SOUTHWEST RESEARCH INSTITUTE®

SPRING 2023

TECHNOLOGY TODAY®

2 DART

13 SwRI DELIVERS NEXT-GENERATION SPACE INSTRUMENT

16 THE ART OF THE ANTENNA

22 ENHANCING THE HUMAN EXPERIENCE

SwRI is building the Wide Field Imager (WFI) for the Polarimeter to UNify the Corona and Heliosphere, or PUNCH, mission — as well as leading the mission itself. Dark baffles in the top recess, themselves hidden from the Sun by protective vanes, protect the aperture from moonlight. In space, the instrument will image solar wind features a thousand times fainter than the Milky Way.

Scheduled to launch in 2025, PUNCH will use four suitcase-sized satellites to study the Sun's outer atmosphere, the corona, and how it generates the solar wind. This continuous supersonic stream of charged particles fills the solar system, forming the bubble-like region of space known as our heliosphere. One satellite carries a coronagraph, the Narrow Field Imager, that images the Sun's corona continuously. The other three each carry WFIs, SwRI-developed wide-angle cameras optimized to image the solar wind. These four instruments work together to form a single field of view spanning 90 degrees of the sky, centered on the Sun.

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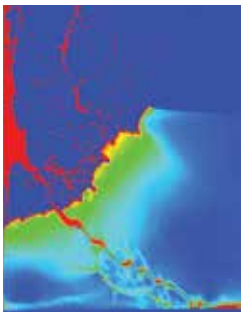
TECHNOLOGY TODAY

CONTENTS

2 DART
10 Lucy Mission Adds Asteroid Encounter
11 Techbytes
12 Heavy-Duty Hydrogen Combustion Vehicle
13 SwRI Delivers Next Generation Space Instrument
14 CESM Around the World
16 Advancing the Art of the Antenna
22 Enhancing the Human Experience
27 Techbytes
31 Icy Origins of Life
32 Awards & Achievements

ON THE COVER



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SwRI engineers and scientists work with NASA to better understand how crashing a spacecraft into an asteroid bearing down on Earth could nudge its trajectory to avoid impact. SwRI uses hypervelocity impact experiments and computational modeling (shown) to understand how materials ejected from an impact crater increase the momentum change to the asteroid.

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IN THIS ISSUE

For more than 75 years, SwRI has conducted research and development benefiting government, industry and the public through innovative science and technology. We like to say we help our clients "bridge the valley of death," taking the discoveries made through basic research and transferring that technology to create useful applications for potential product development.

This issue of Technology Today demonstrates this R&D sweet spot. For instance, when a client asked our radio frequency engineers to extend the operating range of an existing direction-finding antenna, our team initially thought it couldn't be done. Then they found an interesting theory from the 1940s that had never been realized due to practical limitations. Soon, the team began chipping away the obstacles, ultimately developing a novel antenna design that not only solved this client's challenge but also can be applied for a range of high-frequency systems.

Meanwhile, biomechanics engineers took the digital twin concept developed around the turn of the century to numerically simulate physical objects and systems and made the concept personal. They created a virtual simulation of the human body to better understand the risk of injury under various conditions, first developing models for classes of individuals. Then they personalized it to model a specific individual over the course of their life, with ultimate goals of enhancing performance and improving the quality of lives by reducing injury and disability in all age groups.

The cover story looks at a unique facet of NASA's exciting Double Asteroid Redirection Test (DART) mission, to understand how to deflect a potential asteroid on a crash course with Earth. The DART spacecraft impacted the moonlet of a binary asteroid and changed its orbit, proving the concept. Now the community needs to create the practical application. SwRI's role is using small-scale hypersonic experiments to characterize the extra push provided when materials eject from the resulting impact craters.

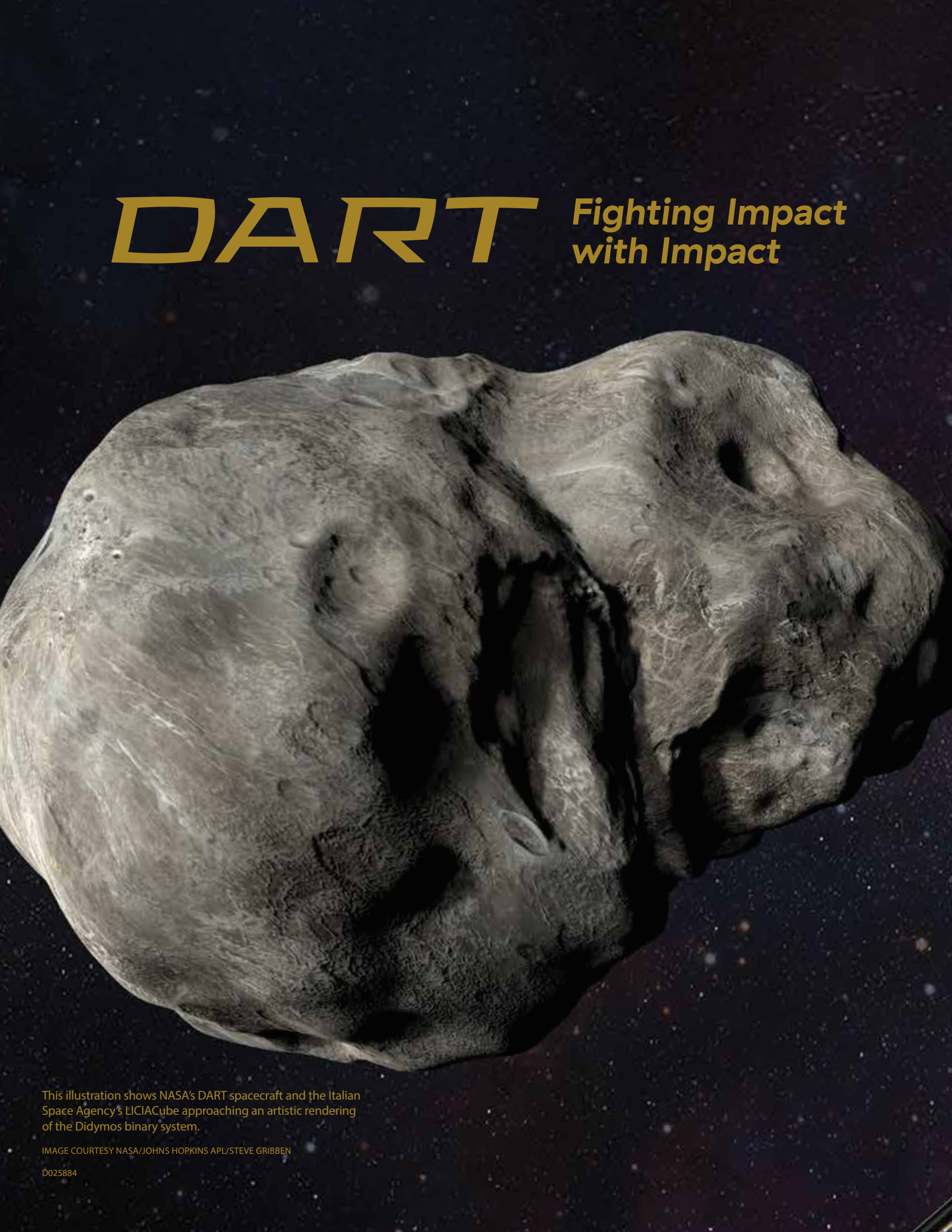
Solving these kinds of problems to benefit government, industry and humankind is squarely in our wheelhouse — applied research and innovative solutions.

Sincerely,

Walter D. Downing, P.E.
Executive Vice President/COO

DART

Fighting Impact with Impact

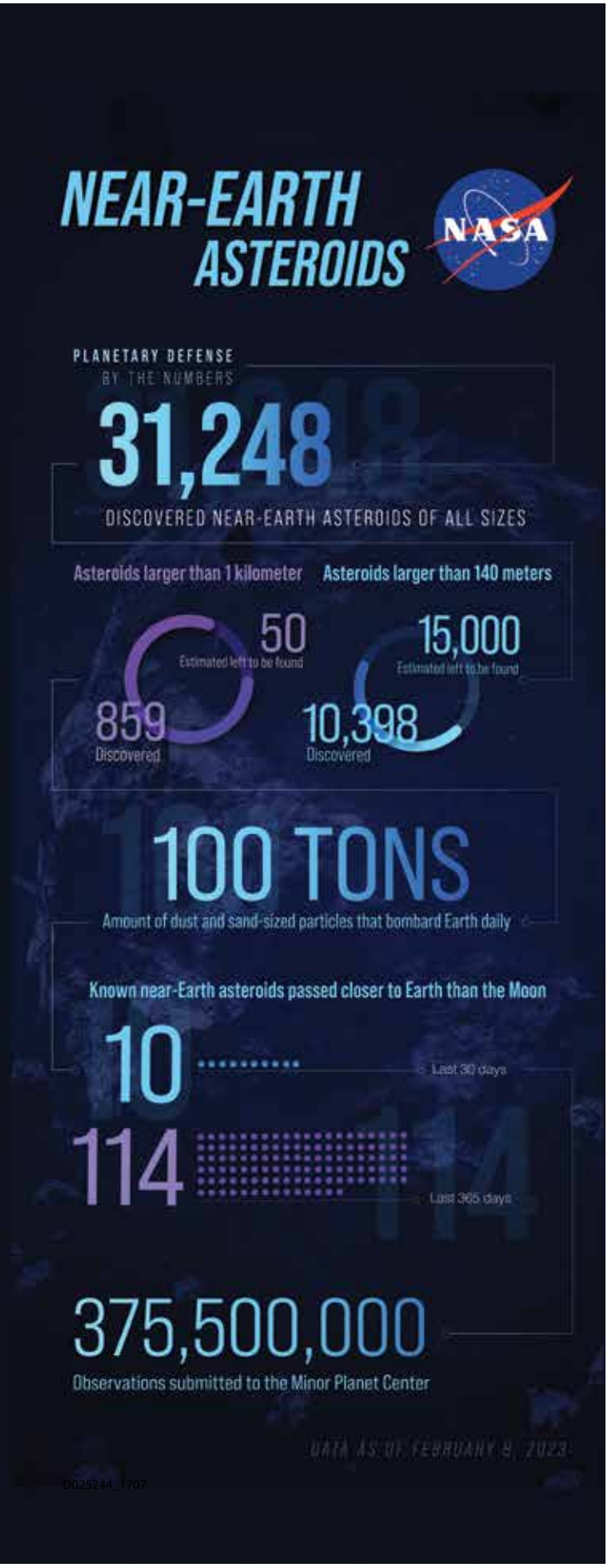


This illustration shows NASA's DART spacecraft and the Italian Space Agency's LICIACube approaching an artistic rendering of the Didymos binary system.

IMAGE COURTESY NASA/JOHNS HOPKINS APL/STEVE GRIBBEN

D025884

By James Walker, Ph.D.,
Sidney Chocron, Ph.D.,
Dan Durda, Ph.D.,
Don Grosch and
Simone Marchi, Ph.D.



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The Earth orbits within a veritable shooting gallery of asteroids. Of particular concern are near-Earth asteroids (NEAs) that pass close to our home planet, which primarily originate in the main asteroid belt between the orbits of Mars and Jupiter. While asteroids are interesting relics left over from the formation of the inner planets, nearly 200 impact craters preserved in landscapes across the world are clear evidence that many have slammed into our home planet in the past, sometimes with globally devastating effects. One of the most infamous impacts happened roughly 66 million years ago, when scientists theorize an asteroid or comet struck the Earth and led to the extinction of the dinosaurs.

Scientists have detected more than 31,000 NEAs to date out of a population thought to number in the millions. The good news is NASA has identified and tracked 95 percent of the potential civilization-enders — those more than half a mile in size — and none are an impending threat to the Earth. But smaller, more likely NEA impacts could potentially be prevented. Unlike the dinosaurs, humans have knowledge of the threat and the technology to deflect the path of a small NEA, diverting an impending impact into a harmless near miss. Only a small change in a threatening asteroid's orbit is needed to swing it away from Earth, as long as it happens in sufficient time before the predicted impact. Southwest Research Institute engineers and scientists who study impacts and asteroids have combined forces with NASA to better understand how to accomplish that.

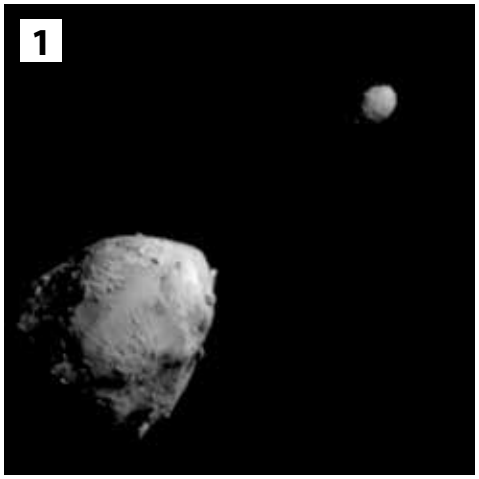
On September 26, 2022, at 6:14 p.m. Central time, NASA's Double Asteroid Redirection Test (DART) spacecraft struck the asteroid moonlet Dimorphos at 13,700 mph (6.14 km/s). About 30 people attended an "Impact Watch" party at SwRI, including members of the DART Investigation Team. DART's goal was to measure how much the moonlet's velocity would change due to the impact. As the DART spacecraft approached the asteroid Didymos and then its moonlet Dimorphos, images of the space rocks came back nearly every second, until only a close-up portion was transmitted to Earth. When the final partial image arrived and the screen flashed red, cheers rang out. The impact had occurred.

IMAGES COURTESY NASA/JHUAPL

READY, AIM, FIRE

For decades, SwRI has studied asteroids and impacts. These two topics converged when the research community considered how to deflect an asteroid bearing down on Earth.

