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The ecological footprint of the average U.S. citizen is approximately ten times that of citizens from developing nations. We will need another four planets if everyone on this one is to achieve the same lifestyle, with the current pattern of consumption, as we enjoy in the United States. Transportation is a major portion of our ecological footprint. So, in the College of Engineering at Michigan State University we have developed twin research strategies focused on developing...
technologies that will reduce our transportation footprint. One concentrates on alternative energy in our new Energy and Automotive Research Laboratories. The other focuses on lightweight structures in the Composite Vehicle Research Center (CVRC).

The CVRC developed from a long-standing research relationship that Professors Cloud and Liu have with the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) in Warren, Michigan. The research exploited their expertise in mechanics of composites subject to high-energy impacts and in mechanical joining of composites. These topics formed the core from which four additional thrust areas have been developed in the CVRC: multifunctional materials in which we plan to take advances in material science at the nanoscale and integrate them into structures at the macroscale; self-diagnostic composites that will be able to provide real-time feedback on their own condition and structural viability; structural integrity of composites, which will include research to predict the in-service performance of composite structures; and consideration of the integration of these features in the design and manufacture of composites. In order to stimulate new approaches, a seventh thrust area has been established based on biomimetics that involves looking at the design of composites in nature and translating the lessons learned into our own structures.

While we have created thrust areas to provide direction and focus for our efforts, we seek to collaborate across the size scale from nano to macro and thus also across traditional disciplines. To stimulate this approach our researchers are housed in open-plan offices and laboratories because research has shown that 80 percent of an engineer’s ideas are generated by direct contact with other engineers and that visual contact with the work of other engineers is essential. We also have seeded cross-disciplinary work in specific projects that tap into technological advances in several thrust areas.

In addition, we try to collaborate throughout the entire innovation process from breakthrough research through technology validation to product development by forming close relationships with participants in this process, such as research organizations, designers, manufacturers, suppliers, and end-users. We have two spin-out companies associated with our research, and we are forming relationships with international partners to pursue our ambitions in technology exploitation.

The CVRC is very young. We started with an empty building in 2007. Our first research grant began in 2008. Half of our eight faculty members have been appointed for two years or less. However, the sign-in register on our front desk for employees and students now has 50 names on it. So it has been an exciting time for the CVRC, and I hope this booklet gives a flavor of our excitement, progress, and direction.

Eann Patterson, CVRC Director
Since 2001 the news stories reporting U.S. soldiers dead or maimed abroad have become a dull, wearisome drumbeat, permeating nearly every major political debate and confronting Americans almost daily with images of young people in their prime, now dead.

In the past couple of years, that drumbeat has gotten faster and louder. Since 2001, 1,085 U.S. soldiers have died in Afghanistan; since 2003, 4,400 U.S. soldiers have died in Iraq. The majority of those deaths, especially in the last two years, were caused by improvised explosive devices (IEDs), which rip through military vehicles and protective gear.

Despite the U.S. military’s continued dominance around the world and the impressive innovations of its weapons and strategies, troop deaths are still too common and too often the result of equipment that can’t adequately protect them.

“The vehicles currently being used in the fighting we’re having in Iraq and Afghanistan, with IEDs and with the Taliban and the insurgents, they’re killing our soldiers,” says Roger Crane, senior composites engineer at the U.S. Naval Surface Warfare Center. “It’s terrible to look at these guys who come back. You go to Walter Reed [Army Medical Center] and look at the missing limbs and the trauma they go through from blasts. We need to protect them better. They’re there fighting for us.”

Protecting soldiers better is core to the mission of Michigan State University’s Composite Vehicle Research Center (CVRC). Founded in 2007 and directed by Eann Patterson, the CVRC currently operates in partnership with the U.S. Army and Navy to research and
design composite vehicle materials and structures for air, ground, and sea that are safe, durable, and lightweight.

The center emphasizes design validated by experiment and employs an elite group of MSU engineering professors, whose areas of research are organized into seven thrust areas, all of relevance to the military. Those thrusts are impact resistance, composite joining, multifunctional composites, self-diagnostic composites, biomimetics, and design and manufacture.

The CVRC’s research also holds potential for the civilian world. Its researchers work with industry to find opportunities to apply their discoveries to mundane dilemmas, like building better bridges and safer, more-efficient automobiles.

“The power and intensity that are part of the design for military vehicles are not the same as for domestic vehicles,” says MSU President Lou Anna K. Simon. “But the same research approach can be used for a number of safety innovations that will be translated into products that are generally available.”
Building a Better Mousetrap

Composite materials are just what they sound like—an engineered material made from more than one material. The possibilities are endless. An engineer might explore ways to combine ceramics, fibers, aluminum or shale, just for starters, and then he might test what happens when heat is added to a material, or nanoparticles. And so on, until a new material is created that has the desired properties.

“There are so many materials out there that we just haven’t discovered yet,” says David Gorsich, chief scientist at the Warren, Michigan–based U.S. Army Tank Automotive Research and Development Center (TARDEC), CVRC’s primary partner.

TARDEC develops and integrates technology
solutions to improve military effectiveness and capabilities.

“The CVRC is coming up with materials that may not break like current materials do and that may conduct current,” Gorsich says. “There’s a wealth of materials and things to manufacture that will make a huge difference to vehicle systems. If we don’t do it, who else will? If not in the United States, shame on us.”

Engineers are problem-solvers by trade. Regardless of their research focus, all engineers are seeking solutions to the world’s inefficiencies and inadequacies. U.S. military equipment, despite decades of innovations, has a lot of problems. It’s too heavy, it’s too vulnerable to attack and it breaks down too fast and too unpredictably.

Solving those problems, however, is complicated. Many lightweight materials aren’t strong enough to withstand attack. Heavy materials drain resources with their fuel-inefficiency and require a lot of maintenance. Even a material that hits the sweet spot of strength and efficiency can be worthless if it’s joined ineffectively to other materials.

“We have an aging fleet in the defense forces, and some of it is because we have two wars going on right now and many of the things being used in those two theaters aren’t going to be coming back,” says MSU College of Engineering Dean Satish Udpa. “If we’re going to rebuild our transportation fleet we need to make sure it’s done right. Gasoline is really expensive and so we want to make all our vehicles as efficient as possible. We also want to make sure our soldiers are safe. And the survivability of these vehicles poses some very, very important problems.”

Let’s start with weight. Currently the military’s transport and protection equipment depends mainly on steel, which is strong and relatively durable. It’s also heavy, inefficient, and not sufficiently effective against enemy weaponry. “If you add weight to vehicles you waste fuel, the components wear out, and you have to do maintenance to a greater extent on them,” Crane says.

According to Doug Templeton, senior technology expert at TARDEC, a forward-operating base has roughly 1,000 military personnel and uses about 7,000 gallons of fuel per day just to run the base; the base’s vehicles consume about three times that amount. All that fuel drains needed resources from the military and its transport exposes troops to danger. Transport tankers can
carry about 5,000 gallons of fuel. Less fuel usage means fewer tanker trips, and that means less risk to troops. “The logistics train is very long,” Templeton says. “We want to do anything we can to reduce our dependency.”

Clearly, the lighter the material, the better. But in order to be useful a material must also be strong and pliable. It must tolerate a high strain rate. In other words, it must be able to handle intense impacts like those from bullets and high-speed crashes.

