CAVS

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ANNUAL REPORT 2019

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DIRECTOR’S MESSAGE

I am excited about the accomplishments of our team during this past year. It is my great pleasure to report that during 2019, we received a record $33 million in awards. This represents the largest amount of award dollars in the history of CAVS and was the direct result of the hard work of our researchers, staff and students from all of our affiliated centers – CAVS-Research, CAVS-Extension, the Institute for Systems Engineering Research, and the Institute for Imaging and Analytical Technologies.

In this year’s annual report, we have chosen to focus several articles related to our work in mobility with applications varying from off-road to the football field. This year we have also made strategic investments in infrastructure to support the challenges related to off-road autonomy. These investments include our MAVS simulation platform, as well as acquiring 50 acres of wooded terrain and developing a vehicle proving ground. In addition, this publication highlights the work of our steel researchers that are supporting the NASA journey to MARS mission. Finally, this report highlights our ongoing work of supporting the advanced manufacturing technologies that make a difference in the lives of many people throughout the state of Mississippi.

We look forward to interacting with you throughout the upcoming year. Please follow us on Facebook, Twitter, Instagram and LinkedIn.

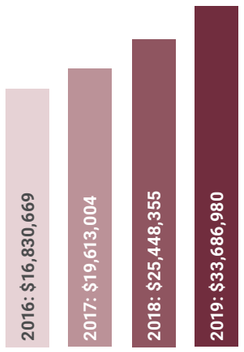
It is a great privilege for all of us at CAVS to serve Mississippi State University and our great state.

Hail State!

Clayton T. Walden
Executive Director
Center for Advanced Vehicular Systems

OUR VISION

The Center for Advanced Vehicular Systems (CAVS) will be a global leader in interdisciplinary education and research for the development of engineering solutions that expand and enhance the design, technology, production, and infrastructure necessary for sustainable mobility.



2016-2019
TOTAL AWARDS
$95,579,008

OUR MISSION

CAVS strives to be a world-class center of excellence for research, technology and education equipped to address engineering challenges facing US mobility industries. Utilizing high performance computational resources and state-of-the-art analytical tools for modeling, simulation and experimentation, CAVS will provide a distinctive interdisciplinary environment wherein next-generation engineers and scientists train alongside field experts to investigate, design and verify novel solutions in materials, propulsion and design for efficient human and vehicle mobility. Harnessing our broad impact research along with our state, national and international industrial alliances, CAVS will support economic development and outreach activities throughout the State of Mississippi.

CAVS RECEIVES $3 MILLION GRANT TO SUPPORT ARMY GROUND MOBILITY RESEARCH

BY JAMES CARSKADON | PHOTOGRAPHY BY BETH WYNN

Backed by a $3.08 million grant from the U.S. Army Engineer Research and Development Center (ERDC), Mississippi State University will support the Army's ground mobility research in several key areas.

Led by MSU's Center for Advanced Vehicular Systems, the project addresses areas such as remote sensing on autonomous vehicles, additive manufacturing, human performance and modeling and simulation development powered by the university's High Performance Computing Collaboratory. The research will be among the first to utilize the Proving Ground, a 50-acre property recently acquired by CAVS to advance the center's off-road autonomous vehicle research.

"This is a really exciting project with ERDC and a great continuation of our off-road autonomous mobility research, much of which is done in support of the Army," said Clay Walden, CAVS executive director. "In addition, we are developing a digital twin of the Proving Ground, which will allow us to develop autonomous environmental sensing algorithms and then test them on the physical property. Autonomous vehicles are dependent upon being able to accurately sense their environment in order to execute a particular mission."

The ground mobility research will involve collaboration among faculty from across MSU's Bagley College of Engineering. The project's technical focus areas for the project include tire and terrain interactions, powertrain modeling, sensor-physics and fusion, dust simulation, materials for design, and human fatigue. By creating advanced ground vehicle performance simulations and computing techniques, the research will create better assessments for manned and unmanned tactical vehicles.

The project is managed by ERDC's Geotechnical and Structures Laboratory. Robert D. Moser, former senior scientific technical manager for the ERDC lab and director of the Institute for Systems Engineering Research, said the new partnership builds upon MSU and ERDC's strong history of innovative research and development programs and will support the Army's future battlefield mobility needs.

"This new effort, supported through ERDC's Military Engineering applied research program, will develop advanced capabilities for autonomy, mobility and materials manufacturing that are strongly aligned with ERDC science and technology efforts under the Next Generation Combat Vehicle modernization priority of the Army Futures Command," Moser said. "Our ERDC team looks forward to continuing this strong collaboration and the outcomes of the proposed joint research activities with MSU and the CAVS team."

Based in Vicksburg, ERDC is the research unit of the U.S. Army Corps of Engineers and is one of the premier engineering and scientific research organizations in the world. MSU and ERDC have a long-standing research relationship and have collaborated on dozens of projects. In 2014, the two partnered to create the Institute for Systems Engineering Research, also housed in Vicksburg.

"Our relationship has grown because of our commonality with high-performance computing," Walden said. "Because we have our High Performance Computing Center here, we have researchers that are very experienced in developing highly granular physics-based codes on our HPC system. We have students here working on ERDC-funded projects who often take the next natural step and go to work for them. ERDC is a tremendous asset for the state of Mississippi, and we're proud to supply the next generation of these researchers."

ERDC is a diverse research organization with approximately 2,000 employees operating more than $1 billion in world class facilities at seven laboratories. Its annual program exceeds $1 billion as it supports the Department of Defense and other agencies in military and civilian projects. For more information, visit www.erdc.usace.army.mil.

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CAVS STEEL AND ADDITIVE MANUFACTURING RESEARCHERS HELP NASA PREPARE FOR MISSIONS BEYOND EARTH

BY KATHERINE CLARKE AND DIANE GODWIN | PHOTOGRAPHY BY BETH WYNN

One of the most prestigious scientific communities is working with researchers at Mississippi State's CAVS Steel Research Center and Additive Manufacturing Laboratory to explore a new and unique method of taking advantage of the famous lunar and red planet's rustiness.

NASA's Marshall Space Flight Center has selected the CAVS researchers to study how to utilize space-based materials. The conversation and research around making products from resources found on other planets is not a novel idea. It's a challenge that scientists have been working on for years to find a solution to lighten payloads to make long term space exploration more affordable. In fact, at the start of this particular partnership, the intentions were a little more conventional and far more earthbound.

Initially, the CAVS researchers were investigating earth applications for NASA developed technology. NASA researchers wanted to transfer their technology of life support systems to earth applications where the systems could reduce the carbon footprint of the steel production process instead of the space application of converting the carbon dioxide output of astronauts into oxygen, water and sequestered carbon.

Blast furnaces are used in steel production to convert iron ore into metallic iron. In this production process, large amounts of carbon dioxide and carbon monoxide are produced. The goal of this first project was to see if the utilization of the NASA technology could effectively convert those carbon gases from the furnaces to produce more environmentally friendly results. In their efforts to meet the goal of lowering the carbon footprint, the CAVS researchers showed the process could reduce emissions while producing carbon by-product that was suitable for steelmaking operations.

