SOUTHWEST RESEARCH INSTITUTE®

SUMMER 2019

TECHNOLOGY TODAY®

FIRE TORNADOS

Through internal research funding, SwRI is using the same physics that creates tornados to address a known technology gap: the need for effective, simple mobile technologies for destroying chemical warfare agents (CWA) in the field.

The "fire whirl" technique combines SwRI's extensive experience with CWA disposal at large-scale incineration facilities and expertise in the fundamental mechanics of combustion to develop an induced draft system for CWA destruction. Engineers are developing an efficient, oxygen-rich combustion environment by drawing in air, creating a well-mixed flame that consumes CWA liquid completely and entrains and consumes all CWA vapors.

The natural circulating air flow occurs without any mechanical assistance and promotes mixing of air and fuel vapors to improve combustion efficiency while increasing flame height and chemical retention time in the flame. A demonstration project will evaluate the effect of design changes with the objective of optimizing destruction efficiency while reducing the weight and footprint of the mobile system.

The fire whirl technology is an elegant approach to provide a simple, low-cost system for complete destruction of CWA and other hazardous materials in the field.

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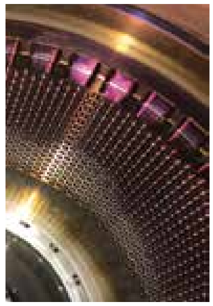

ON THE COVER

This supercritical carbon dioxide turbine could hold the key to revolutionizing how commercial power is produced, improving efficiency while decreasing emissions. The hole pattern seal minimizes internal leakage and adds damping to the rotor in the extreme environment the 10 MWe sCO_2 turbine must withstand.

CONTENTS

EMPLOYMENT

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

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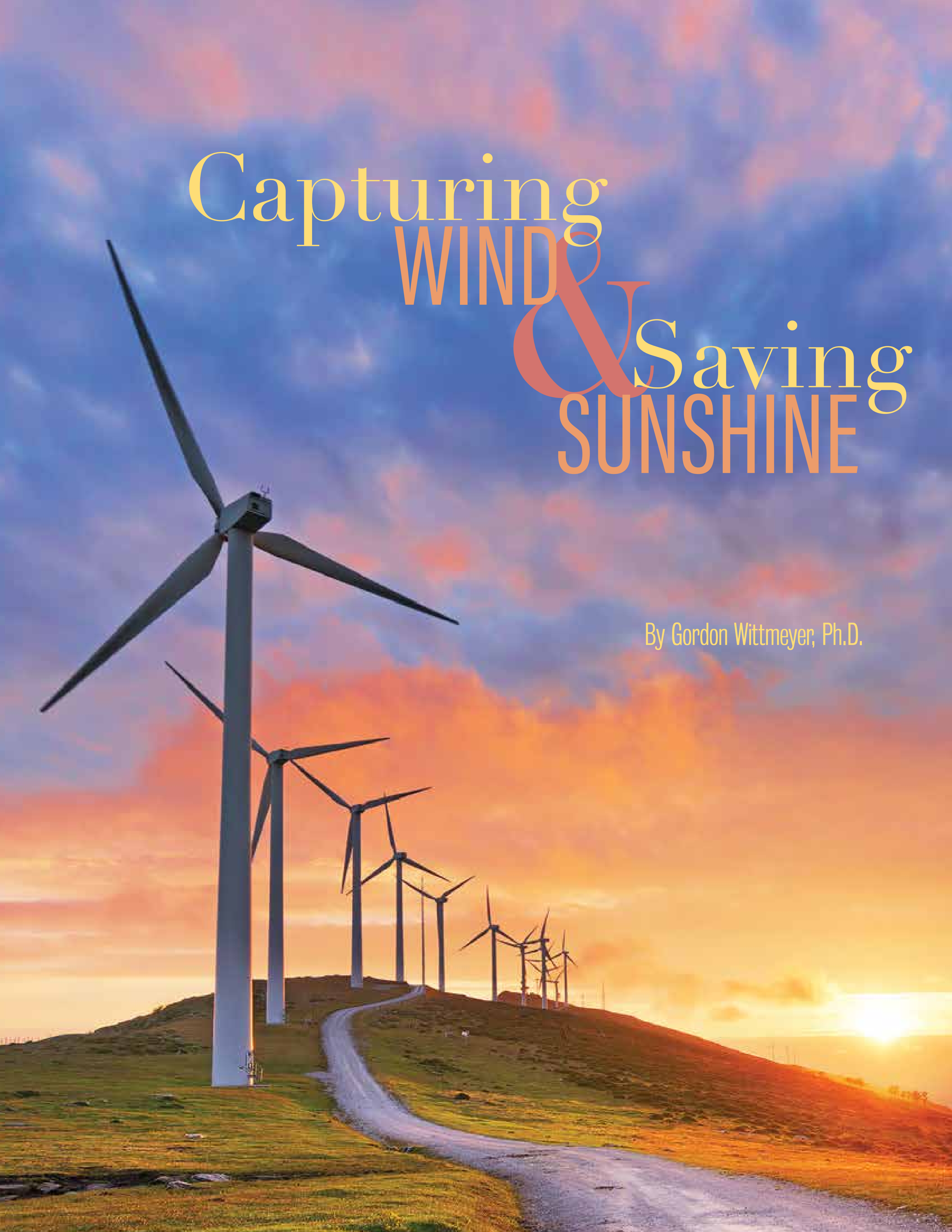
Capturing WIND & Saving SUNSHINE

By Gordon Wittmeyer, Ph.D.



What if you could store the powers of the wind and the Sun in a giant water tank?

Essentially that's what engineers at Southwest Research Institute propose doing, looking at the feasibility of deploying pumped storage hydropower (PSH) units in West Texas. These PSH tanks are off-stream reservoirs, designed to save excess renewable energy to generate electricity — and revenue — when the wind dies down and the Sun has set.

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

SwRI is assessing the use of PSH units where most of Texas' wind and solar farms are cranking out energy. Texas produces more wind power than any other state in the nation. More than 40 wind farms with a total capacity of 22,637 megawatts (MW) produced in excess of 15 percent of the electricity generated in Texas during 2017. However, Texans depend on electricity 24/7, 365 days a year, and wind and solar energy are intermittent resources. While renewable energy can be incorporated into an electric utility's generation mix, it does not provide the on-demand energy that gas-powered peaking plants provide. Peak wind and solar production periods often occur when energy demand is low. Integrating storage systems allows utilities to capture excess energy and send it to the grid later when demand peaks.

SwRI evaluated West Texas topography to find sites that could support PSH and examined infrastructure, including transmission capacity and intermittent renewable energy sources that could benefit from PSH. Engineers also identified a new permitting process to accelerate closed-loop PSH licensing and located water supplies to fill and maintain the off-stream reservoirs. In addition, SwRI has identified some of the benefits that may be realized by entities in the power industry that deploy PSH.

BACKGROUND

West Texas abounds in long stretches of flat landscapes. However, the Pecos River Valley between the Edwards and Stockton Plateaus features mesas and canyons that could support multiple 10 to 1,000 MW capacity PSH units. Pairing reservoirs located on the tops of mesas with reservoirs in the canyons below could potentially store hundreds to thousands of gigawatt hours of energy from wind and solar photovoltaic (SPV) farms in the region. At present, wind generation capacity is 2,300 MW and SPV capacity is over 700 MW in the study area.

For power generation companies, PSH units located and operated with intermittent renewable energy sources can balance power generation, produce "peaking power" and provide ancillary services, such as frequency and voltage regulation.

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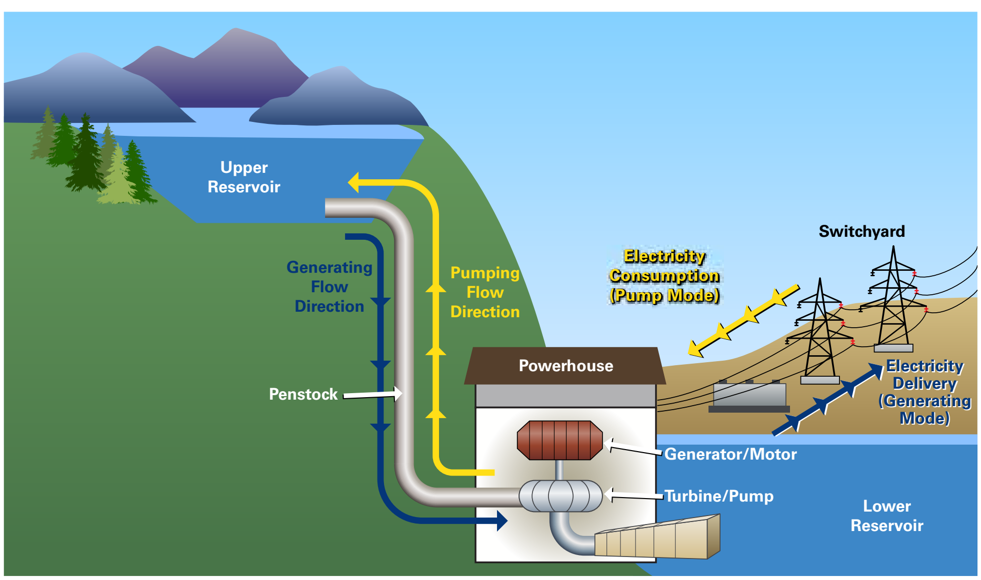
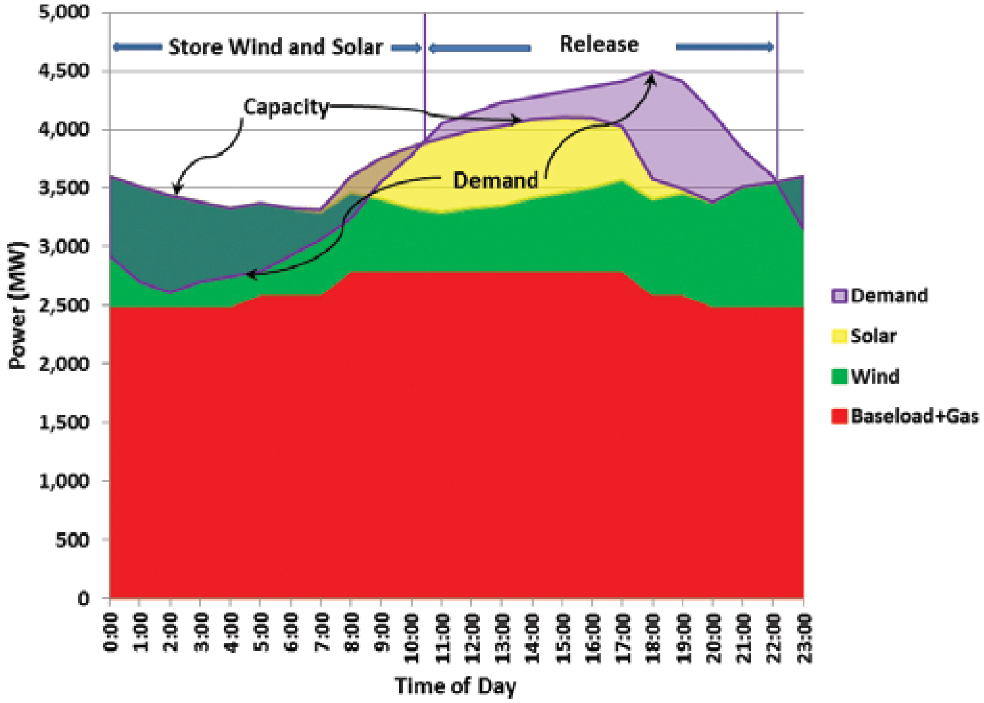


Pumped storage hydropower uses the gravitational potential energy of water, pumped from a lower elevation to a higher elevation reservoir using low-cost surplus off-peak electric power to run the pumps. During periods of high electrical demand, the stored water is returned to the lower reservoir, driving turbines to produce electric power when demand and prices are highest.

DETAIL

Power is the rate at which energy is generated or used. A MW is a unit of power. Energy is a measure of a system's capacity to perform work. A MW hour (MWh) is a unit of energy.



Renewable energy sources such as wind and solar power often produce the most energy during off-peak demand hours. PSH units could store this surplus energy for release during periods of peak demand.

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Traditional on-stream PSH units are subject to a long five-year permitting process by the Federal Energy Regulatory Commission (FERC). In 2019, FERC established an expedited licensing process for off-stream closed-loop PSH units that reduces the permitting process period to two years. By reducing the time needed to obtain construction permits for closed-loop PSH units, FERC is hoping to increase storage capacity and improve grid stability.

Along the Pecos River valley, numerous small, ephemeral streams have eroded softer limestone and marlstone, leaving steep-sided mesas towering 300 to 500 feet above the plains. Highly efficient, compact, closed-loop PSH units could be constructed, with upper reservoirs sited on the mesas' flat caprocks and lower reservoirs in canyons below. Locating the power plant underground would minimize the length of the penstock, or channel for conveying water. Because the reservoirs would not be associated with environmentally sensitive perennial streams, closed-loop PSH units could be licensed under the proposed two-year FERC permitting process. SwRI has examined three potential sites where local topographic relief is sufficient for closed-loop PSH units. The stored energy could supply power for distribution across Texas via existing 345 kV transmission lines.

WEST TEXAS TOPOGRAPHY

Big Mesa is a formation on the north side of IH-10 about halfway between San Antonio and El Paso. A 160 MW wind farm is located on the eastern section of the area. The elevation of the north central section of Big Mesa is about 3,100 feet above mean sea level (amsl), while the bottom elevations of the canyon could be dammed to create a lower reservoir from 2,700 to 2,800 ft amsl. The proposed upper reservoir is 300 acres with a volume of 3,300 acre-feet (ac-ft), while the lower reservoir is 150 acres with a volume of 4,300 ac-ft. The unit could store intermittent wind energy generated during off-peak hours, releasing the energy over eight hours during peak periods.

DETAIL

A mesa is an elevated area of land with a flat top and steep cliffs. The characteristic formation takes its name from the Spanish word for table.

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IMAGES COURTESY USGS/GOOGLE MAP DATA

Just west of Big Mesa is Indian Mesa. Two wind farms with a capacity of 143 MW are located on the mesa, providing electricity to San Antonio and other locales. The elevation of the Indian Mesa caprock is approximately 3,000 ft amsl, while Big Harkey Canyon below has elevations ranging from 2,400 to 2,600 ft amsl. A PSH installation could include a 60-acre, 610 ac-ft upper reservoir and a 32-acre lower reservoir with a volume of 1,120 ac-ft and a water surface elevation of 2,600 ft amsl. This configuration could store surplus wind energy generated during off-peak hours to provide four hours of electricity during peak periods.

King Mountain is five miles north of McCamey, a town known as the wind energy capital of Texas. A 278 MW wind farm there generates more than 750 GWh per year (average of 2,000 MWh per day). A 1,700-acre, 24,500 ac-ft upper reservoir could be located on the caprock, which has an elevation of approximately 3,100 ft amsl. A 385-acre, 32,000 ac-ft lower reservoir could be sited in small canyons to the southwest, where elevations range from 2,550 to 2,700 ft amsl. This PSH unit could store electricity generated during off-peak hours, to release eight hours of energy during the peak demand periods.

