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About the Institute
Since its founding in 1947, Southwest Research Institute (SwRI) has contributed to the advancement of science and technology by working with clients in industry and government. Performing research for the benefit of humankind is a long-held tradition. The Institute comprises 11 divisions engaged in contract research spanning a wide range of technologies.

Southwest Research Institute on the Internet:
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COVER

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About the cover
An artist's rendition shows the four Magnetospheric Multiscale mission (MMS) spacecraft flying in formation through a region of magnetic reconnection on the Earth's magnetopause. Magnetic fields from the solar wind are shown colliding wtih the Earth's field, creating powerful jets of plasma and radiation at their point of contact.

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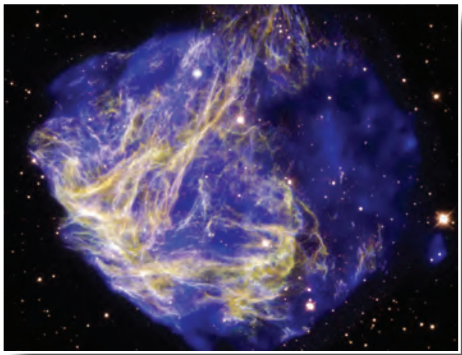

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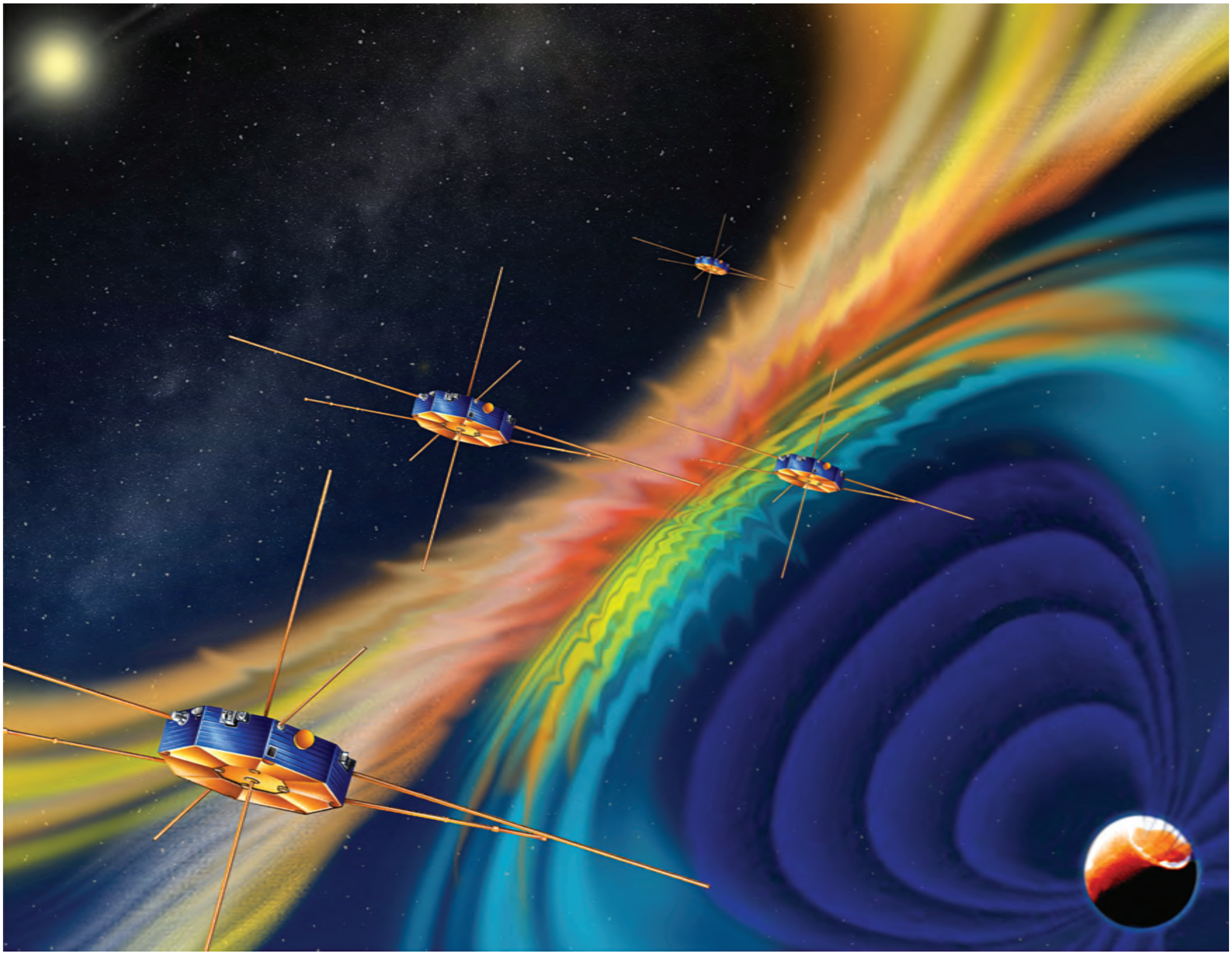

A Cosmic Energy Source in 3-D

SwRI-developed Hot Plasma Composition Analyzers will fly aboard four satellites studying magnetic reconnection as part of NASA's Magnetospheric Multiscale mission

By David T. Young, Ph.D.

Magnetic reconnection is one of the most explosive sources of energy in the known universe. By releasing forces created by highly stressed magnetic fields, reconnection creates powerful jets of charged particles and radiation that result in the Earth's aurora, solar flares, and even X-ray emission beamed from magnetized neutron stars. The latter, for example, can release more energy through reconnection in one second than the sun produces in a million years.

Conceptually, reconnection is easy to describe but important physical details are complex and poorly understood. Nowhere can this enigmatic phenomenon be studied up close than in the Earth's magnetosphere. Here the magnetic fields are relatively weak compared to the sun and stars, but the process remains the same. NASA's Magnetospheric Multiscale mission (MMS), for which Southwest Research Institute (SwRI) has major responsibilities in leadership and instrumentation, is designed to solve the mysteries surrounding this powerful but elusive phenomenon.

Earth's magnetosphere is constantly buffeted by the solar wind, a magnetized plasma consisting of ions and electrons flowing outward from the sun at roughly a million miles per hour. As the solar wind rams into the magnetopause, the boundary of the Earth's magnetic field, magnetic lines of force are draped and stretched across its surface. Although the

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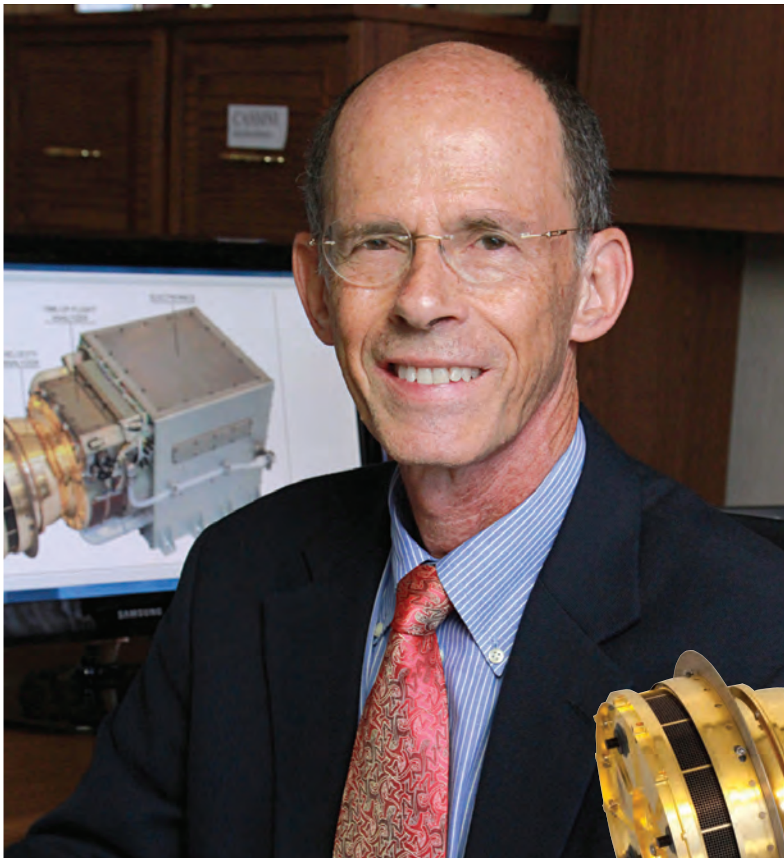
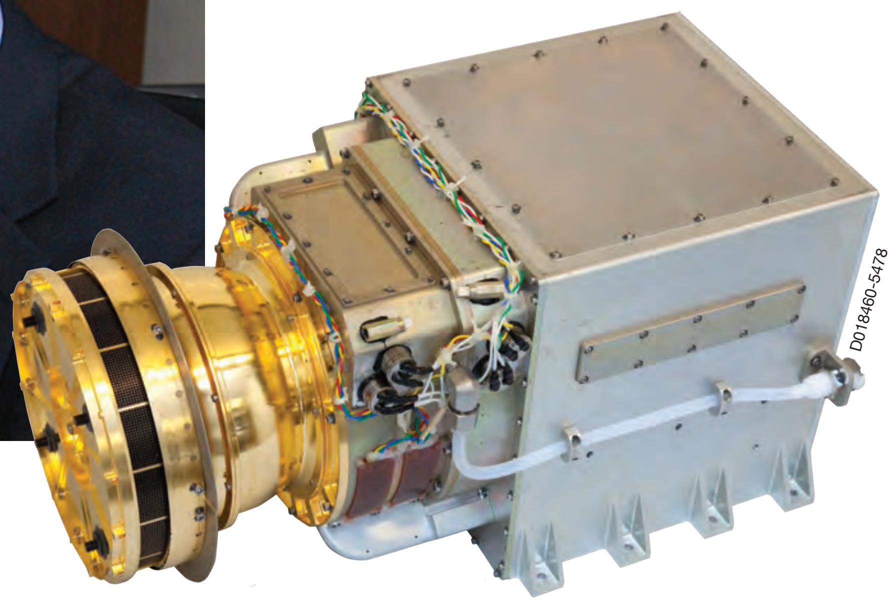


Dr. David T. Young is a program director in SwRI's Space Science and Engineering Division. His expertise is centered on understanding the chemical composition of solar system magnetospheres, ionospheres and atmospheres, and on developing a wide range of mass spectrometers that enable their measurement. Over the past 40 years, he has contributed to the design and development of 13 instruments on 11 NASA and ESA science missions.