"For example, there is red iron ore in the soil of Mars. If we can find a way to extract the metallic iron and mix it with the carbon by-product used in the previous project, we have steel. So that means NASA doesn't need to haul steel components, panels and tools into space. We're thinking NASA can make these materials on Mars."

Haley Doude, an assistant research professor with CAVS, is an expert in steel and additive manufacturing, "We learned that using the carbon waste by-product as an alloying element in steel produced steel equivalent to the quality and durability of steel made from the traditional process."

This project led to discussions about how to use this same process and technology on future space exploration missions.

"For example, there is red iron ore in the soil of Mars. If we can find a way to extract the metallic iron and mix it with the carbon by-product used in the previous project, we have steel," Hongjoo Rhee, a CAVS associate director for engineering mechanics and materials science thrust and mechanical engineering associate professor, explained. "So that means NASA doesn't need to haul steel components, panels and tools into space. We're thinking NASA can make these materials on Mars."

NASA MSFC initiated a second project with CAVS, an exploration of how to use in-situ resources like iron oxide to produce metallic alloys.

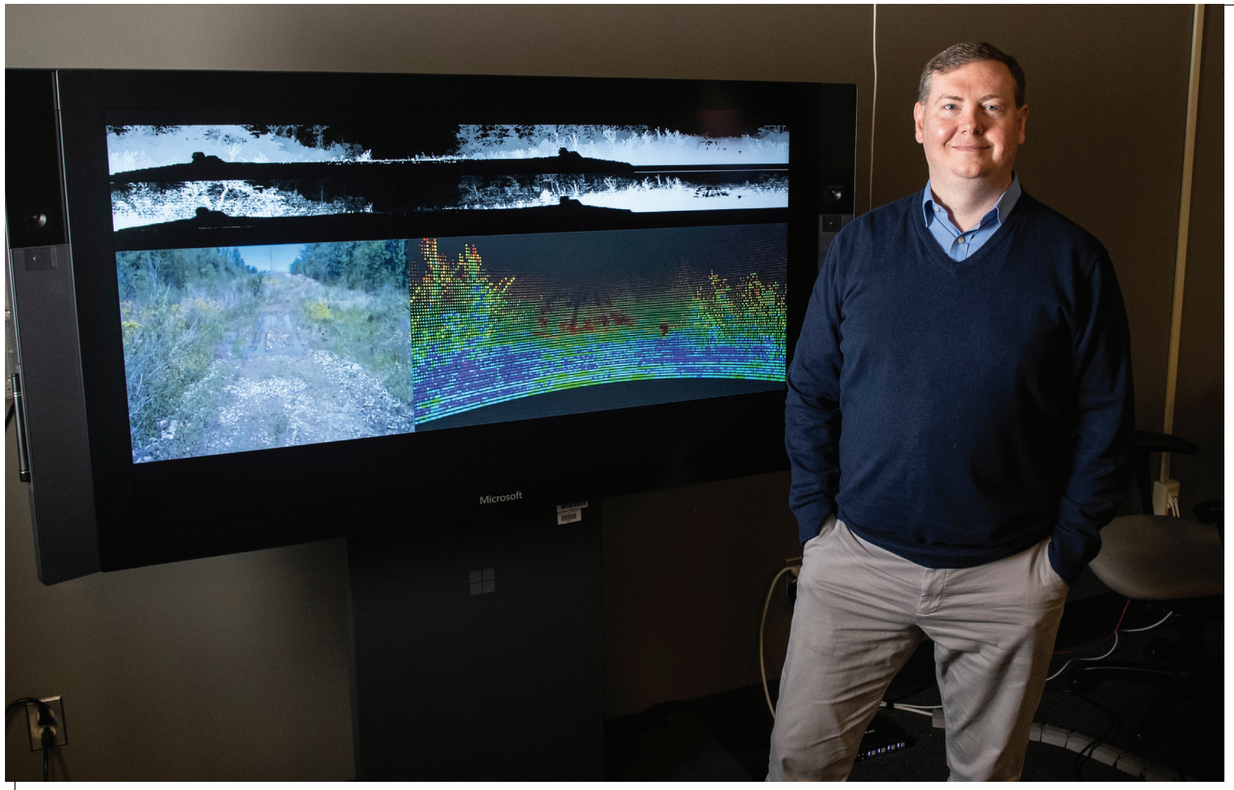
"Iron oxide is one of the most plentiful oxides present on the surface of Mars. We are looking at iron oxide first because iron is the main ingredient of steel and steel is a mainstay of construction of buildings and machines," Doude explained.

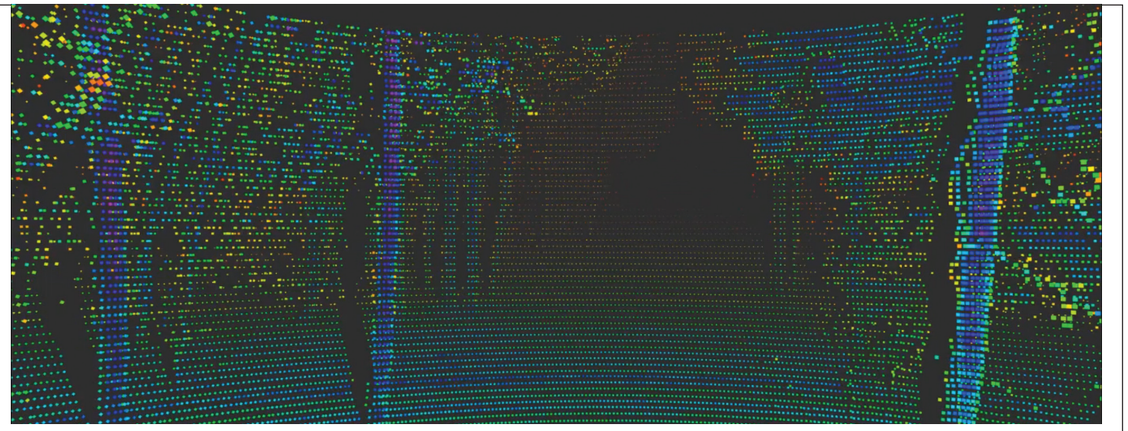
Graduate student, Blake Stewart, is heavily involved in the project's next step of combining the isolated iron from the iron oxide with the carbon by-products from NASA to produce samples of ductile iron. This simplified process of casting is more suited to Mars because of the lower energy requirements.

"By using ductile iron, we can avoid using an extended heat treatment because all you have to do is cast it and there isn't any post processing," Stewart said.

Using the CAVS' Gleeble thermomechanical simulator, the team has the capability to rapidly create small samples of cast iron to view on the microstructural level and compare with commercially available ductile iron. Ultimately, the team's role in the project is to determine if NASA technology can be used to produce pure elements from extraterrestrial soil simulants that can then be used for building or mechanical materials production.

"One of the most prestigious scientific agencies in the world asked us to work with them because we are hands-on through the entire project cycle from concept to completion," Rhee said. "We have the equipment, infrastructure, the knowledge, the university support and the ability to optimize certain process or component as needed to find solutions to some of the world's most pressing engineering issues."





MSU RESEARCH PROFESSOR TAKING LEADERSHIP ROLE IN NATO TEAMS FOCUSED ON OFF-ROAD AUTONOMY

BY JAMES CARSKADON | PHOTOGRAPHY BY LOGAN KIRKLAND

A Mississippi State research professor is helping lead international efforts to advance off-road autonomous vehicle capabilities.