“Flying debris and secondary projectiles create a lot of problems,” Templeton says. “A single piece of sand can blow a pretty big hole. When you say ‘armor’ people tend to think tanks, but it’s more than that. We’re trying to change the lexicon to include more protective materials. We trying to both understand how things react and respond and how we can make some changes to ensure they respond in a positive way.”

The same forward-operating base that requires 7,000 gallons of fuel a day needs 15,000 gallons of water. That’s three daily tanker trips. So even as the military works to reduce fuel demands and hence its transport needs, it also must improve the materials those tankers are made from to protect the men and women whose daily job requires them to traverse that long logistics chain.

The military wants materials that are lightweight yet strong. But that’s not enough—they must also be able to endure over time, a tall order for equipment that spends its days careening down bumpy roads. In fact, research on structural
integrity is critical for composites, whose relative newness means there is insufficient data on how they hold up over time.

“As we run into more cars, airplanes, and ships being made from composites, one of the things we don’t have a good handle on is the lifetime of these components,” Templeton says. “If you look at the 787, that plane is 80 percent composite. The reality is we have no aircraft that are almost all composite that have been out there flying for 10, 20, 30 years. We worry about the overall structural integrity. What’s the real lifetime of these structural components? What kind of failure modes will we see?”

Automotive industry research has generated insights into composite materials’ structural integrity, but needless to say, military vehicles deal with different loads and impacts than the typical sedan.

“Metals will gracefully degrade. You can tell it’s getting weaker and weaker and then it breaks,” Templeton says. “When you flip a tab on a soda can back and forth, you can watch it weaken. Composites, on the other hand tend not to have that. They hold their integrity but all of a sudden when they go, they go. We’re in the early stages of looking at how to model that. There’s a lot of discussion among researchers about the best fatigue models.

“The classic issue is Corvettes,” he adds. “If you hit the back end of a Corvette, you get cracking at the front corner. We’re looking at how damage passes through a composite, the material’s lifetime expectancy, and how to repair damage to composites.”

To solve these conundrums, TARDEC turned to MSU.

The CVRC’s Founding: MSU Takes On Washington

MSU’s College of Engineering had a 25-year history of collaboration with TARDEC and the U.S. military even before the CVRC got its start.

In 1982, University Distinguished Professor of mechanical engineering Gary Cloud and his colleague, David Sikarskie, a professor in the former Department of Materials Science and Mechanics, received federal funding for research on composites in a three-year contract administered through TARDEC. Sikarskie ultimately left to become dean at Michigan Technological University, leaving Cloud at the sole principal investigator. Another TARDEC contract followed later that decade.

In 1996 TARDEC asked Cloud to conduct research on non-destructive inspection for heavy-duty vehicles, fastening for composites for use in heavy-duty vehicles, and impact resistance in heavy-duty vehicles. Cloud solicited the help of MSU mechanical engineering professor Dahsin Liu, who took on the impact resistance research.

“The work on fastening grew quite a bit—we were looking at ways to improve fastener performance on structures involving composites,” Cloud says. “Blast loading was added to impact loading. So the projects grew.”

Cloud and Liu landed successive contracts with TARDEC through 2007. During one of the researchers’ routine briefings of TARDEC in early 2005, Templeton suggested starting a dedicated research center at MSU that could extend beyond contracts with individual researchers to bring together MSU’s expertise across the engineering spectrum to bear directly on the military’s needs.

“Literally this started from an offhand comment that I made,” Templeton says. “To Gary’s credit, he kind of seized on that. Instead of saying, ‘Oh, we don’t want to do that,’ he said, ‘Let’s do it.’”

Cloud remembers the CVRC’s genesis a bit
differently. He was thinking about retiring and was not sure about trying to establish a center. However, he passed Templeton’s suggestion to Eann Patterson, who was chair of the mechanical engineering department at that time. “Eann picked up on this idea. He got back to me and said, ‘Why don’t we do this?’ So, I went back to Doug and said we were interested.” Cloud took the lead in the many discussions about the project, especially with the Department of Defense.

Meanwhile, Patterson began orchestrating meetings with TARDEC officials and potential political allies, especially U.S. Senator Carl Levin, D-Mich., and U.S. Congressman Mike Rogers, R-Mich., in hopes of landing federal funding.

Levin, who has visited the center several times since its creation and who serves as chair of the Senate Armed Services Committee, said he was struck by the center’s “extraordinary combination of creativity and reality.” [See article on page 18.]

“The center reflects one of the great strengths of Michigan and Michigan State,” he says. “And that is, in addition to being very creative in terms of its focus, it’s also very real in terms of its goals. It’s not just theoretical, not just doing theoretical research; it’s doing very practical research that is addressing real-world needs.”
With Levin and Rogers’ support, Patterson and Cloud departed for Washington, D.C., to solicit help from the politicians who control the nation’s purse strings. “I was really nervous,” Cloud says. “I’d never done that before—a bashful west Michigan farm boy going off to Washington.”

He pauses. “I have to admit, it turned out pretty well.”

Indeed. Congress awarded $5.5 million over two years to the endeavor, with the money administered by TARDEC and the Office of Naval Research. A second chunk of money, $1.6 million, was granted to the CVRC through the Army Research Laboratories (ARL). [See sidebar, right, for an explanation of the CVRC’s funding.]

Meanwhile, Patterson and Cloud met with university officials, in particular J. Ian Gray, vice president for research and graduate studies, to ensure the necessary university support. “VP Gray is unique in that he is willing to take some risk,” Cloud says. “And he backed us to the hilt in helping us get this place going. I will never forget his help.”

Cloud was integral to the CVRC’s creation, yet he says its approach to research represented a departure for scholars of his generation. “During most of my career, when I was a graduate student and became self-sufficient.

Federal funding will continue until 2013, but already CVRC Director Eann Patterson is working to put together an industry consortium to help fund the center’s work into the future. And faculty members are now expected to generate matching funds for their work. The intent, Patterson says, is “to make the CVRC self-sustaining. We want to use this money to leverage additional funding.”

The CVRC was initially supported by $5.5 million in federal funds from the FY 2007 budget. That money created a two-year cooperative agreement between the CVRC and both the U.S. Army Tank Automotive Research and Development Center (TARDEC) and the Office of Naval Research. Of that initial funding, $4.8 million went to the university (agencies withhold a part of the funding for managing research).

A second federal award of $1.6 million ($1.4 million to the university), administered through the Army Research Laboratories (ARL) from the FY 2008 budget, extends until June 2011. The CVRC did not request federal funds in FY 2009.

The federal budget for FY 2010 set aside $6.8 million for the CVRC, with $3 million administered through TARDEC and $3.8 million through ARL. TARDEC’s portion will last until December 2012; ARL’s will expire in June 2013.

Patterson’s work on forming an industry consortium has thus far generated a letter of intent from a European aircraft manufacturer and a Canadian research organization to support the center with $2 million each over five years. These letters stipulate that the CVRC must have at least two additional letters providing the same level of support.

“I have a cup half full,” Patterson says. “I’ve approached representatives at a number of blue chip companies, but they tell us, ‘Your ideas are great but we haven’t got the money.’ I hope as the United States and Michigan come out of this economic crisis, I can go back and get positive responses.”