WATER SUPPLIES

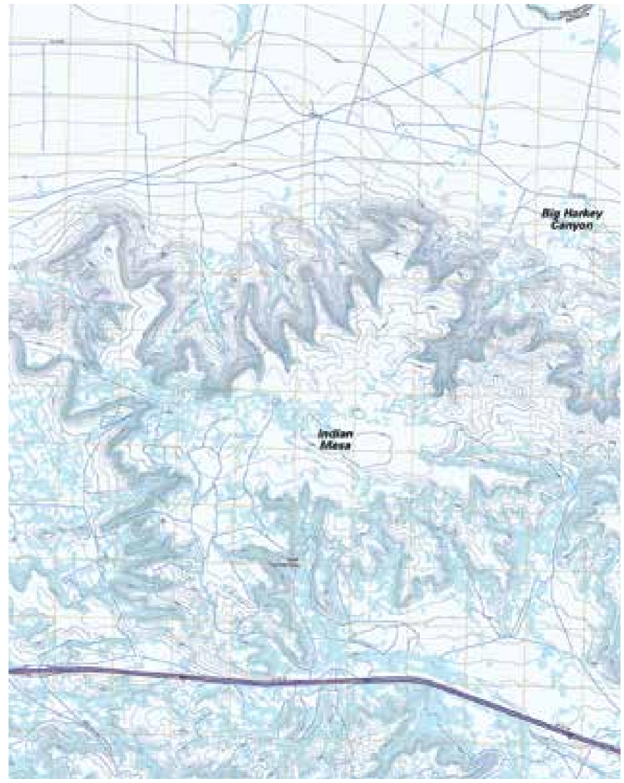
SwRI identified topography suitable for PSH units, but there remained a question of how to fill the reservoirs. The West Texas climate is semiarid, with an annual precipitation of just 13 inches. Other than the Pecos River, the region has few perennial streams. Primary tributaries to the Pecos River are Independence and Live Oak creeks, which join the Pecos 40 to 60 miles southeast of the study area. Because existing water rights on the lower Pecos River fully appropriate the annual flow and all land is privately owned, constructing infrastructure to store and divert Pecos River water to fill and maintain water levels in an off-stream, closed-loop PSH is probably not feasible.

Regional water for irrigation, livestock, industry and municipal supplies is pumped from wells in the shallow Pecos Valley or the Edwards-Trinity aquifer. The Dockum, Permian Rustler and Capitan Reef aquifers provide smaller volumes of water. However, water from these deeper aquifers is generally too saline and high in total dissolved solids for municipal and agricultural use.

Filling the Big Mesa, Indian Mesa and King Mountain reservoirs would require more than 44,000 ac-ft of water. Because the mean annual lake evaporation ranges from 63 to 71 ac-ft, the annual volume of make-up water required is more than 11,000 ac-ft. Building higher dams to shrink reservoir surface areas could decrease evaporative losses from some reservoirs.

SALINE SOLUTION

Given the limited supply of fresh water in the study area, using brackish water to fill and maintain a PSH unit may be an option. And using saltwater in a PSH unit is not unprecedented. From 1999 to 2016, Japan operated a 30 MW PSH unit in Okinawa using water pumped from the Philippine Sea into an elevated reservoir. To mitigate corrosion from seawater, its penstock was made of fiber-reinforced plastic. Other components exposed to high-velocity seawater flows were made of corrosion-resistant stainless steel. An impermeable fabric lined the reservoir to prevent seawater from seeping into the groundwater.



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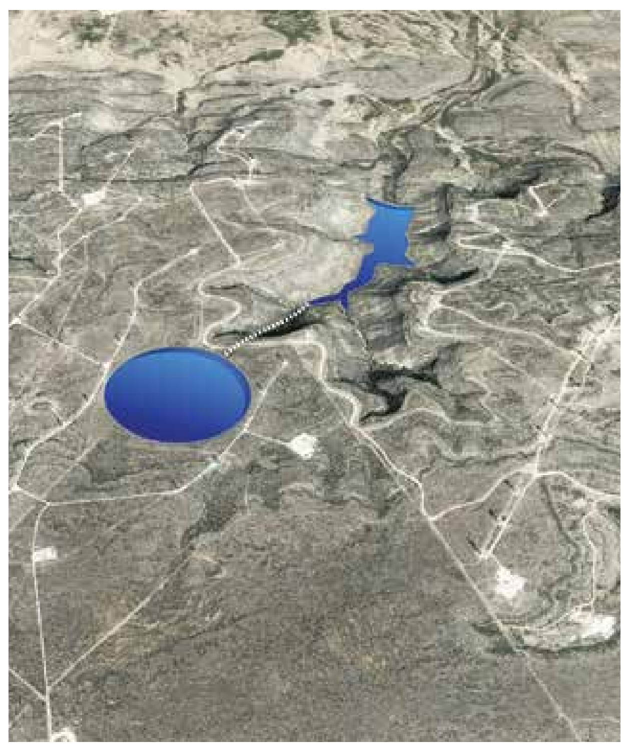
Steep-sided mesas tower 300 to 500 feet above the Pecos Valley. This could allow closed-loop PSH units to operate, siting upper reservoirs atop the mesas' flat caprocks and lower reservoirs in the canyons below.



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SwRI identified Big Mesa as a potential PSH site where an upper reservoir (circle) could be built on top of the mesa and lower reservoirs could be built into the canyons below, as illustrated on this Google Earth background image. These dual-reservoir "storage" systems could improve the availability of renewable energy by pumping and releasing water between the reservoirs to generate electricity to profitably meet demands.

News reports indicate that this PSH unit was closed and dismantled due to low rates of electricity demand in Okinawa, not technical problems. The unit operated for 17 years, long past the intended 10-year pilot study, suggesting that any corrosion was manageable.

DETAIL

The Permian Basin spans West Texas and southeastern New Mexico and is the largest petroleum play in the United States, with more than 20 of the nation's top-producing oil fields. Enhanced oil recovery techniques — such as hydraulic fracturing — have contributed to the success of the Permian.

This case study indicates that it would be technically feasible to operate a PSH unit using moderate- to high-salinity water pumped from the Dockum aquifer. Hydrogeologic studies are needed to determine if the aquifer can provide the required fill and evaporation make-up water without impacting other water users. If the Dockum Aquifer cannot be used to fill and maintain the PSH reservoirs, other sources of saline water in the study area are also a possibility.

PRODUCED WATER

The Permian Basin, located just north of the study area, produces vast amounts of oil — four million barrels per day in 2019. For each barrel of oil pumped in the Permian, seven barrels of high-salinity wastewater are generated, requiring recycling or disposal. In 2019, oil production activities will likely produce 10.2 billion barrels or 1.32 million ac-ft of saline wastewater. This "produced water" is often re-used in hydraulic fracturing, but even a thousand very large frac jobs would still leave 1.18 million ac-ft requiring disposal.

The chemistry of this produced water includes brines that are saltier than seawater as well as chloride concentrations more typical of seawater. Using these latter supplies to fill and top off the reservoirs for the three proposed PSH units should work if they are modeled after the Okinawa PSH unit. If available produced water is too saline, or if the reservoir water becomes too salty from evaporation, refilling the reservoir with low- to moderate-salinity groundwater from the Dockum aquifer could manage the salinity. Because of the high evaporation rates, the salinity of reservoirs would need to be monitored and managed. This could require injecting moderate volumes of highly saline reservoir water into existing deep disposal wells.

DETAIL

Produced water is an oil industry term describing water produced as a byproduct along with oil and gas.

SUMMARY

SwRI has identified topography in West Texas' wind and solar producing region suitable for constructing PSH units with upper and lower reservoirs that could "store" four to eight hours of renewable energy. The installed capacity of intermittent renewable energy in the study area is more than 3,000 MW, and 345 kV transmission lines connect the regions to an Electric Reliability Council of Texas operated grid. With FERC's new streamlined permitting process, much of the uncertainty associated with licensing these off-stream, closed-loop PSH units has been eliminated. While water supplies in the area are limited, SwRI identified saline water supplies available to serve the reservoirs as well as the technology needed to outfit PSH to resist corrosion.

Pumped storage hydropower could resolve one of the major challenges limiting the benefits from Texas' solar and wind energy: timing. Peak wind and solar production often occurs when energy demand is low and drops off during peak demand. PSH can store surplus renewable energy for use when electricity demand and prices are highest.

Questions about this article? Contact Wittmeyer at gordon.wittmeyer@swri.org or 210.522.5082.

ABOUT THE AUTHOR

Dr. Gordon Wittmeyer is a hydrologist who specializes in developing and applying computational methods to solve water resource problems. He has extensive experience assembling and leading multidisciplinary teams of scientists and engineers to solve complex engineering and environmental problems associated with a range of activities, from nuclear power production to storage solutions for renewable energy.

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Airborne SLED to Detect Methane Leaks

SwRI's methane leak detection system is taking flight as part of a U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) project to automate inspections of oil and gas facilities. SwRI researchers are adapting the Smart LEak Detection System/Methane (SLED/M) technology to detect methane leaks in real time from aboard a drone. SLED technology, winner of an R&D 100 Award in 2017, uses cameras and artificial intelligence to detect liquid hydrocarbon leaks on pipelines and facilities such as pump stations. SwRI then developed SLED/M to detect gaseous leaks with DOE NETL funding.

"After successfully developing SLED/M for stationary applications, such as fence-line monitoring of midstream facilities, we are advancing the technology to perform autonomously from drones," said SwRI Engineer Heath Spidle.

The system identifies small methane leaks, known as fugitive emissions, by pairing passive optical sensing data with artificial intelligence algorithms. The new NETL project will enable SwRI to collect data, test midwave infrared cameras (MWIR) on drone flights and develop machine learning algorithms to detect methane leaks.

"This drone/camera configuration presents unique challenges because it captures data at different heights, distances and speeds," Spidle added. "This funding enables development and testing to adapt the technology for commercial aerial inspections."

SwRI designed SLED/M to pinpoint small methane leaks that typically go unnoticed along pipelines and storage facilities. Conventional detection systems, designed to locate larger leaks, suffer from false positives and missed detections, which hamper effectiveness and utilization by industry. By optimizing algorithms to reliably detect leaks under a variety of environmental conditions, SLED/M substantially reduces false positives and discovers leaks that might otherwise go unnoticed.

The project also leverages SwRI's ongoing research into unmanned aerial systems (UAS), drone automation, navigation, perception and data analytics. Recent drone innovations include adapting technology to autonomously inspect damaged nuclear reactors and other hazardous facilities.

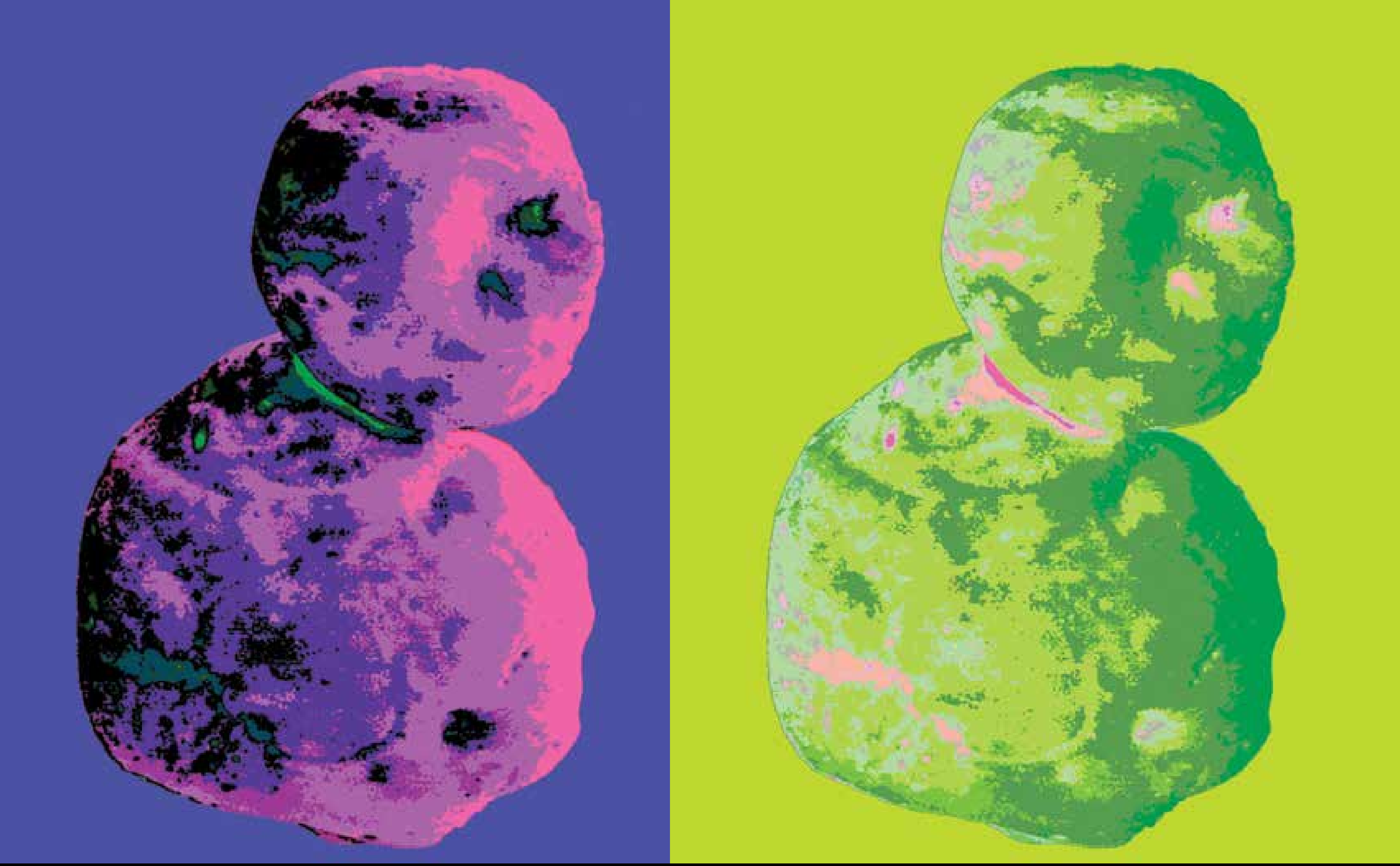
SwRI Engineer Heath Spidle prepares a drone outfitted with technology designed to autonomously detect methane leaks.

"SwRI's R&D investment in drone payloads and analytics aligns with our mission to advance science and technology that benefits government, industry and humankind," said Dr. Steve Dellenback, vice president of SwRI's Intelligent Systems Division. "This effort is helping address a significant challenge facing the world right now."