Daniel Carruth, associate director for advanced vehicle systems at MSU's Center for Advanced Vehicular Systems, is part of a North Atlantic Treaty Organization research task group examining autonomous vehicle modeling and simulation tools. The group will work through 2023 to determine standards for modeling and simulation tools, allowing military and research personnel to more effectively develop algorithms that will allow autonomous vehicles to navigate off-road and unknown terrain.

The research task group is part of the NATO Science and Technology Organization's applied vehicle technology panel. Carruth said the ongoing work with NATO brings together advances in virtual environment and mobility modeling.

"With mobility modeling, it was mostly about dynamics between the tire/track and the terrain it's driving on," Carruth said. "With autonomy, you have more questions about the environment and need to account for things such as trees, people, animals and other obstacles. We're trying to take two domains that have advanced a lot over the last 10 or 15 years and bring them together to improve off-road vehicles."

At CAVS, researchers use the MSU Autonomous Vehicle Simulator to test navigation software in virtual environments. Recently, MSU acquired 50 acres adjacent to CAVS to also test autonomous vehicles in a variety of physical off-road environments. The center recently was awarded over $3 million from the U.S. Army Engineer Research and Development Center to support the Army's ground mobility research.

"Off-road autonomy is a new space that's being created, and we're right there at the forefront," said CAVS Executive Director Clay Walden. "It's invaluable to have Dr. Carruth being involved with the NATO working group, which allows us to better see the vision for future military research and puts our work in mobility on the international stage."

Carruth led two NATO sub-groups in 2019—one focused on virtual environments and sensors, and another focused on benchmarking modeling and simulation tools. He said the benchmarking group will help determine gaps in current simulation software. The group plans to test autonomous vehicles in the real world and compare their performance to the modeling tools. Starting this year, Carruth is leading the organization of a competition designed to compare performance of different autonomous vehicle modeling and simulation tools.

"Once we can show that the modeling and simulation tools work, we can help set standards for them," Carruth said.

Paramsothy Jayakumar, co-chair of the NATO task group and U.S. Army Combat Capabilities Development Command Ground Vehicle Systems Center senior technical expert, said it is important for NATO to be able to reliably judge the performance and applicability of autonomous technologies in military contexts.

"It is critical to set up standard methods and tools for assessing military autonomous vehicles and be able to confirm their ability to fulfill strategic maneuvers and wider operations in a quantitative manner, especially since the military context provides extremely challenging and rough situations," Jayakumar said.

"Given that this activity is likely to result in a long-lasting methodology and/or tool similar to the current NATO Reference Mobility Model (NRMM), which is widely used in military acquisitions by NATO member nations, such development will be a valuable investment for the future. The leadership and contributions provided by MSU's Dr. Daniel Carruth are extremely critical to the success of the NATO Task Group."

Carruth's research interests include modeling and simulation of human interaction with autonomous vehicles, as well as the study of human task performance in law enforcement, military and industrial work. He earned his doctorate in psychology from MSU, in addition to a bachelor's in degree in computer science.

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MSU DEBUTS CUSTOM-BUILT MASCOT VEHICLE

BY AMANDA MEELER | PHOTOGRAPHY BY MSU OFFICE OF PUBLIC AFFAIRS

During the 2019 Mississippi State Bulldogs home opener on September 7, traditional football festivities included the unveiling of a new pregame attraction, crafted from hands of the university's own students and engineers.

With thousands of cowbells ringing and kick-off time approaching, MSU's mascot Bully took the field atop the maroon and white Bully Car, debuting a comprehensive update of the university mascot's official ride. Emblazoned with MSU logos and the "Hail State" motto, the self-propelled vehicle was a significant upgrade from the previous doghouse structure, which had to be pulled on-field by multiple spirit squad members.

Born from an in-class project for a Bagley College of Engineering automotive engineering course, the vehicle transformation was initially funded through Bagley College's Department of Mechanical Engineering. Led by Professor Andrea Strzelec, MSU undergraduate engineering students spent the 2019 spring semester designing the concept for Bully's new vehicle. Top designs were presented to members of MSU's athletic department, who then chose the vehicle design that would lead the Bulldogs on-field each game.

After design selection, raw material lists were generated and additional features, such as underglow lighting and a backup camera, were integrated into the chosen design plan. As the semester came to a close, the preparation process then shifted into CAVS' state-of-the-art engine lab for construction.

Built from a go-kart frame, the monster truck-inspired vehicle underwent three months of rigorous fabrication funded by CAVS, including welding efforts from Taylor Machine, as well as problem-shooting and safety evaluations. Student lead John Thomas Kerr, accompanied by research engineer Michael Gibson, led a team of student researchers and engineers in utilizing CAVS' unique on-site capabilities in both advanced vehicles and materials science, to transform the frame into a functional enclosed vehicle.

> "Even though in the grand scale of engineering it's a small project, my belief is that this experience has made this team even more prepared to work as real-world engineers."

Constant collaboration with athletic department marketing members, as well as MSU's head cheer coach and turf management crew, ensured that the mascot could ride atop the vehicle safely, without causing any damage to the award-winning turf located within Davis Wade Stadium.

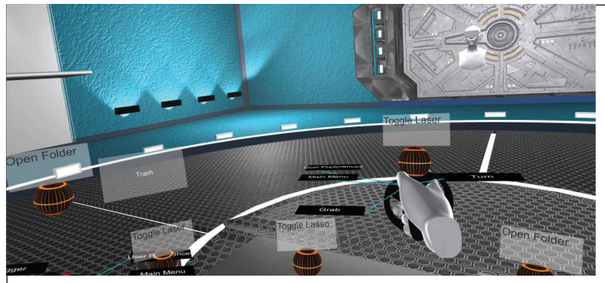
"We were able to inspect the equipment that the grounds team uses and evaluate the contact pressure of the tires to make sure that our vehicle didn't create issues on the grounds that they work so hard to perfect," said Gibson.

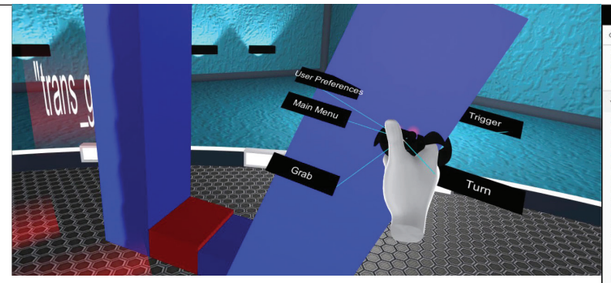
These specific needs of the athletic department paired with a quick production deadline simulated a realistic product life cycle with a tangible customer, from conception to a finished deliverable.

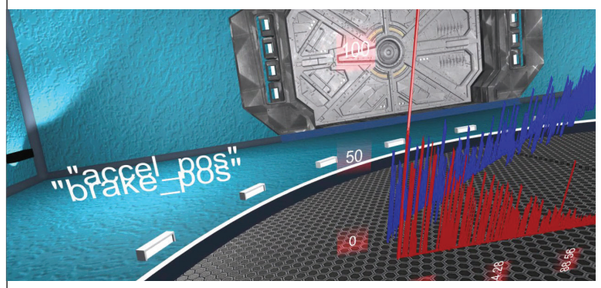
"Even though in the grand scale of engineering it's a small project, my belief is that this experience has made this team even more prepared to work as real-world engineers," said Gibson.