A spacecraft or other hypervelocity projectile aimed at the object could slam into it, changing its momentum enough to cause the minor orbital change required to avert impending disaster. Changing the momentum of an asteroid this way offers a veritable one-two punch: the direct momentum transfer of the impacting projectile pushing it forward and the asteroid's recoil from the crater ejecta, or debris, erupting from the impact crater. The ejecta transfers momentum, propelling the target away in an "action-reaction" fashion, much like a rocket launches when high-speed gas erupts from the rear of the vehicle. Knowing just how much momentum is needed to



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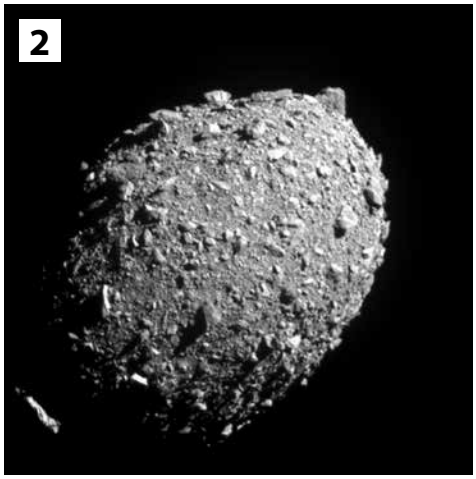

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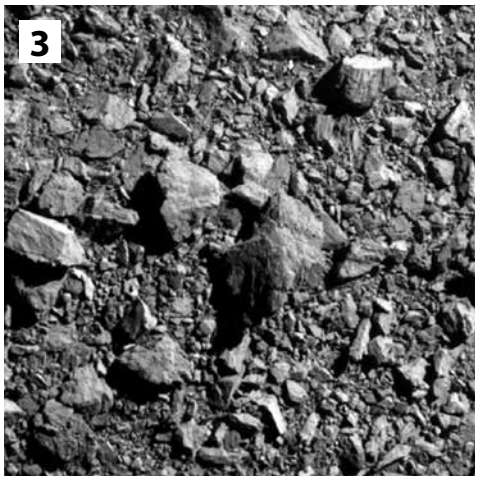

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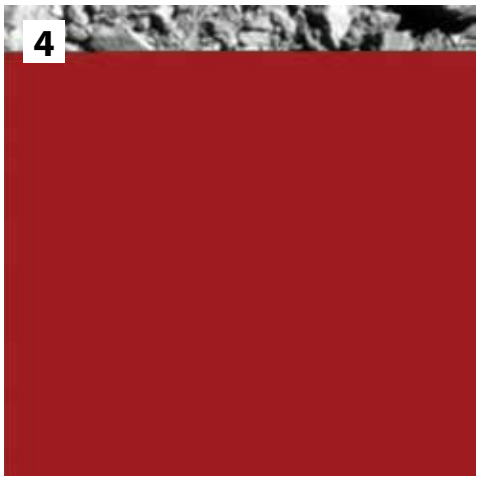

D025912

DART's only scientific instrument, a telescope/camera, provided these images of Dimorphos and Didymos. Image #1 is 2.5 minutes before impact from 570 miles (920 km) away and shows Didymos (bottom left) and its moonlet Dimorphos. Image #2 is the last full image of Dimorphos on approach at 11 seconds before impact from 42 miles (68 km) away. Image #3 is roughly two seconds before impact, 7 miles (11 km) away. Image #4, taken roughly 1 second before impact and 3 miles (5 km) out, is truncated because it was not fully transmitted before impact.

DETAIL

Comets are small balls of ice and dirt that orbit the Sun. As a comet approaches the Sun, the heat evaporates the comet's gases, causing it to emit dust and microparticles in a distinctive tail. **Asteroids** are rocky objects that also orbit the Sun. They are smaller than a planet but larger than objects known as **meteoroids**. A **meteor** is a meteoroid that burns up as it enters Earth's atmosphere. If a meteoroid survives its trip through Earth's atmosphere and hits the Earth's surface, it is called a **meteorite**.

change an NEA's path adequately is a function of its size, composition and structure.

The mission was not the first time NASA intentionally slammed a spacecraft into a solar system body. In the early 2000s, SwRI supplied a flight control computer for the Deep Impact spacecraft that struck the comet Tempel 1 at 22,750 mph (10.2 km/s) on July 4, 2005. Cameras on the impacting module as well as the main spacecraft imaged the impact. The success of the Deep Impact mission led to thoughts of conducting a spacecraft-asteroid impact to measure how an impact could change the velocity and trajectory of an asteroid.

When the planetary defense community considered how to make this measurement, they considered landing a transponder on the surface. Then, scientists could assess the Doppler change in the radio communication with the transponder to accurately measure the difference. Unfortunately, this approach requires a rendezvous with, and landing on, the asteroid before the impact — an expensive endeavor.

The community came up with the clever idea of selecting an asteroid with a moonlet to solve the measurement challenge. An impactor mission would aim for the moonlet and then measure its orbital period before

DETAIL

Ejecta is material forced or thrown out by an impact.

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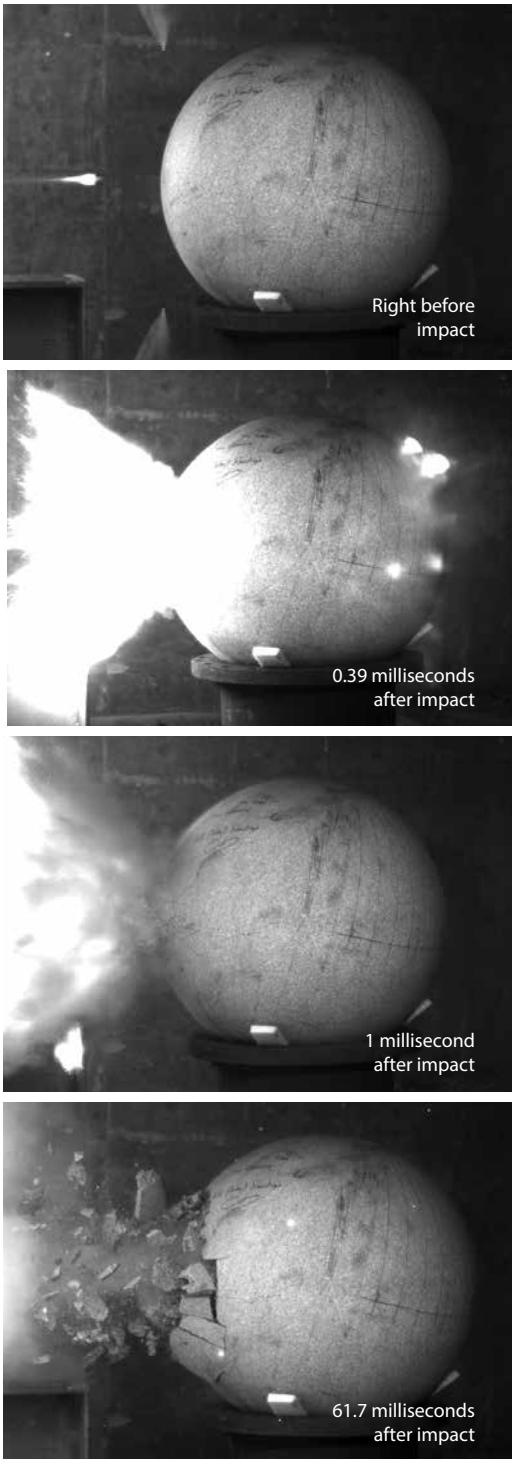
This graphic illustrates the DART spacecraft aiming for Dimorphos as it orbits Didymos.

DETAIL

Planetary defense protects the Earth from impacts. **Planetary protection** protects other planets from contamination and germs from Earth.



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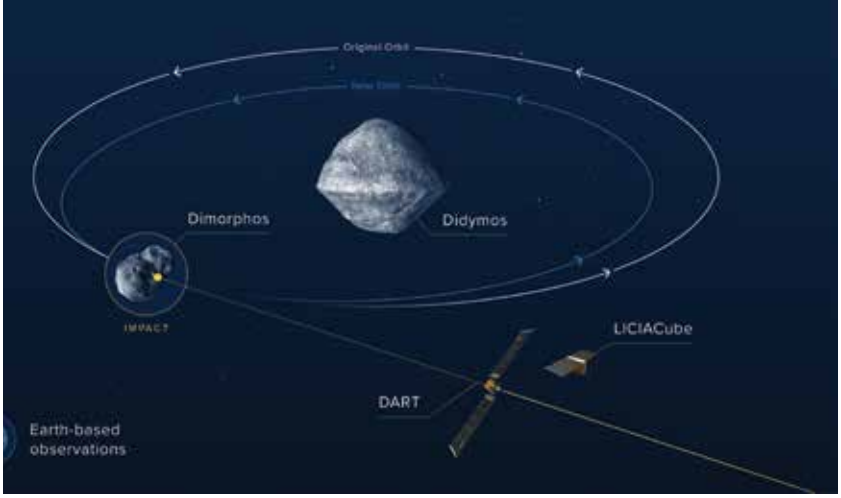
A series of images of a 1.75-inch-diameter (4.45-cm) aluminum sphere impacting a 3-foot-diameter granite sphere at 4,500 mph (2.01 km/s). The first frame is right before impact showing the aluminum sphere with a vapor trail, the second at 0.39 milliseconds after impact, the third at 1 millisecond after impact and the fourth at 61.7 milliseconds after impact. Note the granite ejecta moving in the opposite direction of the incoming projectile. The ejecta increases the momentum transfer to the rest of the granite sphere.



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The planned impact shows how the DART impact on Dimorphos changed the orbit of the moonlet around Didymos. LICIACube is a European CubeSat that DART released three weeks before impact to take pictures as it passed.

IMAGE COURTESY NASA/JHUAPL

and after the impact. Using this information, scientists could determine the speed change of the moonlet. If an asteroid flew close enough to Earth, the orbital period could be determined from Earth-based telescopes to avoid the need for a rendezvous or a flyby spacecraft. Only the impacting spacecraft would be required.

Then the search for known binary asteroids — asteroids that orbit in pairs — began. An asteroid discovered in 1996 was found to have a small moon in 2003. It was named "Didymos," which is "twin" in Greek. Didymos is in the Amor family of asteroids, which approaches Earth's orbit as it circles the Sun. Near-Earth objects have a trajectory that brings them within 1.3 astronomical units (AU) of the Sun and within 0.3 AU, or approximately 28 million miles (45 million kilometers), of the Earth's orbit. Specifically, Didymos is an NEA. At times, it is close enough to Earth to measure the orbital period of its moonlet Dimorphos. Another piece of information required and determined by ground-based radio (radar) telescopes is the distance between Didymos and Dimorphos. Once the target was found, mission development began in earnest.

DETAIL

An orbital period is the time it takes an astronomical object to complete one orbit around another object.

The DART spacecraft launched from Vandenberg Space Force Base in California on November 23, 2021. Over the next 10 months, the spacecraft never ventured far from Earth's orbit. As the Didymos/Dimorphos system approached Earth, the impact between the DART spacecraft and Dimorphos occurred 6.8 million miles from Earth. Round-trip transmission time between Earth and the spacecraft was over a minute, so the final approach to impact was entirely autonomous.

ORBITAL FORENSICS

What was the result of the impact? The original, pre-impact orbital period of Dimorphos was 11.9 hours. The impact shortened that by 33 minutes. Assuming the initial orbit was circular and the final orbit elliptical, with its farthest distance the original distance between the bodies, then the speed imparted to Dimorphos was 2.7 mm/s.

This speed increase seems minuscule. How long, in the context of deflecting an asteroid or a comet nucleus, does it take to produce large distances? Real orbits are very complicated, especially over time, but if we just use a linear extrapolation, after a day the deflection would be 750 feet

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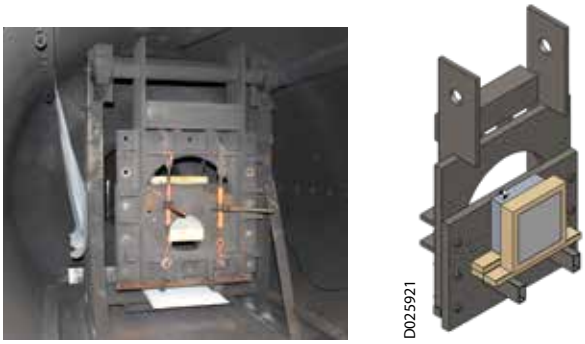
SwRI conducted a momentum enhancement experiment using rocks in a wooden frame, shown before (left) and after cement was poured (right).



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The experiment used a target hung from a pendulum in a vacuum chamber. The back side of the pendulum is shown before the impact experiment (left) and in a CAD file image of the pendulum assembly from the front (right).

(230 meters). After a month it would be 5 miles (7 km). After a year it would be over 50 miles (85 km). To deflect a distance the radius of the Earth would take 75 years.

However, Dimorphos is relatively large, around 500 feet (150 meters) in diameter, roughly the size of the Great Pyramid of Giza. To move a smaller asteroid, say one that was only 50 meters across, then its mass would be 27 times less and the time to deflect the Earth's radius distance would be less than three years. The Chelyabinsk meteor that entered above Russia in 2013 was estimated to be 20 meters across and probably weighed around 0.2% of Dimorphos. Deflecting it out of the way with an impact would require two months of drift after an impact. However, impacts into small asteroids risk breaking them into pieces rather than deflecting them. Scientists must consider a wide range of scenarios.

The DART impact experiment explicitly determined the change in velocity. That value is specific to this spacecraft, Dimorphos and the impact arrangement. To extend the results of this impact to other scenarios, scientists need a way to use the data to estimate the deflection effect for any arrangement. For over a decade, SwRI has been studying the momentum transfer of high-speed impacts into various targets. In 2010, we crashed an aluminum sphere into a 1-yard-diameter granite sphere at 4,500 mph (2.01 km/s). The impact formed a crater, and crater materials were violently ejected in the opposite direction. This ejected material transferred more momentum to the granite sphere than the aluminum sphere brought with it. So, the impact ejecta more than doubled the momentum change. The impact physics community measures the impact ejecta momentum transferred to the body by dividing the target post-impact momentum by the incoming projectile momentum, and refers to the momentum enhancement provided by the impact ejecta ratio as β. In the experiment with the granite sphere, β=2.1. β is called momentum enhancement because, when greater than 1, it measures how much additional momentum was transferred over just the impact alone.

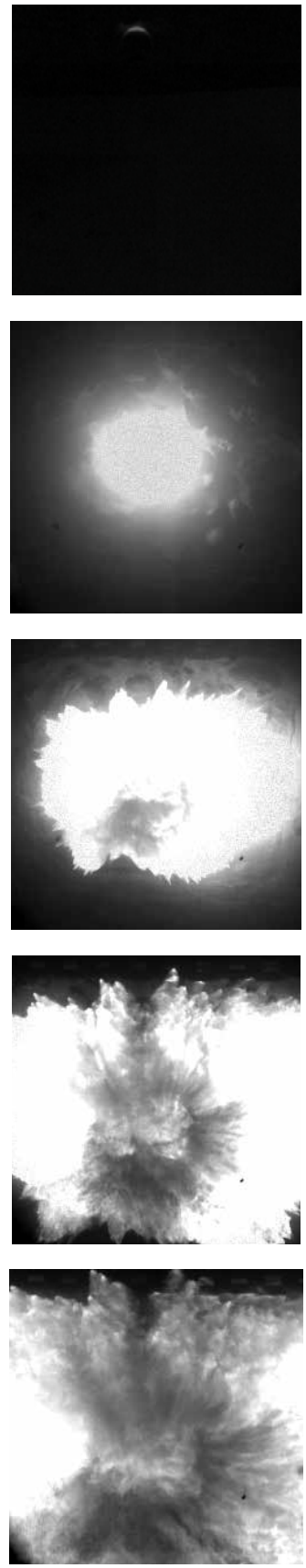
The momentum enhancement β is important because it can be applied in a variety of circumstances, including future impact scenarios. In the DART/Dimorphos impact, the current value of β is not well defined because the mass of Dimorphos is unknown. However, based on an assumption that the density of Dimorphos is the same as Didymos, β=3.6. The European Space Agency is planning a mission, called Hera, to rendezvous with the Didymos/Dimorphos system as early as December 2026. Hera will study the crater and other post-DART spacecraft impact features of the system and seek to pin down the mass of Dimorphos.