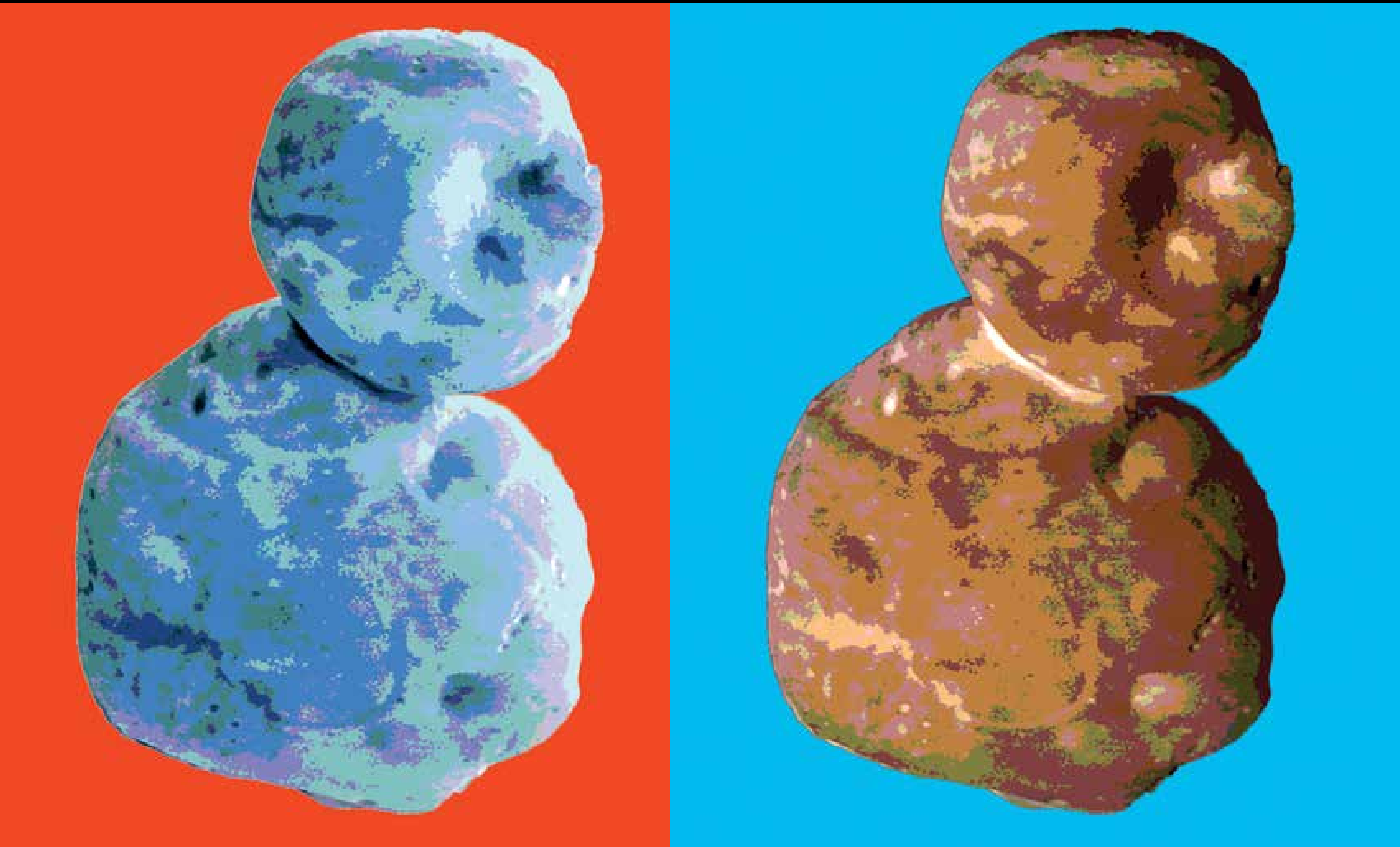
Methane, the main component in natural gas, is considered a more threatening greenhouse gas than carbon dioxide because it absorbs heat more effectively. The World Meteorological Organization recently reported that methane levels are 2.5 times higher than in pre-industrial times.

SwRI is addressing methane leaks from multiple directions. A team of fluids engineers participated in the Methane Detectors Challenge, developing a solar-powered system to identify fugitive emissions in the gas-producing sector as well.

SwRI is also processing satellite data from space with algorithms to identify large methane leaks from midstream facilities as well as crude oil spills on ocean surfaces.



THE FARTHEST, MOST PRIMORDIAL OBJECT EVER



Ultima Thule: New Horizons explores where no probe has gone before

VISITED

By S. Alan Stern, Ph.D., Cathy Olkin, Ph.D., and John Spencer, Ph.D.

IN 1992, scientists at the Mauna Kea Observatory in Hawaii discovered the first small Kuiper Belt Object (KBO) at the edge of the solar system. Since then, thousands of KBOs have been discovered. Most are ancient "planetesimals," smaller objects left over from the formation of the solar system. However, a handful, including Pluto, are larger bodies, known as dwarf planets. This third class of planets outnumbers all the terrestrial and giant planets combined, transforming our understanding of the solar system and how it formed.

With this information, NASA accelerated exploring the Pluto system, with an emphasis on mission concepts that could continue past the dwarf planet to explore other KBOs as well. In 2001, NASA selected the Southwest Research Institute-led New Horizons mission to explore the Pluto system and beyond.

New Horizons launched in 2006 and used a 2007 gravity assist from Jupiter to slingshot it toward its primary target — Pluto. Its epic and scientifically remarkable Pluto flyby in the summer of 2015 detailed its dynamic surface and system of moons. Before all the flyby data were downloaded back to Earth, the spacecraft fired its engines to target a small KBO planetesimal a billion miles beyond Pluto called 2014 MU69, now nicknamed Ultima Thule.

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

TARGETING ULTIMA THULE

The New Horizons team did not find this second flyby target until shortly before the Pluto flyby, and little was known about Ultima Thule until New Horizons arrived. Hubble images and occultation campaigns — looking for a distant star to wink out as the small object passed in front of it — provided only hints about its size, shape and reddish color.

Ultima Thule was a particularly attractive target because it is one of the so-called cold classical KBOs. These objects originated where they orbit now and so, unlike most KBOs, Ultima Thule has never approached the Sun and warmed. Unlike Pluto, Ultima Thule is too small to have any long-term geologic activity changing its surface. These two facts guarantee that Ultima Thule is probably the most primordial object ever visited, providing the first look at what the original outer solar system

New Horizons is journeying across the Kuiper Belt, a disk-shaped region of small icy bodies and dwarf planets beyond the orbit of Neptune. The Kuiper Belt is a scientific treasure trove and the largest observable structure in our planetary system, holding an estimated 100,000+ miniature worlds with diameters larger than 100 kilometers (or 62 miles) wide.

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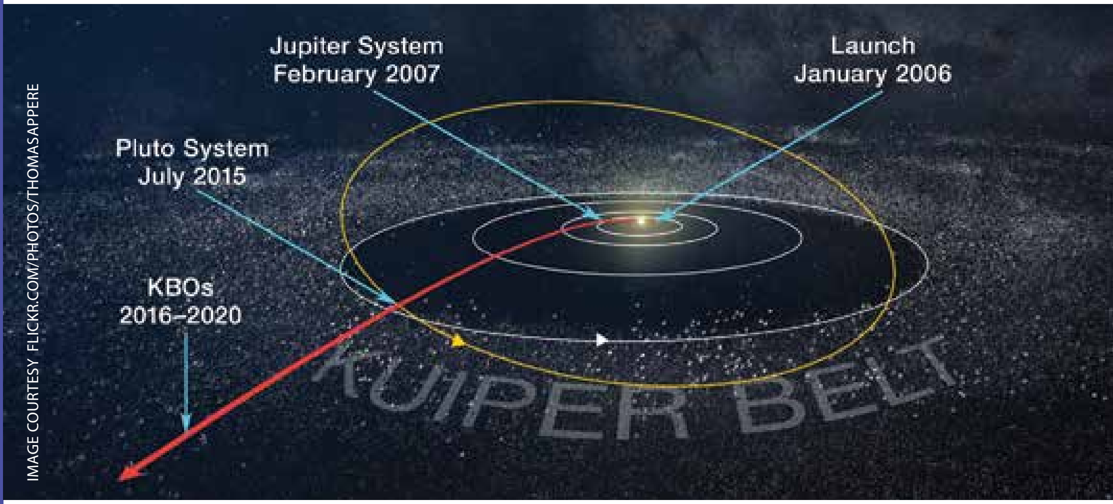
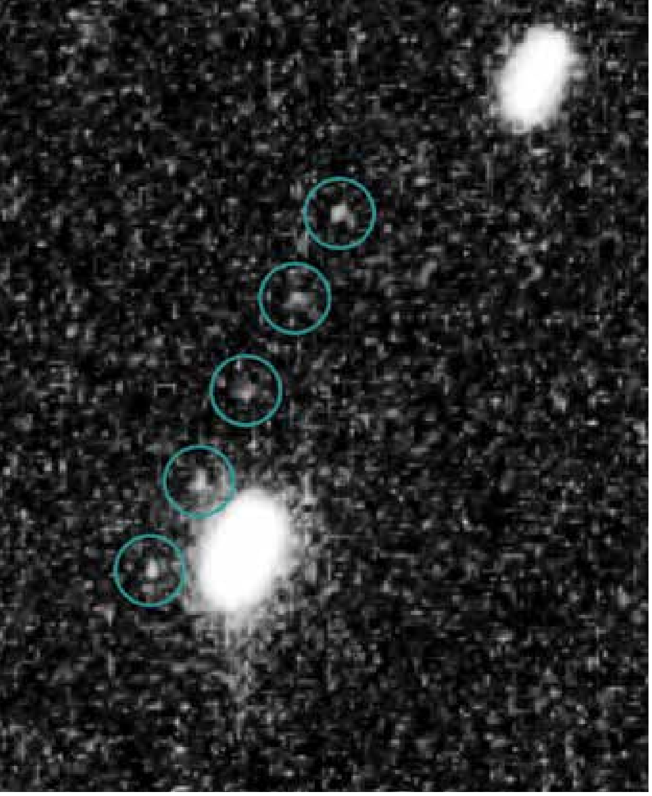
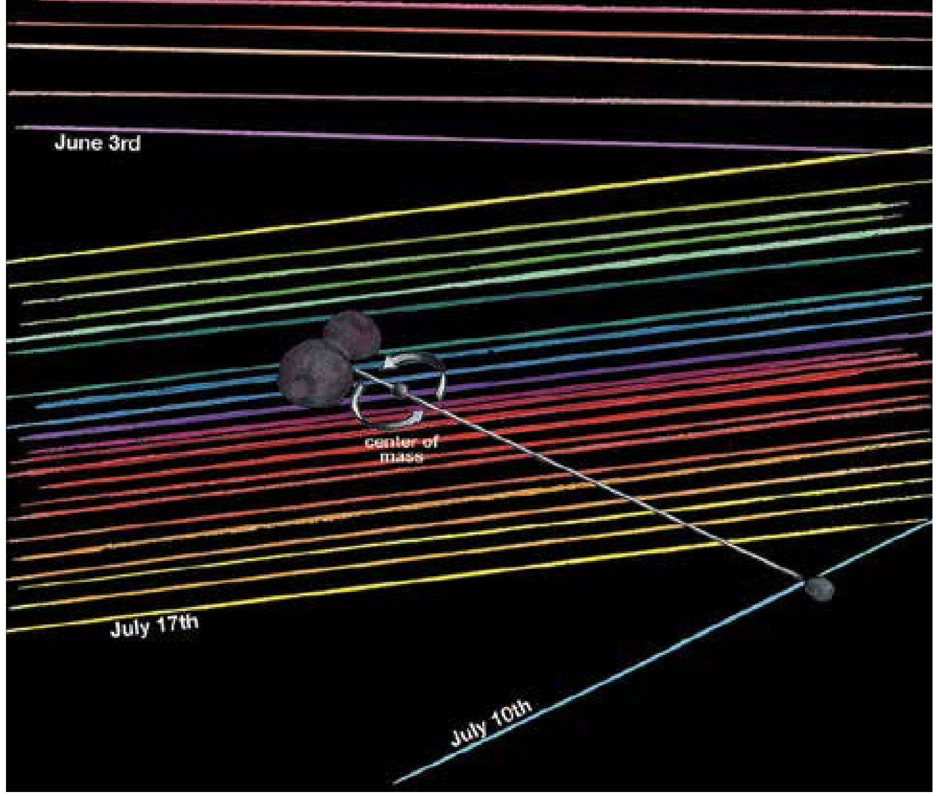


IMAGE COURTESY FLICKR.COM/PHOTOS/THOMASAPPERE



On June 24, 2014, the Hubble Space Telescope discovered New Horizons' second target, MU69, a distant object too faint to be observed by ground-based telescopes.



On three occasions in 2017, New Horizons team members tracked Ultima Thule as it passed in front of a star — an event known as an occultation. The colored lines mark the path of the star as seen from different telescopes on each day; blank spaces indicate the few seconds when MU69 blocked the light from the star. We used these observations to accurately predict the shape of Ultima Thule, shown inserted into the blanks in this figure.

IMAGES COURTESY NASA/ESA/JHUAPL/SwRI/JAMES TUTTLE KEANE D023769/D023764

bodies were like when they formed. Flying to Ultima Thule was the planetary science equivalent of an archeological dig into the ancient past of our solar system.

In addition to mapping Ultima Thule at high resolution in color and in stereo, we planned to characterize its surface composition, take its temperature and attempt to measure its radar reflectivity. We also planned to search for small moons, which are common among the cold classical KBOs, and look for orbiting dust or rings — however unlikely. We would probe for an atmosphere in case sound scientific reasoning, which indicated an atmosphere should not exist, turned out to be wrong. We even would hunt for evidence of Ultima Thule's effect on the local solar wind and charged particle environment, even though the physics told us any such effects would probably be undetectable. In effect, we planned to use New Horizons to its fullest capabilities for exploring Ultima Thule.

DETAIL

Cold classical KBOs have relatively circular, untilted orbits. They orbit the Sun at a nearly constant distance, never nearing Neptune, so they remain "cool," unperturbed by the giant planet's gravity or solar warming.

CONTACT!

It was another first for New Horizons. Never had such a pristine, primordial object — left over from the birth of the planets — been explored up close. And the results were sensational and sometimes surprising.

Ultima Thule is almost 22 miles long, about 10 times larger than the nucleus of a typical comet and about 1,000 times more massive. Ultima Thule turned out to be a contact binary, two objects that are joined. We dubbed the binary's two lobes Ultima and Thule, with Ultima being the larger lobe.

The two lobes likely formed in the same individual "collapse cloud" of the ancient solar nebula as a binary, initially resulting in two separate objects orbiting about one another. From the shape of the two lobes of Ultima Thule, we see that the longest dimensions of each lobe are aligned. This implies that as these objects orbited each other, their orbits became tidally locked. The lack of massive fractures or other signs of violence in the two lobes indicates that, over time, their orbit collapsed until the two gently merged. This hypothesis is supported by the similar reflectivities, colors and compositions of the two lobes.

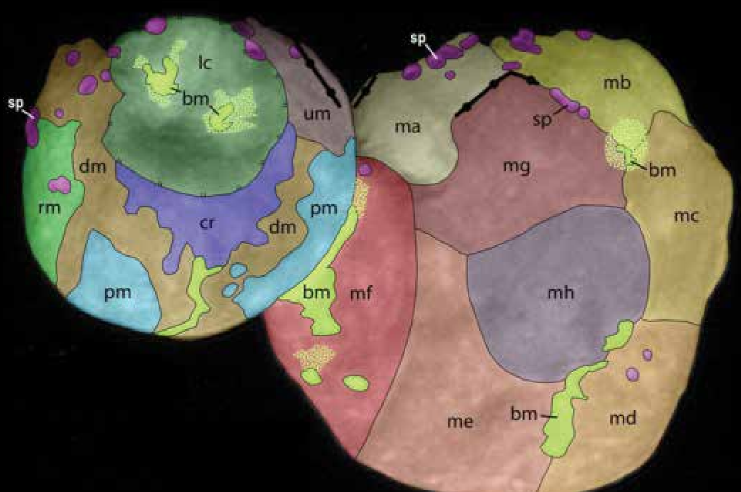
However, the contact zone or "neck" between Ultima Thule's two lobes is covered in brighter material of unknown origin and age. The science team is still debating whether this bright collar was created by the merger itself or evolved later.

Ultima Thule is reddish, like many other KBOs, but high-resolution images revealed patches of significant color variations across its surface. Compositional spectroscopy found evidence for water ice, as expected, and possibly methanol, which could explain its red color. The average surface reflectivity of Ultima Thule is just 7 percent, which is darker than dirt.

The KBO does have remarkably varied terrains across its two lobes. The larger lobe features eight like-sized regions, separated by brighter boundaries. These could represent smaller bodies that

Ultima Thule is very dark red overall, much ruddier than Pluto, with a few brighter areas. This colorized version of a black and white high-resolution image taken by New Horizons integrates hues from its lower-resolution color camera.