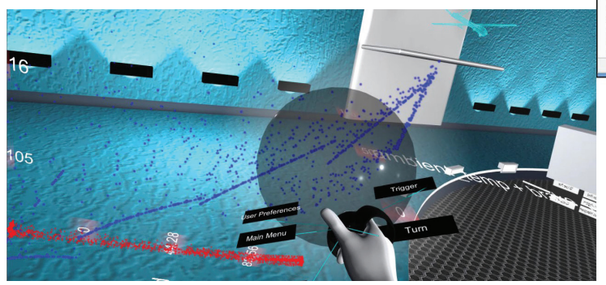
While those three months required fulltime attention, much like a fulltime workforce, the CAVS team produced an impressive vehicle; it also provided the young engineers with hands-on manufacturability experience and a lot of fun, according to CAVS engineer Brian Sprow.

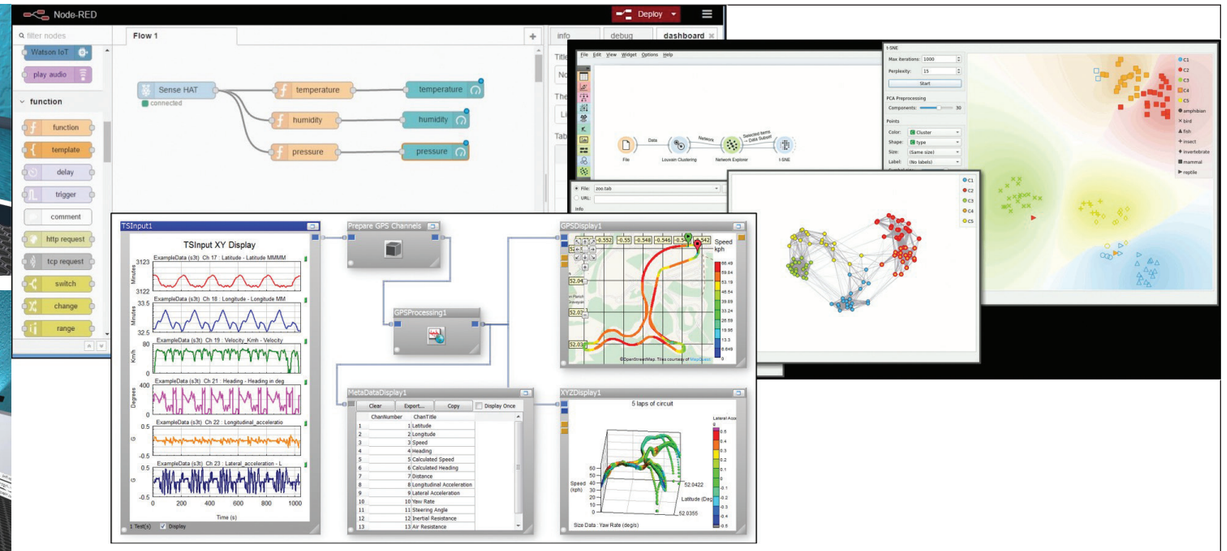
"This is something that I was excited to come to work every day and work on," said Sprow. "Being able to be a part of creating something that so many people see has been such a rewarding experience for everyone on our team."











USING IMMERSIVE ANALYTICS TO BETTER INTERACT WITH DATA

BY DANIELLE HAMILTON | GRAPHICS BY PARKER JONES

Immersive analytics (IA) is gaining relevance and necessity in various fields due to its ability to remove barriers between researchers and their data. IA has emerged from the disciplines of computer graphics; virtual, augmented and mixed reality; data analytics; and human-computer interaction to support the understanding of data and decision-making.

For instance, surgeons utilize augmented reality to interact with anatomically correct models of their patients to explore diagnoses and treatment options. Further, disaster management teams enlist mixed reality to overlay printed topographical models with holographic displays to better visualize the terrain of their local neighborhoods in order to better facilitate rescue efforts. Finally, IA allows scientists and engineers to analyze, manipulate and annotate large amounts of data in closely visualized spaces, as the immersion provides a more natural way for them to explore the data.

The Immersive Visualization Exploratory Engine (IVEE) is a virtual reality module being used at the Institute for Systems Engineering Research. The ISER is collaborating with the U.S. Army Engineer Research and Development Center on their data science research efforts. IVEE was created as a data analytics visualization system that provides graphical visual elements and allows users to explore multiple data sets within the same immersive work environment for cross-data evaluation. The ISER's goal is to investigate the benefits of using immersive analytics to explore large data sets.

"IVEE is basically a graphing system geared toward engineers and scientists," Parker Jones, an ISER research analyst, explained. "We have recreated some of the visualizations available in other software packages and scientific calculators. The main difference with IVEE is that the user is no longer limited by their screen space and three-dimensional graphs are displayed stereoscopically so the user no longer must interpret the projection of the third dimension. We are experimenting with different controls to create a user interface that incorporates more gestures to speed up the data wrangling and visualization process. Eventually, we will conduct experiments to measure if there are any benefits to using this system over traditional methods."

In order to achieve this immersive state by which data can be explored, Jones explained that his team uses the Oculus Rift and Unity 3-D. The Oculus Rift is a virtual reality system which functions as a wearable headset and allows users to experience a virtual environment. Unity 3-D simulation software allows users to run numerous simulations more rapidly than real-time to test, train and validate their projects at scale.

This effort relies upon several fields of study, such as human factors, data analytics, software design and development, physics, mathematics, and industrial engineering, in order to create the finished product. Jones stated that ultimately, the team's goal is "…to create a tool that improves the exploratory analytics process for big data sets and lowers the skill gap so that smaller groups or less experienced individuals can benefit from more data collection and analysis."

As data becomes more complex and larger in size, IA systems such as IVEE equip researchers with the ability to become more deeply engaged with the analysis and decision-making processes. This interdisciplinary collaboration not only yields innovative solutions to critical challenges, but it can also save lives.

VEPRO SYSTEM TO MANAGE AND ANALYZE DATA FOR MILITARY VEHICLES

BY DANIELLE HAMILTON | GRAPHICS BY SARA FULLER

The Institute for Systems Engineering Research is working with the Engineer Research and Development Center to develop a software system to receive, store, extract, and analyze data collected from military vehicles in the field. The Vehicle Performance Reliability and Operations Program (VePRO), is designed to manage and analyze data for a minimum of 20,000 vehicles at one time.

"The objective is to be able to identify anomalies in the performance of military vehicles," David Allen, an ISER research engineer explained. "The analysis and reporting of this information will assist army personnel with mission decisions as it provides the ability to predict mechanical conditions that could lead to vehicle failure."