Recent spacecraft visits to small asteroids — including Itakawa, Ryugu and Bennu — have revealed rocky surfaces, indicative of a rubble pile or gravel conglomeration. Their rugged surfaces look very similar to Dimorphos. Before the DART experiment, SwRI performed an impact into an assembly intended to represent a rubble pile or gravel conglomeration. While the large scale of the DART/Dimorphos impact — a 1,200-pound (580 kg) spacecraft hitting a nearly 500-foot-diameter (150-meter)

DETAIL

Most small asteroids are thought to be rubble-pile asteroids, which form when the parent body is smashed to pieces by an impact and the shattered debris subsequently coalesces, primarily due to self-gravitation. These asteroids are low-density and low-strength bodies due to the extensive fractures and cavities between the chunks forming them.

Impact images from SwRI's high-speed camera show the faint glowing crescent of the incoming sphere at two frames before it strikes the cemented stone target. The glow is associated with heat generated by hypersonic flight. The next frames show the impact and three sequential images following the strike. All images are self-illuminated by light generated by flight or impact.



asteroid — cannot be replicated in the laboratory, engineers and scientists can launch an impactor at a similar speed. SwRI's large, two-stage light-gas gun can launch projectiles to nearly 13,400 mph (>6 km/s).

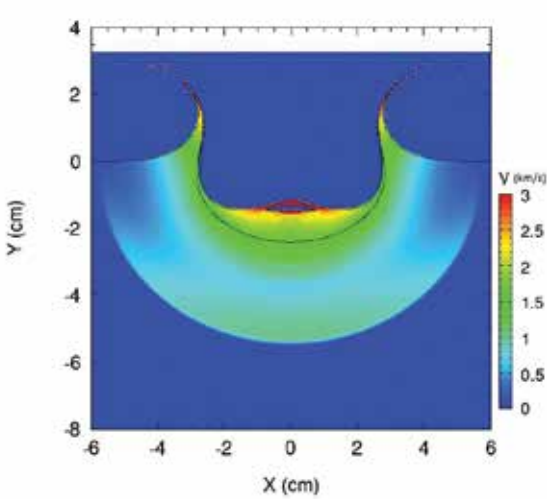
TARGET PRACTICE

To understand momentum transfer, SwRI conducted small-scale experiments using a test target hung on a pendulum within a vacuum tank. The surrogate DART asteroid target was essentially a box of rocks held together with concrete, a scenario that likely exceeds the actual cohesion of the rocks on Dimorphos. While some aspects of the experiment were not representative of the moonlet, the experiment provided an experimental β for a complex geological target at the largest scale to date and at an impact speed of interest.

The SwRI light-gas gun shot a 1.18-inch, 1.36-ounce (3-cm, 38.44-g) aluminum sphere into the rocky target at a speed of 12,150 mph (5.44 km/s), which approached the estimated speed of the DART impact. The impact completely disassembled the rock/concrete target. The debris left over ranged from a fine powder to fragments the size of the original rocks. Engineers measured the impact-based pendulum swing from the impact, determining momentum enhancement β was 3.4 times the impact imparted by the sphere alone. In other words, the ejecta leaving the crater formed by the impact more than tripled the impacting projectile's momentum. Though aspects of the lab experiment were unlike the DART impact, a reasonable estimation of Dimorphos' mass produces a DART value of β=3.6, similar to SwRI's pre-impact experiment value of β=3.4.

A spherical projectile is not geometrically similar to the DART spacecraft, which had distributed mass of a roughly 6.5-foot (2-meter) cube. However, a spacecraft developed to impact and move an asteroid, such as the Deep Impact spacecraft that struck comet Tempel I, would have a consolidated impactor corresponding to a solid sphere.

Well-characterized experiments also validate computation models to compute β for other impact scenarios. SwRI has used computations for more than a decade to explore various aspects of spacecraft impacts on asteroids and comet nuclei. Engineers and scientists have studied how spacecraft shape, as well as asteroid and comet nuclei composition, density, strength and cohesion (tensile fracture strength) affect β, some more than others. In addition to studying these material properties, experiments indicate that overall size affects the results and size scaling is nonlinear. As



SwRI modeled the stone/cement impact using numerical simulations to understand material speed.

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To more accurately simulate a rubble-pile asteroid, SwRI fabricated a target of crushed basalt held together with grout and sand for impact analysis. The right image shows a 12,300 mph (5.50 km/s) impact into the simulated target hung from a pendulum in a vacuum tank 20 microseconds after impact.

the overall size of the event increases, so does the nondimensional momentum enhancement β. The SwRI team is presently performing additional experiments and computations to further understand momentum enhancement. New targets include different distributions of rock sizes and holding them in place with grout and sand to reduce the cohesive strength. SwRI is working to obtain reliable β values to validate computational models and quantitatively analyze future impact scenarios, in case they are needed sometime in the future to make sure humans don't go the way of the dinosaurs.

Questions about this story? Contact Walker at james.walker@swri.org or (210)522-2051.

ACKNOWLEDGMENTS: The authors thank contractor/engineer Nikki Scott and student intern Mackenzie Darilek for assistance with target fabrication and Robert Enriquez-Vargas, Joe Elizondo, Scott Barclay and Chris McGarry for experimental support. This work was funded through the Institute's Internal Research and Development program; the authors thank SwRI for supporting this research. Early impact studies were supported by NASA's Outer Planets Research program, grant number NNG06GE91G. Continuing DART-related momentum enhancement experiments were supported by NASA's Yearly Opportunities for Research in Planetary Defense program, grant number 80NSSC22K0241. Seven SwRI staff were members of the DART Investigation Team. The mission was managed by Johns Hopkins Applied Physics Lab for NASA's Planetary Defense Coordination Office.

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ABOUT THE AUTHORS: The article authors are shown around a three-foot-diameter granite asteroid surrogate after an impact by a nearly two-inch aluminum sphere to characterize momentum enhancement provided by materials ejected from the crater. From left, Dr. James Walker directs SwRI's Engineering Dynamics Department, which researches impacts, including the damage, fracture and failure of metals, composites, ceramics and small-scale surrogate asteroids. Dr. Sidney Chochron manages the Computational Mechanics Section and has extensive experience in using numerical modeling to understand impacts. Don Grosch manages SwRI's Ballistics and Explosives Engineering section, operating onsite and offsite ballistics ranges as well as a two-stage light-gas gun capable of creating small-scale hypervelocity impacts. Dr. Simone Marchi, a staff scientist in SwRI's Solar System Science and Exploration Division in Boulder, specializes in the collisional evolution of asteroids and terrestrial planets. Dr. Dan Durda, also in the Boulder office, is a principal scientist who studies the collisional and dynamical evolution of main belt and near-Earth asteroids, Vulcanoids, Kuiper belt comets and interplanetary dust.

LUCY MISSION ADDS "DINKY" ASTEROID FOR A TOTAL OF 10 TARGETS

The SwRI-led Lucy mission recently added another asteroid encounter to the spacecraft's 4-billion-mile journey. On Nov. 1, 2023, NASA's Lucy spacecraft will get a close-up view of (152830) Dinkinesh, which will be the smallest main belt asteroid ever visited by a spacecraft. The Lucy team will use the tiny asteroid, a mere 0.4 miles (700 m) in size, to conduct an engineering test of the spacecraft's innovative asteroid-tracking navigation system.

Dinkinesh is the Ethiopian name for the human-ancestor fossil also known as Lucy, which was discovered in that country. Dinkinesh means "you are marvelous" in Amharic. The mission was named for Lucy because, just as that fossil revolutionized our understanding of human evolution, this mission will likely revolutionize our understanding of the origin and evolution of our solar system.

"This is really a tiny little asteroid," said Lucy Principal Investigator Dr. Hal Levison, of SwRI's Solar System Science and Exploration Division located in its offsite office in Boulder, Colorado. "Some of the team affectionately refer to it as 'Dinky.' But, for a small asteroid, we expect it to be a big help for the Lucy mission."

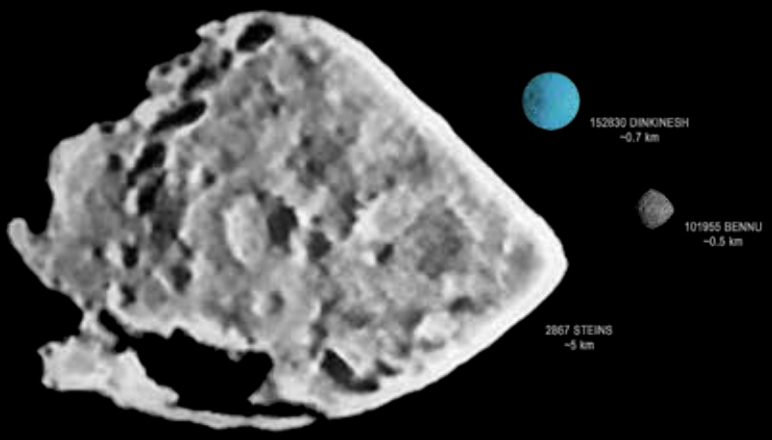
The Lucy mission was already on course to break records by its planned visit of nine asteroids during its 12-year mission to tour the Jupiter Trojan asteroids, which orbit the Sun at the same distance as Jupiter. Originally, Lucy was not expected to get a close-up view of any asteroids until 2025, when it will fly by the main belt asteroid (52246) Donaldjohanson, named for the anthropologist who discovered the Lucy fossil.

The Lucy team realized that, with a small maneuver, the spacecraft could get a close look at this asteroid. On January 24, 2023, the team officially added the asteroid flyby to evaluate the spacecraft's pioneering terminal tracking system. The new system solves a longstanding problem for flyby missions: During a spacecraft's approach to a target, it is quite difficult to determine exactly how far the spacecraft is from the asteroid and exactly which way to point the cameras.

"In the past, most flyby missions have accounted for this uncertainty by taking a lot of images of the regions where the asteroid might be, which is inefficient and produces lots of images of blank space," Levison said. "Lucy will be the first flyby mission to employ an innovative and complex system to automatically track the asteroid during the encounter. The novel terminal tracking system will allow the spacecraft to take many more images of the target."

Dinkinesh provides an excellent opportunity to validate this new procedure. The geometry of this encounter — particularly the angle that the spacecraft approaches the asteroid relative to the Earth and Sun — is very similar to the planned Trojan asteroid encounters. This flyby allows the team to carry out a dress rehearsal under similar conditions well in advance of the spacecraft's main scientific objectives, the flybys of the never-before-explored Trojan asteroids.

"At closest approach, if all goes smoothly, we expect Dinkinesh to be 100s of pixels across as seen from Lucy's sharpest imager," says Dr. Simone Marchi, Lucy deputy principal investigator, also from SwRI. "While we won't be able to see all the details of the surface, even the general shape may indicate whether near-Earth asteroids — which originate in the main belt — change significantly once they enter near-Earth space."



The Lucy team compared the size of Dinkinesh (shown in blue in the artist's concept) to the main belt asteroid Steins and the near-Earth asteroid Bennu. Steins is currently the smallest, independently orbiting main belt asteroid that has been well imaged by a spacecraft (ESA Rosetta). NASA's Osiris-REx spacecraft recently explored the near-Earth asteroid Bennu. The tiny main belt asteroid Dinkinesh will serve as a link between these two populations.

As NASA's Lucy spacecraft travels through the inner edge of the main asteroid belt in the fall of 2023, the spacecraft will fly by the small asteroid recently named Dinkinesh. This graphic shows a top-down view of the solar system indicating the spacecraft's trajectory shortly before the November 1 encounter.

IMAGES COURTESY NASA GODDARD MONTAGE/IMAGE OF STEINS: ESA/OSIRIS TEAM/IMAGE OF BENNU: NASA/GODDARD/UNIVERSITY OF ARIZONA D025875 D025874

WEB-LIKE STRUCTURES IN THE SUN'S MIDDLE CORONA

Researchers from SwRI, NASA and the Max Planck Institute for Solar System Research have discovered how web-like plasma structures in the Sun's middle corona influence the structure of the solar wind. In a study published in Nature Astronomy, the researchers describe an innovative new observation method, imaging the middle corona in ultraviolet (UV) wavelength. The findings could lead to a better understanding of the solar wind's origins and its interactions with the rest of the solar system.

The solar wind is a stream of energized, charged particles, flowing outward from the Sun, and creating our heliosphere, a protective bubble around our solar system.

"As the solar wind evolves, it can drive space weather and affect things like power grids, satellites and astronauts," said SwRI Principal Scientist Dr. Dan Seaton, one of the authors of the study. "The origins of the solar wind itself and its structure remain somewhat mysterious."

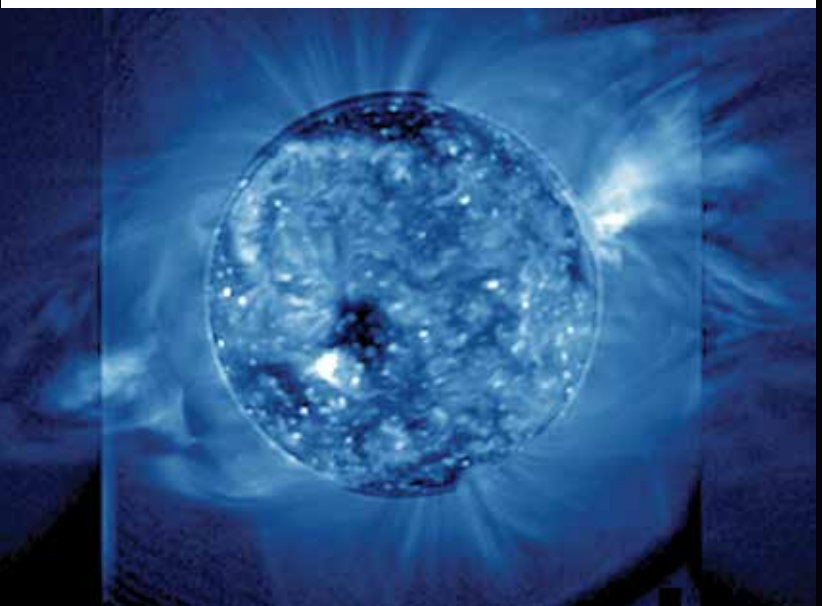
Since 1995, the U.S. National Oceanic and Atmospheric Administration (NOAA) has monitored space weather that could affect the Earth using the Large Angle and Spectrometric Coronagraph (LASCO) aboard the Solar and Heliospheric Observatory spacecraft. However, LASCO has an observational gap that obscures views of the middle solar corona, where the solar wind originates.

Seaton suggested pointing the Solar Ultraviolet Imager on NOAA's Geostationary Operational Environmental Satellites obliquely, from both sides of the Sun, for a month. The data show elongated, web-like plasma structures in the Sun's middle corona. Interactions within these structures release stored magnetic energy propelling particles into space.

"We had no idea if it would work or what we would see," he said. "The results were very exciting. For the first time, we have high-quality observations that completely unite our observations of the Sun and the heliosphere as a single system."

These observations will inform additional discoveries from missions like PUNCH (Polarimeter to UNify the Corona and Heliosphere), an SwRI-led NASA mission that will image how the Sun's outer corona becomes the solar wind.