IMAGE COURTESY FLICKR.COM/PHOTOS/THOMASAPPERE D023765/ D023773



The science team has color-coded various features, including the large crater (labeled lc) on Thule and eight distinct regions on Ultima. These lumpy mounds may be the remaining outlines of the planetesimals that came together to form the larger lobe.

fused to form Ultima or perhaps they were created geologically after formation. We also discovered a few probable impact craters, including a large one dominating the smaller, Thule, lobe. Other divots are likely pit crater chains formed by either a sinking or collapse of the surface lying above internal voids.

Because any surface ices volatile enough to sublimate into gases would have long since escaped, Ultima Thule was unlikely to have an atmosphere, which was confirmed by our ultraviolet spectrometer. Many cold classical KBOs have moons, and a few current or escaped KBOs are even known to have rings, but Ultima Thule also turned out to be devoid of satellites and rings.

Perhaps Ultima Thule's biggest surprise is the curious shapes of its two lobes. Initially, we compared the binary to a snowman. However, one lobe is flatter, more pancake-like than spherical, while the other is shaped a bit like a walnut. Nothing like that has ever been found among KBOs, or anything else orbiting the Sun. In fact, nothing like that had ever been predicted, so formation modelers are already at work, trying to explain this.

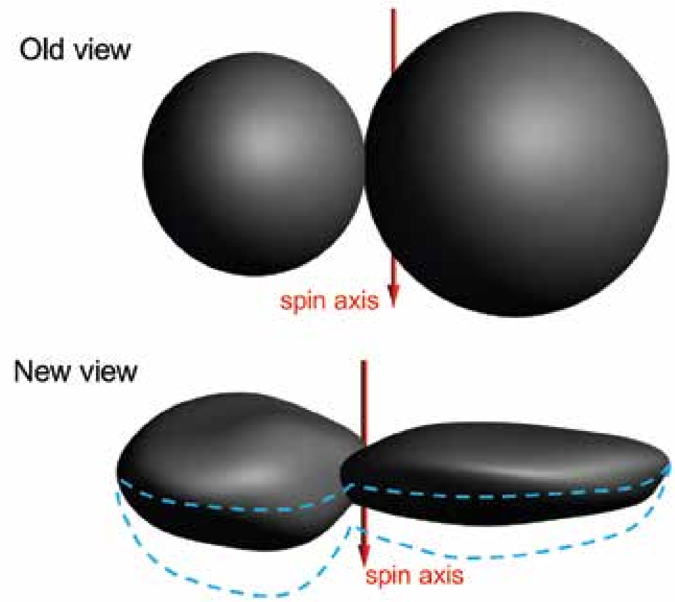
QUESTIONS ANSWERED, QUESTIONS SPARKED

What we've learned about Ultima Thule so far is shedding light on other KBOs, particularly the cold classical population. For example, the heterogeneous geology of the Ultima lobe tells us that other KBOs may contain clues to how they were assembled and evolved. Maybe Ultima Thule's moonless skies mean that KBOs that evolve as contact binaries may eject all their satellites in the orbital evolution that brings the two lobes together.

Discovering that Ultima Thule is a contact binary tells us that many KBOs are likely the same, something else that formation modelers will have to resolve. Ultima Thule's highly tilted spin axis will make that more challenging. Most current models for KBO formation predict uninclined, "up and down" spin axes corresponding with the angular momentum of the solar nebula, the disc-shaped cloud of gas and dust left over from the Sun's formation.

Meanwhile, Ultima Thule's crater counts will characterize the small-body KBO population that have impacted it, allowing us to infer size populations much too small for detection with telescopes. Unlike Pluto and some other dwarf planets, Ultima Thule lacks exposed volatile ices like molecular nitrogen, carbon monoxide and methane. This discovery appears to confirm models that indicate small, low-gravity KBOs cannot hold onto the atmospheres that would naturally form when these volatiles outgas.

Despite all we learned, New Horizons could not tell us everything about dwarf planets or KBOs. The spacecraft carried a limited payload and many aspects of KBO and dwarf planet science require different instrumentation. New Horizons visited only one of the many dwarf planet systems of the Kuiper Belt



Ultima Thule's two lobes have a flatter shape than the spherical projection suggested by the flyby's initial pictures. The dashed blue line marks the remaining uncertainty in the shape of each lobe.

D023768

IMAGES COURTESY NASA/JHUAPL/SwRI/HENRY THROOP

and one small KBO thus far. To understand the full range of such objects requires new missions to orbit Pluto and fly by new dwarf planets and small KBOs.

NEXT HORIZONS

Thirteen years and four billion-plus miles later, New Horizons is healthy and operating well, thanks to its designers, builders and flight team. If no serious malfunctions occur, the spacecraft could fly for another 15 years or more — past the edge of the Kuiper Belt — before its power supplies run out. However, New Horizons' communication capabilities reach far beyond that. Devising lower-power operations could allow more distant explorations.

DETAIL

An astronomical unit is roughly the distance from the Sun to the Earth, about 93 million miles.

Currently, New Horizons is funded into 2021. Its tasks include completing the down-link of Ultima Thule flyby data and observing other KBOs from a distance. The spacecraft also will survey the Kuiper Belt's radiation, solar wind and dust environment to 50 astronomical units (AU), the outer limit of Pluto's orbit.

Our science team will soon begin working on a second mission extension proposal to explore the Kuiper Belt's farther reaches. This proposal focuses on pushing the radiation, dust surveys and long-distance KBO observations out to 60 AU, which is still within the outer limits of the Kuiper Belt as we know it. We hope this mission will include flying by yet another KBO, much farther out than Ultima Thule.

The amount of fuel remaining is the limiting factor for flyby feasibility. Currently, engineers estimate that more fuel than it took to target Ultima Thule will be left for another flyby attempt. After we complete the current phase of intense Ultima Thule science data analyses, the New Horizons team will plot how to find a third, as yet undiscovered target. We will explore using large ground-based telescopes, the Hubble and James Webb space telescopes, and even New Horizon's onboard camera to find a new flyby target within "fuel reach."

We don't know how this will turn out. We must seek before we can find. So, stay tuned for more news about Ultima Thule, as well as the possible discovery of future flyby prospects.

Questions about this article? Contact Olkin at catherine.olkin@swri.org or 303.546.9670.

D023778

ABOUT THE AUTHORS

Planetary scientist Dr. S. Alan Stern (far left) is the principal investigator of NASA's New Horizons mission to Pluto and an associate vice president of SwRI's Space Science and Engineering Division. Dr. Cathy Olkin and Dr. John Spencer are New Horizons coinvestigators and Institute scientists, both specializing in outer solar system bodies.

D023775

Dr. Brian May (upper left) and other science team members discuss real-time Ultima Thule data.

NEW HORIZONS TO EXPLORE

So begins the ballad about New Horizons by Dr. Brian May, an astrophysicist better known as the lead guitarist of the rock band Queen. May serves on the New Horizons science team, mostly working on data analysis for stereoscopic imaging.

At the request of mission PI Dr. Alan Stern, he penned, created, and recorded a video for a song about the Ultima Thule flyby, which was released worldwide on New Year's Eve during the encounter.

"What hit me," May said, "was how inspiring the whole project was from the point of view of the human spirit of adventure. So that's really what I wrote this song about, as a tribute to the New Horizons team."

May was studying astrophysics when Queen rocketed to the top of the charts in the mid-1970s. He left the Ph.D. program to pursue music but returned to Imperial College to earn his doctorate in 2007. He joined the New Horizons team in 2015.

"Brian's ode to New Horizons touched our entire team," Stern said, "but even more importantly, it touched millions around the world in a way that few space missions do."

View May's music video at: https://youtu.be/j3Jm5POCAj8

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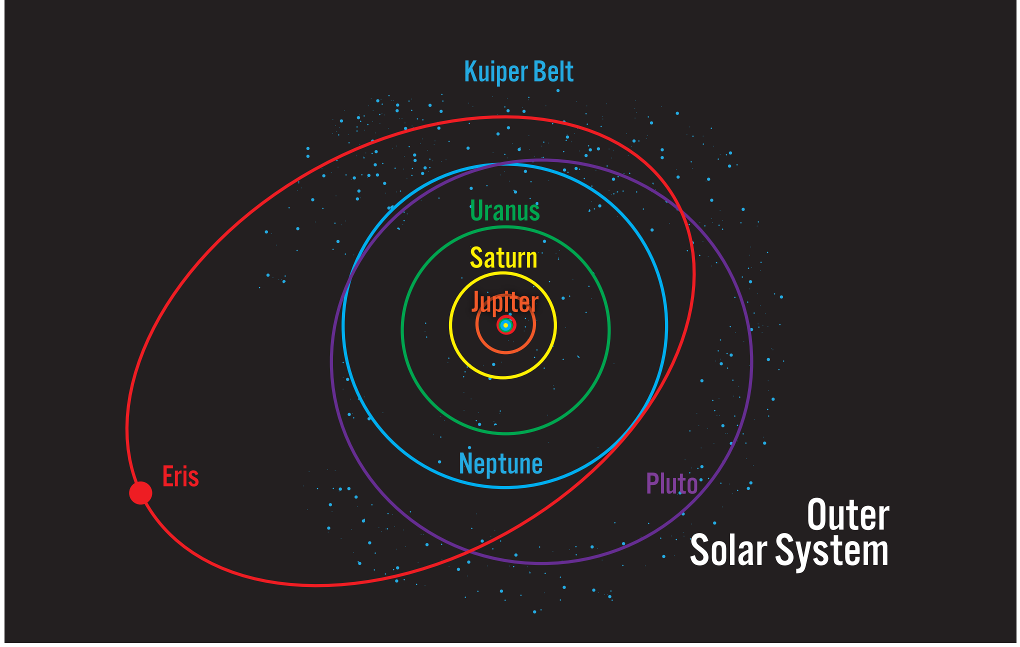


SURVEYING THE KUIPER BELT

NASA's Space Telescope Science Institute (STScI) recently awarded SwRI the largest Hubble Space Telescope (HST) solar system program ever, with 206 of Hubble's orbits around the Earth allocated to the project. The Solar System Origins Legacy Survey (SSOLS) will focus on Kuiper Belt Objects (KBOs), particularly binary populations.

"The Kuiper Belt is a unique remnant of the solar system's primordial planetesimal disk," said Dr. Alex Parker, the SwRI planetary scientist leading the survey. "This cold, calm region has preserved an extraordinarily large population of binary objects, particularly those where the two objects have similar mass."

Binary objects orbit around each other as they collectively circle the Sun. Recent models of small body formation suggest that binaries are leftovers of the infancy of our solar system, when pairs of bodies could form directly from collapsing swarms of small-scale "pebbles." The Kuiper Belt is a distant reservoir of ancient material that lies at the edge of our solar system, beyond all the terrestrial and giant planets.

Currently, the properties of the Kuiper Belt's unique population of binary systems can only be accurately measured with Hubble. Hubble orbits at an altitude of about 350 miles, circling the Earth every 97 minutes. Most HST time is dedicated to studying interstellar space phenomena.

"2014 MU69, also known as Ultima Thule, is the same kind of object that we are targeting — cold classical Kuiper Belt Objects," Parker said. "But it is a contact binary, which would not appear as separate objects in Hubble images. 2014 MU69 is sort of like a sibling to the targets we are interested in, as we are studying its more widely separated family."

SwRI leads this large HST project focused on characterizing the binary and color properties of over 200 unique KBOs. Team members are spread across the U.S., Canada and Northern Ireland.

D023770

Hubble Space Telescope orbits above the distortion of the atmosphere, rain clouds and light pollution, providing an unobstructed view of the universe

D023790

D023789

SwRI designed and built the pressure hull and transfer skirt for the Pressurized Rescue Module (PRM) Falcon, the U.S. Navy's submarine rescue vehicle. SwRI is collaborating with Phoenix International and other organizations to create a similar rescue system for the Royal Australian Navy.

SwRI DESIGNING RESCUE SUB DOWN UNDER

SwRI is designing and supporting the fabrication of a state-of-the-art remotely operated rescue vehicle as part of a $7.7 million project for the Royal Australian Navy (RAN). The system will feature shallow- and deep-water vehicles designed to connect with disabled submarines to rescue people trapped on board. They will be among a handful of remotely operated air-transportable submarine rescue systems in the world.

SwRI designed, fabricated and tested the pressure hull and transfer skirt for the U.S. Navy's first remotely operated submarine rescue vehicle in the early 2000s (see "Voyage from the Bottom of the Sea," Summer 2006 Technology Today). The Navy realized the need for such a vehicle after more than 100 sailors perished when an internal torpedo explosion sank a Russian nuclear submarine in the Arctic Ocean. Difficulty locating the Kursk and the inability to connect a rescue submersible to the escape hatch of the sub resulted in the death of 23 Russian sailors who had survived the initial explosion.

SwRI's Matt James is leading a team of engineers designing the hull of the deep-water remotely operated rescue vehicles (RORV) to accommodate up to 12 evacuees and two crew members. SwRI is designing and fabricating uniquely dexterous transfer skirts for both the deep-water RORV and the shallow-water vehicles. Submarines contain a small compartment, known as an escape trunk, used to exit a disabled sub. The transfer skirt is a rotating apparatus on the rescue vehicle that attaches to the hatch of the escape trunk.

"The deep-water RORV will reach depths up to 600 meters," James said. "The shallow-water rescue vehicle will operate up to 80 meters. The U.S. Navy submarine rescue vehicle has a transfer skirt that can rotate 45 degrees, but the RAN vehicles will rotate up to 60 degrees, giving them increased flexibility."

A main concern in deep-water rescues is decompression sickness, a dangerous condition caused by depressurizing too quickly. If a person transitions too quickly between pressurized and ambient states, dissolved gases can come out of solution, forming bubbles that move throughout the body, causing joint pain, paralysis and even death.

"The deep-water RORV will be pressurized to match the pressure of the disabled submarine," James said. "This allows for a rescued person to transfer to a decompression chamber when they reach the surface and avoid the risk of decompression sickness."

The rescue system will be transportable via aircraft and will launch from ships, mobilizing within hours of an incident. While they will primarily serve Australia's navy, the systems will also be able to support other nations that use NATO standard escape hatch designs on their submarines.

SwRI is supporting the SEA1354 Phase 1 Submarine Escape, Rescue and Abandonment System project in collaboration with Phoenix International and multiple subcontractors in Australia.

TRICKING OBJECT DETECTION TECHNOLOGY

SwRI has developed new adversarial techniques that can make objects "invisible" to image detection systems that use deep-learning algorithms. These techniques can also trick systems into thinking they see another object or can change the location of objects. The technique is designed to mitigate vulnerabilities in automated image processing systems.

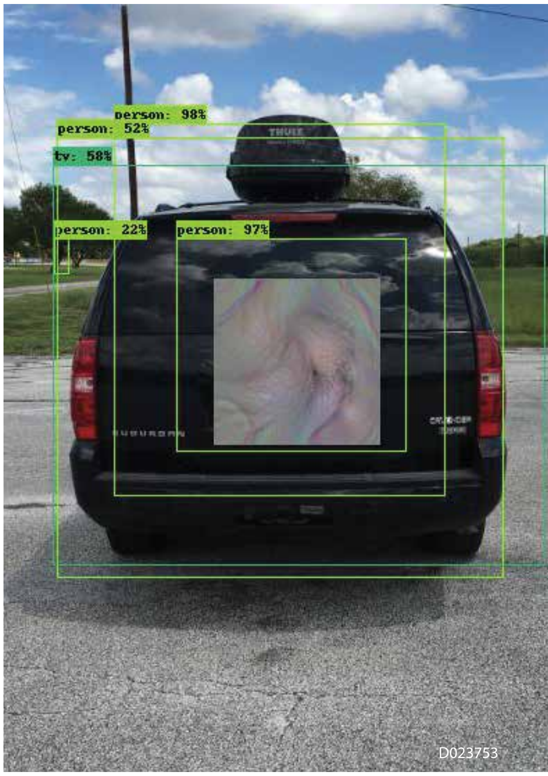
"Deep-learning neural networks are highly effective at many tasks," says Abe Garza of the SwRI Intelligent Systems Division. "However, deep learning was adopted so quickly that the security implications of these algorithms weren't fully considered."