The consortium’s chief purpose will be pre-competitive research to transition the fundamental studies the CVRC does with the Department of Defense agencies to the point where private companies could pick them up on their own, in order to foster a competitive development of technologies.

CVRC faculty must also do their part. Initially faculty members were permitted to get their bearings in the new endeavor and conduct their research free of the impetus to secure their own funding. With the center about to embark on its fourth year, expectations are increasing. Full professors are now expected to bring in $1 of additional research money for every $1 received from CVRC funds. A sliding scale of matching funding also has been set up for associate and assistant professors. “This is a new approach for the College of Engineering at MSU,” says Patterson, who hopes that the approach will make researchers build on their successes and pursue new ideas.
and as a university professor, individual effort was rewarded,” he says. “If you did collaborative research it was discounted in the promotion and raise process. Somewhere in the 1980s this idea of collaborative research became a hot buzzword. Unless you had a group together, it was hard to get funding. That put us in a real bind, people my age, because we were used to working as loners; it’s how we were trained.

“The National Science Foundation led the charge on this; everything had to be centers,” he continues. “Well, then everyone started calling themselves centers. There were one-man centers all over the country. We decided early on [with the CVRC] if we were going to do a center it would be a real center, with its own space, its own people, its own offices, and that we would create
something that had some national prominence.”

In 2007, the MSU Foundation purchased the building that now houses the CVRC. The university entered into a lease for the CVRC’s portion of the building, giving it a bricks-and-mortar center to point to from its inception. As researchers began to gradually relocate their research to the new building, the question became when they could officially refer to themselves as a center.

“Eventually I gave a presentation and found out there weren’t any university rules at that time,” Cloud says. “During my presentation one of the slides said in Latin, ‘We think, therefore we are.’ We had the funding; we had the building; why not call ourselves a center? We were able to hire new faculty members. So the thing is an ongoing concern.”

**The CVRC: A Center Apart**

The military could have chosen any number of other universities to build a center like the CVRC. So why did it choose MSU? The 25-year history with TARDEC was important. But so too was MSU’s group of researchers, who bring a unique range of expertise and research specialties to the endeavor.

“The primary thing, in my view, is the fact that we are combining all of these areas together and they’re synergistic,” Templeton says. “I could find another university that is doing one or a couple of these areas. There is none that is doing all of this, which ranges from nano up to vehicle-sized work.”

The experimental orientation of the MSU engineering faculty was also critically important. MSU has the largest faculty group in the area of experimental mechanics in the United States. The CVRC’s guiding principle is *design validated by experiment*, and its researchers conduct both experiments and analysis.

A bit of context: Engineering is divided largely into experimental and analytical approaches; historically, unsophisticated computers limited researchers’ ability to conduct analytical modeling. As computers evolved, computer modeling came to dominate. Such modeling is still highly useful, but has come under some criticism when utilized to the exclusion of experiments. Many funding programs now require a modeling approach to be validated with experiment.

“People fly airplanes; they want to make sure they’re going to stay in the air,” Cloud says as an example. “You can do modeling all day, but unless you do testing you’re going to drift off into never-never land where you can’t be sure your plane is going to stay in the air.”

“This is where we have a unique advantage, with a large number of experimental mechanics,” he adds. “A lot of universities have drifted toward almost all computer modeling and abandoned experimental work. So we were very well positioned to get this funding. We can do the experiments and testing of the designs.”

Simon agrees that it’s the CVRC’s blending of both engineering approaches that sets it apart. She also says the emphasis on experiment means the center’s research results are more readily usable.

“What’s exceptional about the CVRC is the creativity and innovation that is required not only to identify new materials but to be able to develop an experimental model to test those materials
in ways that approximate the challenges of the battlefield," Simon says. "This approach speeds the translation of the research-and-development findings to actual vehicles, having an immediate impact on the way in which TARDEC is able to promote the safety of our troops and the effectiveness of the military."

The center's emphasis on experiment means its 22,000-square-foot lab is full of huge machines that conduct sophisticated tests to gauge what happens to materials that are dropped, blasted, slammed, heated, etc. Its laboratory blast simulator (LBS), which is based on a shock tube, is considered perhaps the most powerful in the world and can release a pressure wave akin to an IED exploding. The lab's drop-weight impact tester (DWIT) also is used for testing impact resistance. The addition of a high-speed camera allows its user to take high-speed photos of an impact. Other machines allow engineers to conduct tests on materials post-impact.

“If you have a fender-bender, you want to drive away,” Patterson says. “The Army is in the same position. It wants to drive away. It wants to know how long materials will last after an impact.”

In addition to its exceptional collection of brain power and equipment, the CVRC's very physical design is unusual. Faculty and graduate students' offices share the same open floor plan, making it easy for colleagues to pop in and ask a question or talk over a problem.

The lab is even more integrated. As Patterson says, he let the lab "grow organically; we avoided discreet zones." Researchers and equipment are all mixed together, so that someone researching impact resistance may work next to someone studying multi-functional composite materials or self-diagnosing composites. Such a setup, Patterson says, means researchers are regularly "checking out each other's work."

For TARDEC, such intermingling is a key asset. "One of the advantages of the CVRC, and Eann was one who really pushed this, is the way the office areas are designed," Templeton says. "When I was in graduate school, I sat in a trailer and if I
wanted to find my thesis adviser, I had to walk into the building. The way they’re set up, it’s almost the antithesis of the standard university research setup."

With such free flow between researchers, Templeton says, “You encourage collaboration between the thrust areas [in the lab]. They literally cannot avoid each other because they’re running into each other all the time. It’s the same thing in the office areas. Eann has been very proactive in encouraging his faculty members to have this cross-pollination and collaboration.”

**From the Research Lab to the Real World**

The CVRC’s research has the power to enhance more than the safety and effectiveness of U.S. troops. It also has significant economic potential, especially in Michigan.

“It may be in the future that all vehicles will be designed out of materials coming out of this center,” Gorsich says. “That’s the kind of potential this center has. It could spin off whole new manufacturing industries. That’s especially huge in Michigan where we’ve lost all these jobs. They’re through new technology. And already two of the center’s researchers have launched private companies to take their work to market.

Professor Dahsin Liu’s Liuman Technologies and University Distinguished Professor Lawrence T. Drzal’s XG Sciences are the beginning of what the CVRC hopes will be a broad spectrum of economic endeavors.

XG Sciences makes nanographite platelets—tiny pieces of graphite—that can be added to composite materials to improve their mechanical, thermal, and electrical properties.

The particles have two main advantages, Drzal says. They’re multi-functional, able to make a material stiffer, stronger, and less flammable, for example. That gives their application obvious potential for the military, but also for manufacturers of consumer products ranging from batteries to automobiles, fuel cells, greases, and more.

The particles’ other main perk is that they’re a bargain, at about $15 per pound. “If I could borrow an old marketing slogan [from General Electric], it’s not that we’re going to make the things you buy, we’re going to make the things you buy better,” Drzal says of his company’s vision.

Drzal started XG with three partners, including two of his former graduate students. The company now has a pilot plant in Lansing and six employees. The plant makes small amounts of the graphite material to sell as samples to potential client companies.