IMAGE COURTESY SwRI/NOAA D025873



JIP AIMS TO IMPROVE SOUR WELL MODELS

SwRI has launched the first phase of the In Situ Measurement of Hydrogen Sulfide to Validate Thermodynamic Calculations Joint Industry Program (JIP), which aims to more accurately model caustic environments in sour wells and better define the materials needed to withstand those harsh operating conditions. OLI Systems Inc. is collaborating on the sour well JIP.

Sour wells produce gases mixed with hydrogen sulfide (H_2S). Deeper sour wells combine higher pressures and temperatures, creating particularly challenging environments. Currently, the industry uses expensive corrosion-resistant alloys during exploration and production. The alloys are qualified using both documented field experience and laboratory testing, but a recent review of the chemistry of sour wells suggests that these environmental test conditions are harsher than required. The industry could save millions of dollars on the materials used in sour well conditions.

"The aim of SwRI's JIP is to create a new, more accurate model of the chemical conditions in sour wells," said SwRI Senior Research Engineer Florent Bocher, who is leading the project. "We will learn more about the chemistry of these wells at high pressures and temperatures. To accomplish this, we will use existing equipment at SwRI to measure hydrogen sulfide in the gas and liquid phases at the pressures and temperatures that exist in those wells."

During the JIP's first year, engineers will generate an experimental matrix at the intersection between the industry needs, published data and model limitations and will validate in situ analytical techniques. In the second phase, engineers will measure in situ H_2S over the experimental matrix. These measurements will be input into the modeling software to offer a more accurate and reliable simulation of sour well conditions and ultimately better define what materials are necessary and lower the cost of components.

DEVELOPING A HEAVY-DUTY HYDROGEN COMBUSTION VEHICLE

SwRI has launched a joint industry program (JIP) to retrofit a Class 8 heavy-duty vehicle with a hydrogen engine to demonstrate the potential of hydrogen-powered engines using current technology.

"The new initiative will create a working demonstration of current technology's capabilities for decarbonization and achieving zero or near-zero emissions of both greenhouse gases and criteria pollutants," said Dr. Terry Alger, executive director of SwRI's Sustainable Energy and Mobility Directorate. "We believe that sustainably sourced hydrogen in an internal combustion engine (ICE), when used in combination with other decarbonization and clean emissions technologies, can provide low emissions that are competitive with both battery and fuel-cell electric vehicles."

The SwRI-managed Hydrogen Internal Combustion Engine (H_2-ICE) JIP aims to design and build a working H_2-ICE vehicle. The vehicle will have an on-board emissions measurement system to validate near-zero carbon dioxide emissions and ultra-low emissions of nitrogen oxides (NOx) and particulate matter pollution production.

JIP members will contribute vehicle components. SwRI will integrate its best-in-class, ultra-low NOx aftertreatment technology, originally developed to help diesel engines meet California Air Resources Board (CARB) regulatory standards for target date 2027. CARB is charged with combatting air pollution in the country's most populous state.

SwRI has decades of experience working with regulatory agencies, vehicle manufacturers and suppliers to address emissions challenges. Once completed, the H_2-ICE vehicle will be tested to ensure it aligns with standards in the Phase III Greenhouse Gas Rules to be set by the U.S. Environmental Protection Agency (EPA) in 2023 and the 2027 CARB regulations for heavy-duty vehicles, as well as the anticipated EURO VII rules for heavy-duty vehicles.

"Battery electric and fuel cell-powered vehicles tend to dominate the conversations surrounding zero-emission vehicle technologies," Alger said. "Through this program, we are working with industry to ensure that current technology, like internal combustion engines, is not left out of the decarbonization conversations by federal and state regulators. We have a significant number of industry members and donors sharing hardware to show the potential of H_2-ICE technology."

Once completed, the H_2-ICE vehicle will make appearances at trade shows and ride-and-drive events across the country to demonstrate the technology's potential as a realistic pathway for decarbonization. The targeted vehicle completion date is December 2023 with vehicle demonstrations planned throughout 2024.

The H_2-ICE JIP kick-off meeting was in November 2022. SwRI received majority approval from a project advisory committee to manage H_2-ICE. Arising intellectual property will be owned by SwRI and shared with funding members.

SwRI launched an industry program to develop and build a unique hydrogen combustion engine demonstration vehicle. The joint industry project will use current technology to create a "zero-emissions" heavy-duty vehicle.

D025930

SwRI DELIVERS NEXT-GENERATION SPACE INSTRUMENT

SwRI delivered a groundbreaking new mass spectrometer for integration onto NASA's Europa Clipper spacecraft. Scheduled to launch in 2024 and arrive in the Jovian system by 2030, the spacecraft will conduct a detailed science investigation of the moon Europa and study whether it could harbor conditions suitable for life.

The MAss Spectrometer for Planetary EXploration (MASPEX) instrument is one of nine science instruments in the mission payload, which also includes Europa-UVS, an SwRI-developed Ultraviolet Spectrograph, the latest in a series of UV instruments. MASPEX will analyze the gases near Europa to understand the chemistry of Europa's surface, atmosphere and suspected subsurface ocean. MASPEX will study how Jupiter's radiation alters Europa's surface compounds and how its icy surface and subsurface ocean exchange material.

"MASPEX has a mass resolution hundreds of times finer than anything that has flown to space before," said SwRI Senior Vice President Jim Burch, who serves as MASPEX principal investigator. Burch leads the Institute's Space Sector, with three divisions devoted to space science, solar system science and space systems. "SwRI has used internal funding and NASA resources to develop an instrument able to differentiate between molecules with almost identical masses based on the energy binding the atoms. It also differentiates isotopes — atoms with equal numbers of protons but a different number of neutrons. These capabilities are critical to revealing the secrets of Europa."

Once it arrives, Europa Clipper will orbit Jupiter and perform repeated close flybys of the icy moon. MASPEX works by taking in gas molecules lofted from the surface of Europa and converting them into charged particles called ions. It bounces the ions (atoms and molecules missing an electron) up to 400 times back and forth within the instrument. By timing their transit through the instrument, MASPEX measures the mass of these ions, which reveals each molecule's identity, which in turn will help determine whether Europa is habitable.

"We hope to identify and fly through plumes and other sources of gas venting from cracks in Europa's icy surface," said SwRI's Dr. Christopher Glein, MASPEX co-investigator and a planetary geochemist. "We know microbes on Earth exploit any molecule that can serve as a food source. MASPEX is going to help Europa Clipper determine whether there is anything for microbes to eat, such as organic molecules that might be sourced from hydrothermal vents at the bottom of a deep ocean. The data from this exciting mission will give us a much richer perspective on the habitability of Europa."

The Space Science and Space Systems Divisions developed a groundbreaking new mass spectrometer for NASA's Europa Clipper mission to study the potential habitability of Jupiter's moon Europa. The MAss Spectrometer for Planetary EXploration (MASPEX) instrument has a mass resolution hundreds of times finer than anything that has flown to space before.

IMAGE COURTESY SwRI/NOAA D025738_1349

Canadian Navy since **1980**

D025879

300+

IMAGE COURTESY MC2 KRISTOPHER WILSON, USN/US NAVY

For more than 70 years, SwRI has worked in the Communications Electronic Support Measures (CESM) arena. Using signals intelligence, antennas and software, SwRI helps U.S. and allied militaries gather communications intelligence and develop electromagnetic techniques to thwart adversarial operations. CESM specialists develop electronic warfare techniques and technology to control the electromagnetic spectrum and deny advantages to an opponent, while ensuring friendly dominance of the spectrum. Around the world, SwRI specializes in gathering intelligence to identify signals of military interest and to detect, intercept, identify, locate, record and/or analyze the RF spectrum for immediate threat recognition or longer-term operational planning.

U.S.Navy since **1951**

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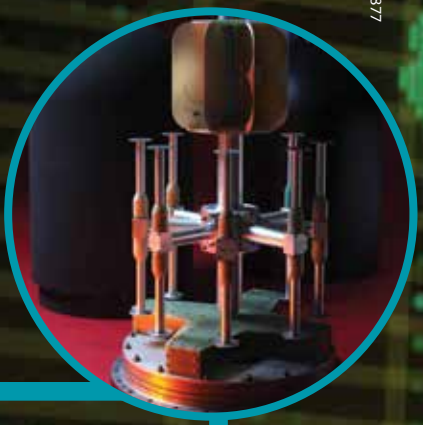

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>200 maritime applications

CESM
AROUND THE WORLD

applications worldwide

DM018916_2863

70+ years of CESM experience

Allied European Navies

U.K. Royal Navy since **2002**

IMAGE COURTESY ROYAL NAVY AUTCAZ DAVIES/MOD

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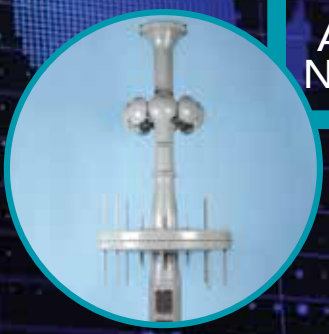
Royal Australian Navy since **2010**



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ADVANCING THE ART OF THE ANTENNA

by Patrick Siemsen

By the onset of World War II, militaries around the world depended on radio signal transmissions to communicate with their forces, particularly air and naval assets. Nearly simultaneously, militaries began monitoring the communications of combatants, sometimes to great advantage, playing a key role in World War II's Battle of the Atlantic. Determining the direction of arrival of enemy combatant communications helped pinpoint their actual location. Direction finding, or DF, was directly or indirectly responsible for 24% of all U-boats sunk by Allied Forces during the war.

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ABOUT THE AUTHOR:
Patrick Siemsen, shown with the cylindrical continuous-slot antenna array being tested atop a 70-foot tower at SwRI's 200-acre antenna test range, has been developing innovative direction-finding (DF) antenna arrays to support tactical communications intelligence at Southwest Research Institute for over 28 years. He has led the development of a variety of novel DF antennas, among them a body-worn DF antenna vest, a portable DF "tent" antenna and a low-profile, vehicle-mounted distributed DF antenna array. He has also developed low Radar Cross Section (RCS) antennas using conductive composite technology.

Modern-day DF systems are used not only to determine the directions of enemy combatants, but also to locate emergency transponders for search and rescue as well as for situational awareness. By combining the directional information from two or more suitably spaced DF systems, the location of the transmitter can be calculated by triangulation. A key component of naval direction-finding systems is the DF antenna. It consists of one or more arrays of antennas, or elements, and for higher frequencies is distributed around a central mast. The other key component is the processing equipment, which consists of high-end radio receivers and computers.

Southwest Research Institute was founded just after WWII, and some of the very first internally funded research programs advanced antenna technologies. In the 75 years since, the radio spectrum has become exponentially more crowded, jammed with every conceivable wireless signal, pushing operating frequencies higher and higher. What began in the high-frequency (HF) band during WWII has grown to now include very-high-frequency (VHF), ultra-high-frequency (UHF) and the lower ranges of the super-high-frequency (SHF) bands. SwRI has developed an extensive communications electronic support measures program and is continually looking for novel solutions in this technical arena to pinpoint the source of increasingly sophisticated signals (see infographic on page 14).

Today's radio signals are increasingly higher in frequency and bandwidth with complex modulations. It is in this environment that a client asked SwRI to extend the upper frequency range of one of its current shipboard DF antenna systems. SwRI had originally designed, fabricated and installed these systems in the 1980s and supported numerous upgrades to them over the years.

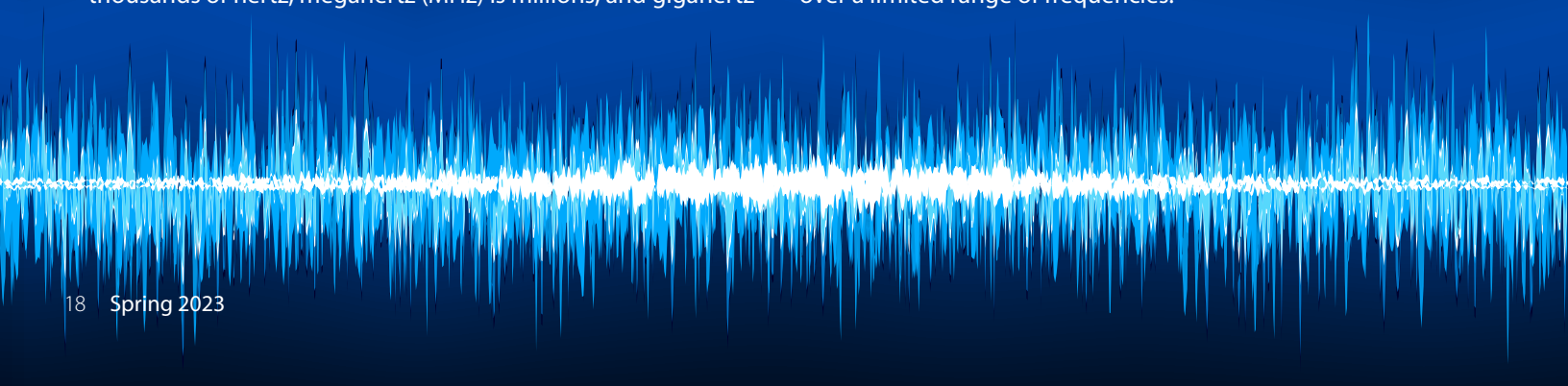
ANTENNAS 101

Antennas are transducers that capture arriving radio signals from the air and convert them into electrical signals at its feed, or connection point. The signals are then sent to processing equipment. Conversely, a radio transmitter generates an electrical signal and sends it via an antenna, which converts it into a transmitted radio signal. Radio signals are electromagnetic waves, a combination of magnetic and electric fields that oscillate at a specific

DETAIL

A transducer is an electronic device that converts energy from one form into another. Antennas are transducers that capture radio signals out of the air and convert them into electrical signals.

Radio signals, or electromagnetic waves, consist of electric and magnetic fields oscillating together at a specific frequency. A cycle is the pattern of a wave before it repeats itself, while its wavelength is the distance it travels in one cycle. The number of cycles, or times that a wave repeats in a second, is its frequency, which is measured in hertz (Hz). Kilohertz (kHz) is thousands of hertz, megahertz (MHz) is millions, and gigahertz (GHz) is the billions range. The electromagnetic spectrum ranges from 3 kilohertz up to 3,000 gigahertz. Radio signals are generated by a transmitter and detected by a receiver. An antenna allows a radio transmitter to send radio signals across the airwaves and a receiver to analyze these signals. Transmitters and receivers are typically designed to operate over a limited range of frequencies.



frequency, traveling at the speed of light. In an imperfect analogy, radio signals are like waves on a pond emanating out when a stone is dropped, weakening over distance. The distance between peaks or valleys in the wave is the wavelength. The higher the frequency of the radio signal, the smaller the wavelength. Antennas scale to the size of the wavelength, becoming smaller at higher frequencies. Antennas come in many sizes and shapes depending on their intended operating frequency and usage, which can range from shipboard applications to stationary land installments to mobile body-worn systems.