Deep-learning algorithms excel at using shapes and colors to recognize the differences between humans and animals or cars and trucks, for example. These systems reliably detect objects under an array of conditions and, as such, are used in myriad applications and industries, often for safety-critical uses. The automotive industry uses deep-learning object detection systems on roadways for lane-assist, lane-departure and collision-avoidance technologies. These vehicles rely on cameras to detect potentially hazardous objects around them. While the image processing systems are vital for protecting lives and property, the algorithms could potentially be deceived by malicious parties.

Security researchers working in "adversarial learning" are finding and documenting vulnerabilities in various machine-learning algorithms. SwRI developed futuristic, Bohemian-style patterns that, when applied to objects or people, can trick detection systems into thinking they aren't there, that they're something else or that they're in another location. Malicious parties could place these patterns near roadways, potentially creating chaos for vehicles equipped with object detectors.

"The first step to resolving these exploits is to test the deep-learning algorithms," Garza said. "The team has created a framework capable of repeatedly testing these attacks against a variety of deep-learning detection programs, which will be extremely useful for developing solutions."

To see how object detection cameras visualize the patterns, watch our video on YouTube at https://youtu.be/ylbVMMR4Eqg.



Many of today's vehicles use object detection systems to help avoid collisions. SwRI engineers developed unique patterns that can trick these systems. In the photo above, an object detection system sees a person rather than a vehicle. Engineers are using these patterns to thoroughly test object detection systems and improve the security of the deep-learning algorithms they use.

At left, Research Engineer Abe Garza displays the special imagery used to deceive object detection systems fueled by deep-learning algorithms. SwRI researchers are developing techniques to mitigate risks associated with these systems.

DEEP OCEAN SIMULATION

For more than 50 years, Southwest Research Institute has been simulating extreme underwater conditions in a land-locked Ocean Simulation Laboratory in San Antonio. Facilities recreate the pressures and temperatures equipment must endure as a final quality and operational integrity check for clients in the oil and gas, ocean research, and naval or other defense industries. Pressure capabilities far exceed deep ocean conditions to simulate the geologic and wellbore environments that equipment must withstand. We also evaluate diving equipment as well as civilian and military submersible technology, including submarine rescue systems and the titanium hull of the Alvin research submersible. SwRI evaluates all types of equipment — from tubular goods to ROVs and even fishing lures — in high-pressure chambers, simulating deep ocean conditions to measure strength and durability and help avoid offshore catastrophes.

SwRI pressure tested this commercial submarine acrylic sphere in our **90-inch, 18-foot-deep** pressure chamber to ensure that it would withstand sea pressures without leaking.

3 buildings/ 18,000 square feet

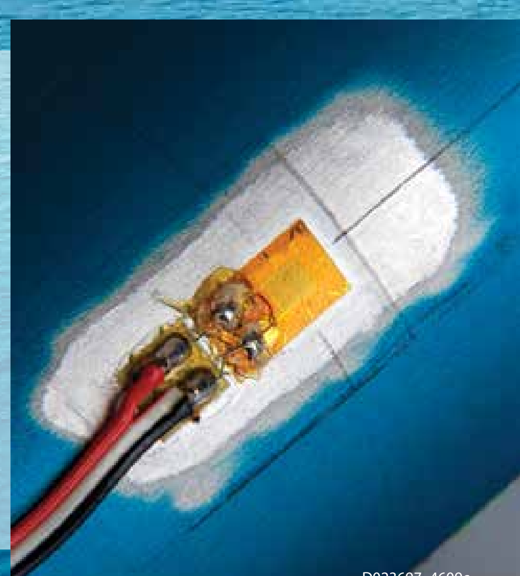
Engineers used an array of strain gauges to evaluate the pressure hull and dome windows of this deep-sea **3-man** submersible tested in SwRI's high-pressure chamber.

PRESSURE TESTING

- Internal & external hydrostatic
- Stress analysis & instrumentation
- Electrical & hydraulic penetration
- Collapse & burst of:
  - API steel casing and line pipe
  - Fiberglass/other composite pipe
  - Valve bodies
- Verification of:
  - Prototype equipment
  - Pressure housings
  - Subsea instrumentation
  - Cables
  - Connectors
  - Oilfield equipment

An excess of **60,000 psig** internally burst this valve body at SwRI's remote outdoor testing facility.

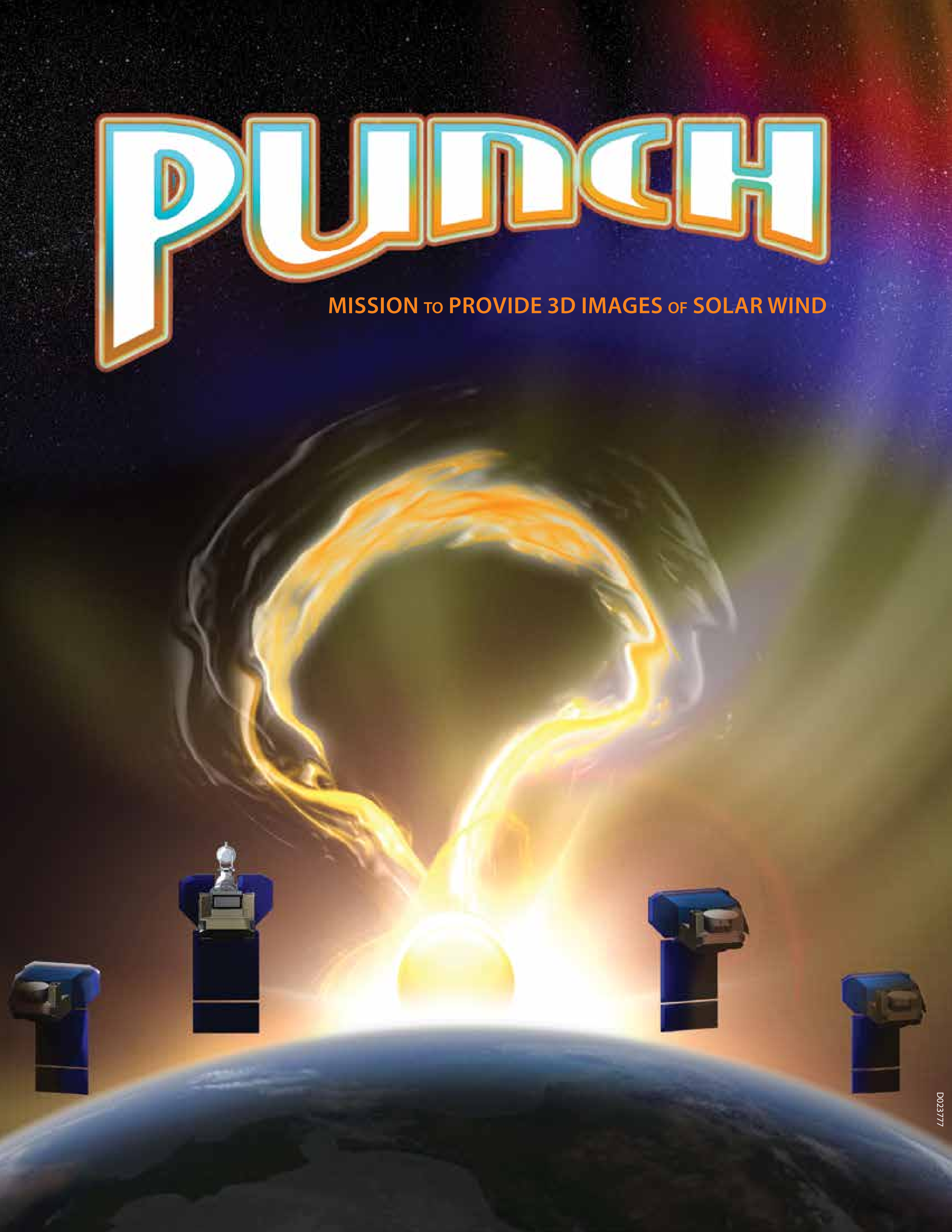
SwRI has installed **1,000s** of strain gauges in the field combined with custom-configured data acquisition systems that assess the performance of components and materials both at the surface and under high pressures.



SwRI has **20 deep ocean pressure vessels**

- 2–90 inches internal diameter
- Up to 22 feet internal depth
- 2,500–60,000 psi
- 32–650° F

The Technology Today Podcast offers a new way to listen and learn about the technology, science, engineering and research impacting our lives and changing our world. Check out Episode 6 for a more in-depth discussion of deep ocean simulation with SwRI's Joe Crouch. https://www.swri.org/podcast/ep6


PUNCH
MISSION TO PROVIDE 3D IMAGES OF SOLAR WIND
D023777

NASA has selected Southwest Research Institute to lead the "Polarimeter to Unify the Corona and Heliosphere" (PUNCH) mission, a landmark Small Explorers Program mission that will image beyond the Sun's outer corona. PUNCH will consist of a constellation of four suitcase-sized microsatellites or "microsats" that will launch as early as 2022. The microsats will orbit the Earth in formation to study how the Sun's atmosphere, or corona, connects with the interplanetary medium. PUNCH will provide the first global images of how the solar corona infuses the solar wind with mass and energy.

"The vacuum of space between the planets is not completely empty — it is actually filled with a tenuous, hypersonic 'solar wind' that streams out from the corona and affects spacecraft and planets — including our own," said PUNCH Principal Investigator Dr. Craig DeForest, a scientist and program director in SwRI's Space Science and Engineering Division. "PUNCH will observe the 'no-man's land' between the outer solar corona and the solar wind, giving us our first clear images of the entire system connecting the Sun and Earth."

PUNCH will track and image the solar wind as it emerges from the solar corona, transitions to interplanetary space and streams through the solar system, bathing the planets and other solar system bodies. These measurements will reveal how and why the material coming from the star becomes gusty and turbulent en route to Earth. In addition, the PUNCH satellites will track in 3D the Sun's coronal mass ejections, also known as "CMEs" or "space storms," as they erupt from the corona out into interplanetary space. CMEs cause some "space weather" events that affect Earth, which can threaten astronauts, damage satellites, black out power grids, and disrupt communication and GPS signals.

"Most of what we know about the space weather delivered by the solar wind comes from direct sampling by spacecraft embedded in it," said PUNCH Project Scientist Dr. Sarah Gibson, acting director of the High Altitude Observatory in Boulder, Colorado. "This is like understanding global weather patterns based on detailed measurements from a few individual weather stations on the ground. PUNCH is more like a weather satellite that can image and track a complete storm system as it evolves across an entire region."

The four spacecraft will fly in a distributed formation spread around the globe, operating in sync to produce polarized images of the entire inner solar system every few minutes. Each of the four PUNCH spacecraft carries a specialized camera to capture faint glimmers of sunlight reflected by free electrons in interplanetary space. One spacecraft carries a Narrow Field Imager that captures the outer corona itself, and the others carry SwRI-developed Wide Field Imagers (WFIs). Dark baffles enable the WFIs to photograph space weather effects that are over a thousand times fainter than the Milky Way, despite flying in direct sunlight.

"Photographing the sky in polarized light is the secret sauce of the mission," DeForest said. "When sunlight bounces off electrons, it becomes polarized. That polarization effect lets us measure how solar wind features move and evolve in three dimensions, instead of just a 2D image plane. PUNCH is the first mission with the sensitivity and polarization capability to routinely track solar wind features in 3D."

"The Explorers Program seeks innovative ideas for small, cost-constrained missions that can help unravel the mysteries of the universe," said Dr. Paul Hertz, director of NASA's Astrophysics Division. "PUNCH absolutely meets the standard to solve mysteries about the Sun's corona, the Earth's atmosphere and magnetosphere, and the solar wind."

The Small Explorers program provides frequent flight opportunities for world-class scientific investigations from space using innovative, efficient approaches within the heliophysics and astrophysics science areas.

For an animation of the PUNCH launch, see https://www.youtube.com/watch?v=7keLZtTIrB4

SwRI developed, prototyped and environmentally tested the Wide Field Imager using SwRI internal research funding over a period of two years. The dark baffles that form the top surface of the instrument allow the wide-angle camera to image objects over a thousand times fainter than the Milky Way.

EXT

An SwRI-led team of engineers created this 15-megawatt (10 MWe) supercritical carbon dioxide turbine at right that can increase efficiency and lower the cost of power generation for solar power plants. The air dynamometer at left was designed to absorb the net power output of the turbine during testing.

D023795

Powerful, desk-sized 10 MWe turbine operates at 1,300 F to improve power production

Steam turbines, invented by Sir Charles Parsons in 1884, currently generate about 80% of the world's commercial electric power. Heat, typically produced by burning fossil fuels, turns water into steam, which spins turbine blades to convert energy into rotation. A generator then transforms that rotation into electricity.

Replacing steam with supercritical carbon dioxide (sCO_2) as the working medium could revolutionize the power generation industry. Carbon dioxide typically behaves as a gas at ambient temperatures and pressures, or as a solid — dry ice — when frozen. Increasing the temperature and pressure to a supercritical point (above 73.9 bar, or 1,071 psi) for carbon dioxide creates fluid properties somewhere between a gas and a liquid.

The economic and environmental benefits of sCO_2 power plants would include higher efficiency, reduced fuel consumption and lower emissions. Additionally, the compact design and small footprint of sCO_2 technology would lower capital costs and decrease cooling water consumption.

HOT NEW TURBINE

A team of Southwest Research Institute and General Electric (GE) engineers designed, built and tested the highest temperature sCO_2 turbine in the world. The turbine was developed with $6.8 million from

DETAIL

Megawatts electric or MWe refers to the electric output capacity of a plant. Megawatts thermal, or MWt, refers to the input energy required. A coal-fired power plant rated at 1,000 MWe and 3,000 MWt requires 3,000 MW of heat from burning coal for every 1,000 MW of electricity it produces with 2,000 MW of energy lost as waste heat. That's why most older plants operate at around 30% efficiency.

TREME TURBINE TECHNOLOGY

By Jeffrey Moore, Ph.D., Meera Day Towler, P.E., and Stefan Cich

D022794_9808

DETAIL

Concentrated solar power systems generate power by using mirrors or lenses to concentrate a large area of sunlight into a small area. The concentrated light is converted to heat, typically heating water into steam that drives a turbine connected to an electric power generator.

the U.S. Department of Energy (DOE) Solar Energy Technologies Office (SETO) and $3 million from commercial collaborators.* The DOE's Advanced Research Projects Agency – Energy (ARPA–E) Full-spectrum Optimized Conversion and Utilization of Sunlight (FOCUS) program provided additional financial support to validate advanced thermal seals for the device.

The new 10 megawatt electric (MWe) turbine is the size of a desk and yields the highest power density of any industrial turbine, rivaled only by the turbopumps used in space shuttle engines. This small powerful turbine was designed specifically to withstand the tough operating conditions associated with concentrated solar power (CSP) plants. However, sCO_2 technology is heat agnostic, and could potentially improve the efficiency of fossil fuel, solar and nuclear power plants. The technology also lowers the cost of waste heat recovery and energy storage and is highly scalable. Engineers envision use in a 300 MWe utility plant. It could result in a 2–4% efficiency increase for fossil fuel plants over current state-of-the-art steam plants while reducing CO_2 emissions by the equivalent of 14 million cars.