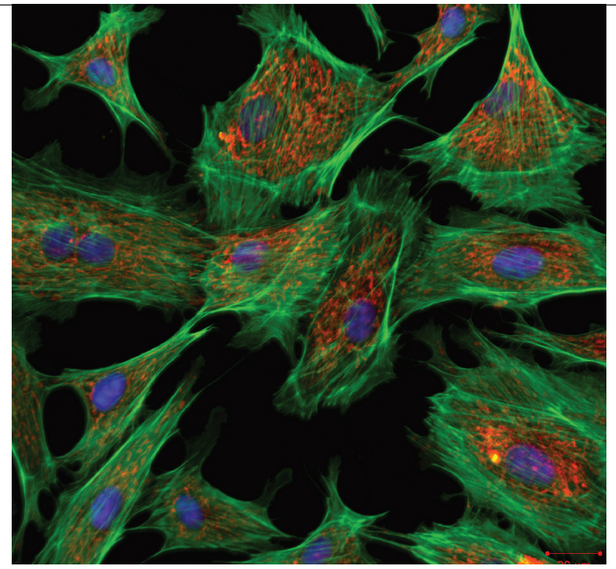
Collection, storage and reporting of the data are some of the research phases for the VePRO project. Allen is working on the visualization and analysis aspects. Allen detailed the inability of desktop or laptop computers to handle the required number of vehicles. Therefore, Mississippi State University's HPCs (High Performance Computers) are being used to perform this research.

"The HPCs provide the ability to process large data sets in short amounts of time. Once the data has been computed on the HPC, we create simulations to visualize the vehicles' performance changes in real time," Allen said.

Unity 3-D is the software Allen uses to generate the digital models for the visualization process. Unity allows Allen to produce two and three-dimensional visualizations of the data, which will provide a convenient method for users to detect abnormalities in vehicle performance.

The Markov chain is another simulation technique Allen uses to analyze data from the vehicles. A Markov chain is a mathematical model which predicts a future state with a matrix of transition probabilities from a preceding state. Markov chains are largely used in a variety of fields, from biology to manufacturing. This model is also enlisted by other industries such as engineering to distinguish abnormal patterns in data based upon its past interactions. Researchers like Allen analyze those patterns from the past to predict future trends and the risks that may accompany them.

Technological advancements are the gateway to innovation and discovery for projects such as VePRO. Allen and his colleagues are merging their skills in mathematics, engineering and computer science with modern research to offer solutions to these complex challenges. A better understanding of the operational usage data which forms the VePRO system is critical to improve readiness and to reduce danger to the warfighter. These efforts are a clear indication that VePRO is being remarkably primed to offer enduring prognostic solutions for the vast fleet of military vehicles.



I2AT LETS RESEARCHERS DISCOVER NEW INSIGHTS AT THE MICROWORLD LEVEL

BY ZACH ROWLAND | PHOTOGRAPHY BY ZACH ROWLAND

The Institute for Imaging and Analytical Technologies (I²AT) continues to move forward with the construction of a new facility for the relocation and consolidation of high-resolution imaging, advanced analytical technologies managed by I2AT and the highly qualified staff. The facility, located in the Thad Cochran Research Technology and Economic Development Park, will be a world-class facility that provides capabilities and expertise to support education, advanced research, industry outreach and economic development opportunities.

Currently, I2AT manages instruments located in various locations on campus and strives to make utilization easy for customers. One measure that has streamlined operations is an online system that allows users to view availability of the instruments and make reservations that are convenient for them. I2AT's current operations are during normal business hours, but the new facility will allow experienced users the ability to access instruments 24/7. The concentration of equipment and trained personnel, in a single facility, provides that synergistic utilization of equipment and personnel, fostering interdisciplinary interaction and promoting university-industry partnerships and furthering resources for economic development.

The instruments and personnel Mississippi State University has invested in for over 30 years have created a state-of-the-art resource to enable extraordinary imaging and advanced analysis via electron and atomic force microscopy (SEM, TEM, AFM), X-ray computed tomography (XRCT), advanced Solid Analyzer (DMA) and other advanced technologies to gather data on and analyze a wide range of materials or substances.

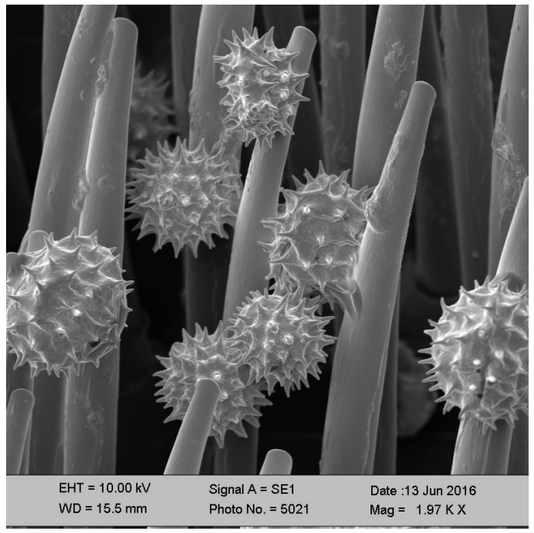
I2AT's electron, confocal, and optical microscopes provide imaging capabilities and yield valuable information in support of biological, bioengineering, forestry, entomology and other areas of study at the University. Electron microscopes are used to investigate the ultrastructure of a wide range of biological and inorganic specimens, including microorganisms, cells, insects, metals, crystals, micro-electronics and much more. Industrially, electron microscopes are often used for quality control and failure analysis. It is possible to magnify samples over 1,000,000 times to help determine what is really happening.

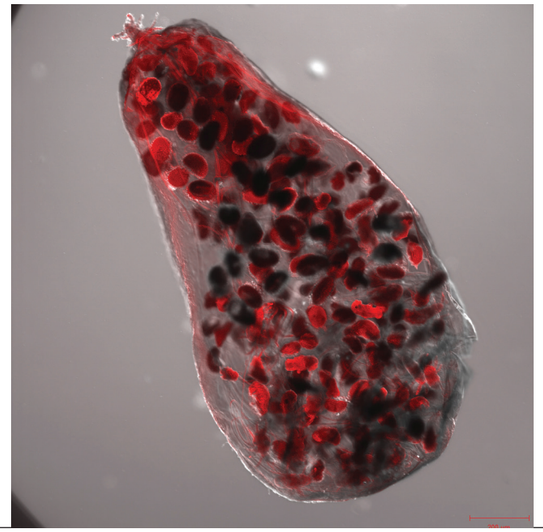
Using X-ray technologies [X-ray Computed Tomography] we look inside materials to see voids and material distribution, review mechanical devices to determine damage during manufacturing, and analyze cross-sections of springs to examine heat treatment processes and advanced forestry products to understand the extent of termite damage. With X-ray Diffractometry, we can analyze a material revealing the structure near the surface, in-plane and normal geometry phase identification, quantitative analysis, lattice parameter refinement, crystallite size, structure refinement, density, roughness and multilayer thicknesses (from reflectivity geometries), and depth-controlled phase identification.