“We’re waiting for one of them to say, ‘Gee, we need a gazillion pounds of this,’ and when they do we’ll try to scale up to a larger company,” he says.

Liu’s Liuman Technologies is earlier in its gestation. The company specializes in designing dynamic testing facilities, which can test a material’s response to various strain rates. The company’s equipment can simulate ballistic impacts and blast attacks, for example, along with low-velocity impacts. Its three products are a drop-weight impact tester, a split Hopkinson’s pressure bar, and a laboratory blast simulator (LBS).

“If you want to test stress on a football you can’t just place dead weight on it—you need to throw it to simulate activity,” Liu says. “This sort of testing is important in engineering design. A computer model is important but it needs to be validated by the testing, and that’s what we are doing.” Potential customers for the company’s equipment include universities and automotive suppliers.

Liuman Technologies has applied for funding through the federal government’s Small Business Innovation Research (SBIR) project, which provides support to small companies to conduct research that can result in a commercial product. “We are very much in the early stages,” Liu says. “We’re applying for an SBIR project to grow our research into design and products. We are ready to do anything,” he adds. “It just takes time to get the word out.”
learning things nobody knows how to do yet."

In fact, the CVRC has already spun out two private companies: Liuman Technologies, which develops dynamic testing facilities; and XG Sciences, which develops nano graphite platelets that can be added to the composite materials to improve their properties. [See sidebar on previous page.] Patterson says the center has a target of spinning out a new company every couple of years, and wants to position itself as a center of expertise for industry.

Additionally, it’s creating new materials and technology that, once proven effective, will require manufacturing for application in the military. Again, Michigan stands to benefit, because the state is home to companies that make military vehicles.

In fact, the CVRC’s research has broad potential across all vehicle types. “A lot of the discoveries and designs are immediately applicable to civilian vehicles, including automobiles, trains, water vehicles of all sorts, snowmobiles, and construction equipment of all kinds,” Cloud says. “There can be a double payoff here. We can improve vehicle performance, lower their cost, and reduce their weight for the military; but we can also benefit the civilian market hugely. We know automakers are using more plastics and composites in cars. They still have problems fastening them together and that’s one thing we work on. We can benefit the armed services on the one hand and industry on the other.”

Kristin Zimmerman, a graduate of MSU’s doctoral program in materials science and mechanics and now a member of the General Motors Research and Development Center working on the Chevy Volt, says the CVRC’s research on
Scholars with expertise in composites are in high demand, and few universities have strong graduate programs in composites engineering.

“The Army’s always looking for good people who understand materials and how those materials can be incorporated into a system,” Gorsich says. “For the people coming out of this center, there are jobs for them.”

The problem that TARDEC faces, Templeton says, is competition for graduates from industry, which typically pays better than the federal government. Among TARDEC’s goals for its collaboration with the CVRC is a partial remedy of this dilemma. The contract with the CVRC encourages the center to accept U.S. students (the Army can hire only U.S. citizens); in turn, TARDEC hires several of them for its highly competitive summer program, thereby giving them a taste of TARDEC’s work in the hopes that some might be willing to return permanently after completing their degrees. This summer kicked off the effort with five CVRC students working at TARDEC.

“All the work they’re doing ties in with research at the CVRC and meets our needs,” Templeton says. “The idea is to show them what we do here and get them excited about what they do. If we can hire 50 percent of them [after they complete their degrees], I’ll be a pretty happy camper. They wouldn’t be coming in inexperienced. “The opportunity I offer here is you get a lot of responsibility right up front, and you get a chance to make a difference,” he adds. “When we screw up, people die. Money doesn’t drive everything. There are tangible results from what you do at TARDEC.”

The CVRC: Looking Forward

The CVRC is funded through 2013. But even now the center’s funding approach is starting to evolve. This year the money will be allocated among the seven thrusts in part on merit rather than in seven equal pieces, creating a more competitive environment at the center. “They’re doing what industry does—good industry,” Templeton says of the CVRC’s move to tie funding to results.

Ultimately the goal is for the CVRC to be self-funded and possibly even profitable. But until then, the center’s work depends on the public’s support. “It is an investment,” Cloud says. “It’s an investment in our future. It’s raising our level of skill and knowledge and the research will ultimately pay off. It’s got to, but that takes time.”
LEVIN SEES NATIONAL VALUE IN CVRC

U.S. Senator Carl Levin, D-Mich., helped secure federal funding for the Composite Vehicle Research Center. Levin visited the center most recently in February 2010. He spoke about why the center’s work is worth championing.

**Talk about your visit to the CVRC. What struck you about its work?**
What struck me is the extraordinary combination of creativity and reality. Their focus is obviously on trying to come up with materials that will be usable in vehicles, and from my perspective as chair of the [Senate] Armed Services Committee but also representing Michigan, I’m interested in materials that are lighter and stronger and more durable.

**Why did you decide to advocate for funding for the CVRC?**
I’ve been focused for a long time on dual-use technology or research. We’ve got a huge base for the commercial vehicle research world in Michigan. We’ve
got a huge base for the military vehicle world in Michigan. Decades ago those worlds were apart; now they’re truly united and married. It’s always been a major focus of mine to bring them together, because a lot of the research is usable in both worlds. Composite vehicles are an excellent example of that.

About 20 years ago or more, I led the way to a cooperative research and development agreement between military services and vehicle producers. They used to agree on joint development of a specific technology—it could be a material, an engine, a new type of pump, it could be a million different things. They used to have these separately written and designed agreements for each new technology that they were jointly working on. It could take the Navy and a car company working together a year just to get the agreement.

We designed a common agreement where all you had to do was plug in the name of the technology and the names of the two entities involved and not have to reinvent the legal agreement every time. Now we have maybe 100 agreements out there. It was always something I was passionate about because of our tremendous capacity in Michigan. You’ve got the military world, the academic world, and the private world very well represented in Michigan. Pulling them together gives you a great plus.

**What challenges did the funding process face, politically or otherwise?**

The usual effort to persuade colleagues of the value of something to the country, that it’s not just something for your home state or home district but a national value to be gained. That’s always the challenge. It’s pretty obvious here—if we can design a stronger material and a better material there’s a huge benefit, including reduced energy use, and appeal for our military because everybody knows most of the deaths are due to explosive devices.

**What do you think is most significant and compelling about the research of the CVRC?**

The most compelling thing is their overall purpose. Looking at composite materials has a huge benefit and potential. One of the things that struck me is the way they look at materials in nature—taking something in nature that has unusual strength or lightness or durability to try to look at that and analyze the structure and materials. It creates a very exciting potential because there are so many things in nature that somehow or other have survived a long time. If you take a Darwinian view of things, these are materials that have been proven over millions of years. What is able to resist penetration from an outside force? What is lightweight? We’ve had a laboratory in nature for millions of years. It is a very exciting, a very imaginative approach.

**Why is it important that the CVRC’s work be located in Michigan? What impact do you think it could have on our state?**

Michigan’s the obvious place because of the location of three things—vehicles in the commercial world, the military vehicles world, and the universities that have such extraordinary depth and breadth. The advantage to Michigan is the work it produces on the development and production side of whatever the new technology is.