The Hot Plasma Composition Analyzer was developed and constructed at SwRI for use on the four Magnetospheric Multiscale mission spacecraft, set for launch in 2014.

solar wind's magnetic field is highly variable, it points oppositely to the Earth's field roughly half the time. Where the two magnetic fields collide, thin sheets of intense electrical currents arise to keep them apart. This topology is inherently unstable, setting up ideal conditions for reconnection. A similar situation exists in the long tail of the magnetosphere where field lines from the northern and southern polar regions reconnect across the current sheet that maintains the tail.

Theoretical models suggest that reconnection starts when turbulence in the current sheet causes the current-carrying electrons to scatter within a small volume, tens of kilometers (km) across, called the electron diffusion region. Plasma resistivity increases sharply as the electrons diffuse across magnetic field lines, ultimately disrupting the currents supporting the fields. Current breakdown destroys the magnetic field, releasing enormous amounts of stored energy in a matter of seconds. Magnetic fields bordering the electron diffusion region then "reconnect" and relax from their stressed condition. The relaxing field lines contract, acting like slingshots that accelerate the plasma into high-speed jets seen from far away as exhaust byproducts of reconnection. At Earth, the jets provide evidence for the existence of reconnection. Similarly, X-rays from neutron stars thousands of light years away are evidence of reconnection on a cosmic scale.

Although a universal phenomenon, reconnection can be studied *in situ* only at Earth. While telltale magnetic fields and plasma jets have been seen by satellites, the electron diffusion region where the whole process begins is so small it can easily be missed. A similar but somewhat larger ion diffusion region is another unknown. Finding these relatively small volumes of space is like stumbling on needles in a very large haystack. But that is the primary task of MMS.

MMS relies on four spacecraft flying in a pyramid-like tetrahedral formation to track down reconnection events scattered across the magnetopause and magnetotail. Each spacecraft is equipped with 10 state-of-the-art plasma and field experiments designed to capture the 3-D aspects and temporal behavior of reconnection in exquisite detail. The spacecrafts' orbits will skim the day-side magnetopause and penetrate the plasma sheet on the night side out to distances of 150,000 km from Earth. Probabilistic studies indicate that MMS should capture more than 50 of these elusive events during its two-year mission.

The Hot Plasma Composition Analyzer (HPCA), developed by SwRI scientists and engineers over the past five years, identifies and measures the energy of ions participating in reconnection. Using novel technologies developed at SwRI, the four HPCA instruments, one on each spacecraft, will give scientists a detailed 3-D snapshot of the highly dynamic ion diffusion region once every ten seconds. By separating solar wind composed of ions of hydrogen (H^+) and helium (He^{++}) from terrestrial plasmas, primarily ions of hydrogen (H^+), helium (He^+) and oxygen (O^+), HPCA can lead scientists to the source of the plasma and

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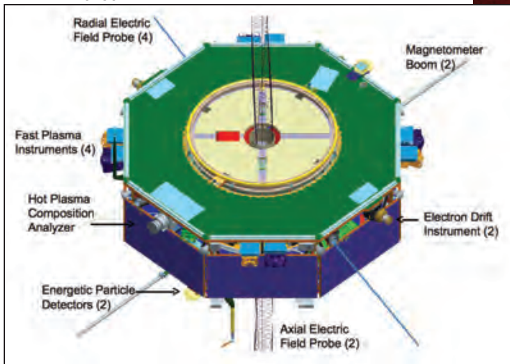
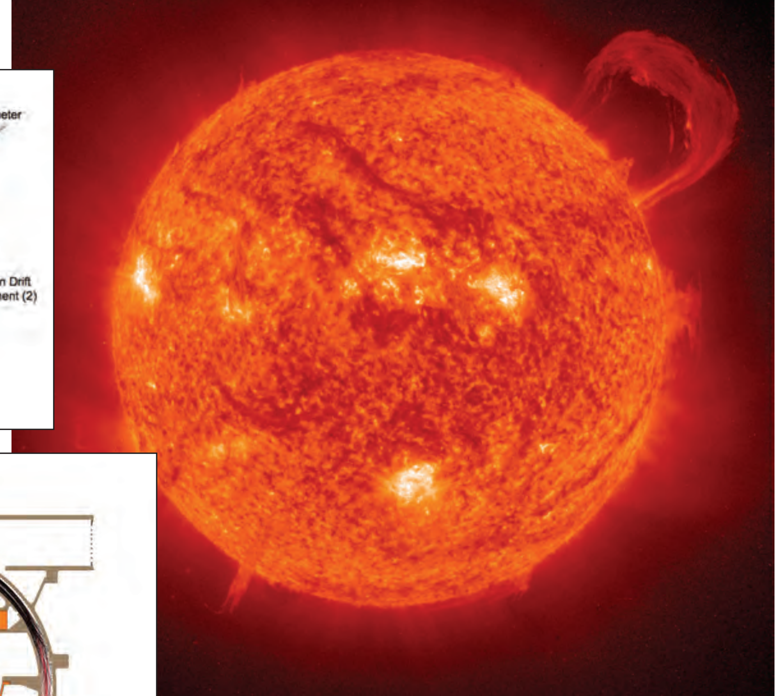


An MMS spacecraft contains a suite of scientific instruments stowed for launch within its 12-foot-wide body. Below is a cross-section schematic drawing of the Hot Plasma Composition Analyzer instrument's ion optics.



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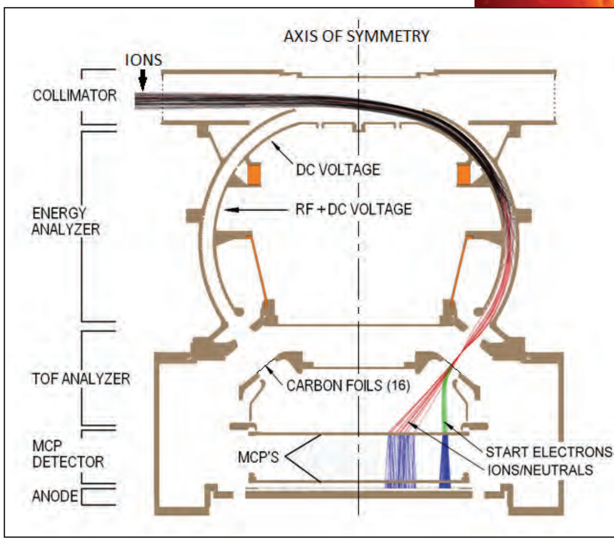

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pin down the rate at which it flows into the diffusion regions. Outside of reconnection, HPCA will also contribute to our understanding of other important processes, such as geomagnetic storm growth and decay.

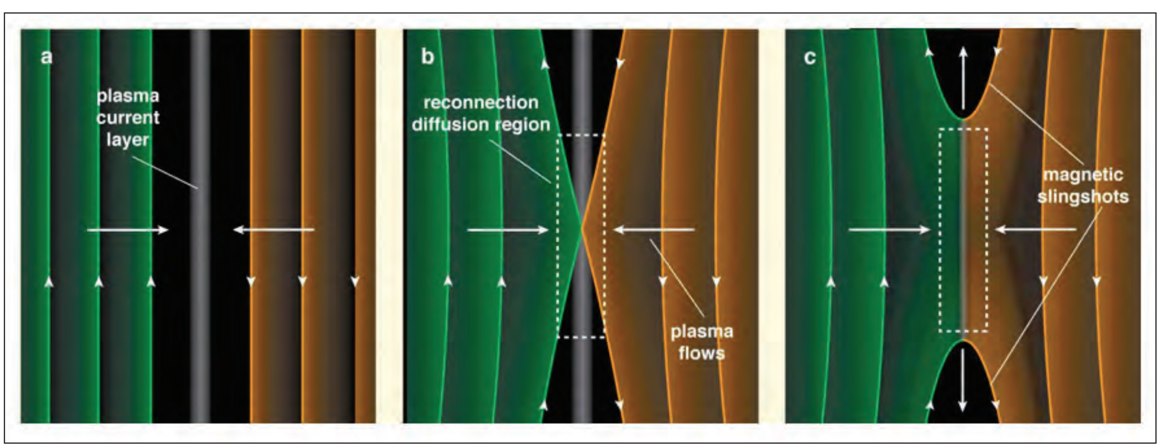
HPCA capabilities are defined by the properties of reconnection. For example, ions flow into reconnection with energies of roughly 1 kilo-electron-volt (keV) and are spit out in jets at up to 40 keV, defining the HPCA energy detection range. Moreover, ion jets can come from almost any direction in the sky. In response, HPCA must be able to view the entire sky every 10 seconds in synchronization with the spacecraft rotation rate of 3 rpm.

The HPCA can be thought of as a kind of camera, but with optics made from electric fields rather than glass, to focus and transport ions. Unlike an ordinary camera, HPCA optics are separated into two very different elements. A collimator and electrostatic energy analyzer (ESA) first separate the ions according to their energy and direction of arrival. Then a time-of-flight spectrometer measures ion velocities from which their mass, and hence their identity, can be determined.

The ESA optics comprise two concentric toroids. An adjustable voltage applied to the inner toroid creates an electric field that matches the entering ion's energy. Setting a particular voltage determines the energy and arrival angle of incoming ions. HPCA electronics sweep this voltage, capturing an energy spectrum every 625 milliseconds.

HPCA optics al feature 360-degree cylindrical symmetry, which is divided into 16 pie-shaped "pixels" capable of detecting ions arriving from any direction. Spacecraft rotation sweeps the pixels across the sky, yielding a 3-D measurement resolved into 256 pixels. While this angular resolution is not particularly high, at each pixel the HPCA collects 32,000 bytes of data representing one 256-channel time-of-flight spectrum taken at each of 64 energy steps.