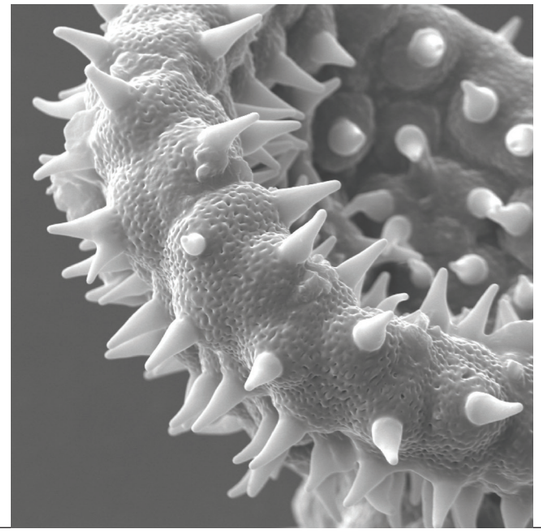
Models and simulations are vital tools researchers use to understand and predict how things will behave or react. Microanalytic systems applied to a wide spectrum of materials and substances supply the data used to drive the simulations. The advanced instruments show elemental composition, surface roughness, hardness, plasticity, stress reaction, grain size and much more. Incorporating this data into the models improves the simulations and allows engineers and scientists to better understand performance and predict outcomes.

I2AT has a proven track record in the support of industry and University research activity. The resulting consolidation of existing equipment and ongoing acquisition of new instruments provide greater opportunities for meeting the region's increasing need of research and industrial growth. With images approaching the atomistic level, I2AT has been able to support the development of new and exciting alloys for lightweight automotive applications by providing technologies to allow researchers to determine material characteristics and composition critical to performance.

Outside of traditional research efforts, I2AT provides classroom education and outreach projects which support K-12, undergraduate and graduate level students. The ability to expose young minds to a world few can experience is priceless. These students can see the micro-world up close, which allows their imaginations to run wild and drives a desire to explore and investigate the world around them.







RESEARCHERS TAKE OFF-ROAD AUTONOMOUS RESEARCH ‘OFF-THE-BEATEN PATH’

WRITTEN BY DIANE GODWIN AND KATHERINE CLARKE | GRAPHICS BY CHRIS GOODIN

Researchers at CAVS are designing a revolutionary software program to address the unique learning needs of off-road, self-driving vehicles. MAVS, short for MSU Autonomous Vehicle Simulator, allows researchers to regularly experiment with and test the software of off-road, self-driving vehicles in virtual settings.

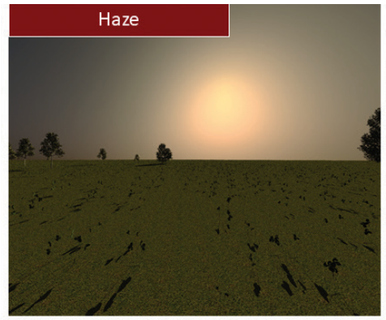
Off-road autonomous vehicle experts state that less than one percent of the Earth’s surface is paved. Not surprisingly, developing autonomous vehicles to navigate these more remote areas are of most interest to the U.S. Army. Yet, most of the motoring world’s research is related to getting self-driving cars onto the road, where they have the advantage of a map that informs the artificial intelligence about location that connects to GPS to guide the way on a smooth paved surface. For autonomous off-road driving, it is a much more difficult situation, because remote areas lack the advantage of having a chart of the geographic area. In addition, off-road autonomous vehicles also have to recognize, adjust and navigate alternate terrains.

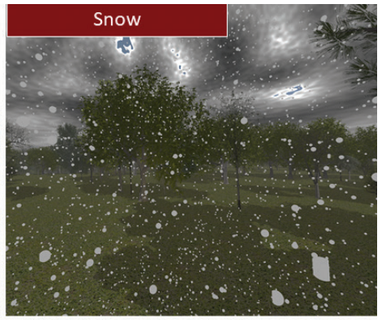
With the Department of Defense being one of their primary clients, CAVS is putting the focus back on autonomous off-road vehicles. Chris Goodin, an assistant research professor and specialist in autonomous vehicle simulation, is creating and programming MAVS software to teach off-road autonomous vehicles how to react and deal with different weather situations, alternate terrains and surface conditions like fog, ice, snow, rain, dirt, mud and rock.

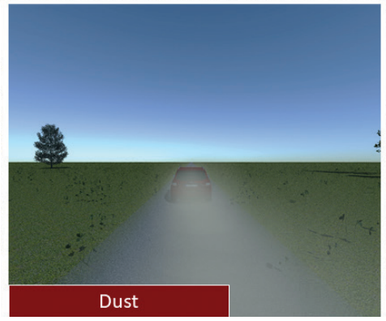
“We are also writing the algorithms to train the off-road vehicle to overcome obstacles of infinite shape and size and to recognize changes in geographic gradient like rock crawls and water surface hazards,” Goodin said.

Historically, in order to train the kind of machine learning algorithm used in autonomous machines, a person would need to perform the time-consuming process of entering and creating a labeled training data set, labeling a series of images into a database for the machine to learn from. MAVS can perform this task automatically, reducing an estimated six weeks of work into one day. And that’s not the only way it can save time.

“Practically speaking, when developing autonomous vehicles, you’re often working with a limited amount of funding in a limited time window. At the same time, you’re developing the hardware of the vehicle, the software team needs to be working too. But typically, they can’t test anything until the vehicle is ready. For example, in a three-year program, by the time the car is ready, the programmers may only have one year to really test the software,” explains Goodin, “With a simulator like MAVS, they can begin testing immediately.”







The MAVS machine-learning techniques also allow testing to proceed throughout an entire eight-hour workday and even over a weekend, no matter the weather conditions, which eliminates rushing the research process, as well as reduces time and the cost of hauling the vehicle to and from the testing grounds. Apart from the logistics side of testing, this also makes an enormous difference in how researchers are able to test the safety of autonomous vehicles.

“We’re programming the MAVS algorithms to include far more sophisticated and vast amounts of data into its simulations to ensure the autonomy is learning what we want it to learn and can handle any weather condition or terrain,” Goodin explained. “We’re even considering having the camera angles, infrared and lidar it uses turn upside down or sideways at times, so that if a vehicle were to tip, it would still know, for example, what a tree is regardless of orientation.”

The CAVS researchers are taking up the challenge of training algorithms to respond to circumstances that might not happen, are difficult to predict and complex to create. For instance, testing the vehicle in sporadic virtual situations that include natural disasters such as mud and rockslides, flooding and wildfires. The virtual environment gets even more real, with the ability to help the vehicle identify a location based on the simulation’s accurate locations of 9,000 stars.

What most sets MAVS apart from other simulators like it are its speed and its realistic physics. Using MSU’s High Performance Computing Collaboratory’s supercomputers, MAVS can run up to 100 different cars through simulations at once. And while most other autonomy simulators are built based on video game software, MAVS is not.

“Many simulators have amazing visuals but fall short when it comes to the vehicle and terrain interactions. Gaming systems also aren’t able to account for GPS or lidar correctly,” explains Goodin, “MAVS however is designed specifically with the physics of the real world in mind and to account for cameras, GPS and lidar all together.”

It is also designed to allow anyone to learn it. While the core capability of MAVS is written in the C++ software language, the interface of MAVS uses a code language called Python, an open source language known for being intuitive and easy to use for its interface. This allows students at MSU, as well as the Department of Defense, to use MAVS as a non-commercial open source, provided that they request and obtain access from CAVS. For the students currently using it, it plays a valuable role in developing their research and theses on autonomy. For the DoD, it allows them to benefit from MAVS even when working with classified information they can’t share with their CAVS partners. For Goodin, the benefits of sharing this resource are already clear.