In a DF antenna array, the antenna elements are arranged to capture an incoming radio signal at various spatial locations to ultimately determine the direction of arrival. Depending on frequency, traditional DF antenna elements are usually of the dipole or spiral type, which respond to the electric field, or the loop type, which respond to the magnetic field. They are usually oriented for vertical polarization, which refers to the direction of the electric field portion of the electromagnetic wave; most radio signals used for communications are vertically polarized.

LOCATION, LOCATION, LOCATION

Most higher-frequency wireless communications today range from 100 MHz to 10 GHz, requiring a direct line of sight from one antenna to another to establish a link. Due to the curvature of the Earth, the range of a radio signal is proportional to the height of an antenna above ground. On a ship, the ideal location for any antenna is the very top of the mast. From that vantage point, an antenna has the best reception and a clear unobstructed 360° omnidirectional view. As one can imagine, this real estate is very valuable on the high seas.

Typically, VHF/UHF DF antennas serve as an extension to the mast of the ship, allowing other antennas of higher priority, i.e. navigational and threat-warning capabilities, to be mounted above them. DF antennas include a central mast with elements extended out around it. The higher the frequency of the radio signal, the smaller the wavelength and the closer the element spacing must be to prevent undesired "ripples" in the beamformed antenna patterns, which are the combination of two or more element outputs. These ripples degrade DF performance and reduce sensitivity. Above a certain frequency, this proper electromagnetic spacing is difficult to maintain using traditional DF elements given their physical build and the required diameter of the central mast. In addition, traditional elements experience destructive mutual coupling in their outputs when spaced too close together. When the client asked SwRI to retrofit an existing antenna to extend its upper operating frequency range into the SHF band, the engineering team at first thought it could not be done without a complete redesign of its mast. With no obvious solutions to the problem, the team had to think outside the box.

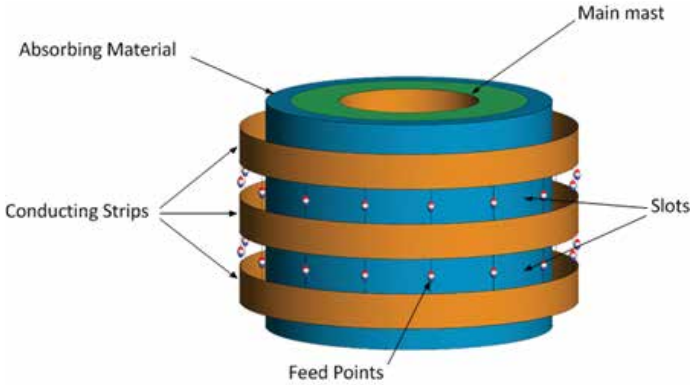
A literature search unearthed an unorthodox concept for a wide-band antenna array design originally conceived by Harold Wheeler in 1948, which until now was largely theoretical due to

D019795_0064

SwRI's 200-acre antenna test range includes two 70-foot towers to simulate and evaluate antenna systems on the masts of naval vessels at sea.

DETAIL

Beamforming technology combines two or more antenna element outputs for a given purpose. For example, traditional DF antenna elements beamform outputs to create the "sine" and "cosine" patterns used to determine direction. In next-generation smart antennas, beamforming is used to "steer" radio signals in a specific direction, as opposed to broadcasting in all directions.



This exploded view of the cylindrical continuous-slot array concept shows three vertically stacked conductive rings spaced away from one another, forming two slots in between having closely spaced feed points. Absorptive material is placed on the inside to prevent interactions with the mast.

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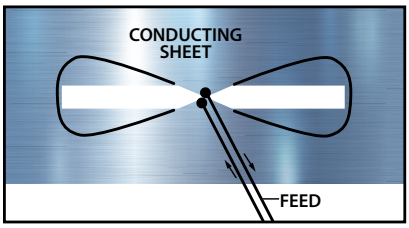

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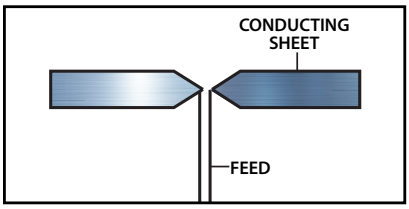
SLOT ANTENNA



COMPLEMENTARY DIPOLE ANTENNA

DETAIL

A slot antenna is the complement to the dipole antenna. If a dipole antenna is cut out of a conducting sheet, the remaining material makes a slot antenna, fed across the center.

practical limitations. In this concept, an infinite two-dimensional array of electrically small dipole elements spaced close to each other would offer beneficial mutual coupling and, as a result, achieve wide-band operational performance from the lowest frequencies to the highest. Upper frequency cutoff is based on how closely spaced the elements are. Such an array of closely spaced elements could conceivably solve the ripple problem, eliminating pattern distortion in a circular array. But how to reduce the idea of an infinite array to a practical solution seemed elusive. Different methods described in the literature proved impractical.

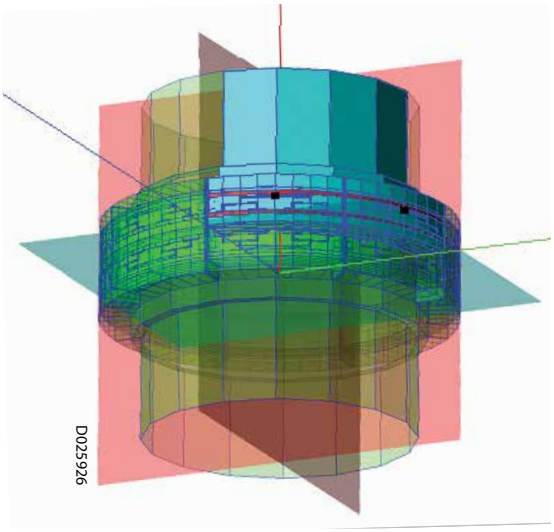
However, one method found in the literature caught the team's attention: using slot elements in place of dipole elements in Wheeler's theory. A slot antenna is complementary to a dipole antenna and in its simplest form is just a narrow slot cut out of a conducting sheet and fed from the center. The slots are horizontally oriented for vertically polarized signals, opposite a dipole. Merging electrically small slot antennas long ways, connected end to end, creates a continuous cylindrical slot but with many closely spaced feed points. Multiple slots could then be layered on top of each other. The final product would consist of a cylindrical stack of conductive rings spaced to form slots in between. This design would solve the infinite dimension problem in one dimension but still leave the other dimension and the seemingly insurmountable task of an extremely large number of feeds.

The team was nevertheless intrigued by the idea and set out to model such an array using computer-aided design and electromagnetic numerical modeling software. Eventually the team developed an arrangement that achieved the desired frequency bandwidth while requiring only two adjacent continuous slots in the model to be fed. Additional slots above and below were necessary for electrical loading purposes but did not require feeds. Electromagnetic absorbing material placed inside the slots prevents electrical interactions with the antenna mast.

To feed the two slots, the team devised a symmetrical dual-ring corporate feed network using microstrips on the backside of the conductive rings, providing a uniform distribution of up to eight feeds for a single input. This effectively divided the array into sections, or equally spaced DF elements. Each DF element, including its microstrip feeds, could be fabricated on a single printed-circuit board. The array would be fed by a network of 180-degree hybrids — one for each DF element. Individual antenna elements could be constructed separately and then be assembled around an existing mast in a pie-like manner.

The team obtained internal funding to further refine this design, which they referred to

Using computer-aided design and electromagnetic numerical modeling software, SwRI was able to successfully design and predict the performance of the cylindrical slot antenna array before the first piece of metal was cut.



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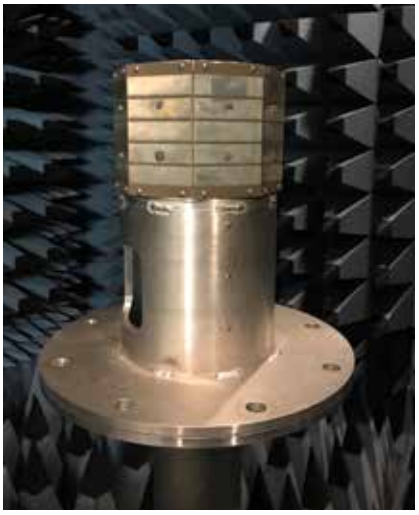

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SwRI prototyped the initial design and evaluated its performance in an anechoic chamber and through computer modeling.

as the cylindrical continuous-slot antenna array, and build a proof-of-concept prototype. This prototype was simple in nature, octagonal in shape and had eight flat antenna sides, or DF elements, with 64 total antenna feeds. Any final version would be curved to create cylindrical appearance. Each element was fabricated using 3D printing technology. From this prototype, SwRI validated the numerical modeling and conducted performance analysis, collecting antenna patterns inside an anechoic chamber. Successful validation and encouraging performance gave the team confidence in further electromagnetic numerical modeling to design the final antenna version for the client and apply for a patent.

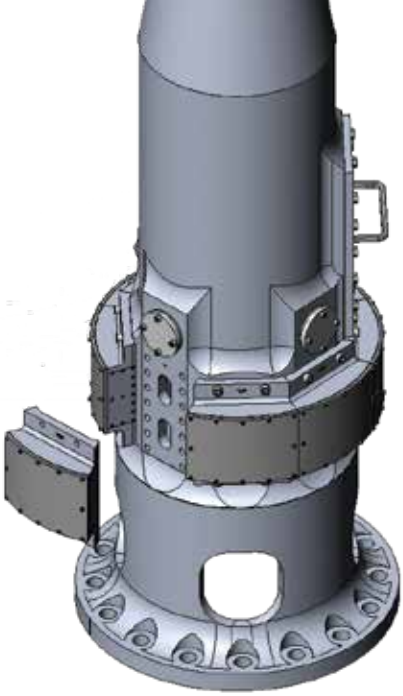
As the team initiated the final version, they wondered if the array could be designed to mount in an abandoned location in the lower portion of the existing antenna mast. The DF antenna had already been retrofitted once, removing a lower frequency array from the bottom half of the antenna mast, leaving behind a series of sealed bolt holes. It was initially assumed the upper portion of the mast would have to be redesigned to accommodate the new array. Taking advantage of this unused real estate at the bottom portion of a mast would eliminate the need for a complete redesign of the entire upper half of the antenna. A mast redesign would have been an expensive endeavor, considering all the design, fabrication and testing involved.

Because the bottom portion of a mast is wider in diameter, the number of antenna feeds would have to increase significantly, a rather intimidating endeavor. However, the successful numerical modeling after the prototype validation allowed the design to move forward without a hitch. The final version consisted of eight antenna elements that individually mated to the existing bolt-hole pattern on the antenna mast. The elements came together like a puzzle, creating the appearance of one continuous curved antenna around the mast with 128 total antenna feeds. The resulting antenna patterns and DF performance were exceptional, solving the ripple problem that plagued previous higher-frequency designs.

The first retrofitted antenna with the new array was deployed late last year with positive results. Currently, SwRI is under contract to retrofit additional ships over the next several years. In addition to the antenna, the team is updating the below-deck processing equipment with wider bandwidth receivers and next-generation processing capabilities, using SwRI's Frontier software architecture. The client also plans to provide these advanced capabilities to its next generation of warships.

As this novel antenna illustrates, SwRI remains on the vanguard in developing the latest state-of-the-art antenna technology. Moving forward, the SwRI team plans to utilize a version of this patented slot array in future higher-frequency designs. Other applications of the slot array are under investigation, including airborne and land-based systems. Its lightweight conformal design could also support clandestine law enforcement operations. SwRI is also exploring dual-polarized versions as a research initiative and a reduced-channel version using innovative beamformer combinations for N-channel DF and advanced DF processing with antenna steering algorithms.

Questions about this story? Contact Siemsen at patrick.siemsen@swri.org or (210) 522-2995.



For the final design, the elements individually mated to the bolt-hole pattern on the existing antenna mast abandoned after a previous retrofit. The elements came together seamlessly, creating the appearance of a continuous, conformal antenna. Radomes covered each element for environmental protection.

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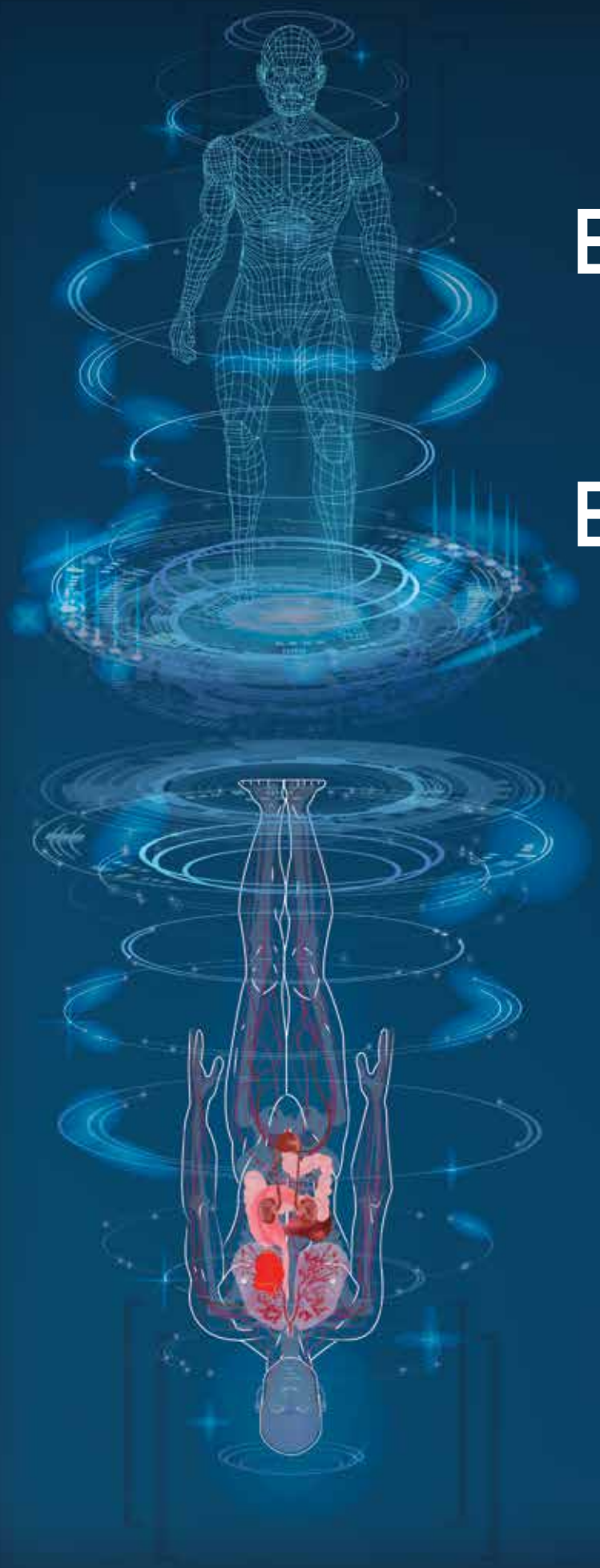
SwRI engineers designed the cylindrical slot array to fit near the base of this shipboard antenna to take advantage of existing unused space, extending the operating frequency range of the antenna while avoiding an expensive redesign of the upper mast.



