, WORKSHOPS and TRAINING COURSES HOSTED by SWRI:

Compressor Skid Design and Foundation Considerations, November 4, 2020. Free training.

Sensitivity Analysis: Probabilistic Methods for Uncertainty Quantifications Webinar Series, November 10, 2020. Free training.

ISO Internal Auditor Training, November 12, 2020. Free training.

Surrogate Models: Probabilistic Methods for Uncertainty Quantifications Webinar Series, November 17, 2020. Free training.

7th International Supercritical CO_2 Power Cycles Symposium, February 22, 2021. Free training.

Penetration Mechanics Short Course, March 1, 2021, San Antonio. SwRI is hosting this short course.

CONFERENCES/MEETINGS:

ASNT Annual Conference 2020—Virtual. November 9, 2020.

Aircraft Structural Integrity Program (ASIP) Conference—Virtual. November 30, 2020, Booth 11.

RIA Robotic Grinding and Finishing Conference—Virtual. December 2, 2020.

Feedwater and Secondary Systems Reliability Users Group Conference, San Antonio, January 18, 2021.

Waste Management Symposium, Phoenix, March 7, 2021, Booth 802.

Technology & Maintenance Council (TMC) Annual Meeting, Orlando, March 8, 2021, Booth 1446.

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