“This model of making MAVS free is providing us with tons of projects which use its code in various applications and the great thing about having so many users, with students especially, is they immediately find ways to break the software. From this, we’ve already found numerous ways to improve MAVS. It just keeps getting better.”

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IMPACTING MISSISSIPPI'S MANUFACTURERS: HELPING COMPANIES EXPAND AND GROW

WRITTEN BY DEBBIE MILLER | PHOTOGRAPHY SUBMITTED | GRAPHIC BY CHASE SAUNDERS

The Center for Advanced Vehicular Systems–Extension (CAVS-E) has been a leader at Mississippi State University in developing industry partnerships within the state of Mississippi. Headquartered in Canton, Mississippi, with additional offices located in Starkville and Biloxi, CAVS-E is an engineering outreach organization with an extensive record of serving the manufacturing and health care industries in the state. CAVS-E helps meet the needs of Mississippi's manufacturers by providing technical expertise in the areas of advanced engineering tools, professional development training, technical assistance and applied research. Professional development courses include Lean, Six Sigma, Simulation Modeling and Analysis using FlexSim, Facilitation and Team Building, Statistical Process Control, 8D Problem Solving and many other topics, including a Health-care Lean Certificate Program. Engineering and technical assistance services include Site Master Planning, Virtual Reality, Solid Modeling and Design, Reverse Engineering using SolidWorks, 3-D Laser Scanning and 3-D Printing. From an applied research perspective, CAVS-E and MSU's Institute of Systems Engineering Research collaboratively developed a Manufacturability Assessment Knowledge-based Evaluation tool to help guide manufacturers in the analysis of improvements on the manufacturability of product designs. Other areas of CAVS-E's assistance include Logistics and Transportation, K-12 Outreach and the Mississippi-Made Catalog, which is designed to showcase and promote products made in the state.

Over the years, substantial automotive industry projects have been conducted with companies such as Nissan, Faurecia, Navistar Defense, Tower Automotive, Johnson Controls, and Systems Electro-Coating. CAVS-E is an affiliate center for the Mississippi Manufacturing Association-Manufacturing Extension Partnership. One of its first successes was to assist Navistar Defense in the effort to launch a new Mine Resistance Ambush Protected (MRAP) military vehicle, by taking the lead role in the manufacturing system design and implementing the overall production system. CAVS-E was recognized through the University Economic Development Association's 2010 National Award for Excellence in Business Assistance and Entrepreneurship for its significant contribution to the successful launch of Navistar Defense's West Point, Mississippi, armored vehicle plant. This work is an exceptional example of successful deployment of best practices within a strategic automotive manufacturing facility and is recognized by National Institute of Standards Manufacturing Extension Partnership as its first ever national case study. Mississippi State University's Executive Vice President and Provost, David Shaw, said, "…the Navistar Defense project is a stellar example of how the university works with industry to create sustained economic benefits, stimulating hundreds of jobs…"

Blue Ridge Foods and Lynx Grills are just two of the many companies that the CAVS-E team assisted this past year. The Blue Ridge Foods project in Greenwood, Mississippi, included the layout design of a facility to handle their unique needs of beef processing and distribution. The new facility provides additional resources for the company to expand distribution and reach suppliers located west of the Mississippi River. In

Brian Waldrop (center), President of Blue Ridge Beef Greenwood; Billy Peacock (left), MSU CAVS-E Senior Project Manager; and Glenn Dennis (right), MSU CAVS-E Director

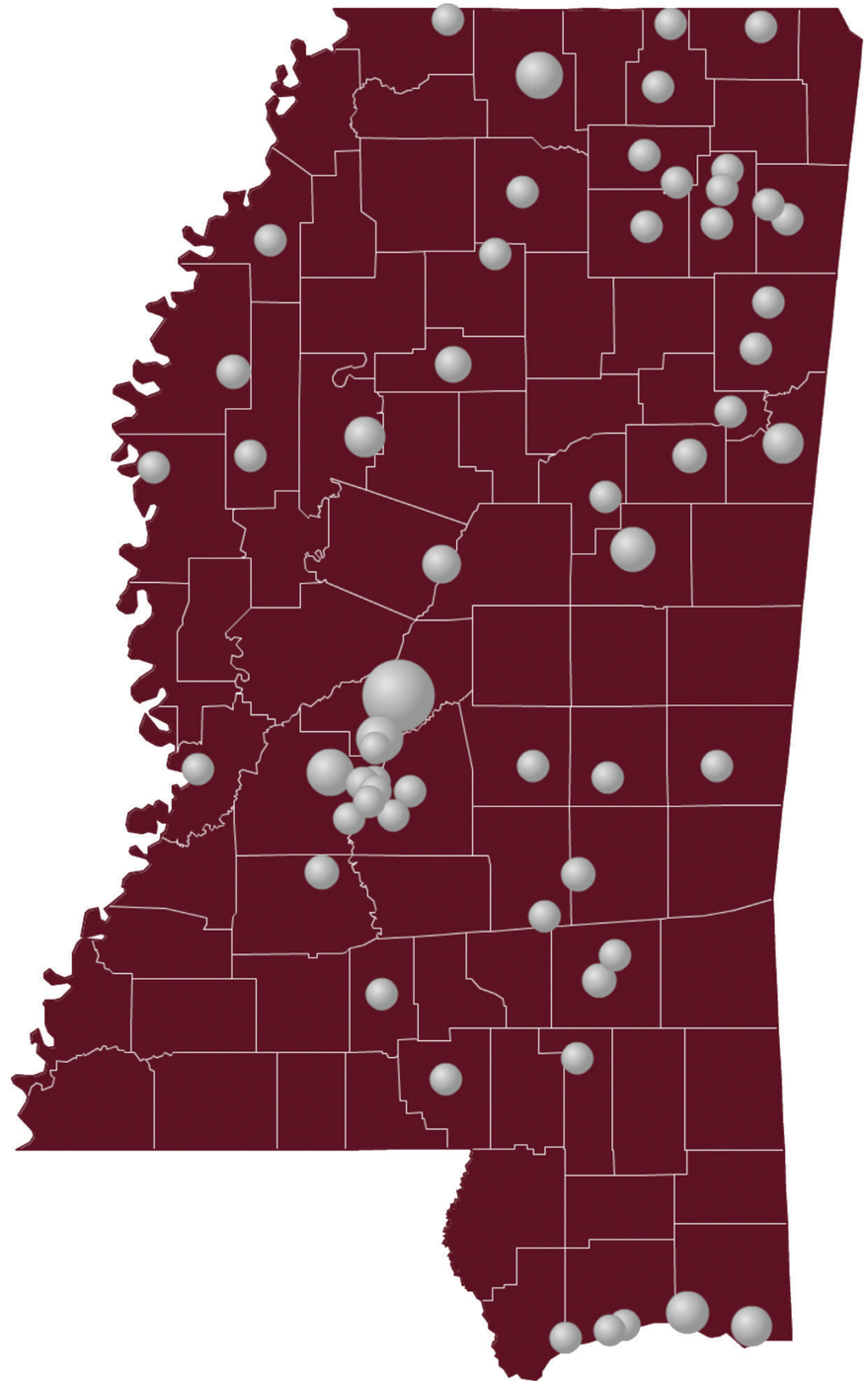
another project, a team from CAVS-E helped to expand Viking Range's operations to include Lynx Grills, one of the most highly recognized appliance brands of luxury grills and outdoor kitchens. After conducting a feasibility study of relocating the company from California to Mississippi, the CAVS-E team created a conceptual layout for the space requirements of the new facility, a detailed layout plan for the plant, a project schedule for operations, and a staffing plan for the manufacturing plant.