Once the ion energy is known, it remains to measure velocity, from which ion mass can be calculated using the high school physics formula $E = ½mv^2$. Unfortunately, there are no simple "velocity meters" that can be flown in space. Instead, HPCA determines velocity by measuring ion time-of-flight across a very short but well-established distance of 3.4 centimeters. Ions leaving the ESA are accelerated by 15 keV, giving them enough energy to punch through ultra-thin carbon foils roughly 50 atoms thick. The foils give off electrons that strike the detector, starting a timing circuit. Meanwhile the ions continue onward, reaching the detector some 10 to 150 nano-



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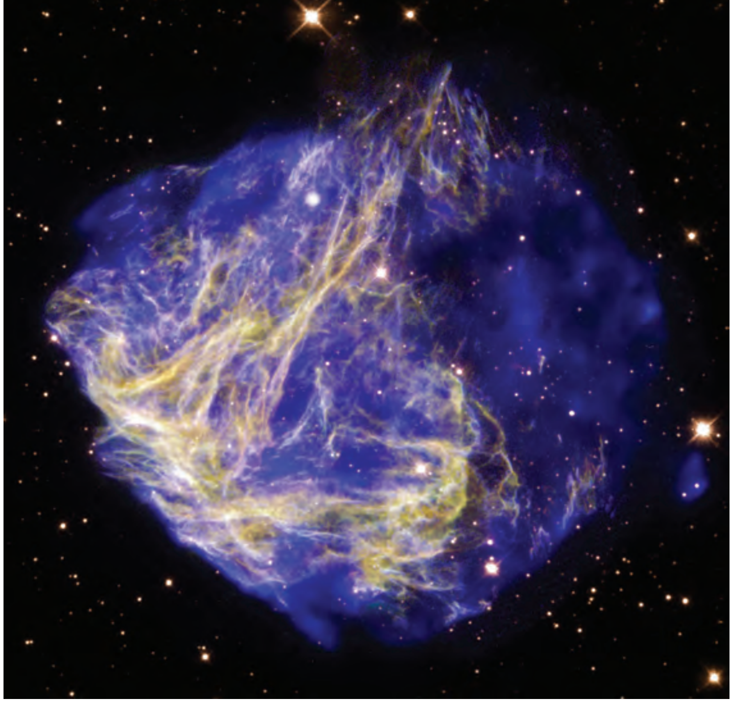
A three-view panel illustrates the progression of magnetic reconnection between two plasmas. Magnetic fields are oriented upward on the left (green) and downward on the right (brown). The arrows indicate the direction of plasma flow into and out of a region of reconnection.



Powerful jets of charged particles can be ejected from the Sun, shown with an arch of magnetic fields and hot, turbulent plasma erupting at its top right-hand corner; and Nebula N49, a supernova remnant in the Large Magellanic Cloud. Buried within the nebula is a highly magnetized neutron star.

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seconds later. Their arrival stops the timing circuit, allowing HPCA's high-speed electronics to calculate their velocity and identify the ion species. Ion flux, another important parameter, is derived from the number of ions arriving at the detector per second.

The flood of data reaching the ground helps scientists locate the source of reconnection as well as the energy, density and composition of the jets. In order to accurately measure these parameters, HPCA needs very high sensitivity in the Earth's magnetotail, where oxygen ion densities can be as low as 1,000 per cubic meter. However, at the day-side magnetopause on the magnetosphere's leading edge, the proton densities can be nearly a million times higher, posing a threat to the sensitive detector and a problem even for HPCA's electronics with gigahertz response.

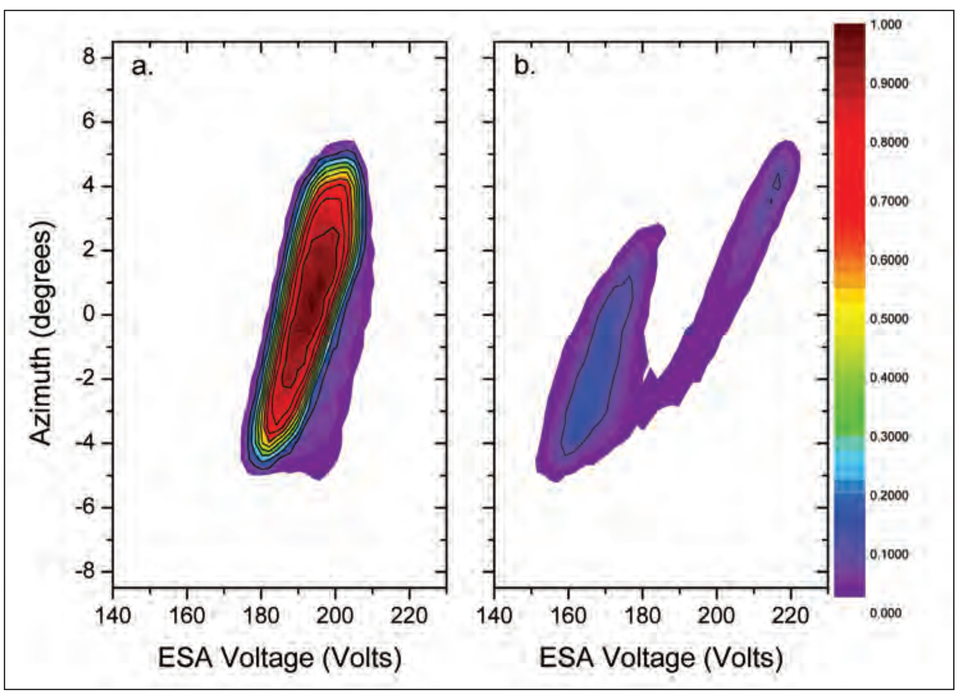
SwRI scientists and engineers addressed this problem in a novel way by adding a radio frequency (RF) electric field to the static ESA field that determines ion energy. The protons dominating plasma composition on the dayside have energies from 1 to 4 keV, corresponding to velocities from 400 to 900 kilometers per second. The RF field is tuned to a frequency that matches proton velocities, causing them to hit the walls of the ESA toroids. Although protons are lost, the tuned RF field does not match the velocity of the heavier ions, so they are transmitted. Using this technique, proton fluxes can be attenuated by factors of 30 or more before they get to the detector.

Because HPCA measures such a wide range of ion energies, arrival angles, masses and densities, calibration is a challenge. SwRI engineers solved this problem by building a unique facility that accelerates ion beams of any composition from 0.01 to 40 keV, at intensities as low as one-tenth of a trillionth of an amp.

The first HPCA flight unit was calibrated and delivered to NASA's Goddard Space Flight Center for integration on the first MMS spacecraft in May 2012. The other three units are scheduled to be calibrated and delivered before the end of 2012. Following delivery of all instruments, each spacecraft is then integrated to form an "observatory." Once all four observatories pass environmental tests, they are stacked together and shipped to Cape Canaveral for launch, scheduled in October 2014.

Initial studies of reconnection will begin on the day side of the magnetosphere. Over the following six months the observatory orbits will move to the night side of the magnetosphere and then back to the day side. Once the data start flowing, theories of reconnection developed over the past 50 years will be put to the test. If history is any guide, data returned by HPCA and other MMS instruments will turn out to be more surprising than the theories could ever have predicted.

Comments about this article? To discuss this article online see www.swri.org/forums



To illustrate how applying a radio frequency (RF) electric field limits the dynamic range of ion flux within the electrostatic energy analyzer, the image at left shows angle and energy response of the HPCA instrument to a 995 eV proton beam. Applying the RF electric field (at right) dampens the signal by 85 percent. Normalized particle intensity is indicated by the color scale at right.

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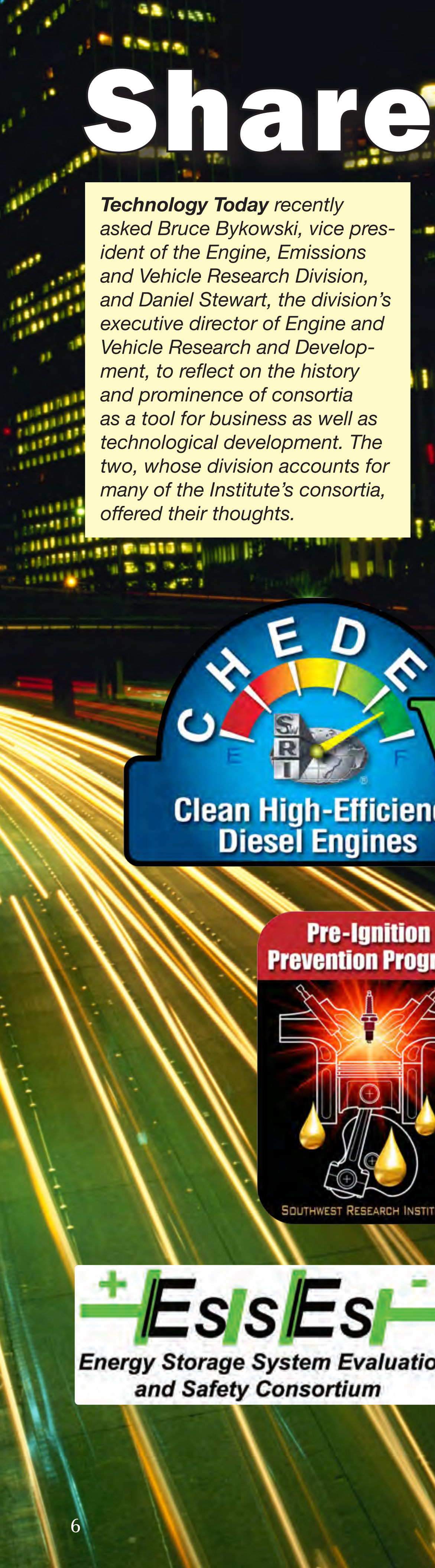
Shared Research

SwRI's extensive consortia experience stems from a 1984 law



Technology Today *recently asked Bruce Bykowski, vice president of the Engine, Emissions and Vehicle Research Division, and Daniel Stewart, the division's executive director of Engine and Vehicle Research and Development, to reflect on the history and prominence of consortia as a tool for business as well as technological development. The two, whose division accounts for many of the Institute's consortia, offered their thoughts.*

What was the origin of SwRI's consortium approach to research?

BB: The consortium approach to research came into being at the Institute in the early 1980s. Diesel engine manufacturers were being challenged to meet particulate emissions limits. At that time the manufacturers were comfortable with one approach, and that was improving combustion through engine design. They did not have any groups in their companies that focused on emission control, or aftertreatment. They didn't understand the technology and felt they didn't need the technology. When the technology of diesel filters, or diesel particulate traps, was developed as a possible solution, the engine manufacturers, government and academia were applying the technology without understanding fully how it worked. There was a lot of trial and error. Money was being spent to apply a technology that had mixed results. At about the same time, President Reagan signed the National Cooperative Research Act. It was designed to promote innovation, facilitate trade and strengthen the competitiveness of the United States in world markets. What it really did was to limit the antitrust liability of joint research and development ventures. The law was passed on October 14, 1984. Ten days after the act was signed, on October 24, we solicited a pre-proposal to more than 32 recipients to use this concept to obtain joint funding for pre-competitive project work, basically to understand this new fledgling technology.