The center reflects one of the great strengths of Michigan and Michigan State University. That is, in addition to being very creative in terms of its focus, it’s also very real in terms of its goals. It has very real-world goals. It’s not just theoretical, not just doing theoretical research; it’s doing very practical research that is addressing real-world needs.
cvrc thrust
Multi-Functional Composites:  
*The heart of the work*

“Can we make a composite that is not only stiff and strong and tough, but one that will have other attractive properties, such as high electrical or thermal conductivity or barrier properties? That has been the focus of our work historically,” says Lawrence T. Drzal, University Distinguished Professor of chemical engineering and materials science and the director of MSU’s Composite Materials and Structures Center. He oversees the Multi-Functional Composites thrust area of the CVRC. “That focus rests heavily on the incorporation of a new generation of multifunctional nanomaterials into traditional fiber reinforced composite materials.” Integration of nanomaterials by their selective placement on or between reinforcing fibers to produce a “nanostructured” composite is the foundation for producing multi-functional composite materials.

Drzal’s research on composite materials goes back more than three decades starting with his tenure at the U.S. Air Force Materials Laboratory at Wright Patterson Air Force Base. His expertise with nanoparticles used in composites started with the

Experience, enthusiasm, and passion for composite materials research. These are the keys to the success of the Composite Vehicle Research Center (CVRC) at Michigan State University. The center boasts a highly integrated, versatile team of experimentalists and modelers with a very high concentration of skills ranging from molecular to structural and into processing, design, and manufacturing. Researchers collaborate and share ideas with the goal of showing tangible results validated by experiments for their sponsors in a timely fashion.

The research is focused on seven thrust areas. An inside look at each of these areas shows how the research is progressing and why the overall research continues to set CVRC apart from other research centers across the United States and around the world.
Drzal’s research group focuses on nanoparticles from graphite. That’s because graphite has attractive properties—it’s stiff, strong, and both electrically and thermally conductive, and it does not burn easily. However, the most attractive attribute of using graphite is that the material and the process to produce nanomaterials from graphite is inexpensive.

The graphite nanoparticles that have the greatest potential are called Exfoliated Graphite (Graphene) Nanoplatelets (xGnP). “What we produce are nanoscopic platelets of graphite that are only
a few nanometers thick but can be microns in
diameter,” says Drzal. “The platelet morphology is
also an attractive feature of these nanoparticles.
When they are added to a composite, they
assemble into a complex network creating a very
tortuous path for a gas or liquid molecule diffusing
through the composite. That results in very high
barrier properties.” So, for example, if you make a
composite container and fill it with gasoline, over
time the gasoline molecules will diffuse through
the polymer chains through the walls of plastic,
and into the atmosphere. “If xGnP is added in the
composite, the presence of the tortuous network
will prevent the gasoline vapors from diffusing
through the container walls,” says Drzal.

The suite of properties present in
nanoparticles such as xGnP (mechanical, thermal,
electrical, fire, and barrier) can be added to
composite structures by the addition of only a
few percent of these materials. Their presence
will make more durable composite structures
for Army systems, a major thrust of the CVRC.
That includes everything from jeeps to armored
personnel carriers, to tanks and other vehicles.
“Structures made from composites will be much
lighter,” says Drzal. “But the military has the
additional requirement that vehicles made out
of these materials must provide protection for
personnel. So the composites used in the vehicles
have to be impact resistant, blast resistant, and
fire resistant.”

In addition, for some applications the
structures have to be electrically conductive,
thereby making the vehicles less vulnerable to
electronic observation or attack. Drzal’s research
group has shown that adding only a couple of
percent of these nanoparticles to a composite
can make them very electrically conductive. “This
means that it could be possible to change the
electronic signature of the vehicle or device made
from the composite, so it could, for example, elude
radar detection,” say Drzal. In addition, if someone
inside the vehicle is using a computer or other
electronic device, it sends out electro-magnetic
radiation, and it is possible to read what that
person is putting on the computer. With these
types of composites, it can be used as a ground
and prevent radiation going outside of the vehicle.

Drzal’s research is to provide multifunctional
composite materials through incorporation of
these nanoparticles that also have improved
impact and blast resistance. Beyond the
multifunctional advantages that will accrue
to the Army and Marines as a result of these
multifunctional composites, the research at MSU
has shown that xGnP has the potential to be very
inexpensive to manufacture. “As a result of our
research, we have come up with a process to make
these platelets very inexpensively, and we have
transferred that knowledge to a spin-out company
under the sponsorship of MSU to make these xGnP
nanoplatelets in large quantities.”

The research in this area is well ahead of
other groups because no one has the ability to
make the nanoparticles in quantities like this
group does. The nanoparticles are key to most
of the other research areas at the CVRC. For example, one project is trying to increase impact and fracture resistance. “It is difficult to make something totally impervious to a blast load. If the material is brittle, the crack easily goes through the whole material and it fails,” says Drzal. “So we are trying to find a way of strategically blunting that crack and we believe we can use nanoparticles to deliver materials that will blunt the crack. So, to increase impact performance, we are looking at combining nanoparticles with materials that absorb a lot of energy. When you have a fracture growing in the composite as a result of an impact or blast, the crack front would encounter the platelets where it would be deflected or stopped.”

**Impact Resistance: New materials testing, survivability validation**

Enthusiasm is infectious, and it takes only a few minutes to see that Dahsin Liu is enthused about his research, which may be one of the keys to his
continued success. Liu began working on projects for the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) in Warren, Michigan, along with Gary Cloud in 1996. At the time, Liu was working on composites and Cloud on joining, so it was a natural way to team up. Because of their previous research, they were able to make immediate contributions to TARDEC, which helped in getting additional funding over the years and was instrumental in obtaining approval for the funding to set up the CVRC. Now after almost 15 years of work with the Army, Liu is continually exploring new avenues, and conducting innovative research that will expand the activities of the CVRC.

“My research is especially focused on vehicle survivability and occupant safety,” says Liu, professor of mechanical engineering, who has overall charge of the Impact Resistance thrust area. “I study the effects of impacts from blasts and crashes on the composite materials used in military vehicles.” In most cases impact testing is done with a drop-weight impact tester (DWIT), which is a popular and standard industrial testing machine that is also used at the CVRC. However, over a period of time, Liu and members of his research team have developed a powerful laboratory blast simulator (LBS), which is based on a shock tube and can also be used for impact and crash tests.

“The fundamental technology for the shock tube is not new, but most of the uses for it are for aerodynamic testing, not materials testing like we are doing,” says Liu, who estimates that there are less than 10 LBS shock tubes in the country used for this kind of testing. “And ours is the most powerful,” declares Liu with obvious pride. The LBS at the CVRC is capable of producing 1,000 atmospheres of pressure. The next most powerful LBS, according to Liu, is one in Germany that can apply about 200 atmospheres of pressure.

“Instead of using chemicals to produce explosions and blasts, we use high pressure air,” says Liu. In order to evaluate all of the results from LBS tests, there is also an array of electronic equipment to measure what happens during the testing. Some of these are one-of-a-kind sensors. “We also wanted to be able to see what was happening during the impact. Of course, we could not put a high-speed camera in the chamber because the pressure is too high, so we built a periscope.” This helps to redirect the needed images to the high-speed camera located outside the LBS.