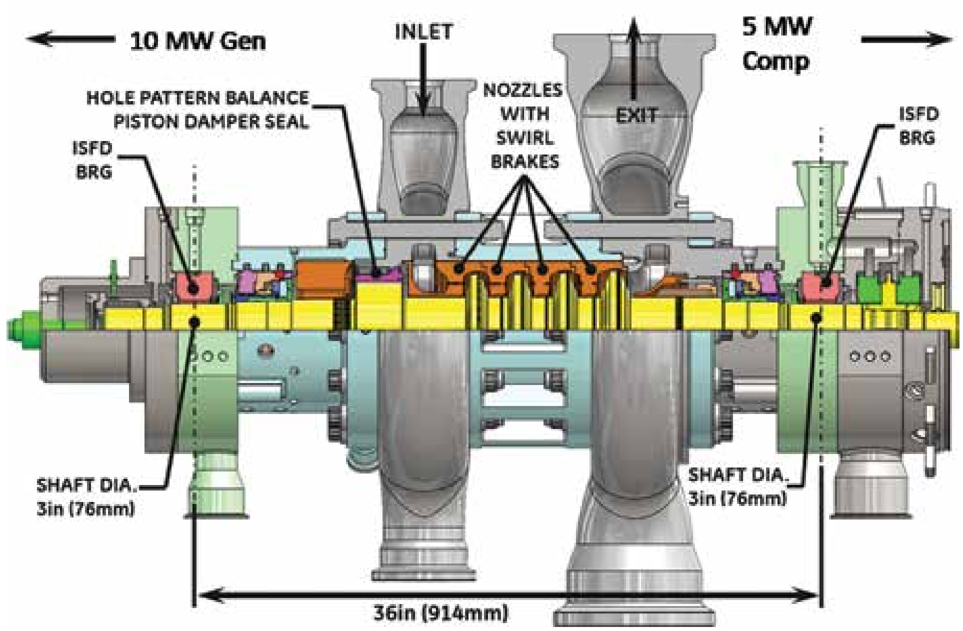
Achieving the conditions needed for sCO_2-based systems required the project team to overcome significant engineering challenges for operating under high-temperature, high-pressure conditions. Over the past five years, the SwRI team worked with its collaborators and SETO to create a multi-stage axial flow sCO_2 hot gas turboexpander. GE Research contributed significantly to the turbine's design, especially in the turbine's rotor.

TURBINE FEATURES

The turbine has a four-stage rotor assembly. A rotor is a shaft or drum with blades attached. As moving fluid acts on the blades,

SwRI developed this 10 MWe sCO_2 four-stage axial flow turbine under DOE's Sunshot Program in collaboration with General Electric. The turbine generates 15 MW gross power at inlet conditions of 715 degrees C and 250 bar.

D023793



they spin and impart rotational energy that a generator converts into electricity. Axial flow compressors use multiple stages or blade wheels to expand the working fluid. These turbines offer high efficiency and large mass flow rate, particularly for their size and cross-section.

The new turbine expands high-pressure sCO_2 gas to produce enough power to drive the compressor and generator that create electricity in CSP plants. These turbo-expanders must operate at temperatures greater than 1,300 degrees Fahrenheit and pressures over 3,600 pounds per square inch (psi) under a wide range of load conditions. They must also maintain high efficiency, a fast start-up time and the ability to handle rapid swings in transient heat input.

The turbine features dual inlets and exhausts to accommodate large gas flow in a small package. Its four stages extract energy from the high-temperature (715 C or 1,320 F) flow, while decreasing the pressure from 250 bar (3,600 psi) to 80 bar (1,200 psi) at the exhaust stage. The full-flow turbine will generate 15 MW (20,000 horsepower) gross power, or 10 MW of net electric power after subtracting the compressor power, while running at 27,000 revolutions per minute (rpm). Considering the rotor weighs less than 82 kg (180 pounds), this turbine has the highest power density — horsepower to pound — of any industrial turbine, second only to rocket engine turbopumps.

SwRI fabricated and machined the turbine's high-temperature, high-pressure casing out of nickel-chromium-based superalloys. These oxidation- and corrosion-resistant materials with high creep strength are ideal for extreme environments. Using an advanced five-axis electrode discharge machining (EDM) process, the team manufactured the rotor from one piece of a high-temperature, oxidation-resistant nickel-based alloy. Engineers developed thermal seals at each end to reduce temperatures and protect the mechanical seals designed to minimize atmospheric leaks.

Most conventional CSP systems operate at a thermal efficiency of 30–40%. The newly designed turbine with the sCO_2 power cycle can approach 50% efficiency. With more efficient and cost-effective power, the new turbine makes CSP plants more economically competitive with fossil fuel power plants.

ROTORDYNAMIC RESISTANCE

Rotating machinery produces vibrations during operation. Because this turbine operates in such extreme conditions (high speed, vibration and temperature), engineers designed the components to minimize imbalance and manage the fluid dynamic forces acting on the rotor. This reduces the risk of catastrophic failures and improves reliability, targeting a 20-year operating life.

DETAIL

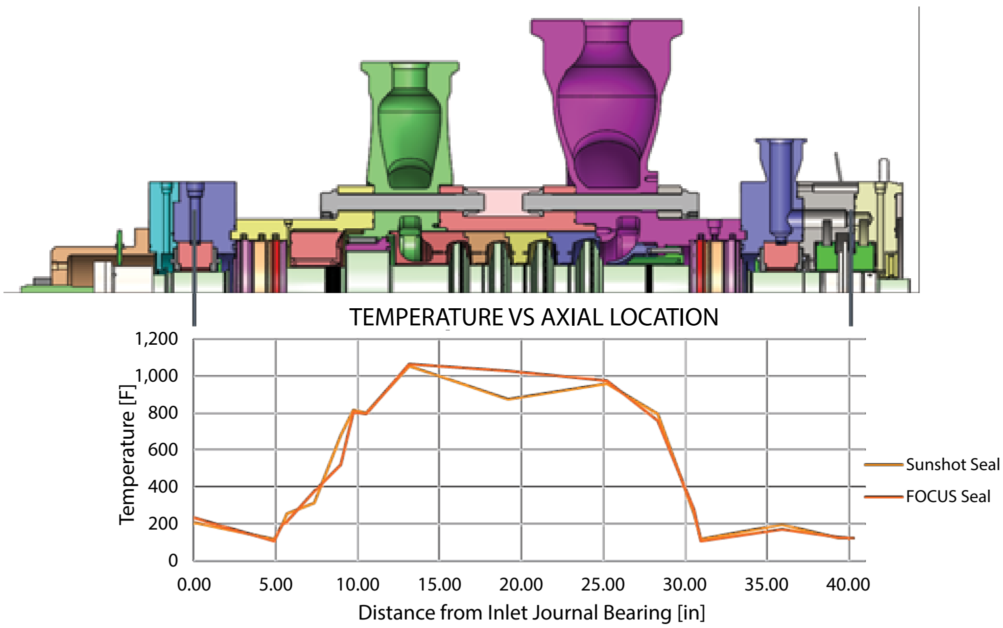
Bar is a metric unit of pressure, comparable to pounds per square inch or psi. Many engineers use bar as the standard unit of pressure. To convert psi to bar, divide the pressure by 14.50.

SwRI engineers assembled the thrust bearings on the 10 MWe sCO_2 turbine. The radial tilting-pad bearings are outfitted with dampers to improve rotordynamics.

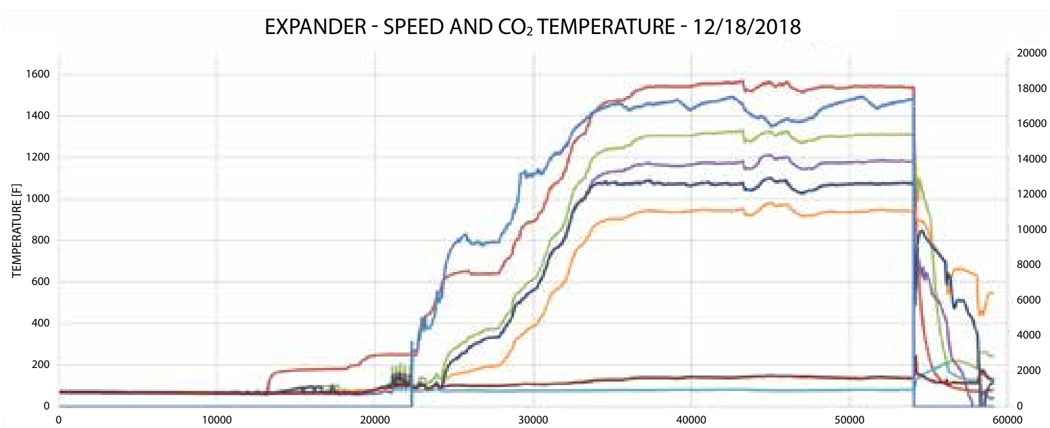
D023791

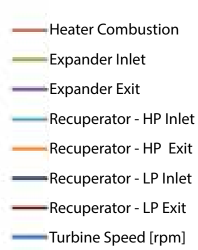
This test fixture constructed in SwRI's Turbomachinery Research Facility incorporates a high-temperature natural gas-fired heater, a recuperator to capture exhaust heat and ancillary equipment such as mechanical seals and bearings.

D023792



Engineers tested two different thermal seals. Both exhibited a linear temperature gradient at each end of the turbine to minimize thermal stress in the casing and rotor.





SwRI performed a six-hour endurance test at the maximum temperature of 715° C. The turbine accommodated a rapid transient shutdown at the conclusion of the test.

Engineers designed the turbine bearings to utilize squeeze film dampers to improve the turbine's rotordynamic response. These films between the bearing and the housing soften the bearing support and increase damping effectiveness. Other advanced features implemented include swirl brakes and hole pattern damper seals, components that improve rotor-dynamic stability at extreme conditions.

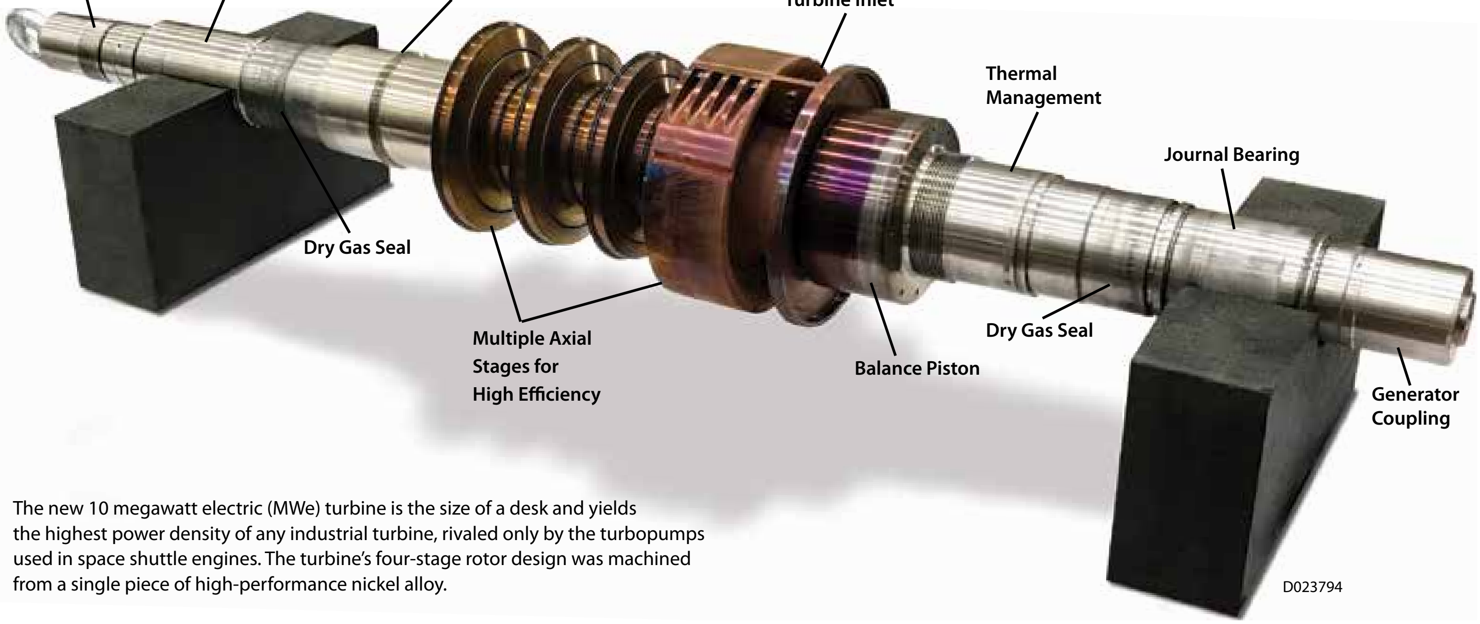
TURBINE TESTING

The Institute's custom-built, high-pressure sCO_2 1-MWe test loop's size represents a compromise between capability and cost. The turbine internal flow path was reduced to match the test loop but provided nearly identical pressure and temperature distributions through the turbine. SwRI and its collaborators also designed the primary heater. Fabricated by an outside commercial entity, it is built from the highest-temperature-resistant piping available.

In this facility, engineers put the turbine through a rigorous series of tests, varying speed, temperature and pressure. The turbine met all mechanical and performance objectives, hitting maximum targets of 27,000 rpm, 715 C and 250 bar. The rotor experienced low vibrations throughout the test and demonstrated good stability under the full range of operating conditions.

APPLICATION

A full 10 MWe version of the turbine will be incorporated into the Supercritical Transformational Electric Power (STEP) 10 MW demonstration plant, a $119 million sCO_2 pilot plant currently under construction at the Institute. Developed through a collaborative effort among Gas Technology Institute, SwRI and GE and funded by DOE's National Energy Technology Laboratory, STEP will demonstrate a fully integrated sCO_2 power plant that generates power at higher



The new 10 megawatt electric (MWe) turbine is the size of a desk and yields the highest power density of any industrial turbine, rivaled only by the turbopumps used in space shuttle engines. The turbine's four-stage rotor design was machined from a single piece of high-performance nickel alloy.

efficiency and lower costs with a smaller carbon footprint than conventional plants.

SwRI broke ground on the project in October 2018, with construction set to begin in early 2019 and a completion goal set for April 2020. STEP technology, including the high-temperature turbine, could revolutionize the power generation industry, providing economic and environmental benefits including higher efficiency, reduced fuel consumption and lower emissions. In addition, the small footprint of sCO_2 technology would lower capital costs and decrease cooling water consumption.

Future turbine concepts under development are incorporating direct-fired oxy-fuel combustors that can burn natural gas with oxygen, allowing much higher turbine temperatures and producing CO_2 and water as its only by-products. Because combustion is performed at elevated pressures, the CO_2 can be easily captured to create a true emission-free power source with efficiencies that rival the current state of the art with no carbon capture.

What this all means is that the same gas largely blamed for Earth's climate change may be the one that prevents it.

Questions about this article? Contact Moore at jeff.moore@swri.org or 210.522.5812.

ABOUT THE AUTHORS

Dr. Jeff Moore (right) is an Institute engineer who specializes in high-speed rotating equipment. He led the team that developed the supercritical carbon dioxide turbine. Senior Research Engineer Stefan Cich (left) led the mechanical design, analyzing the stresses, flow and dynamics of rotating equipment. Research Engineer Meera Day Towler specializes in data acquisition systems, instrumentation and control systems to evaluate turbomachinery.