How did the industry respond?

BB: We obtained sufficient responses such that on March 18, 1985, we developed the formal proposal content of the consortium and began solicitation. During those five months, a lot of time and effort were spent to educate the industry on what the National Cooperative Research Act was, and that there was no fear of collusion in working together, and then trying to promote the objective. The consortium was formed on July 1, 1985, and ended December 1, 1987. So, in no more than three years after the Act was signed we ran this first consortium. It ended up with 28 members. Since that time we've had about 20 consortia, with the peak year being 1991 when we formed seven in our automotive divisions.

DS: I didn't get involved in consortia until about 1990. We were visiting all the diesel engine companies around the world and realized that they didn't have a good technical solution to meet U.S. 1991 emissions standards. This lack of combustion technology provided the idea for a new consortium. The Clean Heavy Duty Diesel Engine consortium was initiated in 1991. It was a four-year program that started with just seven members. The success of the first Clean Diesel consortium led to five more successive four-year programs. During Clean Diesel IV we obtained as many as 46 members. The consortium grew into a major technical and social event for the diesel industry. Meetings had to be held off the SwRI campus to accommodate more than 100 attendees. Clean Diesel is still going on today, although with a slightly different emphasis. By the end of Clean Diesel V, our members were concerned about the new fuel economy standards for on-highway trucks, so we created Clean High-Efficiency Diesel Engine VI. The new program is developing technologies to reduce carbon dioxide emissions at fixed NOx and particulate levels.

How do you know when a consortium is the right approach?

BB: We have many tools to not only identify whether a consortium is feasible, but how to form it, put it in place and run it. If you have a group of clients that are asking for a consortium, that's the simplest way; you prepare a proposal and go to it. Or you may send out a letter of interest, like a survey. If you get enough response, you go to the next step. Or, you might put together a symposium at the Institute to discuss a specific topic. You try to see if there are unanswered questions, and whether the audience would be interested to work together to develop solutions. Through the years, we've gotten so good at identifying consortium potential that we can streamline them and get them in place pretty quickly.

DS: We have developed a business culture around the formation and management of consortia. It's an important part of our business, because we've got six key consortia going on right now with a total revenue exceeding $25M. Bruce kicked it off, but now the next generation of engineers is picking it up. They're the ones actually initiating these new consortia.

If selling clients on the first consortium was difficult, how hard is it now?

BB: One of the strengths that make consortia an — I won't say easy sell, because nothing's ever an easy sell — is that when members are pooling their resources together, it's very difficult not to understand that the return on their investment is multiplied times the number of members. So 10 members, 10-to-1 return on your investment. Twenty members, 20-to-1 return.

DS: Consortia are attractive today, for two reasons. One is, there aren't many companies that can cover all the research subjects. There's so much technology, and it's growing at such a rapid pace, that companies no longer can do all research in-house. And the other point, as Bruce said, is that everybody can't afford to do all the research work themselves. It's much more efficient to do it as a group.

Once the legal obstacles were removed, did clients find it easy to join consortia?

BB: We have had to do a lot of educating and convincing our client base not only of the value of consortia, but also of improving the comfort level of working with their competitors. Now, as we expand to other areas with perhaps a new group of clients, those companies also are having the same concerns and sensitivities about their confidential data and working with their competitors. You can see that that same potential could exist in other divisions at SwRI, which have still other client bases.

DS: I remember when we were starting the Clean Diesel consortium. When you first bring competitors into the meeting room, they're all very uncomfortable because they've never worked together in a group. But over time they get used to it. I'm seeing the same thing now, with the new EssEs consortium, because we are pulling together battery companies that are really competitors. They've never worked together before. Some companies are very active in meeting discussions where more conservative companies sit back and listen.

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Bruce Bykowski

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Daniel Stewart

How do consortia affect your core business of confidential, single-client research?

BB: In many cases, we hope consortia will be the seeds for larger single-client projects. Remember, it's pre-competitive, which means it's more basic and less product-oriented, so everyone starts at the same point in time and dataset. Then, to make it competitive, they can dip into that database and start applying it specifically to their product. A lot of the preliminary work was done and cost-shared, and now we can have single-client, confidential, one-on-one projects with our members.

DS: Sometimes it's a little of a double-edged sword. Maybe sometimes we don't get the single-client project because clients are already working with us in the consortium. A consortium can have a lot of different objectives. One is to help develop the base technology and then pursue single-client research, but it's also a way for us to advertise our capabilities. If you conduct a single-client project, you can't talk about it because of confidentiality, whereas if you do a multi-client consortium project, the objective is to advertise the consortium to the whole world.

Who owns the intellectual property rights to the technology developed by a consortium?

DS: SwRI retains the IP, but we give the members royalty-free licenses to use it. Clients participate knowing they'll get free use of the intellectual property. Sometimes that's actually a strong marketing point: We tell companies that they can't afford to be left out. If all your competitors are developing IP in a large program, you need to join, if nothing else, as an insurance policy against the IP going to production.

Is that the main reason why clients decide to join?

BB: Clients join for so many different reasons. I've heard soup to nuts. We've had them jump on the bandwagon, as Daniel said,

because they may be missing out on something that their competitors are doing. I've had people say they're using it as a training ground for their younger engineers because it's a cost-effective way to do it. I've had companies say, "We're trying to expand our market, and we have all our clients in the room."

DS: Each member joins for different reasons. If you understand what that reason is, you can get them to participate. For example, when visiting companies that are trying to develop new products, the selling point is that the audience we bring together for a consortium meeting might have more than 100 participants, representing 40 companies from all over the world. If you bought airline tickets to visit all those clients individually, it'd cost more than the consortium membership, so come join and I'll give you an opportunity to present your technology to the whole group.

In addition to science and engineering resources, what does SwRI bring to the table?

DS: We share the results of our internal research projects that are the building blocks for the consortium. We typically put together a whole string of internal research projects in new technology areas before and during the consortia. We let the clients know that SwRI's contribution is sharing our internal research. In some consortia we've shared the results of four or more internal research projects. It adds value for the members.

Who sets the agenda for the consortium, and who guides and manages the research program?

BB: The short answer is that SwRI sets the agenda and our engineers manage the consortium. However, it's more complex than that. One of the characteristic traits of a consortium manager is that you have to be a good diplomat, an arbitrator in many cases, because the consortium's Program Advisory Committee is an advisory committee, not a steering committee. A steering committee is quite different. It is made up of several companies, and all of the decisions are made by committee vote. With the advisory committee, we basically are seeking their advice so we can make the sole decision. You have to look at every member's interest and give at least their money's worth. Sometimes that can be a little contentious.

DS: It comes back to trying to understand what each client wants from the consortium. A typical consortium might have four or five research projects in it. Selecting the projects so that you keep the interest of all your members sometimes can be quite challenging.

Did the recession help, or hurt consortium participation?

BB: Consortia are multi-year and the members are already committed. The value they get as a member is one of the last things that they would cut. They might cut internal spending or major project spending, but I don't think we had hardly anybody drop out of our consortia during the recession.

Can you point to tangible technological advances that have come about as a result of SwRI's consortia over the years?

DS: One example is the application of exhaust gas recirculation (EGR) to diesel engines. EGR reduces diesel combustion peak flame temperature, which, in turn, reduces the formation of nitrogen oxide (NO_X) emissions. We applied EGR to a diesel engine in 1991 during the first Clean Diesel consortium. SwRI conducted basic research to determine the effect of EGR gas composition, temperature and introduction method on NO_X formation. Today diesel engines in passenger cars, trucks and off-road vehicles employ EGR. Diesel particulate traps, lean NO_X catalysts and the Dual Coil Offset ignition system, which won an *R&D 100* Award last year, were also developed within our automotive consortia and are available for use by consortium members.

BB: There are also technologies that were developed outside the consortia, but as a result of them. For example, in one consortium several candidate materials were identified for high-temperature trap media. One, silicon carbide, had been previously studied under SwRI internal research and was patented. Several clients went on to commercialize it and other materials. Other examples would be gasoline engine cold-start emission reduction technologies and approaches, such as molecular sieves and burners; and improvements to diesel particulate trap regeneration using fuel additives, burners and electronic control strategies. Consortia also have led to studies of the importance of lubricating oil effects on the performance of aftertreatment equipment and to the development of tools to study those effects, such as SwRI's FOCAS® catalyst aging system.

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What are the prospects for enlarging or expanding the consortium program?

DS: Consortia can be more expensive to promote than single client projects so typically we make them four years long so we can get a better return on the investment. With Clean Diesel being the business model, now in its 21st year, some of our other multi-year consortia are also being extended. We hope they continue to go on and grow, but at the same time our younger staff members are coming up with new ideas for consortia, so we encourage them to start new programs.

BB: Another opportunity for consortia that we are starting to see is the formation of multidivisional groups that include experts outside of automotive engineering, like the International Alternative Fuels Technology Center. Another effort, the Energy Storage Technology Center, could involve at least five SwRI divisions. When you have these multidisciplinary capabilities, the concept of a consortium is something made in heaven.

DS: We've set up consortia where we're the expert in the field, like some of the early particulate trap consortia or Clean Diesel, where we had 40 years of diesel experience before we started. But I think we've also successfully used consortia to get into new markets. The EssEs consortium is a good example of that. We purchased the equipment for a new cell-level battery facility and started the EssEs consortium before we even had a chance to install all the equipment. We have some very talented staff in the division who made this project a success despite the steep learning curve.

Do other institutions make use of consortia as much as SwRI does?

BB: It is difficult to match not only our experience, but the structure of the Institute that allows it. Because we have such an active internal research program, because we encourage creative thinking and innovation from our staff, ideas for consortia flow. Others have tried but they have not been as successful, and for whatever the reason there do not seem to be many challenges to our concept with consortia. What we need to strengthen is the public perception that we are not just a research institute, but that we understand it all the way to production.