Since the CVRC has become a reality, Liu has been able to look at ways to make the LBS more powerful and with higher pressure and to simulate current military conditions. For example, in Iraq some of the improvised explosive devices (IEDs) are buried in sand. So Liu has done research adding sand with the air when doing testing. Liu and his research team are also looking at filling the chambers of the LBS with water to simulate certain Navy applications and to look at blast impacts in a totally different environment.

Generally the samples of composite materials
used for impact testing are small squares. “My goal is to scale up to a larger size for testing with the LBS,” says Liu. Making specimens bigger and thicker is more difficult because it requires uniformity throughout the entire test specimen, and there are manufacturing issues with recently invented materials. “But I want to know what happens to the impact resistance as you scale up these materials. Is that going to change the results?” says Liu.

He is also working on developing what he calls “quasi” three-dimensional composite materials. “It is not exactly three-dimensional, but it has an effective three-dimensional network, so that’s why I call it quasi 3-D.” The idea is to weave together adjacent layers of the composite, thereby making it stronger in resisting delamination. This type of research adds yet another dimension to what Liu can test using the LBS.

In addition to all of these areas of research, Liu wants to take the next step in the validation of his work with the LBS. “One of the questions is whether the high pressure air that we use is the same as with chemical explosives, such as TNT. I believe that it is, but I owe it to the CVRC sponsors and others to show that a blast with high-pressure air produces the same results as a chemical explosion.” So, Liu is trying to get approval to run tests in the LBS at the CVRC with small amounts of TNT to record the pressure history and structure performance and, if necessary, adjust the design of the LBS. This, Liu hopes, will make it possible to say without a doubt that the results from tests in the LBS with the high pressure air are the same as with chemical explosives. “Then I hope people will be convinced that this is the way to do it.”

**Biomimetics: Looking to nature for inspiration**

A passion for nature combined with an expertise in impact mechanics brought Srinivasan Arjun Tekalur to MSU and the CVRC in 2008. That
A combination of skills is helping to drive the research in the Biomimetics thrust area under his direction. "Studying nature is not new," says Tekalur, an assistant professor of mechanical engineering. "There has been research for a long time that tries to mimic nature. For example, a lot of buildings have been made to look like something in nature." The distinctive design of the Eiffel Tower in Paris is supposed to have been inspired by human bone.

However, putting a mechanics perspective to it is novel. Tekalur believes that is what will set the CVRC’s study of biomimetics apart from what has been done. One of the first projects undertaken in the biomimetics area was the study of the ramming activities of certain species. "There are several species that fight by ramming against each other, and we identified seven species that ram with high velocity. They actually run quite a distance and slam against each other," says Tekalur, who compares this to American football players who run into each other during a game. "The difference is that many times the football players suffer concussions, but the animals don’t. Why is that?"

This research group relied on biological studies to learn how and why ramming occurs
and on high-speed motion analysis to predict the velocity of the ramming and the impact forces. With the help of Barbara Lundrigan, associate professor of zoology and curator of mammalogy and ornithology at the Michigan State University Museum, Tekalur acquired bighorn sheep horns. Then the horns were taken to the MSU Radiology Department for a CT scan.

“Other researchers who have done this have looked at the cross section, but they simplified everything into layers of solid materials. They did not pay attention to the fine microstructure.”

This of course was a labor-intensive project, but eventually everything was captured in a computer model. Tekalur credits a post-doc, Parimal Maity, who works with him, for the perseverance to complete this valuable project. “Now we have a model that has captured everything in terms of shape, geometry, microstructures, and the skull itself.” Researchers can look for answers using the computer model. Is it the horns or the horns combined with the sinus, or the layering in the horns that is important? What is the most important factor or combination of factors that transmits the energy away from the point of impact?

The researchers can see from the computer simulation that the sinus is directly connected to the horns, and Tekalur believes this aids in the transmission of the impact. “It acts like a spring that takes the impact down to the neck and does not affect the brain at all. Instead of suffering a concussion, the sheep goes on with its life.”

The next task of this research group is to figure out how that information could be of benefit for Army projects. “We believe we can offer good input on the design of helmets used by the military,” says Tekalur. While the current helmets are excellent in terms of ballistic resistance, if the solder is wearing the helmet and falls on it or is thrown to the ground, for example, the impact transfers to the brain. “How can we improve the helmet against this kind of blunt impact? That is what we are working on right now.”

There are companies that sell pads to insert into military helmets. However, the pads take up space in the helmet and there are problems with thermal transmission. Tekalur believes it might be possible to develop a single composite material with ingredients in it that can sustain the high speed impact of a bullet as well as blunt impact.

Another area of investigation for the biomimetics research group is the design aspects of layering in seashells. Seashells are made of a compound similar to chalk. If you take a piece of chalk and twist or bend it, it breaks almost immediately, by what is called brittle fracture. Imagine starting with a sheet of chalk, coating it with glue, and placing another sheet of chalk on top, and so on; now if you try to break it, it will not be so easy. The crack or fracture does not propagate so readily. It tends to divert into branches. “This crack branching is very beneficial. It is the microstructure that is giving it very good fracture toughness.” That had been well understood from previous studies, but Tekalur’s research group is creating a data base of layering morphology in 11 subspecies of seashells. Is the layering similar or different and what dominates the layering arrangement, and how can it be scaled up?

In order to do this, the researchers are relying on two techniques—scanning electron microscopy and nanoindentation (a means of testing the mechanical properties of materials)—to create maps of material properties and understand the logic of how they have evolved. “Then if we can make something similar to a seashell with the same qualities, could the army use this material as a panel or small building block for ballistic...
or impact protection," says Tekalur who hopes the result is a prototype material that mimics naturally observed phenomenon.

“This looks like the most basic research in the whole center, and it is because many aspects of nature have not been well understood by human beings, partly because we may not be looking at it from the right perspective. It is very tough for an engineer to understand all aspects of nature’s designs. So we are seeking the help of biologists here at MSU and other research centers to understand how these things work.”

**Self-Diagnostic Composites: Preventing catastrophic failures**

Think about your body’s nervous system. In simple terms, it is a network of nerves and sensors that can alert you when something is wrong with your body. Now apply that same sort of sensing network to composite vehicles. That’s the task of Soonsung Hong, assistant professor of mechanical engineering, who has oversight of the Self-Diagnostic Composites thrust area. The emphasis is on embedded sensor networks for structural
health monitoring and non-destructive inspection of composite vehicles.

“The unique part of the research here is that the emphasis is on vehicles made with composite materials,” says Hong, who worked with University Distinguished Professor Gary Cloud for his master’s degree, specializing in the application of laser optics in experimental solid mechanics. For his PhD, Hong studied fracture mechanics, using optical techniques, and as a postdoc, Hong conducted research on dynamic fracture phenomenon.

All of that background is useful in developing self-diagnostic techniques for what is the relatively new area of composite materials—and those composite materials are continually evolving.

“The Army has a different perspective than what might be applicable for a consumer vehicle,” says Hong. “If something goes wrong with a military vehicle while it is on a mission, you must be able to evaluate what is wrong without going outside of the vehicle. Do they abort the mission and go back or continue?” So sensors should be strategically placed in critical areas where structural integrity must be maintained or, alternatively, there may be a sensor network. In either case information can be sent to a remote location where command decisions can be made.