*GE Research, Thar Energy, Electric Power Research Institute, Aramco Services Company and the Naval Nuclear Laboratory collaborated with SwRI on this project.

D023747

NEW SCOUTING ANTENNA

To operate safely in remote and potentially hostile parts of the world, the U.S. military collects signals intelligence, or SIGINT, detecting electronic communications, locating their source and assessing their significance to the mission at hand. Scout™ is an SwRI-developed, portable, wideband radio frequency survey and monitoring system that has aided the intelligence community for over five years.

Recently, SwRI engineers developed this AF-369 antenna to estimate the direction of the arrival of signals across the 20 MHz to 3 GHz spectrum. This fixed-site, low-cost VHF/UHF direction finding antenna augments Scout's SIGINT collection capabilities.

IMAGE COURTESY NASA/JPL/USGS/PSI/AMANDA HENDRIX

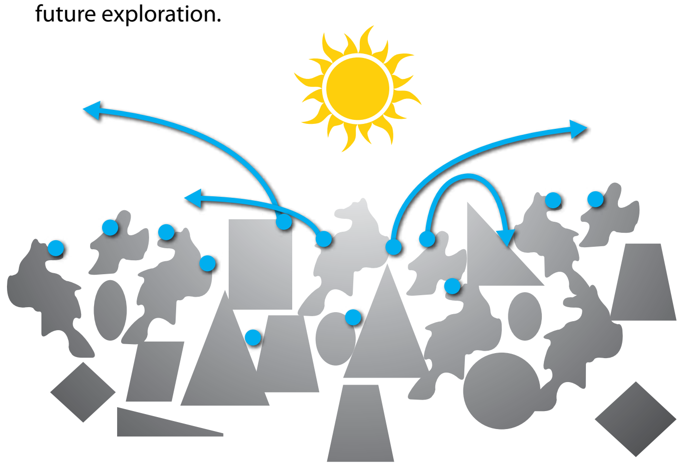
LAMP Sheds Light on Lunar Water

Using the SwRI-led Lyman Alpha Mapping Project (LAMP) aboard NASA's Lunar Reconnaissance Orbiter (LRO), scientists have observed water molecules moving around the dayside of the Moon. A paper published in Geophysical Research Letters describes how LAMP measurements of the sparse layer of molecules temporarily stuck to the lunar surface helped characterize hydration changes over the course of a day.

Up until the last decade or so, scientists thought the Moon was arid, with any water existing mainly as pockets of ice in permanently shaded craters near the poles. More recently, scientists have identified surface water in sparse populations of molecules bound to the lunar soil, or regolith. The amount and locations vary based on the time of day. This water is more common at higher latitudes and tends to hop around as the surface heats up.

"This is an important new result about lunar water, a hot topic as our nation's space program returns to a focus on lunar exploration," said SwRI's Dr. Kurt Retherford, the principal investigator of the LRO LAMP instrument. "We recently converted the LAMP's light collection mode to measure reflected signals on the lunar dayside with more precision, allowing us to track more accurately where the water is and how much is present."

Water molecules remain tightly bound to the regolith until surface temperatures peak near lunar noon. Then, molecules thermally desorb and can bounce to a nearby location that is cold enough for the molecule to stick or populate the Moon's extremely tenuous atmosphere, or "exosphere," until temperatures drop and the molecules return to the surface. Characterizing the water on the Moon is critical to planning future exploration.



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This graphic illustrates water molecules scattering on the lunar surface. As rough, irregularly shaped grains heat up over the course of a day, the molecules detach from the regolith and hop across the surface until they find another location cold enough to stick to.

CURING CANINE CANCERS

More than 100,000 dogs are affected by canine melanoma every year. SwRI has licensed its patented calcium phosphate nanoparticle delivery system exclusively to MBF Therapeutics (MBFT) to develop advanced immunotherapeutic treatments for canine melanoma.

The non-toxic, biocompatible drug delivery vehicle safely dissolves under specific conditions. MBFT will conduct clinical trials of an advanced immunotherapeutic vaccine to prevent and treat cancer in "man's best friend" and eventually other companion animals and livestock.

"We have successfully encapsulated various active pharmaceutical ingredients in this formulation and demonstrated controlled release," said SwRI Senior Research Scientist Dr. Hong Dixon. "The material safely and effectively dissolves under the right conditions to directly deliver the therapeutic to its target."

Nanoparticles can carry a positive or negative charge to deliver the therapeutic into the targeted cell. SwRI applies different surface charges to this vehicle as needed to enhance drug delivery.

"SwRI's nanoparticles are the ideal delivery vehicles for our immunotherapeutic vaccines," said Dr. Lorraine Keller, chief science officer of MBFT. "Beyond this agreement, we look forward to working with SwRI on other projects to create effective and durable immunotherapeutic vaccines for animal health."

SOLAR ADVANCES

The U.S. Department of Energy Solar Energy Technologies Office (SETO) has awarded SwRI two concentrating solar-thermal power (CSP) research and development projects. Both will support CSP power cycles that use supercritical carbon dioxide (sCO_2) as the working fluid, which has the potential to yield higher thermal efficiencies at lower costs than steam (see story about related sCO_2 technology on p. 20 of this issue).

The first project, valued at $1.5 million, will develop and test a compact dry-cooling heat exchanger for sCO_2 power cycles. While dry cooling reduces the water used by power plants it can also reduce the thermal-to-electric conversion efficiency of the power cycle. The SwRI design will efficiently exchange heat between sCO_2 and ambient air to conserve water and optimize peak power cycle performance.

"We'll also test the performance and reliability of the dry cooling system within a MW-scale sCO_2 test loop," said Dr. Tim Allison, manager of Rotating Machinery Dynamics. "This concept could reduce the cooler cost from $168 per kilowatt to $95 per kW and reduce cooling power consumption in CSP plants by 14 percent."

In the second project, valued at $2 million, SwRI will develop a high-temperature dry-gas seal for sCO_2 power cycle turbomachinery. CSP plants with sCO_2 power cycles use mechanical seals to prevent fluid leaks. The increased temperatures and pressures of sCO_2 power cycles, however, require novel materials to reach the targeted thermal-to-electric power conversion efficiency of 50 percent.

"By replacing the temperature-sensitive elements with more durable components, the new seals will withstand temperatures over 500 degrees C," said SwRI's Dr. Jason Wilkes. "This high-efficiency sCO_2 turbine design will be smaller and simpler to improve reliability and efficiency."

SwRI is teaming with commercial collaborators as a part of the Energy Department's effort to invest in research to lower solar electricity costs and support a growing solar energy workforce.

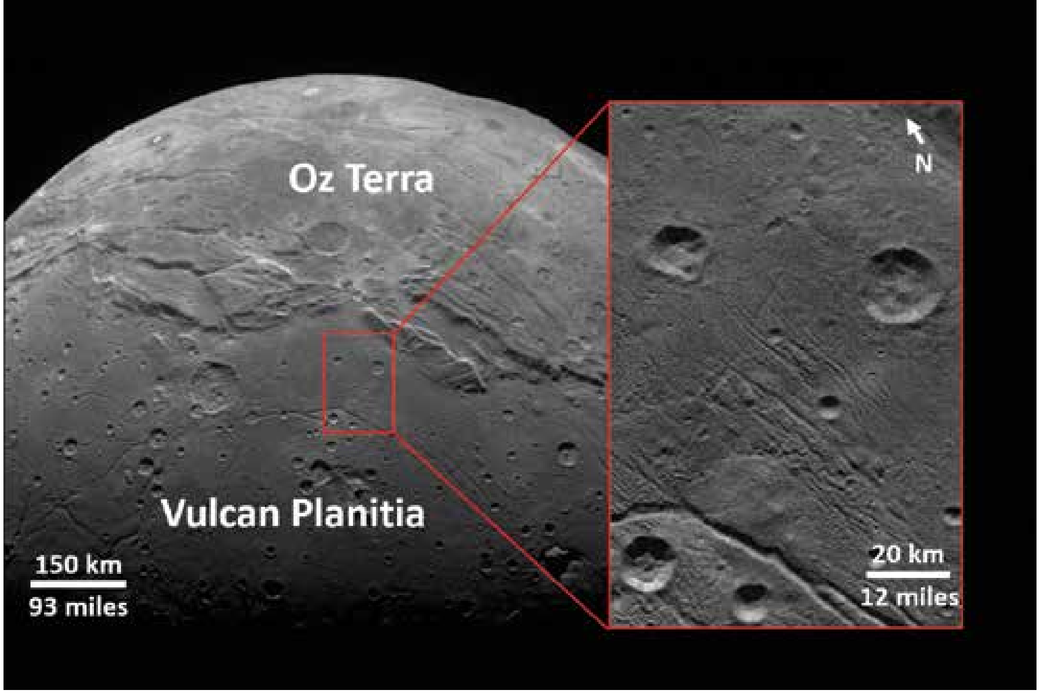

IMAGE COURTESY NASA/JHUAPL/LORRI/SwRI D023763

An SwRI-led team studied the craters and geology on Pluto and Charon and found there were fewer small craters than expected. This implies that the Kuiper Belt contains relatively small numbers of objects less than 1 mile in diameter. Imaged by New Horizon's LORRI camera, the smooth, geologically stable "Vulcan Planitia" on Charon illustrates these findings.

KBOs Smaller Than a Mile in Diameter Are a Rarity

Using New Horizons data from the Pluto-Charon flyby in 2015, an SwRI-led team of scientists has indirectly discovered a distinct and surprising lack of very small objects in the Kuiper Belt. The evidence for the paucity of small Kuiper Belt objects (KBOs) comes from New Horizons imaging that revealed a dearth of small craters on Pluto's largest satellite, Charon, indicating that impactors from 300 feet to 1 mile (~100 meters to 1.5 km) in diameter must also be rare.

The Kuiper Belt is a donut-shaped region of icy bodies beyond the orbit of Neptune. Because small Kuiper Belt objects were some of the "feedstock" from which planets formed, this research provides new insights into how the solar system originated. This research was published in the March 1 issue of the prestigious journal Science.

"These smaller Kuiper Belt objects are much too small and far away to see directly with any current telescopes on Earth," said SwRI's Dr. Kelsi Singer, the paper's lead author and a coinvestigator of NASA's New Horizons mission. "New Horizons flying directly through the Kuiper Belt and collecting data there was key to learning about both larger and smaller bodies of the Belt."

Craters on solar system objects record the impacts of smaller bodies, providing hints about the history of the object and its place in the solar system. Because Pluto is so far from Earth, little was known about the dwarf planet's surface until the epic 2015 flyby.

"This breakthrough discovery by New Horizons has deep implications," added the mission's principal investigator, Dr. Alan Stern, also of SwRI. "Just as New Horizons revealed Pluto, its moons, and more recently, the KBO nicknamed Ultima Thule in exquisite detail, Dr. Singer's team revealed key details about the population of KBOs at scales we cannot come close to directly seeing from Earth."

D023755

VALIDATING CLEAN WATER METHODS

SwRI played a crucial role in helping the Environmental Protection Agency validate a method for detecting and quantifying fecal contamination in fresh and marine water as well as wastewater. These methods help determine if recreational waters and wastewater are safe for swimming and other uses.

"We conducted a study to validate a modification EPA wanted to establish to a water sampling protocol," said Senior Research Scientist Spring Cabiness. "Based on our participation and the participation of other labs nationwide, the method has now been validated and posted on the EPA Clean Water Act Analytical Methods page."

The EPA started with an established method developed for smaller sample volumes, so the procedure required filtration techniques to concentrate the samples prior to evaluation. Samples were then prepped and poured into plates. After overnight incubation, scientists would assess contamination levels of the sampled water.

The SwRI team received an EPA letter of gratitude for helping characterize the performance of the methods and establish quality control acceptance criteria. Feedback allowed clarifications and revisions to be included with posted methods.

SEEING PAST THE SHINE

SwRI in association with the open-source project ROS-Industrial developed a solution that enables industrial robots to scan and reconstruct metallic objects that had previously been too "shiny" for machine vision to process.

The solution for reconstructing shiny or featureless objects leverages an algorithm that pulls together many views of an object to create high-fidelity virtual representations of the to-be-processed object. SwRI showcased this approach using a second-generation Robot Operating System (ROS2) framework in an industrial demonstration system at the Automate 2019 trade show.

"This is a great case study in the benefits and challenges of integrating ROS2 into industrial robotics," said Matt Robinson, an SwRI manager who supports ROS-I. "It also shows how advanced perception algorithms can enable faster, more reliable scanning of metallic objects."

The latest ROS-I solution uses ROS2 to integrate cameras affixed to a robotic arm, collecting data at a high frame rate to create a 3D output mesh that optimizes path planning. Machine vision cameras and algorithms have historically struggled to render accurate 3D images of metallic objects due to the "visual noise" that scatters off highly reflective surfaces. This significant challenge limits automation of welding and surface finishing processes in aerospace and automotive manufacturing.

ROS-I overcomes this challenge by integrating algorithms that stitch together several images, or point clouds, at a higher rate. The solution uses TrajOpt, or trajectory optimization, for motion planning within the ROS-I Scan-N-Plan framework, enabling real-time trajectory planning from 3D scan data. Though demonstrated in ROS2, solutions are compatible in legacy ROS versions as well.

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

GREEN CAR TECHNOLOGY

SwRI's automotive engineers are advancing connected and automated hybrid vehicle technologies with the goal of improving fuel economy by more than 20 percent.

Working with the University of Michigan and Toyota Motor Corp., SwRI has developed control algorithms to optimize a hybrid vehicle's route, speed profile and power flows. This real-time control is more efficient than dynamic cruise control and improves the power-split between battery and liquid fuel based on the preview of the road ahead, producing fuel savings in excess of 10 percent and up to 20 percent in certain scenarios.

Routes are optimized for both energy savings and arrival times. The technology uses existing applications such as Google Maps to preview the route ahead, including highway grade, stop signs, lights and traffic volume to choose the most energy-efficient route. Integrated vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technology will help achieve maximum fuel economy.

The project is funded by the Advanced Research Projects Agency-Energy (ARPA-E) NEXTCAR program.

NEW CORROSION FACILITY

SwRI has launched a new facility to cost-efficiently conduct standardized corrosion testing for oil and gas clients. The facility evaluates the sulfide stress cracking resistance of carbon steel alloys for oil wells and offshore drilling applications.

"Previously, our laboratory work has been predominantly fit-for-purpose testing," said SwRI's Dr. Elizabeth Trillo, one of the leaders of the project. "Those tests simulate an environment with specific solutions, temperatures and pressures to evaluate materials used in specific drilling environments and determine whether they can withstand those conditions. Every test is different, but our specialty is catering to the client's end-use need."

As a part of SwRI's comprehensive oil and gas sour corrosion testing capabilities, the new facility is dedicated to cost-effective standardized testing to National Association of Corrosion Engineers TM0177. This test certifies carbon steel materials used in casings for down-hole drilling applications with high hydrogen sulfide levels. The casing is a large pipe inserted into the ground to protect equipment and support the well stream. It's usually held in place with cement and endures massive pressures, high temperatures and corrosive liquids.

"We've typically designed new test methods that give us flexibility and control over individual environmental parameters," said James Dante, manager of SwRI's Environmental Performance of Materials Section. "In the new facility, we can perform repetitive testing in a cost-effective and repeatable manner while providing our clients with the same level of service they have experienced with more complex testing."