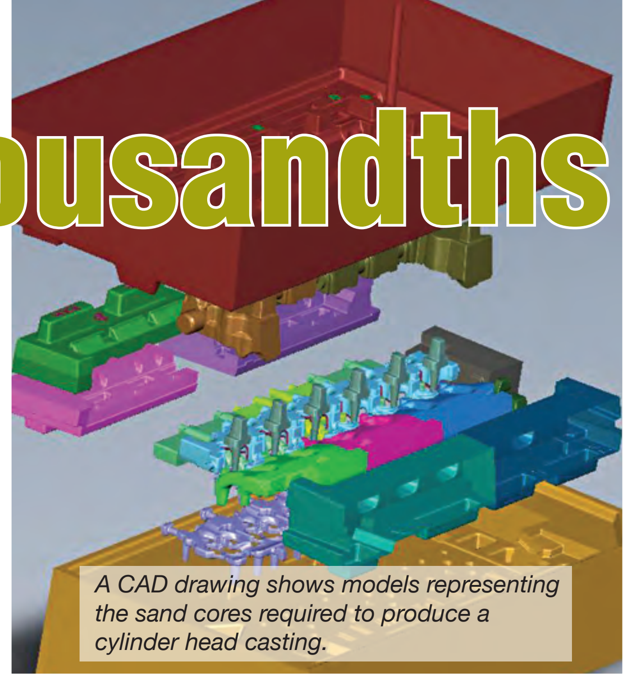
Questions about this article? Contact Bykowski at (210) 522-2937 or bruce.bykowski@swri.org, or Stewart at (210) 522-3657 or daniel.stewart@swri.org.

Automotive Consortia at SwRI

- Particulate Sensor Performance and Durability (PSPD), organized in 2012.
- Pre-ignition Prevention Program (P3), organized in 2011.
- Energy Storage System Evaluation and Safety (EssEs), organized in 2011.
- Clean High Efficiency Diesel Engine (CHEDE), organized in 2011, sixth round of consortium originated as Clean Diesel in 1991.
- Diesel Aftertreatment Accelerated Aging Cycle (DAAAC), organized in 2008.
- High Efficiency Dilute Gasoline Engine (HEDGE), organized in 1995 and in its third iteration.
- Diesel Particulate/NOx Exhaust Aftertreatment Using Plasma or Corona Discharges, 1995-97.
- Diesel Aftertreatment Sensitivity to Lubricants/Non-Thermal Catalyst Deactivation (DASL/N-TCD). 1991-95.
- Investigation of the Potential Poisoning Effects of Lubricating Oil on Diesel Flowthrough Catalysts, 1991-93.
- Feasibility Study on Using Zeolites for Lean NO_x Control, 1991-92.
- Development of a High Temperature-Resistant Diesel Particulate Trap, 1988-90.
- Evaluation of the Mechanisms of Heavy-Duty Diesel Particulate Trap Regeneration, 1985-87.

A Cast of Thousandths

An SwRI-developed method of casting diesel engine cylinder heads with greater precision wins an R&D 100 Award



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A CAD drawing shows models representing the sand cores required to produce a cylinder head casting.

A novel method that combines sand and space-age ceramics to cast precision metal engine parts was recognized as one of the 100 best innovations of the year by *R&D Magazine*.

Southwest Research Institute (SwRI) has won 37 R&D 100 Awards, sometimes called the "Oscars of Innovation."

The new process, called Hybrid Ceramic-Sand Core Casting, combines aerospace ceramic and automotive sand core casting processes, enabling precision casting of extremely small passages in automotive cast iron or steel components. This product was developed in a joint effort with United Kindom-based Grainger and Worrall, Ltd., as part of a three-year, multi-phase research and development program. The goal was to develop a new generation of heavy-duty diesel engine architecture with significantly higher peak cylinder pressure (PCP) capability than current state-of-the-art engines. This is needed to enable future exhaust emissions-reduction and high-efficiency combustion technologies without sacrificing engine performance, size or weight characteristics.

Cylinder head manufacturing

The conventional method for manufacturing iron cylinder heads for internal combustion engines is to use a sand-casting process, because the internal fluid passages are geometrically complex and sand casting is inexpensive. With its intricate shape capability, ease of extraction from finished castings and low material cost, sand casting is well-suited for the functional and economic requirements of making engine cylinder heads. However, newer geometries that allow higher peak-cylinder-pressure operation, as well as high cooling velocity and efficiency, require internal passages that are too small to manufacture reliably using conventional sand casting.

The critical limiting factor of sand casting is the minimum achievable size of internal passages. As cross-sectional dimensions are reduced, the ability to resist premature breakdown in the presence of molten metal is also reduced. Thus, there are limiting dimensions below which a sand core will disintegrate during casting because of factors such as thermal shock, evaporation of chemical binder agents and physical penetration from the molten metal.

By contrast, ceramic cores, such as those used in the aerospace industry to cast cooling passages in turbine blades, do not break down in the presence of molten metal, even at very small sizes. However, because they are relatively expensive they are not commonly employed in the automotive industry. They have never before been used in a hybrid ceramic-sand core design.

A ceramic-sand hybrid

For the new hybrid ceramic-sand core product, the ceramic portion forms the coolant passages between the engine's gas exchange port walls and fuel injector or spark plug boss in the lower water jacket core. The ceramic section is used to form valve bridge passages as well as the annulus around a cast injector sleeve. Using ceramic for this part of the core allows much smaller passages to be formed than if the core were made entirely of sand.

To demonstrate this technology, samples were cast using a core profile manufactured using both a conventional 100 percent sand core technology with representative minimum cast passage diameters of ~5 mm, and the new hybrid ceramic-sand technology employing varying section thicknesses through the valve bridge area to quantify its benefit with a minimum width on the order of 1.5 mm. Casting trials using the conventional sand core technology resulted in extensive sand burn-in that blocked passages through the injector bore and valve bridge regions. The ceramic-sand core casting trials resulted in completely clean bridge areas free of burn-in, even at the smallest bridge width. Additionally, no finning or defects of any kind were observed at the sand-ceramic interface, indicating a sufficient bond between the core materials.

The hybrid process is extremely scalable, unlike the conventional technology. This allows it to be considered for future downsized, high-output engine concepts designed for optimized cooling and high PCP structure rather than having to design around the limitations of sand cores.

Integrating ceramic and sand

The ceramic insert is a preformed shape designed to fit into the same core-box into which the sand core is blown, thereby consolidating the insert. The insert is manufactured from a ceramic slurry, using an injection molding process that involves relatively low-cost tooling and processing. Ceramic inserts are mechanically and chemically stable, which translates to long shelf life and the capacity for high-volume repeat usage.

The interface design between the sand core and the ceramic insert is designed to provide maximum grip to maintain overall mechanical integrity of the hybrid sand core and offer maximum surface area for subsequent dissolution in caustic media during the clean-out process.

The ceramic material, silicon carbide (SiC), has extremely low thermal expansion which in all trials thus far has enabled the core to survive the thermal loading during pouring of the casting at 1,300 degrees C. This survival ensures that liquid metal is unable to penetrate the core and obstruct the eventual passageway. By comparison, conventional sand cores are a mixture of sand grains bound by a thermosetting resin binder, neither of which is immune to extreme thermal loading, even when coated with a protective barrier known as "core wash." The eventual failure mode of a conventional sand core will be initiated by a fracture of coating or core under the influence of thermal expansion and or buoyancy loads in the liquid metal such that penetration occurs and the passageway is obstructed.

The relatively small volume of the ceramic insert does not affect in any measurable way the solidification dynamics of the casting. Removal of the insert is mostly via dissolution in a caustic bath, although some mechanical removal is considered possible as well.

The final shape of the passageway formed by the ceramic insert is extremely accurate and smooth. This confers the benefit of highly repeatable dimensions and pressure drop rates for optimized coolant flow. This innovation has been successfully used at dimensions smaller than 2 mm, a value unobtainable by sand core alone.

Improvements over conventional products

Zircon sand with core wash in a hot box configuration can approach the performance of the ceramic-sand hybrid design, but zircon sand is expensive and also is currently in short supply. A key benefit of the Hybrid Ceramic-Sand Core Casting technology is its scalability to smaller-bore diameter engine components. As the engine bore becomes smaller, so does the bore spacing and the available space for cooling and air passages. Most conventional casting technologies have minimum section thresholds that limit their ability to implement features for high cylinder pressure and high cooling efficiency on engines with bores below ~110 mm. Finally, high-velocity targeted cooling in cast components can be achieved using machined drillings. This is possible where access allows, and may not be feasible when considering the more complex diesel porting and six-bolt pattern configurations imagined for high-PCP engines. The issue with employing the machined drilling approach is that it requires line-of-sight access to drill the passages and as such cannot be packaged within concealed regions, unlike the hybrid core technology.

Principal applications

Principal applications of this product include complex cylinder head and block castings for high-efficiency, low-pollutant/greenhouse gas emission, high-power density diesel, gasoline and gaseous fuel engine applications, especially smaller-bore diameter (<120 mm) applications, because space to package all necessary features for high-cylinder pressure, good cooling and good volumetric efficiency becomes significantly limited. High cylinder pressure is critical to high power density as well as ultra-low-pollutant emitting, high-efficiency, low CO_2 emission diesel, natural gas and gasoline combustion technologies. Additionally, this technology can be used in any industry currently using sand-core metal casting techniques where small diameter passages may be advantageous but unattainable or experiencing high scrap rates due to the process limitations of conventional sand casting.

The innovation also is realistically "future-proof" in terms of scalability, both larger and smaller, where the latter permits similar concepts to be incorporated in passenger-car-size engines, for example. Financial benefits to the consumer are derived from overall combustion efficiency and fuel economy improvements, and the potential to position such technology in the premium sectors confers pricing opportunity to manufacturers as well.

Questions about this article? Contact Marc Megel at (210) 522-3079 or marc.megel@swri.org.

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SwRI members of the Hybrid Ceramic-Sand Core Casting Technology Development team are (from left): Principal Designer Doug McKee, Assistant Director Marc Megel and Program Manager Barry Westmoreland, all from SwRI's Engine, Emissions and Vehicle Research Division.