Hong and a group of researchers at the CVRC are currently developing fiber-optic sensors embedded in smart composites as well as laser-optic diagnostic tools to detect very small flaws in a composite structure. “We want to be able to make real-time updates on a structure’s reliability in order to make informed decisions about repair or replacement of composite components,” says Hong. “Ultimately we are striving to prevent catastrophic failures of composite structures in ground, air, and marine vehicles without costly tear-down inspections.”

**Composite Joining: Creativity with three-dimensional problems**

Joints, whether mechanical, adhesive, or hybrid, are critical to the performance of composite structures because they transfer high loads even as they create significant stress concentrations. That’s why structural failures usually originate at joints. So, research into composite joining is a significant thrust area of the CVRC.

This area utilizes the expertise of Gary Cloud, University Distinguished Professor of mechanical engineering, who has almost 30 years of research experience in this area, including extensive research for the U.S. Department of Defense (DOD). Cloud received the original funding that eventually lead to the funding for the CVRC. His experimental mechanics work in composite fasteners lays the groundwork for additional research in this area. Now, Gaetano Restivo, assistant professor of mechanical engineering and assistant director of the CVRC, brings a new experimental and computational mechanics perspective to this thrust area.

“Many composite fastening problems have arisen over the years as we have worked with the DOD on fasteners for land and marine vehicles
as well as aircraft,” says Cloud. “However, you see those same problems when working with fasteners for civilian projects, such as aircraft and consumer durable goods on everything from boats to refrigerators.”

Restivo agrees that composite fasteners offer unique problems. “There has been a lot of progress with experimental mechanics here at the center. However, many of the experimental methods are applied to two-dimensional problems. Joints are three-dimensional, and there is very little research on how to validate research on three-dimensional problems like composite joints.” While it is possible to do computer simulations, Restivo points out these simulations are not experimental, but rather numerical. “So you need to experiment to verify the results and at the same time you need to do experiments to get input for the computer simulations.”

A particular problem with joints as well as with composite materials, in general, is to be able to measure the stress and strain inside the structure or material. “One of the methods we use is an embedded optical fiber,” explains Restivo. The optical fiber includes a sensor, and it can be embedded in the joint or other component during manufacturing. “This allows us to measure the
strain profile through the thickness. So far to my knowledge, we are the only research group in the world to do this,” says Restivo. This allows researchers to validate 3-d computer models with experimental data from the surface and inside the material. “It is easy to compare the outside, but under normal operation, there is stress distribution inside as well, and we want to be able to know about this.” With this information it should be possible to tell when and if the component will crack or break and to compare various designs.

This research group is currently focusing its attention on bolted joints and on the parameters that affect the joint strength, including the use of inserts. “We want to look at how to improve the joint with a novel injected insert and compare it to traditional inserts. For the injected insert we use a specially designed bolt that we fabricate at the CVRC,” says Restivo. Researchers also look at how to modify the shape of the hole for better distribution of complex stresses.

Restivo, like many other researchers, dreams of things he would like to do, including a whole range of bonded, bolted connections. In addition to his research work and managing the day-to-day operations of the center, Restivo enjoys teaching and mentoring. He has three graduate students who work with him in this thrust area. One of his key philosophies is to enjoy the research. “If you cannot have fun while you are doing the research, then there is no point in it.”

Cloud takes the long-term perspective of all that has been accomplished, while still looking ahead to the future. “We have expanded our funding, facilities, and personnel, which has increased our capabilities and strengthened our intellectual base. In the future we have to continue this process of expanding our intellectual and physical resource capabilities. That means being aware of the needs of our customers. We hope that we help solve problems and that new and interesting research arises from those problems.”
It was the educational and research points of view that attracted Xinran (Sharon) Xiao to CVRC. “First I thought it was time to transfer my knowledge to the next generation of engineers, but I also realized my work on composites for my PhD and in R&D at General Motors could be beneficial to the CVRC,” says Xiao, an associate professor of mechanical engineering. She came to the CVRC in 2008 and like other CVRC researchers carries a full load of teaching assignments while supervising the Structural Integrity of Composites thrust area.

The aim of this thrust area is to evaluate and predict the fatigue life and durability of composite materials and components. Composite materials tend to possess good fatigue resistance. However, there is no one proven methodology for fatigue prediction of three-dimensional composite components. This has limited the applications of composites. “We have analyzed the capabilities and limitations of available modeling methodologies, and identified the requirements for a general composite fatigue model,” says Xiao. “Now we are developing a model based on numerical analysis to try to predict how long a
design will last. We also validate our computer models with actual tests in the lab and determine whether the results from tests on the computer model match the tests in the lab.” She is aided in her research in this area by Andrew Conway, a postdoc who works full-time at the CVRC. [See article on Conway on page 38.]

Fatigue predictions are difficult to determine, and a small sample of a composite material is not necessarily like the real structure. But Xiao and Conway see the possibilities and are developing their capacity for additional research. Some of the factors that have to be taken into consideration in the development of a conceptual fatigue model for predicting the life and durability of composites include understanding the complexities of existing damage, if any; varying environmental conditions; and uncertainty about the strain history of the composite or structure made with the composite. The ultimate goal is to help engineers design composite structures for vehicles that are more efficient—lighter, stronger, and longer lasting.

Xiao points out that one of the differences between the CVRC and other research centers is that the CVRC has a close relationship with its sponsor, TARDEC, and is focused on developing the technology to help TARDEC have better equipment and better strategies to protect soldiers. “We can gear our research in a certain direction that is applicable for a real need. I see that the technology and the application will come together and meet TARDEC’s needs, and then the results will benefit other sectors as well.”

**Design & Manufacture:**
**Enlarging CVRC’s scope**

If you build it, they will come. That saying about baseball fields can apply to the Design and Manufacture thrust area. It focuses on ensuring that the innovations generated by research at the...
CVRC can be converted into practical designs that can be manufactured at an acceptable cost. This ability, of course, increases the value of the work of the center and opens up new opportunities with current and future sponsors.

“Right now we are focused on selecting and developing processes that can be used to fabricate composite structures,” says Alfred Loos, professor of mechanical engineering. He has overall charge of the Design and Manufacture thrust area. One of the first steps for Loos was to establish laboratory capacity to actually build and fabricate materials at CVRC, and that is ongoing as this thrust area explores new ideas. The group also has the capacity to produce components needed for research in other thrust areas. The long-term goal is to be able to offer industry safe and affordable techniques for the manufacture of lightweight, durable, and safe vehicles.

“So what we are interested in are the best cost-effective approaches,” says Loos. “We are developing new types of composite materials for characterization.” There are various composite materials, including some that use uni-directional reinforcements, and others that use two-dimensional and even three-dimensional reinforcements. A new quasi 3-d composite is being developed at the center. Composites are also being fabricated with fibers coated with
nanoparticles. In addition, there are different forms of reinforcements as well as many chemical formulations for the binders or resins used with composite materials.

To achieve the goals of this thrust area, there is extensive use of science-based process simulation models and design by experiment. One of the processes being used is Vacuum Assisted Resin Transfer Molding (VARTM). Originally developed for the shipbuilding industry, the process has been modified for high performance structures. In the VARTM process, dry, net-shaped, fibrous textile reinforcements are infused with a liquid resin and cured in a single step to produce a structural part. Computer models of this process are being validated and eventually will aid in developing prototype fabrications.