Previously, a sample batch tested with several others might fail early in a 30-day test. Initiating a new test would disturb the other samples still under test. In the new facility, samples are evaluated in isolated test cells, giving SwRI the ability to change samples without disturbing other tests.

SwRI's new facility houses multiple test cells allowing triplicate samples to be run within a customized glove box.

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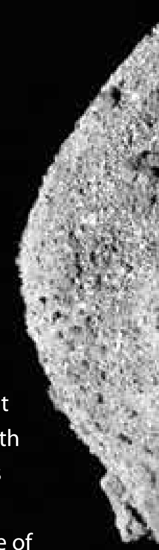


IMAGE COURTESY NASA/GSFC/UNIVERSITY OF ARIZONA D023760/ D023759

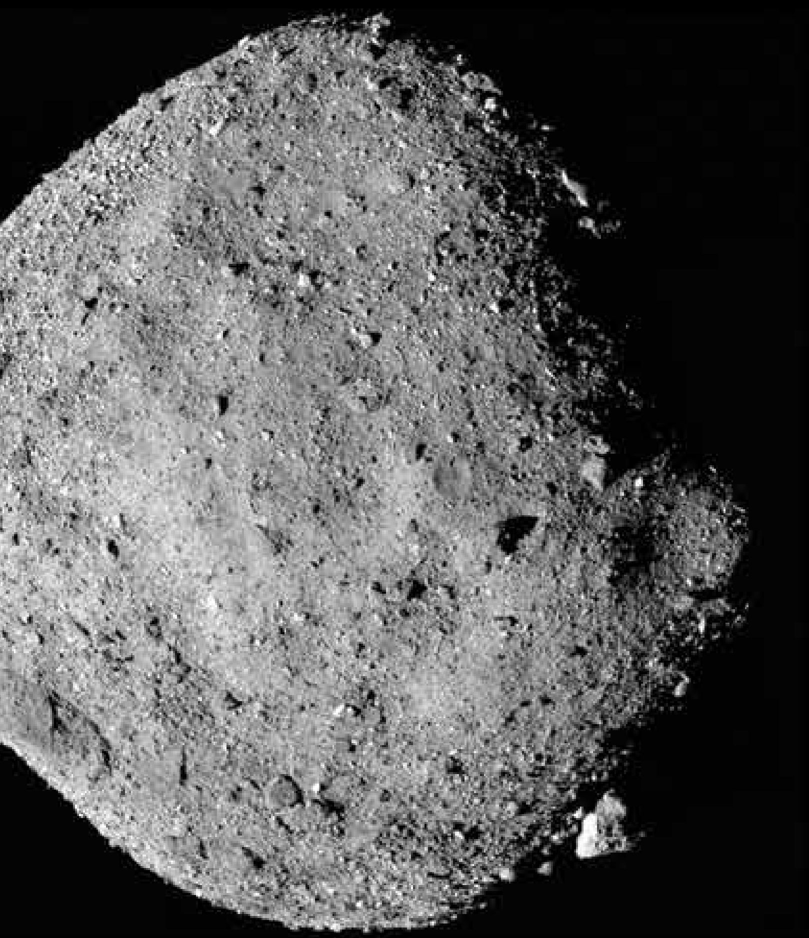
WATERY MINERALS ON BENNU

An SwRI-led team discovered evidence of abundant water-bearing minerals on the surface of the near-Earth asteroid Bennu. Using early spectral data from NASA's OSIRIS-REx spacecraft orbiting the asteroid, the team identified infrared properties similar to those in a type of meteorite called carbonaceous chondrites.

"Scientists are interested in the composition of Bennu because similar objects may have seeded the Earth with water and organic materials," said SwRI's Dr. Victoria Hamilton, a mission co-investigator, deputy instrument scientist, and lead author of a paper outlining the discovery published March 19 in Nature Astronomy. "OSIRIS-REx data confirm previous ground-based observations pointing to aqueously altered, hydrated minerals on the surface of the asteroid."

Around 4.6 billion years ago, our solar system formed from the gravitational collapse of a giant nebular cloud. The Sun, planets and other objects such as asteroids and comets formed as materials within the collapsing cloud that clumped together in a process known as accretion. Carbonaceous chondrites, which come from asteroids, show evidence for post-accretion interactions of some asteroids with water and/or ice that led to chemical reactions that produce hydrated minerals. Because these meteorites and their asteroid parent bodies have remained unchanged since the earliest years of the solar system, they provide clues to the distribution, abundance and movements of water in the solar disk at that time.

"During planetary formation, scientists believe that water was one of many chemical components that accreted to form Earth. However, most scientists think additional water was delivered in part by comets and pieces of asteroids, including water-bearing carbonaceous meteorites," Hamilton said. "Many of these meteorites also contain prebiotic organic chemicals and amino acids, which are precursors to the origin of life. The details of water delivery to Earth, as well as the larger issue of the different inventories of water ice in the early solar system, affect how we view solar system formation."



RESULTS FROM NASA'S OSIRIS-REx MISSION

ASTEROID'S ANCIENT VISAGE

An SwRI-led team has discovered that the surface geology on asteroid Bennu is older than expected. Early observations of the near-Earth asteroid (NEA) by NASA's OSIRIS-REx mission indicate a surface that is between 100 million and 1 billion years old.

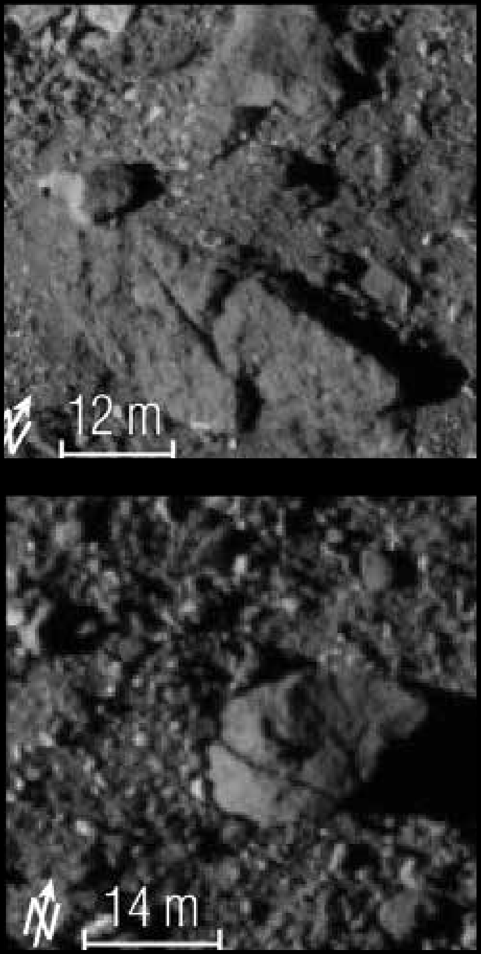
"We expected small, kilometer-sized NEAs to have young, frequently refreshed surfaces," said SwRI's Dr. Kevin Walsh, a mission co-investigator and lead author of a paper outlining the discovery published in Nature Geoscience.

"However, numerous large impact craters as well as very large, fractured boulders scattered across Bennu's surface look ancient. We also see signs of some resurfacing taking place, indicating that the NEA retains very old features on its surface while still having some dynamic processes at play."

The OSIRIS-REx spacecraft is visiting Bennu, a carbonaceous asteroid whose surface may record the earliest history of our solar system. Bennu was chosen based on its size, composition and proximity to Earth, passing nearby every six years. Its dusty regolith may contain molecular precursors to the origin of life and the Earth's oceans.

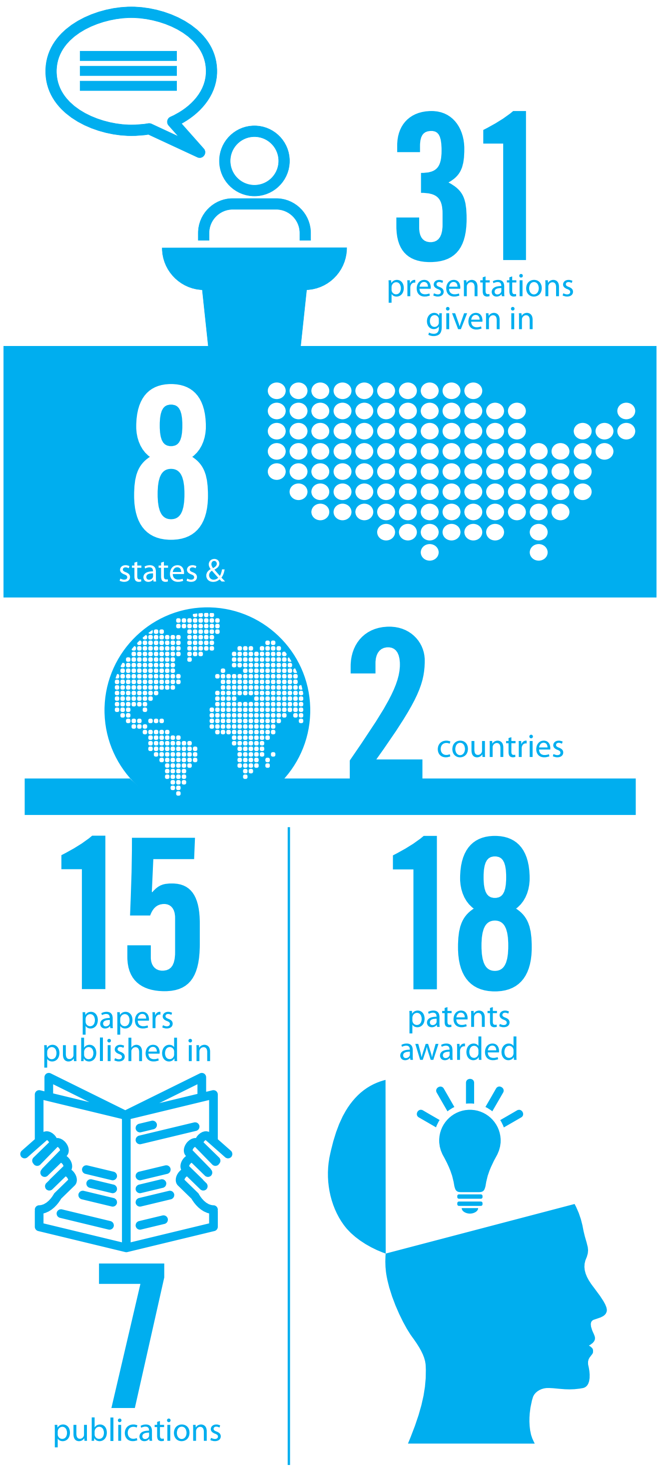
Bennu is a "rubble pile" asteroid held together by its own gravity. Small rubble-pile asteroids likely formed in the main asteroid belt from debris accumulated following the breakup of a much larger asteroid. While in the main asteroid belt between Mars and Jupiter, these objects would be constantly bombarded by impactors, but once they leave the main belt and become NEAs, they are subject to further evolutionary processes.

"Both large craters and a widespread population of fractured boulders date back hundreds of millions of years to when Bennu was in the main asteroid belt," Walsh said. "Meanwhile, we found signs of more recent surface movement, but it is either too localized or too infrequent to modify Bennu as much as expected. Maybe it hasn't gotten close enough to a planet or the Sun to be modified on a large scale," said Walsh.



Using data from NASA's OSIRIS-REx mission, an SwRI-led team discovered that the surface of near-Earth asteroid Bennu is geologically older than expected. Craters and large, often fractured boulders (shown here) likely date from the time the asteroid was still orbiting in the main asteroid belt between Mars and Jupiter.

BY THE NUMBERS FEBRUARY – JUNE 2019



D023756/ D023757

SwRI engineers gave presentations detailing our wide range of testing and research capabilities at the 2019 Offshore Technology Conference (OTC) in Houston from May 6 to 9.

OTC is an annual conference that allows energy industry professionals to exchange ideas and collaborate to advance scientific and technical knowledge for offshore resources and environmental matters. SwRI made presentations and offered a set of live technology demonstrations, including discussions about:

- MsSR®v5, which uses ultrasonic guided waves to perform cost-effective inspection and structural health monitoring of industrial drilling structures
- Applying strain measuring devices in atypical situations, such as extreme pressures and temperatures
- Hydrostatic pressure testing in SwRI's Ocean Simulation Laboratory
- Fire testing capabilities for offshore technologies
- Multiphase flow loop performance testing
- Measurement and processing equipment for multiphase flows
- Automotive engineering research and testing resources
- Evaluating and qualifying offshore risers, conduits that transport material from the seafloor to the platform

COMING UP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Three SwRI staff members were inducted into the inaugural class of the Academy of Distinguished Alumni in The University of Texas at Austin's Department of Aerospace Engineering and Engineering Mechanics. The award was conferred upon graduates of the University's aerospace and engineering mechanics programs with distinguished careers in industry, government or academia.

President and CEO **Adam L. Hamilton**, P.E. earned both his master's and bachelor's degrees in aerospace engineering from UT Austin. Before joining SwRI, Hamilton was the founding president and CEO of Signature Science, LLC. Based in Austin, Signature Science is now a wholly-owned subsidiary of SwRI specializing in national security, biotechnology, chemistry, environmental science, and engineering. Hamilton assumed the role of president of SwRI in 2014.

Associate Vice President **Dr. Alan Stern** (Space Science and Engineering) earned four degrees from UT Austin including dual bachelor's degrees in physics and astronomy, and master's degrees in both aerospace engineering and atmospheric science. He earned a doctorate degree in astrophysics and planetary design from University of Colorado at Boulder. Stern is the principal investigator for NASA's New Horizons mission, a successful mission that took us to Pluto and the Kuiper Belt.

Retired Executive Vice President **Dr. Norm Abramson** earned two degrees from UT Austin, a bachelor's degree and doctorate in mechanical engineering. In between those degrees, he completed a master's degree in mechanical engineering from Stanford University. Abramson retired as SwRI's Executive Vice President in 1991, following 35 years of service where he developed a nationally recognized major research and development program in solid and fluid mechanics.


D023785

Rice University honored **Dr. James L. Burch**, vice president of SwRI's Space Science and Engineering Division, as a distinguished alumnus at its 2019 Laureates Awards ceremony. Burch earned a bachelor's degree in physics from St. Mary's University, a master's degree in research and development management from George Washington University and a doctorate in space science from Rice University. Burch is a renowned experimental space physicist who founded the first space science group at SwRI in 1977. The division, which now includes 380 staff members, is recognized as one of the preeminent space research organizations in the world.

The prestigious journal Science featured the flyby of Ultima Thule on its May 17 cover. SwRI's Dr. Alan Stern is the principal investigator of the New Horizons mission that set new records visiting this Kuiper Belt object. More information about the exploration of the farthest, most primordial object ever visited is on page 8 of this issue of Technology Today.

TRAINING

SwRI is hosting these short courses:

Manufacturing Supervisor Certification Program, San Antonio, July 30, 2019

Introduction to Propulsion Simulation Using NPSS, San Antonio, July 30, 2019

Lean Manufacturing Certification Program, San Antonio, September 18, 2019

CONFERENCES

Annual Meeting & Exposition of the Controlled Release Society, Valencia, Spain, July 21, 2019, Booth 102

33rd Annual AIAA/USU Small Satellite Conference, Logan, Utah, August 3, 2019

Texas Groundwater Summit, San Antonio, August 20, 2019

IEEE AUTOTESTCON, National Harbor, MD, August 26, 2019, Booth132

48th Turbomachinery & 35th Pump Symposia, Houston, September 10, 2019, Booth 2906

American School of Gas Measurement Technology (ASGMT), Houston, September 16, 2019

CH4 Connections – The Methane Emissions Conference, Fort Collins, CO, September 18, 2019

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

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