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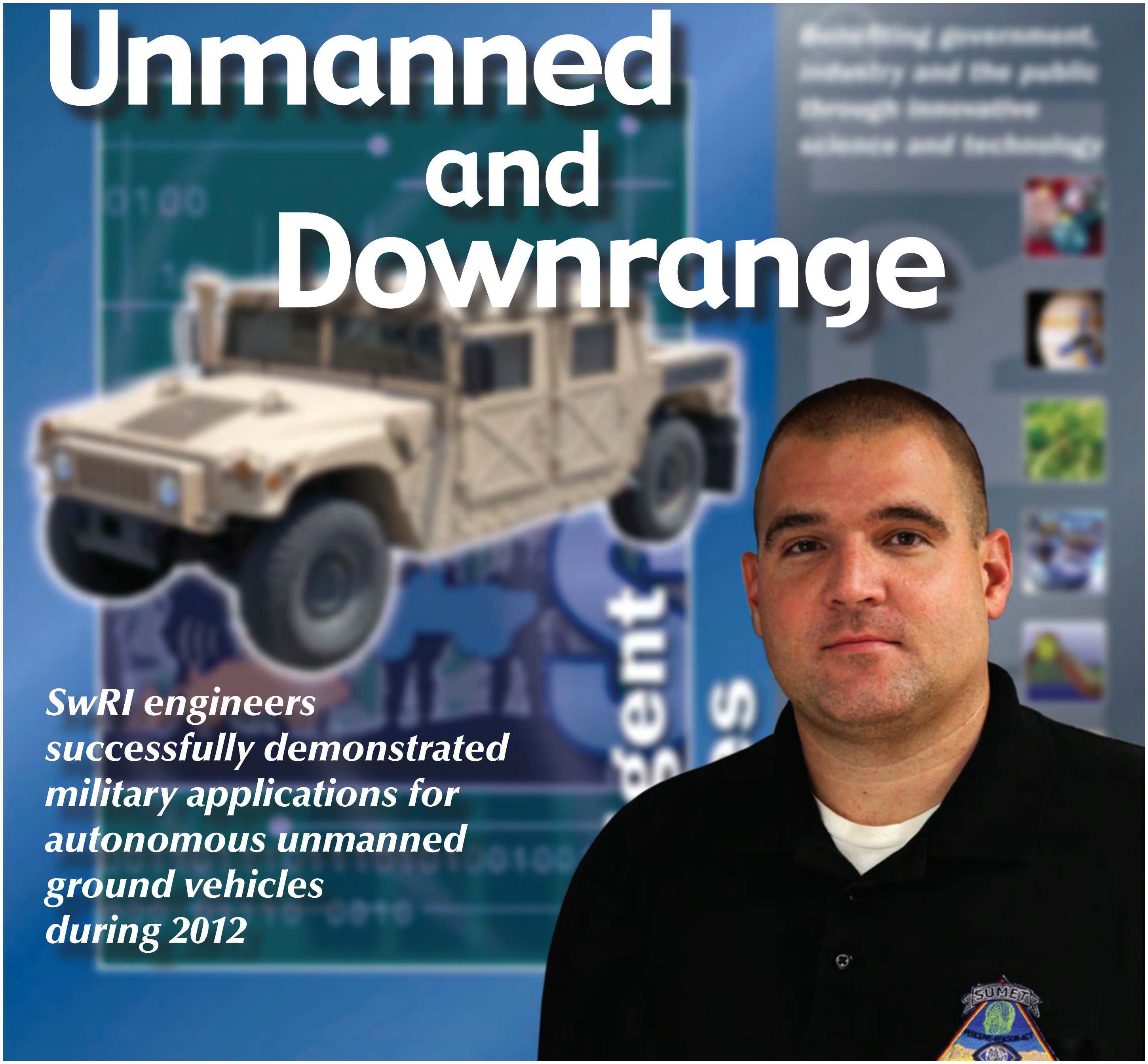
A traditional, reddish sand core contains white ceramic material at its center (left photo) to produce the finished product (right photo).

Unmanned and Downrange



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SwRI engineers successfully demonstrated military applications for autonomous unmanned ground vehicles during 2012

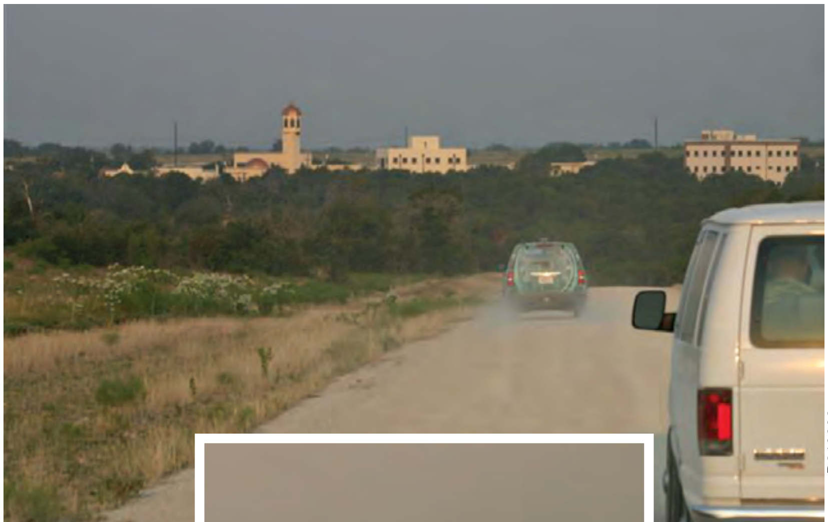
Ryan D. Lamm is a manager in the Intelligent Systems Department of SwRI's Automation and Data Systems Division. He has more than 15 years of experience in intelligent vehicle system research and development, foreign and domestic. He is a senior member of IEEE and a U.S. expert for ISO TC204 in Vehicle/Roadway Warning and Control Systems, and has published more than 20 technical articles.

By Ryan D. Lamm

Although combatants experimented with remote-controlled, explosives-laden vehicles for land, sea and air as early as World War I, by World War II Germany successfully deployed an unmanned ground vehicle (UGV). "Goliath," a small, tracked vehicle fielded in 1944, was controlled via a 400-meter cable and was intended solely to deliver an explosive charge at a stand-off distance.

By the late 1960s, one of the first autonomous vehicles, a mobile robot nicknamed "Shakey," was developed in the United States. Its practicality was limited, however, in that it took almost an hour to decide where and how to move about in the laboratory.

Over the next 40 years, scientists and engineers, by then referred to as roboticists, strived to develop electro-mechanical vehicle systems capable of real-time perception and navigation in unstructured environments to perform various dull, dirty and dangerous operations. The technology has made great strides in the past two decades, largely led by the Defense Advanced Research Projects Agency's two Grand Challenges in 2004 and 2005 and the Urban Challenge in 2007. These challenges resulted in impressive demonstrations of autonomous navigation by full-size passenger vehicles, but at an extremely high and deployment-prohibitive cost for their sensor and computing implementation.



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Southwest Research Institute demonstrated its MARTI unmanned ground vehicle (green vehicle) in both leading and following positions in a convoy operation at Fort Hood, Texas.

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The military deployed thousands of small tele-operated robotic systems for purposed, deterministic tasks such as route reconnaissance and countering improvised explosive devices in support of Operation Iraqi Freedom, Operation Enduring Freedom and the International Security Assistance Force. While not autonomous, these robotic systems proved effective and saved the lives of hundreds of warfighters. Several recently developed mid-size robotic systems with semi-autonomous functionality are undergoing testing in war zones. To get to the next level, however, fully autonomous tactical unmanned ground vehicles need reliable and safe performance in military-relevant scenarios at a much lower cost.

Since the DARPA Challenges, the science and technology community has continued to advance the performance and reliability of autonomous navigation. The U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) sponsored a Robotics Rodeo in September 2009 at Fort Hood, Texas, and at Fort Benning, Georgia, in October 2010 and again in June 2012, to bring together representatives of industry, the warfighter and those who set requirements for robotic vehicles, to observe the latest technology advancements and facilitate a dialog to accelerate technology deployment. A team of engineers from Southwest Research Institute (SwRI) participated in all three events, showcasing applied technology that addressed barriers to deployment, such as cost and reliability. This applied technology included new, sophisticated algorithms, based on those originally developed under SwRI's internal research and development program known as the Mobile Autonomous Robotics Technology Initiative (MARTI®), as well as technology developed on two externally funded projects.

SwRI created the MARTI software to develop UGV enabling technology for the autonomous control of tactical and combat military ground vehicles, passenger cars, commercial trucks, agriculture/construction tractors and mobile robots. One of the fundamental aspects of the program was rapid portability to multiple platforms. The SwRI team emphasized unique custom perception and control algorithms using commercial-off-the-shelf hardware. The result was an autonomous vehicle benchmarking platform uniquely suited to rapidly assess sensor and algorithm performance over a wide array of environments, missions and behaviors. The multidisciplinary team included engineers with backgrounds in active and passive sensor processing, machine vision, sensor fusion, robotics, control systems, wireless communications, safety and reliability systems, modeling and simulation, multi-agent cooperative systems, engineering dynamics, independent testing and evaluation, software architectures and electrical and mechanical system design. In November 2008, SwRI publically demonstrated MARTI's autonomous capabilities on a Ford Explorer on the streets of New York City, where it successfully negotiated intersections, interacted with other manned and unmanned vehicles, avoided dynamic obstacles such as vehicles and pedestrians, and coordinated maneuvers with other vehicles and roadside infrastructure devices such as traffic signals. The MARTI internal research and development program concluded in 2011.

Robotics Rodeo

At the first Robotics Rodeo at Fort Hood in 2009, SwRI demonstrated how a UGV can reliably support military multi-vehicle convoy operations. The modularity of the SwRI-developed autonomous UGV technology allowed MARTI's autonomous behaviors to be rapidly adapted to directly satisfy a U.S. Army Operational Needs Statement — Convoy Logistics/Operations. SwRI's demonstrated technology at Fort Hood provided the ability for convoy operations to utilize a UGV in numerous ways. For example, a convoy can instruct a UGV to "lead upon command," and "follow where appropriate," in various formations, navigate an urban environment as the lead of a convoy and then fall back into formation upon command, and rapidly switch between human operation and fully autonomous modes. The Cooperative Convoy System (CCS) technology also enables a UGV to convoy using either GPS waypoints and a defined map or active sensors to track a leading vehicle.

At the second Robotics Rodeo one year later, SwRI demonstrated MARTI's ability to autonomously follow a dismounted warfighter at low speed without the need for active RF beacons or tags carried by the soldier, using a combination of electro-optical (cameras) and light detection and ranging (LIDAR) sensing.