In addition to being able to fabricate composite materials for outside sources, Loos wants to make sure that what he and his research group learns is transferred to the researchers in other thrust areas. “We believe this will stimulate cross-disciplinary projects and will help with the overall success of the center.”
POSTDOC’S EXPERTISE ADVANCES COMPOSITE KNOWLEDGE
Andrew Conway is a postdoc from York, England, who has been working at the CVRC for about a year. He is one of several postdocs who work at the center and are vital to the continuing research.

“I’m really interested in fiber reinforced composite materials because I believe they represent the next stage of materials design,” says Conway, who received his PhD from the University of Sheffield in England. “Rather than metals that are homogenous and have the same consistency all the way through, composites allow you to design for individual applications.”

Conway’s PhD research concentrated on analyzing stress in glass and other amorphous materials. He completed this research under Rachel Tomlinson who had worked under Eann Patterson, now director of the CVRC, when he was at the University of Sheffield. Through the course of his PhD studies, Conway met Patterson and was happy to accept a position at the CVRC.

“The problem with composites is that there are really no well-established methods for predicting how they will behave in practice over long periods of time,” says Conway, so he has accepted the challenge of developing methods and models that will predict fatigue in composite materials.

He is working closely with Xinran Xiao, mechanical engineering associate professor, who has overall responsibility for the Structural Integrity of Composites thrust area, which involves the evaluation and prediction of fatigue life and durability.

Currently Conway is creating computer simulations with the goal of applying existing fatigue techniques to composite materials, and then widening the scope so that the simulations can be applied to various loading situations.

“Ultimately, we would like to be able to say that after so many cycles under such and such a load, this material is going to fail. At the moment, that is not out there.” Because of this, engineers and designers using composite materials may use more than is needed or may continue to use components that are unsafe and prone to failure.

“The computer model or simulation allows you to look at every layer of the material and shows how it degrades over time,” says Conway, whose work is starting to produce results. “But we are at the critical point of trying to validate the computer models with experimental results.” A digital image correlation instrument, a servo-hydraulic loading machine, and other lab equipment will be used to do this. That’s the next important step of the process.

Conway sees the CVRC as a great research center that offers unique opportunities for investigations. “It has been a steep learning curve to understand the complexity of composite materials and to learn how to apply my knowledge of stress analysis in other materials to the field. Bringing all of this together has been interesting.”
GRADUATE STUDENTS HELP EXPAND RESEARCH
Michelle Raetz is one of numerous students who are working at the CVRC while completing graduate degrees. She is an example of how students can help expand the research and how the research provides career paths for them.

"Originally I considered going into accounting," says Raetz, who graduated with a BS degree in mechanical engineering with a biomedical concentration in 2009. It was her electrical engineering brother who steered her toward engineering. She decided on an ME major because “I am a person who has to see it to believe it. I can see a motor move or see how stress is distributed throughout an object.”

Raetz did research studying cartilage during the summer of 2008 with Roger Haut, University Distinguished Professor of mechanical engineering and osteopathic manipulative medicine. Arjun Tekalur, who heads up the Biomimetics thrust area at the CVRC, saw one of the posters Raetz developed from the research. He eventually hired her as a part-time researcher at the CVRC while she is working on a master’s degree, which she hopes to complete in December.

She currently is working with bovine femurs as part of the biomimetics focus on trying to use something from nature to help with the design process at the CVRC. "A lot of the research that has been done with bones is with static loads, and we want to better understand the fracture toughness of bones and the strengthening mechanisms for impact loads," says Raetz, who uses a drop-weight tower for many of her tests and photographs the tests using a high-speed camera in order to see the results, which happen faster than the human eye can see.

Bone is lightweight and strong for its density. It is capable of high loads and can withstand a level of impact. “We want to look at what strengthening mechanisms happen and see if we can incorporate this into man-made materials, like composites. It is not so much that we will use bone in a composite but how can we incorporate what we have learned.”

This summer to better understand how the Tank Automotive Research, Development, and Engineering Center (TARDEC) works and vice versa, Raetz and four other students who have worked at the CVRC have been paired with TARDEC engineers who have a similar knowledge base. They will work together at TARDEC headquarters in Warren, Michigan.

“This will help us incorporate more useful studies in our research and it is great work experience. It’s not just CVRC doing good research, but doing research that is useful to our sponsor, which in this case is TARDEC.”

Raetz likes doing useful research, but thinks she will try industry for a while after getting her master’s degree. "I like this experience at the CVRC because I can see where the research leads. I enjoy doing this."
The CVRC brings together an impressive group of researchers whose skills and expertise complement one another and allow many opportunities for collaborative research.

**Gary L. Cloud,** University Distinguished Professor of mechanical engineering and the first director of the CVRC; PhD Michigan State University. Cloud’s research includes experimental mechanics; optical techniques in strain measurement; and fracture, fasteners, and mechanics of composite materials. Cloud has worked with the military on composite materials for vehicles for more than 25 years. About 10 years ago, Cloud and Dahsin Liu received funding from the U.S. Army Tank Automotive Research, Development, and Engineering Center (TARDEC) in Warren, Michigan, for research specifically related to future combat systems for the Army. This original funding with TARDEC was instrumental in obtaining support for the CVRC. Cloud is a fellow of the Society for Experimental Mechanics and of the Institute of Physics. Cloud was the recipient of the M. M. Frocht Award from the Society of Experimental Mechanics in 1999. He was also president of the society and has served on many of its committees.

**Lawrence T. Drzal,** University Distinguished Professor of chemical engineering and materials science and director of MSU’s Composite Materials and Structures Center; PhD Case Western Reserve University. Drzal joined MSU from the U.S. Air Force Materials Laboratory at Wright Patterson Air Force Base. His research interests include adhesion, multifunctional composite materials, nanocomposites, nanostructured materials, and alternative energy storage. He was part of the founding group of the CVRC. He is a fellow of the American Society of Composites, the Society for the Advancement of Material and Process Engineering, the Society of Plastics Engineers, and the Adhesion Society.

**Soonsung Hong,** assistant professor of mechanical engineering; PhD Brown University. Hong was recruited to the CVRC from Sandia National Laboratories in Livermore, California, after completing a postdoc at California Institute of Technology. Hong received his MS degree
from MSU under the tutelage of Gary Cloud. Hong’s research interests include investigating fracture and failure of heterogeneous materials and structures by using full-field diagnostic tools coupled with inverse problem approaches.

**Dahsin Liu**, professor of mechanical engineering; PhD Virginia Polytechnic Institute and State University. Liu joined Gary Cloud in doing research for TARDEC and has continued working on TARDEC projects for more than a decade. Liu’s research interests are in impact dynamics of materials and structures, mechanics of composite materials, photomechanics, and nonlinear computational structures. Liu is a fellow of the American Society of Composites.

**Alfred Loos**, professor of mechanical engineering; PhD University of Michigan. He is a fellow of the American Society of Composites (ASC) and served as the organization’s president in 2008–09. Loos also received the ASC Outstanding Research Award in 2002. His research interests include heat transfer and flow phenomena in materials processing, mathematical modeling of manufacturing processes, mechanics of materials, finite element analysis, polymeric composite manufacturing, and mechanics of composite materials.

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