Enhancing the Human Experience

Optimizing performance through digital twin technology

By Daniel Nicolella, Ph.D.,
Lance Frazer, Ph.D.,
and Ty Templin

In 2002, Dr. Michael Grieves of the National Institute for Standards and Technology (NIST) introduced the "digital twin" concept to describe a numerical representation of a physical object or system. NASA developed the first practical definition of a digital twin in an attempt to improve physical-model simulation of spacecraft in 2010. Since then, digital twin technology has emerged as a disruptive and exciting new approach to traditional engineering practices.

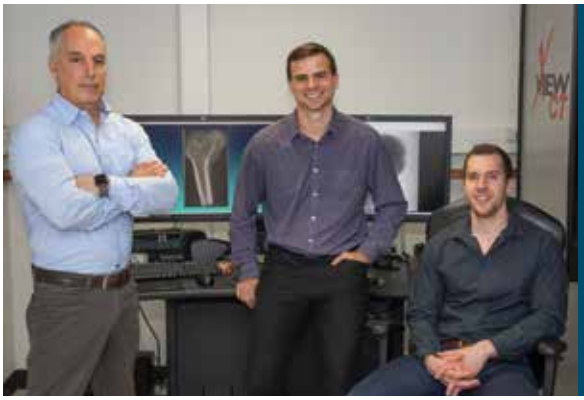
Digital twins are not just facsimiles of their physical counterparts in terms of their geometry or function. Digital twins are immersive virtual models driven by both data and algorithms, which give decision-makers in the physical world access to the nearly infinite exploratory space of the digital world. Advances in digital twin technology follow multiple innovations in engineering coalescing with an exponential boom in modern technologies. These innovations — including smart sensors, machine learning, high-throughput computing, data analytics and advanced simulation capabilities — enable digital twins to dynamically link the digital and physical world. The technology can be used to understand the past with historical data, the present with real-time data and the future with simulations. While testing in the physical world is limited by time, cost, material availability, testing feasibility, etc., digital models are limited only by the data available and computing resources. And smart-sensor technology and other innovative methods are steadily improving data collection while computing power and efficiency continue their exponential growth. Digital twin technology has helped drive the latest phase of the Industrial Revolution, referred to as Industry 4.0.

An exciting and promising application uses digital twin concepts to develop detailed, high-fidelity, physics-based digital twins of the human body. Using a digital representation of a human body, engineers can simulate how the body responds to highly dangerous situations that would be impossible to replicate with live subjects. For example, the technology could characterize how a body would physically respond when faced with a potentially dangerous situation, such as a car crash or pilot ejection from an aircraft. With valid simulations of the physical response of the human body, designers and engineers can improve systems to reduce injuries.

Southwest Research Institute has been developing and applying advanced, high-fidelity digital models of the human body for over 30 years to better understand the risk of injury under extreme conditions, design medical devices and understand how musculoskeletal diseases develop and progress. These digital twins uncover mechanical signals that drive biological tissue adaptation, allowing engineers to optimize protective equipment and safety systems and inform medical advances to ultimately optimize the performance of the human system.

HUMAN DIGITAL TWIN

The human body is a highly complex, sophisticated system. In some respects, it is a typical engineering structure required to resist external loads without failure and protect vital internal organs. This viewpoint allows engineers to apply standard, mature, engineering modeling and simulation techniques to understand how the structure will respond to external and internal forces. Early applications of human body modeling and simulation used medical images such as CT or MRI scans from a single individual selected to represent an average individual for the population. SwRI and other researchers around the country and the world have used these models with great success in applications ranging from predicting injury in a car crash to designing joint replacements to understanding cardiovascular disease development. While these early models and applications were highly successful, they represent how a single, average individual may respond and do not account for considerable variability within and between



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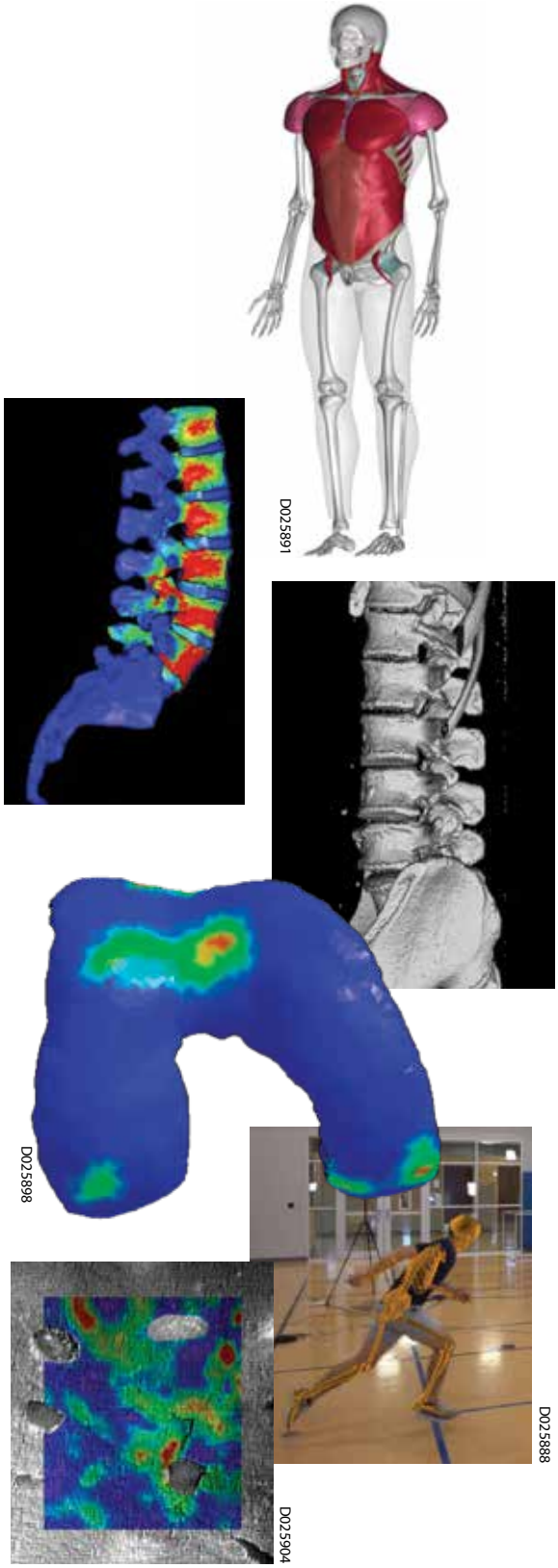
ABOUT THE AUTHORS: From left, Dr. Dan Nicolella has over 30 years of experience in basic and applied research in musculoskeletal biomechanics and bioengineering. His diverse experience includes human performance initiatives, bone mechanics, computational mechanics, human body modeling and advanced materials characterization. Ty Templin uses biomechanics and musculoskeletal modeling and simulation to create dynamic models of the human body, including a physics-driven digital twin of a baseball pitcher. Dr. Lance Frazer is a senior research engineer with eight years of experience in basic and applied research in computational biomechanics with an emphasis on finite element modeling and machine learning.



SwRI has developed a suite of advanced modeling and simulation techniques for human digital twins. Advanced uncertainty quantification methods address the variability and uncertainty in biological tissue mechanical properties and responses. Additional techniques efficiently describe the diversity in anatomical structures by parameters such as size, shape and material variation within a group. This variability is directly quantified from medical image databases representing real population-level variability.

populations. Every human is unique, and differences in anatomical size and shape can have a substantial effect on how the body responds to an external load.

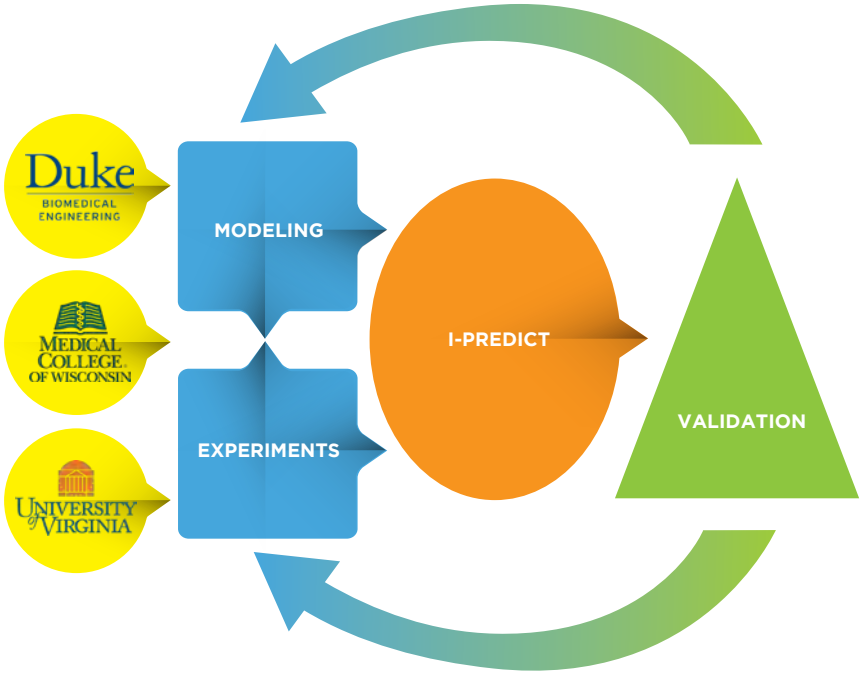
In addition, biological materials making up anatomical structures are highly complex and vary between individuals. For example, bones are externally rigid, fluid-filled composite materials that have different physical properties when measured in different directions. Their shape and density change based on loading. The soft tissues that connect skeletal tissues are fluid-filled composite polymers exhibiting a range of properties. Furthermore, the shapes of human anatomical structures are highly complex and cannot be accurately described using traditional design and analysis concepts, such as straight lines, analytical curvatures, and so on. Finally, no two human bodies are the same. From the overall size and shape down to the mechanical behavior of individual tissues, a tremendous amount of variability exists between individuals and within groups, for example, males and females. To complicate things further, the human system changes and adapts over time in response to external forces, disease and aging.

To address these challenges, the Institute has developed, adopted and implemented a suite of advanced modeling and simulation techniques. First, advanced uncertainty quantification methods address the variability and uncertainty in the mechanical properties and responses of biological tissue. The technique treats important tissue properties such as the strength of bone tissue or the stiffness of a ligament as random variables, using values derived from experimental data to characterize how uncertainty and variability affect model predictions, such as injury risk. When the properties of a specific biological tissue such as bone are fairly well characterized, engineers calculate how the variability affects model predictions to help design robust safety systems for the target population. When physical properties of biological tissues or structures are not well enough understood for accurate model predictions, SwRI determines how sensitive our model predictions, say for risk of injury, are to this uncertainty. This sensitivity information is used to better direct resources to improve the understanding of the tissues that most significantly affect model predictions.

Second, advanced techniques efficiently describe the diversity in anatomical structures by parameters such as size, shape and material variation within a group. This variability is directly quantified from medical image databases representing real population-level differences. Treating parameters in human anatomy as random variables better characterizes how morphological differences affect predictions. Using this technique, SwRI designs systems to robustly protect diverse populations from injury rather than protecting the average individual. Individual differences in anatomical morphology can significantly affect a person's injury risk or chance of developing a debilitating disease. For example, the size, shape and properties of bone tissue within an individual's femur will significantly affect their risk of fracturing their hip. Similarly, we showed that shape of the bones in the knee joint significantly affects the risk of developing arthritis. For the military, the models show how the shape of the bones in the lower leg can contribute to bone fractures associated with under-vehicle blast loading, such as those caused by improvised explosive devices or IEDs.

CYBER SOLDIER

The U.S. Navy funded the Incapacitation Prediction for Readiness in Expeditionary Domains: an Integrated Computational Tool (I-PREDICT) program to apply these techniques to create a digital twin of a warfighter. SwRI is working with Elemance LLC, the Medical College of Wisconsin, Duke University and the



SwRI is working with Elemance LLC, the Medical College of Wisconsin, Duke University and the University of Virginia to develop, verify and validate a warfighter digital twin to predict the risk of injury and functional degradation associated with battleground experiences.

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University of Virginia to develop, verify and validate a computational human body model to predict the risk of injury and functional degradation associated with battleground experiences. The validated I-PREDICT digital twin will guide mitigation strategies for both highly dynamic and long-duration, chronic exposures, which are difficult to replicate experimentally. I-PREDICT digital twin technology will facilitate human-in-the-loop design and analysis to develop protective equipment that balances warfighter functionality with mitigating the risk of traumatic and chronic injuries. The goal is to protect personnel and improve military readiness.

GETTING PERSONAL

Using digital simulations of the human body to understand its response to extreme conditions has contributed to significant advances in the design and virtual testing of military technology. However, another real benefit can be realized by developing a personalized human digital twin for an individual. Because each individual is different, each body may respond differently to similar conditions. Also, other factors such as exercise, nutrition, previous injury, rest and recovery are specific to each individual and can affect performance. SwRI is developing methods to efficiently create subject-specific, high-fidelity computational models of individuals.

The method uses artificial intelligence to integrate a 3D mesh of the outer skin layer with the detailed skeletal data from a single digital photograph of an individual. Then SwRI morphs the full body computational model to match the 3D size and shape of the individual. This personalizes both the exterior and interior of the computational model, transforming the model to match an individual. Using this method, SwRI can rapidly construct a personalized, high-fidelity human body model from simple digital photographs of an individual. Engineers can then use these personalized models to better understand how an individual will respond to potentially hazardous conditions. These individualized models can be used to

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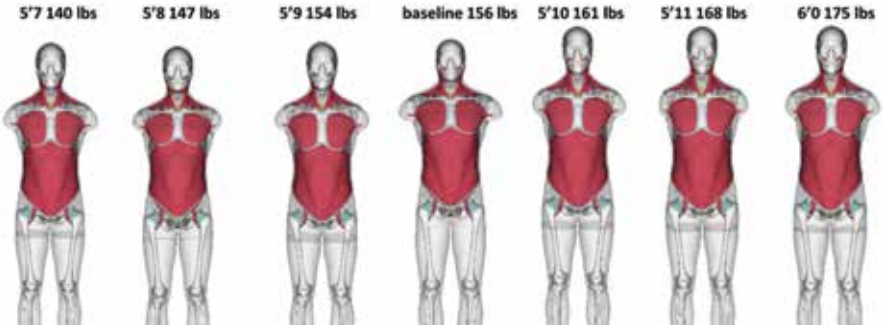

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SwRI and its collaborators are developing methods to efficiently create subject-specific, high-fidelity computational models of individuals. The model uses artificial intelligence to integrate a 3D mesh of the outer skin layer with the detailed skeletal data from a digital photograph. Using the I-PREDICT full body computational model to match the 3D size and shape of the individual, the team personalizes both the exterior and interior of the model to match the individual.

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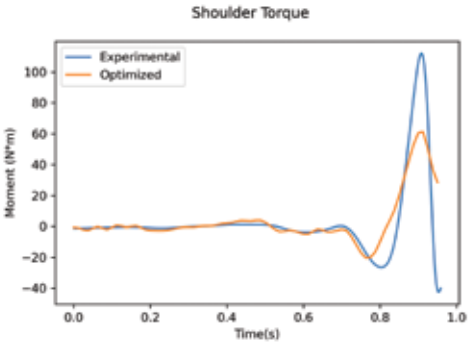

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Using personalized digital twin technology, SwRI assessed pitching mechanics to minimize torque in the throwing shoulder while maintaining pitch speed. Based on the models, slightly altered pitch mechanics could reduce shoulder torque by 30% with minimal impact on pitch speed.

create personalized designs for equipment such as helmets, body armor and boots and inform adjustments to or configurations for safety equipment such as aircraft ejection seats, etc.