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The operator selects the desired dismount from a video image displayed on a touch-screen control unit, and the UGV then identifies and tracks the selected pedestrian. Additionally, SwRI demonstrated a tele-operation capability allowing an operator to remotely control the unit within line of sight, or tele-operate the unit beyond line of sight. The seamless switching between different autonomy modes was highlighted.

The recent 2012 Robotics Rodeo at Fort Benning included one of the largest demonstration operations ever conducted by SwRI. In all, 15 technical and support staff members from the Institute were onsite at various times, using five vehicles in two independent demonstrations, one of which involved two other companies. The demonstrations were successful despite 100-degree temperatures, blowing sand and Georgia clay, high humidity and very long days in the field.

Small Unit Mobility Enhancement Technology (SUMET) Program

The first demonstration highlighted low-cost electro-optical perception on a UGV. Performance results from the Small Unit Mobility Enhancement Technology (SUMET) program, funded by the Office of Naval Research (ONR), were demonstrated in real time to more than 20 government subject-matter experts. The SUMET program aims to increase the platform capability and affordability of unmanned, ground vehicle-enabling technologies to include low-cost, video-based perception systems, advanced video processing techniques, cognitive reasoning architectures and novel algorithm coding methodologies. A primary objective is to achieve reliable autonomous vehicle operation in austere, harsh, off-road environments without depending on GPS. SUMET achieves this by using electro-optical perception and advanced path-planning algorithms.

For the SUMET program, SwRI developed a low-cost perception system that uses data from eight forward-looking cameras (six of which are spectral cameras), two cameras on each side of the vehicle and two cameras in the rear. This pure electro-optical system provides some unique advantages over more commonly used active sensing, such as radar and LIDAR. Additionally, SwRI has been able to achieve full processing at 12 Hz, fast enough for off-road navigation by a tactical vehicle.

Technical approach

The local ground segmentation process uses the disparity image to distinguish between the ground plane and vertical obstacles. Its nodes incorporate the v-disparity and Hough lines to identify which disparities correspond to the ground plane. The disparities that are close to the ground line within a predefined threshold are therefore segmented as the ground plane. All disparities that are not contained on the ground plane are segmented as obstacles. The height of an obstacle is calculated based on height from the ground plane and also published, in addition to the ground and obstacles.

Material classification uses the imagery from all eight forward-looking cameras to classify individual pixels in the scene. The system produces a stream of images labeled to indicate their material classification. Classification features include depth perception, derived from stereo images, whether the object has been identified as part of the ground plane or as an object protruding from the ground plane; the spectral values from the six spectral cameras; the spectral values obtained from the color camera; and a myriad of statistical and textural measurements computed from one of the left images.

The object-tracking process detects and tracks nearby pedestrians and vehicles. The system contains separate detection nodes for pedestrians and vehicles that have been previously programmed offline. As objects are detected, their positions are continuously updated and provided to the tracking node, which updates a "world" model of the vehicle's environment with the objects' positions for continuous tracking. As the objects are being tracked, the world model is also being updated with the new position and trajectory estimates.

The world-model software manages persistent data from the other subsystems into a common frame in a central location. It combines range-sensor and material-classification data into a common frame over time, storing data and querying it for information about tracked objects such as pedestrians and vehicles, vehicle and system state, elevation data, aerial imagery, situational awareness and mission configuration, as well as generating maps for navigation based on the different data models.

The SUMET EV-1 vehicle navigates autonomously over austere terrain using only electro-optical sensing.

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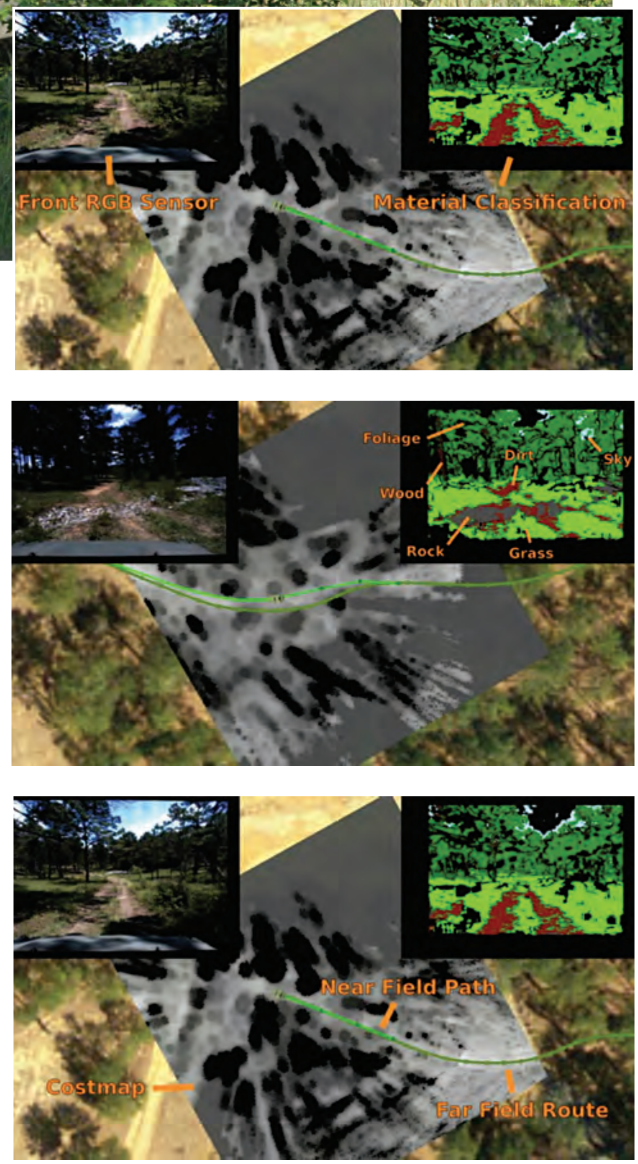

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These images illustrate the SUMET system's real-time visualization applications.

The localization system is connected directly to several traditional, low-cost localization sensors, such as an inertial measurement unit and a fiber-optic gyro. It also is connected to the controller-area network bus and to the vehicle network over ethernet, which allows it to receive sensor data from the low-level controller, the actuators themselves and GPS. The localization system fuses these inputs, along with visual odometry, to provide an estimated positional change from one sample to another. This allows the vehicle to operate without depending on GPS for extended periods of time.

The near-field planning occurs within the platform perception horizon to generate low-level paths that facilitate obstacle avoidance. Costmaps are generated using perception data stored in the world model. These are fused and converted into gridded, or rasterized, representations of ground and voxel (volumetric picture element, analogous to a 3-D pixel) data that assign costs to specific parts of the near-field environment. Higher costs represent less traversable parts of the environment, while lower costs represent more traversable, and desirable, parts of the environment to drive through. The processor runs a search algorithm to find the best path for the vehicle to follow to a goal waypoint. This goal waypoint is generated along the far-field route at a prescribed distance in front of the vehicle. The goal "state" is extended from this waypoint, perpendicularly to the far-field route in either direction, allowing near-field paths to be generated that do not explicitly reach the near-field goal waypoint (useful if the far-field route is partially blocked by obstacles or difficult terrain, thus allowing the vehicle to "wander" or feel its way through difficult environments that the far-field route traverses). The low-level controller runs a control loop that attempts to minimize cross-track and heading error between the current platform position and orientation and the path segment representation of the near-field solution path. Actuator commands are calculated for steering, throttle, and brake according to the control scheme and are passed down to the drive-by-wire system for actuation.

Robotics Rodeo demonstration of SUMET

At Fort Benning, the SwRI team and the Naval Surface Warfare Center Dahlgren Division jointly demonstrated a high-mobility motorized multi-wheel vehicle (HMMWV) equipped with the SUMET system where it successfully navigated a range typically used for testing vehicle mobility. During the demonstration, several visual elements of the real-time system were transmitted to an observation point and were displayed and described in real time to subject-matter experts

attending the demonstration. This included a live image from a forward-looking RGB camera, a processed image highlighting the material classification from the electro-optical algorithms, and an aerial image with a costmap overlay, along with both the far- and near-field planned paths.

The demonstration represented the first time the SUMET system had been tested off SwRI grounds in a tactical environment. Following the demonstration, SwRI engineers were able to capture a significant amount of data relative to different types of terrain around Fort Benning, with help from the Maneuver Battle Lab, also located at Fort Benning, for use in a future program experiment.

Gesture-based signaling instructs an unmanned ground vehicle during SwRI's demonstration of C4ISR applications.

Gesture recognition

The second Robotics Rodeo demonstration of 2012 was a joint demonstration among SwRI, AM General LLC and Synexxus Inc.

The team demonstrated the SwRI-developed AM General Gesture Recognition System for UGVs, consisting of an image-processing algorithm capable of identifying and distinguishing different arm gestures of a dismounted warfighter to allow more natural interaction between the warfighter and the autonomous vehicle and enable the UGV to function as a member of the squad. Commands such as follow-me, stop, and offset right and left were demonstrated through integration of gesture recognition with SwRI's existing dismount following capability. The framework allows for adding other commands to meet specific squad tactics.

In the second part of the demonstration, a Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) system from Synexxus was installed in an SwRI-owned, fully autonomous HMMWV 1165. The HMMWV was directed to a forward position to provide overwatch or surveillance using the C4ISR system. While not integrated directly into the autonomous vehicle's navigation system, the currently fielded C4ISR system was used onboard with the UGV acting as a host mobile platform to give the warfighters monitoring the C4ISR additional standoff distance from the area of operation.

The third element of this demonstration highlighted the ability of the hardware running the autonomy software, and the manned vehicle kit — the hardware used in manned vehicles in a convoy — to be removed in less than 20 seconds and switched between different host tactical platforms. This demonstration element was a direct result of a post-MARTI IR&D program size, weight and power reduction effort during the past 12 months by Automation and Data Systems Division engineers. That effort not only produced packaging for autonomous capability that is no longer deployment-prohibitive, but also reduced the overall system cost.

The MARTI algorithms utilized in the SUMET system have been provided to the government as government-purpose rights, along with background intellectual property rights from subcontractors on the SUMET program. The SwRI team's UGV demonstrations sparked significant discussion within the military community. The focus on technology maturation, platform portability, high functionality and low-cost sensing and packaging, along with tactically relevant and scalable autonomous behaviors, has positioned SwRI as a leader in the unmanned systems industry.