PITCH PERFECT

Human performance optimization is an exciting application for personalized human digital twins. Given a physics-driven, accurate digital replication of an individual, SwRI is using digital human modeling to explore how an individual can optimize their performance on a given task or activity. This virtual replica can be used in nearly endless applications, from improving gait mechanics for reducing the risk of developing knee arthritis, optimizing ergonomics, minimizing overuse injuries for factory or warehouse employees, altering movements and improving athletic performance.

DETAIL

One aspect of biomechanics is the study of how the human musculo-skeletal system generates forces and torques to produce movement.

To investigate this application, SwRI developed a physics-driven digital twin of a baseball pitcher. Baseball is one of the most popular sports in the United States, with over 15 million participants each year. Every play in baseball starts with a high-velocity pitch, associated with strenuous movements of a pitcher's shoulder and elbow. Elbow injuries in youth baseball pitchers are rising, with 30% of youth and high school players reporting pain in their throwing arm each year. Poor pitching mechanics are thought to be a major factor in these upper extremity injuries. Every pitcher will deliver a pitch differently due to differences in body size, shape, muscle strength and individual mechanics, so solutions that might be optimal for one pitcher could create problems for another.

SwRI has set out to investigate how an individual's personalized pitching mechanics can be optimized to maintain pitch speed while decreasing the likelihood of injury. Engineers created a personalized digital twin of a pitcher and replicated that specific pitcher's throwing mechanics, modeling torque activation in the joints. To reduce the risk of shoulder injury, the team developed a numerical approach to assess the pitching motion and recommend changes to minimize torque in the throwing shoulder while maintaining pitch velocity. By slightly altering pitch mechanics, the pitcher could reduce shoulder torque by up to 30% while maintaining pitch velocity to within 2%. Importantly, the changes to the pitching mechanics were realistic and made movements similar to those of high-performing major league pitchers.

FUTURE DIRECTIONS

The digital twins concept originally conceived by Grieves has progressed to permitting the efficient creation of a virtual representation of a specific individual based on medical imaging and baseline data collected during medical examinations. The digital twin can be updated periodically from medical exams or in real time from wearable devices that monitor everything from heart rate to body temperature, glucose levels, physical activity and detailed individual biomechanical movement. Using personalized digital twins throughout a person's lifetime can extend careers by optimizing performance, anticipating disease and injury, recommending treatment strategies and customizing safety systems. This technology represents the future of human performance optimization and holds tremendous promise for improving the quality of lives, reducing injury and disability in all age groups.

Questions about this story? Contact Nicolella at daniel.nicolella@swri.org or (210) 522-3222.

The I-PREDICT program is funded by the Office of Naval Research (ONR) and U.S. Army Medical Research and Development Command (USAMRDC) through the Medical Technology Enterprise Consortium (MTEC). USAMRDC and MTEC produce medical solutions for the battlefield to protect, treat and optimize the health and performance of U.S. military personnel and civilians. The views expressed in this article are those of the authors and may not reflect the official policy or position of the Department of the Navy, Army, Department of Defense or the U.S. government.

Detecting Pipeline Corrosion to Prevent Leaks

SwRI has created next-generation ultrasonic guided wave technology to detect anomalies in pipes, enabling users to prevent leaks before they start. The transducer uses SwRI-developed Magneto-strictive Sensor® (MsS®) technology.

"Pipeline corrosion resulting in leaks is very common," said SwRI Staff Engineer Sergey Vinogradov, who led the development. "We've developed a technology that can consistently monitor the pipe's condition, hopefully preventing leaks from happening."

The Magnetostrictive Transducer (MsT) Collar, originally developed by SwRI in 2002, now has a lower profile allowing its use on pipes in tight spaces. In custom configurations, it can withstand heat up to 400 degrees Fahrenheit. The new, segmented MsT design also features eight sensors to more accurately identify where pipe corrosion is occurring.

The MsT Collar propagates waves along an elongated structure, guided by its boundaries, to travel long distances with little loss of energy. Sometimes a single sensor can inspect hundreds of meters, though obstacles such as couplings would require additional sensors.

"The eight sensors in the transducer collect the full range of signals," Vinogradov said. "Algorithms combine this information to better detect and locate the anomaly both axially and circumferentially. Corrosion growth can also be monitored by examining data sets acquired over time."

The MsS system can send data to a remote terminal via a wireless transmitter unit or through a wired connection. It is designed primarily for oil and gas transmission pipelines to prevent costly and damaging leaks before they begin. However, the versatile technology supports other industrial piping systems.

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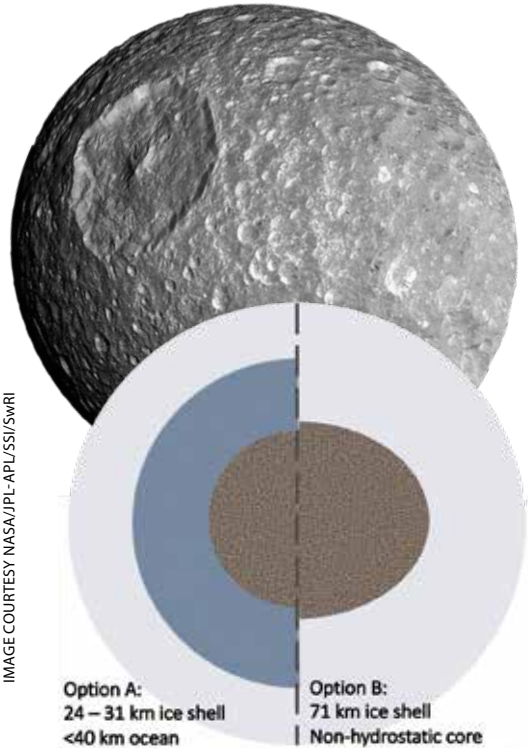

IMAGE COURTESY NASA/JPL-APL/SSI/SwRI

Mimas' heavily cratered surface suggests a cold history, but its librations rule out a homogeneous interior. Mimas must have a rocky interior and outer hydrosphere, which could include a liquid ocean (A) or be fully frozen with an irregularly shaped core (B). An ocean provides a better fit to the phase of the libration but is difficult to reconcile with Mimas' geology.

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MORE EVIDENCE FOR A STEALTH OCEAN WORLD

When an SwRI scientist discovered surprising evidence that Saturn's smallest, innermost moon could generate the right amount of heat to support a liquid internal ocean, colleagues began studying Mimas' surface to understand how its interior may have evolved. Numerical simulations of the moon's Herschel impact basin, the most striking feature on its heavily cratered surface, determined that the basin's structure and the lack of tectonics on Mimas are compatible with a thinning ice shell and geologically young ocean.

"In the waning days of NASA's Cassini mission to Saturn, the spacecraft identified a curious libration, or oscillation, in Mimas' rotation, which often points to a geologically active body able to support an internal ocean," said SwRI's Dr. Alyssa Rhoden, a specialist in the geophysics of icy satellites, particularly those containing oceans, and co-author of a new Geophysical Research Letters paper on the subject. "Mimas seemed like an unlikely candidate. Its icy, heavily cratered surface marked by one giant impact crater makes the small moon look like the Death Star from Star Wars. If Mimas has an ocean, it represents a new class of small, 'stealth' ocean worlds with surfaces that do not betray the ocean's existence."

Rhoden worked with Purdue graduate student Adeene Denton to better understand how a heavily cratered moon like Mimas could possess an internal ocean. Denton modeled the formation of the Hershel impact basin using iSALE-2D simulation software. The results imply that a present-day ocean within Mimas must have been warming and expanding since the basin formed.

"Although our results support a present-day ocean within Mimas, it is challenging to reconcile the moon's orbital and geologic characteristics with our current understanding of its thermal-orbital evolution," Rhoden said. "Evaluating Mimas' status as an ocean moon would help us better understand Saturn's rings and mid-sized moons as well as the prevalence of potentially habitable ocean moons, particularly at Uranus. Mimas is a compelling target for continued investigation."

DARK SECRETS FROM THE FROZEN HEART OF AN INTERSTELLAR CLOUD

An international team including SwRI, Leiden University and NASA used observations from the James Webb Space Telescope (JWST) to achieve the darkest-ever view of a dense interstellar cloud. These observations revealed the composition of a virtual treasure chest of primordial ices, providing new insights into the chemical processes of one of the coldest, darkest places in the universe as well as the origins of the molecules that make up planetary atmospheres.

NASA's JWST has a 6.5-meter-wide mirror providing remarkable spatial resolution and sensitivity, optimized for infrared light. As a result, the telescope has been able to image the densest, darkest clouds in the universe for the first time.

"These observations provide new insights into the chemical processes in one of the coldest, darkest places in the universe to better understand the molecular origins of protoplanetary disks, planetary atmospheres and other solar system objects," said SwRI Research Scientist Dr. Danna Qasim. "The ices we observed contain only 1% of the sulfur we're expecting. The other 99% of that sulfur is locked up somewhere else. We need to figure out where to understand how sulfur will eventually be incorporated into the planets that may host life."

In the study, Qasim and colleagues propose that the sulfur may be locked in reactive minerals like iron sulfide.

"Iron sulfide has been detected in the accretion disks of young stars and in samples returned from comets. It's also the most common sulfide mineral in lunar rocks," Qasim said. "If sulfur is locked up in these minerals, that could explain the low levels of sulfur in interstellar ices, which has implications for where sulfur is stored in our solar system. For example, sulfur in the atmosphere of Venus may have originated from interstellar-inherited minerals."

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IMAGE COURTESY NASA/ESA/CSA/M. ZAMANI (ESA/WEBB)/M. K. MCCLURE (LEIDEN OBSERVATORY)/F. SUN (STEWARD OBSERVATORY)/ Z. SMITH (OPEN UNIVERSITY)/ICE AGE ERS TEAM

NOVEL MICROSCOPY METHOD MAPS DAMAGE TO SAND SCREENS

SwRI has created a more effective method to evaluate changes in sand control screens used in oil and gas production wells. Using accelerated life erosion testing, the new method pinpoints the location of erosion and can be used to evaluate other equipment in harsh environments.

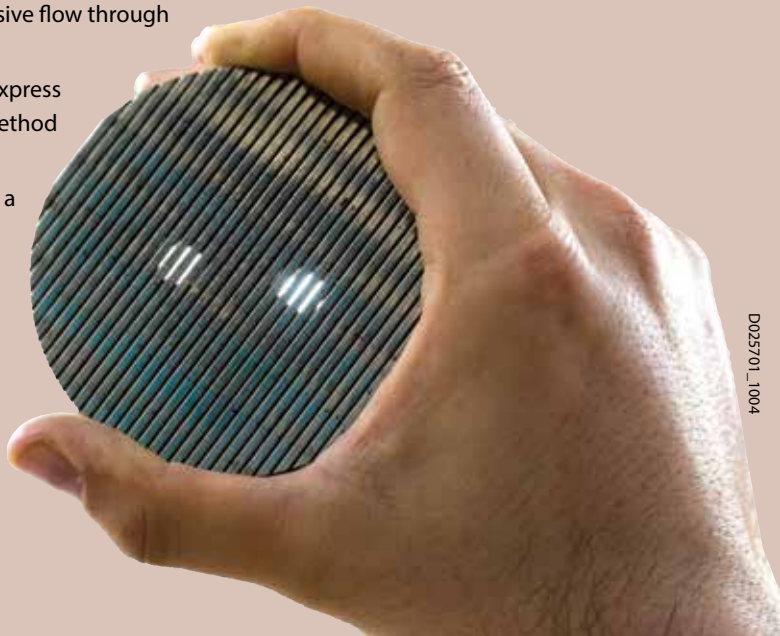
In oil and gas production wells, sand screens keep formation and fracturing sand in the reservoir while allowing fluids to be produced. Fine sands, smaller than the screen gaps, periodically pass through the screens, causing erosion that can eventually lead to screen failure. Sand produced with oil and gas in a well can erode the equipment between the reservoir and the surface, causing costly production halts to repair or replace damaged components.

"Measuring erosion in sand screens is challenging. Current methods use a single point value to describe erosion that differs across various regions," said Jessica Brysch, an assistant program manager in SwRI's Fluids Engineering Department. "These methods identify only the largest gap associated with erosive flow through a sand screen. Our method identifies each gap."

Using internal research funding, SwRI developed a graphical approach to express sand screen erosion, providing a more complete picture of the damage. The method examines both the screen and base pipe layers.

"Using microscopy, we have developed a novel visual technique, providing a spatial understanding of where erosion is occurring," said Luis Gutierrez, a research engineer in SwRI's Fluids Engineering Department. "Our method maps the magnitude and location of erosion experienced in both the screen and base pipe layer."

SwRI has extended the visualization methods to other types of equipment to quantify erosion in harsh environments. The technique can also help predict component life under specific well conditions, rather than waiting for equipment to fail.



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AUTOMATED LEAK DETECTION SYSTEMS FOR THE RAIL INDUSTRY

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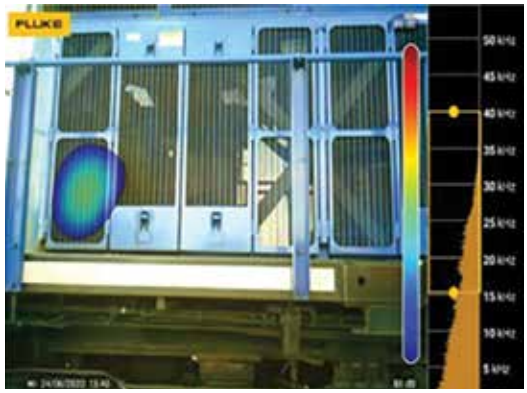

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The team tested the leak detection proof-of-concept system at SwRI's Locomotive Technology Center in San Antonio.

SwRI has developed a proof-of-concept system to autonomously detect compressed air leaks on trains and relay the location of the leaks to maintenance personnel for repair. The automated system could reduce the time, costs and labor needed to find and repair air leaks and ultimately lower the locomotive industry's overall fuel consumption and emissions.

Trains use compressed air for a variety of functions, including air brakes, valve actuation, radiator shutters, horns and bells. Each year, the rail industry loses an estimated 2-3% in vehicle efficiency due to air leaks at various points throughout trains. These leaks can also affect train operability and safety.

"Air leaks significantly increase fuel consumption and reduce the effectiveness of a locomotive's automatic engine stop-start systems, causing it to burn more fuel and reducing the lifespan of parts such as starters, air compressors and batteries," said SwRI Lead Engineer Christopher Stoos. "An automated air leak detection system could save millions of gallons of fuel and reduce carbon dioxide, oxides of nitrogen and particulate matter emissions."

Currently, railroad employees manually search for air leaks, venturing on, under or between railway cars to listen or feel for leaks. Because this inefficient, time-consuming practice introduces unnecessary risk to maintenance staff, the Federal Railroad Administration has established acceptable air leak rates for trains.

To significantly reduce these leaks, SwRI has created a system that uses audio detection technology, visual cameras and machine learning to autonomously detect, identify and report air leaks, even on moving trains. During testing, the prototype system successfully detected a range of air leaks at various locations with a false positive rate of only 0.03%. The system detected 11 out of every 13 leaks on a moving train. Once the system identifies an air leak, it electronically shares an alert and an image of the site with maintenance for repairs.

The system — funded by the Transportation Research Board's (TRB) Rail Safety IDEA program and led by Stoos, Senior Research Engineer Heath Spidle and Research Engineer Jake A. Janssen — needs additional field development and testing.

OCCULTATIONS OF SATURN'S RINGS

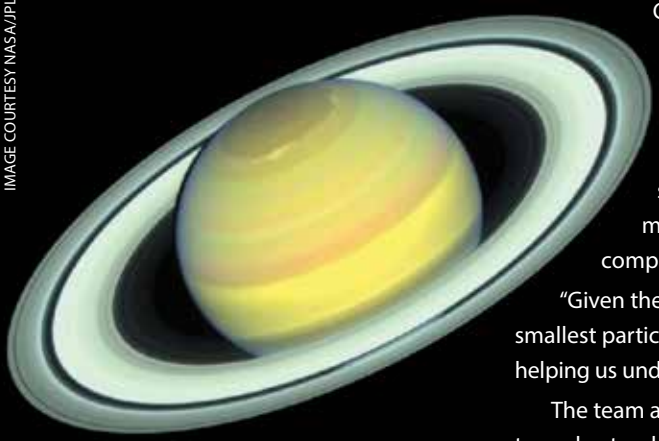


IMAGE COURTESY NASA/JPL-CALTECH/SSI/CORNELL D025701_1004

SwRI scientists have compiled 41 solar occultation observations of Saturn's rings from the Cassini mission. The compilation, published recently in the scientific journal Icarus, will inform future investigations of the particle size, distribution and composition of Saturn's rings, key elements to understanding their formation and evolution.

"For nearly two decades, NASA's Cassini spacecraft shared the wonders of Saturn and its family of icy moons and signature rings, but we still don't definitively know the origins of the ring system," said Dr. Stephanie Jarmak, a researcher in the SwRI Space Science Division. "Evidence indicates that the rings are relatively young and could have formed from the destruction of an icy satellite or a comet. However, to support any one origin theory, we need to have a good idea of the size of particles making up the rings."

Cassini's Ultraviolet Imaging Spectrograph (UVIS) was uniquely sensitive to some of the smallest ring particles, particularly with the observations it made in the extreme ultraviolet wavelength.

To determine the size of the ring particles, UVIS observed them when the instrument was pointed at the Sun, looking through the rings in what is known as a solar occultation. Ring particles partially blocked the path of the light, providing a direct measurement of the optical depth, a key parameter for determining the size and composition of the ring particles.

"Given the wavelength of the light coming from the Sun, these observations gave us insight into the smallest particle sizes with Saturn's rings," Jarmak said. "UVIS can detect dust particles at the micron level, helping us understand the origin, collisional activity and destruction of the ring particles within the system."

The team also studied variations in the optical depth of occultation observations, which can be used to understand major differences in the structure and density of Saturn's rings.

Magnetic Reconnection Between Ganymede, Jupiter

In June 2021, NASA's Juno spacecraft flew close to Ganymede, Jupiter's largest moon, observing evidence of magnetic reconnection. An SwRI-led team used Juno data to examine the electron and ion particles and magnetic fields as the magnetic field lines of Jupiter and Ganymede merged, snapped and reoriented, heating and accelerating the charged particles in the region.

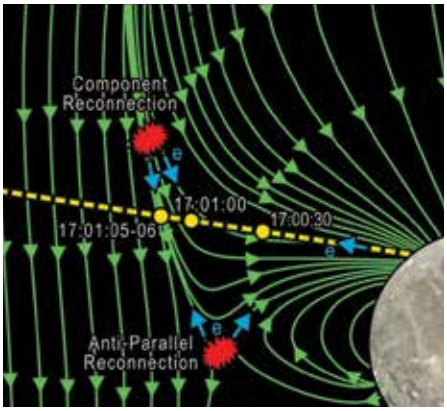
"Ganymede is the only moon in our solar system with its own magnetic field," said Juno Principal Investigator Dr. Scott Bolton of SwRI. "The snapping and reconnecting of Ganymede's magnetic field lines with Jupiter's creates the magnetospheric fireworks."

Magnetic reconnection is an explosive physical process that converts stored magnetic energy into kinetic energy and heat. Ganymede's mini-magnetosphere interacts with Jupiter's massive magnetosphere, in the magnetopause, the boundary between the two regions.

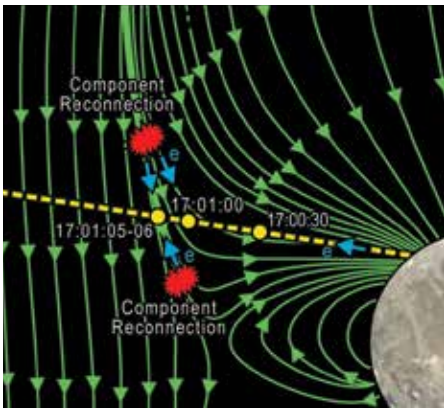
"We interpreted the presence of accelerated electrons traveling along the magnetic field at Ganymede's magnetopause as evidence that magnetic reconnection was occurring there during the Juno flyby," said Dr. Robert Ebert, lead author of a Geophysical Research Letters paper describing the findings. "These observations further support the notion that magnetic reconnection at Ganymede's magnetopause can be a driver of dynamic processes in the local space environment around this moon of Jupiter."

The SwRI-developed Jovian Auroral Distributions Experiment (JADE) aboard Juno observed enhanced electron fluxes, including accelerated, magnetic-field-aligned electrons. Reconnection as observed by Juno is thought to be related to the generation of Ganymede's aurora.

"The accelerated electrons observed by JADE are similar to those observed by NASA's Magnetospheric Multiscale (MSS) spacecraft during reconnection at the Earth's magnetopause," said Dr. Stephen Fuselier, a co-author of the paper. "That's one of the exciting results from the Ganymede flyby: Despite the vast differences between Ganymede and Earth, we find commonality in the universal process of magnetic reconnection."



SCENARIO 1



SCENARIO 2

An SwRI-led team used Juno spacecraft data to characterize the magnetic topology and electron flow direction for two different reconnection scenarios at the magnetopause of Ganymede, Jupiter's largest moon. The yellow dashed line indicates Juno's trajectory.

IMAGES COURTESY SwRI/JIA ET AL (2008) D025931/ D025932

CHARACTERIZING TRANSPORT RISKS

SwRI has received a two-year, $650,000 contract from the U.S. Department of Transportation to study the transport risks associated with gases dissolved in hazardous liquids.

The federal government has well-defined quantitative criteria and regulations for distinguishing hazardous liquids and gases as well as their transport.

"The regulations related to the transportation of hazardous chemicals such as crude oil or gasoline are very different from those for transporting milk," said Dr. Swanand Bhagwat, a fluids engineer leading the project. "However, the DOT lacks regulatory language to classify the liquids containing significant quantities of dissolved gases. Current regulations do not provide guidelines on how much gas can be dissolved in liquid without changing the hazard classification of the fluid."

The regulatory gap makes it difficult to determine how to handle and ship the fluids as well as address compliance issues. The presence of gases such as methane and ethane in crude oil or dissolved air in fuels such as diesel and kerosene could increase the vapor pressure and the volatility of the liquids.

"To safely handle hazardous liquids containing dissolved gases, it is necessary to understand the acceptable thresholds," Bhagwat said. "It is difficult to estimate the risk of leaks associated with pressurization as well as fire or explosion hazards of ignitable mixtures in a shipping tank."

Bhagwat is collaborating with SwRI's Chemistry and Chemical Engineering Division to conduct experiments to ascertain the solubility of gases often found in hazardous liquids transported by rail. The team will then use computer modeling to characterize associated safety risks and hazards. Additional experiments will determine how the concentration of dissolved gas affects the hazardous properties of the liquid and identify how temperature changes and agitation associated with transport affect risks. Experiments will also assess risk associated with venting or leaking vapors of various gases exuded from liquids.

ICY ORIGINS OF LIFE

A new study led by SwRI's Dr. Danna Qasim posits that interstellar cloud conditions may have played a significant role in the origin of key building blocks of life in the solar system.

"Carbonaceous chondrites, some of the oldest objects in the universe, are meteorites that are thought to have contributed to the origins of life," Qasim said. "They contain several different molecules and organic substances, including amines and amino acids, which were critical building blocks for life on Earth. These substances are necessary to create proteins and muscle tissue."

Most meteorites are fragments of asteroids that broke apart long ago in the asteroid belt, located between Mars and Jupiter. These rocky or metallic meteors orbit the Sun — sometimes for millions of years — before transiting the Earth's atmosphere to impact its surface.

Scientists wonder how amino acids were assimilated into carbonaceous chondrites in the first place. Because most meteorites come from asteroids, scientists have attempted to reproduce amino acids by simulating asteroid conditions in a laboratory setting, a process called "aqueous alteration," with limited success.

"However, the asteroid matter originated in the parental interstellar molecular cloud, which was rich in organics," Qasim said. "The molecular cloud could have provided amino acids in parent asteroids, which passed them on to meteorites."

Qasim simulated the creation of amines and amino acids in the laboratory to characterize the environmental conditions favoring formation.

"I created ices common in the cloud and irradiated them to simulate the impact of cosmic rays," explained Qasim, who conducted the experiment while working at NASA's Goddard Space Flight Center in Greenbelt, Maryland, between 2020 and 2022. "This caused the molecules to break up and recombine into larger molecules, which ultimately created an organic residue."

Qasim then reprocessed the residue by recreating asteroid conditions through aqueous alteration and studied the substance, looking for amines and amino acids.

"No matter what kind of asteroid processing we did, the diversity of amines and amino acids from the interstellar ice experiments remained constant," she said. "That tells us that interstellar cloud conditions are quite resilient to asteroid processing. These conditions could have influenced the distribution of amino acids we find in meteorites."

However, the individual abundances of amino acids doubled, suggesting the asteroid processing influences the amount of amino acids present.

"Essentially we have to consider both the interstellar cloud conditions and processing by the asteroid to best interpret the distribution," she said.

Asteroid samples from missions such as OSIRIS-REx and Hayabusa2 will help scientists better understand the role asteroid processes played vs. those the instellar cloud played in distributing the building blocks of life.

Visit **https://www.swri.org/podcast/ep52** to hear Qasim discuss her research on the Technology Today Podcast.

IMAGE COURTESY NASA/JPL-CALTECH

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Dr. Danna Qasim's research conducted with NASA's Goddard Space Flight Center indicates that interstellar cloud conditions may have played a significant role in the presence of key building blocks of life in the solar system. Her team simulated the formation of amines and amino acids as it would occur in the interstellar molecular cloud, forming an organic residue. She then processed the residue under asteroid-relevant conditions.

UPCOMING

WEBINARS, WORKSHOPS and TRAINING COURSES HOSTED by SwRI:

Introduction to Propulsion Simulation Using NPSS Short Course, May 2, 2023. In-person training.

Preliminary Aerodynamic Design Radial Expanders for Beginners, May 10, 2023. Free webinar.

ISO 9001 Internal Auditor, May 15-16, 2023. Two-day in-person training.

Introduction to Microencapsulation, June 12-13, 2023. Two-day in-person workshop.

Tolerance Stack Analysis Webinar, June 26, 2023. Virtual training.

International Human Performance Summit, July 20, 2023.

Penetration Mechanics Short Course, September 11, 2023. In-person training.

CONFERENCES/MEETINGS:

IEEE Radar Conference, San Antonio, May 1, 2023. Booth No. 207.

Offshore Technology Conference, Houston, May 1, 2023. Booth No. 2739.

Athlete Engineering Summit, Starkville, Mississippi, May 10, 2023.

Automate, Detroit, May 22, 2023. Booth No. 5913.

EPRI Nondestructive Evaluation Technology Week, New Orleans. June 19.

National Space & Missile Materials Symposium and CRASTE Joint Symposia, Tucson, Arizona, June 26, 2023. Booth No. 207.

ASME Turbo Expo, Boston, June 26, 2023. Booth No. 424.

Modern Day Marine, Washington, June 27, 2023. Booth No. 749.

Hydrogen Technology North America, Houston, June 28, 2023. Booth No. 1180.

Institute of Food Technologists Conference, Chicago, July 17, 2023. Booth No. S3237.

Controlled Release Society Annual Meeting, Las Vegas, July 24, 2023. Booth No. 210.

Life Cycle Industry Days & Wright Dialogue with Industry, Dayton, Ohio, July 31, 2023, Booth No. 410.

Small Satellite Conference, Logan, Utah, August 5, 2023, Booth No. 50.

Ground Vehicle Systems Engineering & Technology Symposium, Detroit, August 15, 2023. Booth No. 227 & 229

by the numbers

FALL 2022 – SPRING 2023

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Manager **Jody Little** received the Award for Meritorious Civilian Service from the Department of the U.S. Air Force in December 2022. He was given the award in recognition for a temporary two-year assignment serving as executive program manager of the Department of Defense Joint Base San Antonio 5G NextGen Program and Program Management Office.

D025887

Associate General Counsel **Bill Mason** (General Counsel's Office) was recently elected a Fellow of the Texas Bar Association. Fellowship is limited to 1/3 of 1 percent of licensed attorneys in the state of Texas.

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An SwRI research team won SAE International's prestigious John Johnson Best Paper Award for Outstanding Research in Diesel Engines. A committee of industry professionals selected "CARB Low NOx Stage 3 Program – Final Results & Summary" from hundreds of diesel engine articles and papers published in SAE International's journals and conference proceedings. The paper, the latest of several focused on ultra-low NOx emissions initiatives, was authored by Institute Engineer **Christopher Sharp**, Senior Research Engineer **Bryan Zavala**, Senior Research Engineer **Sandesh Rao** and Principal Engineer **Gary Neely**.

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D025803_5096

The San Antonio Business Journal selected three SwRI staff members to receive 2023 40 Under 40 Awards, which recognize professionals under 40 years old who have demonstrated excellence in business, leadership and community involvement. **Dr. Kelly Miller** is a planetary scientist who has served in key roles in a variety of NASA missions, including the upcoming mission to visit Jupiter's moon Europa. She helped develop MASPEX, a groundbreaking new instrument to sample Europa's oceans and atmosphere. **Meera Towler**, a senior research engineer in SwRI's Intelligent Systems Division, specializes in complex robotic and autonomous systems, including an advanced mobility system designed to operate in confined spaces. She has created software for robots designed to operate in outer space. **Angel Wileman** manages SwRI's Thermofluids Section, helping lead an initiative to advance hydrogen fuel projects to transition away from greenhouse gases. She is active in outreach work promoting STEM careers to young women and girls.

TECHNOLOGY **TODAY**

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