Questions about this article? Contact Lamm at (210) 522-5350 or ryan.lamm@swri.org.

Acknowledgments

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U.S. Department of Energy awards $700,000 to advance clean coal technology

Southwest Research Institute and industry collaborator Thar Energy LLC have received $700,000 from the U.S. Department of Energy to demonstrate a novel, supercritical carbon dioxide (sCO_2) power cycle using pressurized oxy-combustion, a process that uses pure oxygen instead of air as the primary oxidant.

"The goal of this one-year effort is two-fold: to achieve 90 percent CO_2 removal at no more than a 35 percent increase in the cost of electricity and to achieve high overall plant efficiencies with 90 percent CO_2 capture and compression to 2,200 psi," said Dr. Klaus Brun, a program director in SwRI's Mechanical Engineering Division.

Project objectives include demonstrating the advantages of the proposed power cycle using an engineering design analysis to refine the cycle, demonstrating cycle efficiencies and identifying critical components that have a significant impact on cycle performance.

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SwRI receives award for lithium-ion battery technology

Southwest Research Institute (SwRI) has been awarded a $712,500 contract from the U.S. Department of Energy to investigate the behavior of lithium-ion batteries during charge and discharge. The contract award is one of 19 projects that will receive $43 million in funding from the Department's Advanced Research Projects Agency-Energy (ARPA-E) to develop breakthrough energy storage technologies.

"This contract will give us the opportunity to analyze the capacity and health of lithium-ion batteries over time," said Jeff Xu, a principal scientist in SwRI's Engine, Emissions and Vehicle Research Division and a co-principal investigator of the project.

The two-year project, "Strain Estimation Technology for Lithium-Ion Batteries," will explore the potential of tracking physical expansion and contraction of lithium-ion batteries during charge and discharge cycles as a new method for analyzing battery capacity and health. The award was given through ARPA-E's Advanced Management and Protection of Energy Storage Devices (AMPED) to focus on innovations in battery management and storage to advance electric vehicle technologies, help improve the efficiency and reliability of the electrical grid and provide important energy security benefits to America's armed forces.

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SwRI, industry collaborators receive funding for energy research projects

Southwest Research Institute and industry collaborators Solar Turbines Inc., Oak Ridge National Laboratories, German Aerospace Center and San Diego State University have been awarded a $3.8 million contract by the U.S. Department of Energy to develop a novel gas turbine combustor for a concentrating solar power (CSP) hybrid gas turbine system. The award was given through DOE's SunShot Initiative, a collaborative national effort to make solar energy cost-competitive with other forms of energy.

The majority of today's commercial CSP plants generate steam to support steam turbine electric power generation. The steam generated by these state-of-the-art commercial CSP plants is limited to a maximum temperature of 400°C, yielding approximately 40 percent thermal efficiencies. Even for developmental CSP technologies, these efficiencies are well below those achievable with gas turbine combined cycle plants, which can be well above 55 percent thermal efficiencies and as high as 62 percent for state-of-the-art combined cycle power plants. This project aims to combine the advantages of highly efficient gas turbine power plants with concentrating solar power systems by operating the gas turbine at up to 1,000°C combustor air inlet temperatures.

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SwRI adds test cell to flow component test capabilities

A new cell for testing valves and other pressure-containing and pressure-controlling products has been added to Southwest Research Institute's Flow Component Testing Facilities.

To ensure the safety of pipelines, refineries, offshore platforms and chemical processing plants, valves and similar devices operating under high pressure must be tested to established standards. SwRI has offered these testing services to the oil and gas and chemical industries for more than 35 years.

"This new test cell augments a suite of test facilities housed in one centralized location," said Shane Siebenaler, a group leader in SwRI's Fluids and Machinery Engineering Department who oversees the facility.

The cell can evaluate products up to 30,000 psi with gas hydraulic pressure. Other capabilities of the cell include cryogenic testing (to –320°F), elevated temperature testing (up to 750°F), fugitive emissions testing and thermal cycling, among others.

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Presentations

Allegrini, F., M.A. Dayeh, R. DeMajistre, M.I. Desai, H.O. Funsten, S.A. Fuselier, P.H. Janzen, D.J. McComas, D.B. Reisenfeld, N. Schwadron and R. Vanderspek. "IBEX-Hi Energy Passbands." Paper presented at the Interstellar Boundary Explorer (IBEX) Science Working Team Meeting, Bad Honnef, Germany, March 2012.

Allison, T.A., A.H. Lerche, J.J. Moore and H.R. Simmons. "Revisiting the Safe Diagram for Analysis of Mistuned Bladed Disks." Paper presented at the ASME International Gas Turbine Institute Turbo Expo, Copenhagen, Denmark, June 2012.

Technical Staff Activities

Anderson, F.S., K. Nowicki, V. Hamilton and T. Whitaker. "Portable Geochronology with LDRIMS: Learning to Date Meteorites Like Zagami with the Boulder Creek Granite." Paper presented at the Lunar and Planetary Science Conference, The Woodlands, Texas, March 2012.

Anderson, F.S., K. Nowicki and T. Whitaker. "Demonstration of a Portable Approach For Rb-Sr Geochronology On The Boulder Creek Granite: Implications For Planetary Exploration." Paper presented at the American Geophysical Union (AGU) Fall Meeting, San Francisco, December 2011.

Anderson, F.S., K. Nowicki, T. Whitaker, J. Mahoney, D. Young, G. Miller, J.H. Waite Jr., M. Norman, J. Boyce and J. Taylor. "A Laser Desorption Resonance Ionization Mass Spectrometer for Rb-Sr Geochronology: Sr Isotope Results." Paper presented at the IEEE Aerospace Conference, Big Sky, Mont., March 2012.

Anderson, F.S., J.H. Waite Jr., J. Pierce, K. Zacny, B. Cohen, G. Miller, T. Whitaker, K. Nowicki, P. Wilson and H.Y. McSween. "*In-situ* Life Detection and Dating: A MSR Precursor Mission Concept." Paper presented at the Concepts and Approaches for Mars Exploration Meeting, Houston, June 2012.

Avery, P. and R. Garcia. "Distributed Control in Multi-vehicle Systems." Paper presented at the 3rd International Multi-conference on Complexity, Informatics, and Cybernetics, Orlando, Fla., March 2012.

Bell, J.M., Y. Ma, I. Sillanpaa, J.H. Waite Jr., J.H. Westlake, B. Magee and K. Mandt. "Modeling Titan's Ionosphere and Its Coupled Chemistry and Dynamics." Paper presented at the AGU Fall Meeting, San Francisco, December 2011.

Boice, D. "The Cometary Dust Environment." Paper presented at the Dust, Atmosphere and Plasma Environment of the Moon and Small Bodies Workshop, Boulder, Colo., June 2012.

Boice, D. "Comets: Ghostly Apparitions or Cosmic Rosetta Stones?" Paper presented at Friday Nights, Celestial Lights, The University of Texas at San Antonio, March 2012.

Boice, D. "Comets: Ghostly Apparitions or Cosmic Rosetta Stones?" Paper presented at the Oasis Center, San Antonio, June 2012.

Boice, D. "The Compleat Astronomical Library — Rare Astronomical Works and Their Authors." Paper presented at the Oasis Center, San Antonio, June 2012.

Boice, D. "Danger! The Biggest Cosmic Threats to Earth." Paper presented at the Oasis Center, San Antonio, April 2012.

Boice, D. "Modeling the Physics and Chemistry in the Comae of Comets." Paper presented at the National Astronomical Observatory of Japan, Mitaka, Japan, May 2012.

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Camann, D., A. Yau, L. Heilbrun and S. Schultz. "Acetaminophen Determination in the Deciduous Tooth: An Exposure Biomarker During Tooth Formation." Paper presented at the 2011 International Society of Exposure Science Annual Meeting, Baltimore, October 2011.

Camann, D., M. Zuniga, M. Rood, A. Yau, C. Hines and R. Whyatt. "Longitudinal Study of Diester Phthalate Stability in Frozen Extracts." Paper presented at the 2011 International Society of Exposure Science Annual Meeting, Baltimore, October 2011.

Cheng, X.G., V.Z. Poenitzsch and R. Bizios. "A Novel Electrochemical Process for Assembling Composite Macrostructures of Collagen Containing Hierarchically Aligned Carbon Nanotubes." Invited talk at TechConnect World Conference and Expo, Santa Clara, Calif., June 2012.

Cheng, X.G., C. Tsao and T. Potter. "Localized, Controlled Release of Human PDGF from Highly Aligned Collagen-nanoparticle Fiber for Tendon Repair." Paper presented at the International Symposium on Ligaments and Tendons, San Francisco, February 2012.

Chiang, K.T. "Formation of Chromia on Copper-Chromium Coatings." Paper presented at the 220th Electrochemical Society Meeting, Boston, October 2011.

Chiang, K.T. "Formation of Chromia on Copper-Chromium Composites and Coatings." Paper presented at the 1st World Congress of Advanced Materials, Beijing, China, June 2012.

Davis, M.W., T.K. Greathouse, K.D. Retherford, G.S. Winters, Y. Bai and J.W. Beletic. "Far Ultraviolet Sensitivity of Silicon CMOS (Complementary Metal Oxide Semiconductors) Detectors." Paper presented at the Society of Photo-optical Instrumentation Engineers (SPIE) Astronomical Telescopes + Instrumentation Exhibition, Amsterdam, Netherlands, July 2012.

Dayeh, M.A., M.I. Desai and R.W. Ebert. "Tracking Extreme Solar Events from the Sun to the Earth." Paper presented at the Extreme Space Weather Events Workshop, Boulder, Colo., May 2012.

DeForest, C.E. "Quantitative Imaging of the Solar Wind: Coronal Mass Ejection (CME) Mass Evolution and the Interplanetary Magnetic Flux Balance." Paper presented at the American Astronomical Society Meeting, Anchorage, Alaska, June 2012.

DeForest, C.E., D. Lamb, A. Davey and R. Timmons. "Southwest Automatic Magnetic Identification Suite (SWAMIS) Magnetic Feature Tracking for Solar Dynamics Observatory (SDO)." Paper presented at the American Astronomical Society Meeting, Anchorage, Alaska, June 2012.

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