Other manufacturers in Mississippi also have benefited from CAVS-E's programs and services. Hol-Mac, one of the largest manufacturers of refuse and recycling equipment in the U.S. and located in Bay Springs, incorporated a new bumper design into its product line that was modified, analyzed and tested by a CAVS/CAVS-E team; at that time, Hol-Mac was the only company in its market with a bumper meeting DOT guidelines. Another significant project involved Taylor Power Systems; a manufacturer of large portable power systems located in Clinton. General Manager of Taylor Power Systems, Steve Duke, said, "Through the efforts of the MSU CAVS-E team, our ability to increase production of generators for the intermodal market has more than doubled."

Companies across the state seek out CAVS-E to identify opportunities for expansion and growth. Through strategy development and planning, these companies have utilized CAVS-E's resources to help diversify their product lines, broaden their supply base, and continue to create more jobs. The breadth of CAVS-E's impact is felt from ship building on the Mississippi coast, to tooling and appliance companies in the Mississippi Delta, and to aerospace companies in North Mississippi. Since its inception in 2003, CAVS-E has created or retained more than 5,800 jobs with a total economic impact of $6.19 billion, signifying how CAVS Extension can assist in business improvements that lead to future growth in Mississippi.

The following map illustrates the economic impact of CAVS-E on companies throughout the state over the last four years, 2016 – 2019.

2016 - 2019 ECONOMIC IMPACT	
Increased/Retained Sales	$163,526,268
Cost Savings/Avoidance	$29,798,788
Total Company Investments	$44,267,362
Jobs Created	1,345



ACCOMPLISHMENTS

CAVS TEAM HITS THE TARGET ON HISTORICAL AXE DESIGN

WRITTEN BY DIANE GODWIN | PHOTOGRAPHY SUBMITTED

A group of CAVS graduate students took a page out of Viking history while crafting a steel-cast axe, making competition judges take notice.

Hosted by the Steel Founders' Society of America, the Cast in Steel Competition challenged universities to design, cast and sharpen a Viking axe, using modern tools like alloy development and selection, computer modeling and additive manufacturing.

The competition saw 20 axe submissions from 17 university teams across the nation. Technical reports and performance tests on edge retention and sharpness were evaluated by a panel of judges, including Ben Abbot, a two-time winner of History Channel's "Forged in Fire" and current guest judge on the show.

MSU's submission, which was noted as one of Abbot's favorite axes, was named the "Most Historically Accurate Viking Axe." While measuring 30 inches in length with a 9-inch cutting edge, the axe only weighed 2.86 pounds.

CAVS REPRESENTED AT MSU'S ORED AWARDS

WRITTEN BY DIANE GODWIN | PHOTOGRAPHY BY LOGAN KIRKLAND

Hosted by the Vice President for Research and Economic Development and the Vice President for Agriculture, Forestry and Veterinary Medicine, the annual ORED awards banquet celebrates those making significant research contributions to Mississippi's premier research university.
Multiple CAVS faculty, staff and student researchers received recognition, including:

- Linkan Bian, ORED Faculty Research Award
- Michael Gibson, ORED Research Support Staff Award
- Yucheng Liu, William L. Giles Faculty Leadership Program
- Ge He, Mechanical Engineering Ph.D. student, ORED Graduate Research Award
- Paulino "PJ" Jarquin, Biomedical Engineering student, ORED Undergraduate Research Award
- Raj Prabhu, patent recognition for "Shock-Wave Mitigating Helmets"
- Wilburn Whittington and Andrew Oppedal, patent recognition for "Serpentine Load Monitoring Apparatus"

Pictured from Left to Right, Interim Vice President, Division of Agriculture, Forestry and Veterinary Medicine and Interim MAFES Director, Reuben Moore; MSU President, Mark Keenum; Will Whittington, CAVS research engineer, Andrew Oppedal, CAVS research engineer; Bagley College of Engineering Dean, Jason Keith, and VP of ORED, David Shaw.

Pictured from Left to Right, David Shaw, VP of ORED; MSU President Mark Keenum; Ge He, ME Ph.D. student; Michael Gibson, CAVS research support; Paulino "PJ" Jarquin, BE student, Linkan Bian, ISE associate professor, and Bagley College of Engineering Dean, Jason Keith. Not pictured, Raj Prabhu, associate director for CAVS Computational Engineering Mechanics Thrust Division.

NSF AND BOEING RECOGNIZE PERSONS' RESEARCH, 'IMPROVING ATHLETIC SAFETY' AS PART OF WOMEN IN LEADERSHIP INITIATIVES

WRITTEN BY DIANE GODWIN | PHOTOGRAPHY BY AMANDA MEELER

The National Science Foundation and The Boeing Company funded six traineeships to develop STEM knowledge base, skills, and competencies of students after a career break. One of those traineeships was awarded to CAVS researcher, Karen Persons, for improving safety in athletics.

At CAVS she performs fatigue testing on the stretch sensor-based foot-ankle wearable sensor solution, to determine the life cycle of the future smart sock that will be produced by the Athlete Engineering program for use by student-athletes. In addition, the NFL invited her to collaborate with researchers on advancing the safety of the game as a result of her work of testing football helmet safety.

Karen Persons plans to use her background in biological sciences and biomedical engineering to expand the use of the soft robotic stretch sensors from human to animal gait. This work will add a new division and research thrust to the Athlete Engineering research group. Persons is working on her second Ph.D. in Biomedical Engineering. Her first Ph.D. was in Biology.

CAVS STUDENT RESEARCHER IS IN ELITE COMPANY AS A RECIPIENT OF THE PRESTIGIOUS ASTRONAUT SCHOLARSHIP

WRITTEN BY DIANE GODWIN | PHOTOGRAPHY BY MEGAN BEAN

Senior mechanical engineering major Jacob Easley is one of just 52 students nationwide named to the 2019 Astronaut Scholar Class by the Astronaut Scholarship Foundation. The nonprofit was established in 1984 by former NASA astronauts to provide scholarships to the nation's brightest college students in science, technology, engineering and mathematics.

Easley said, "My biggest thanks go to Dr. Haley Doude, my research adviser at the Center for Advanced Vehicular Systems. She has pushed me to be the most creative and innovative student I can be by supporting my research projects and ideas."

Easley attended the Astronaut Scholarship Foundation Innovators Gala in Washington, D.C. Easley is the third MSU student to earn the Astronaut Scholarship. Alumnus Phong Ly received the accolade last year as a senior civil engineering major.

The program recognizes outstanding college juniors and seniors who are pursuing a degree in STEM. Recipients can earn a merit-based $10,000 scholarship and may participate in the ASF's Innovative Leadership Mentor Program.

FINANCIAL HIGHLIGHTS ANALYSIS

CAVS-R • CAVS-E • ISER • I2AT

TOTAL CAVS PROPOSALS 2016-2019

2016	$42,929,941
2017	$129,658,763
2018	$29,803,120
2019	$35,833,495

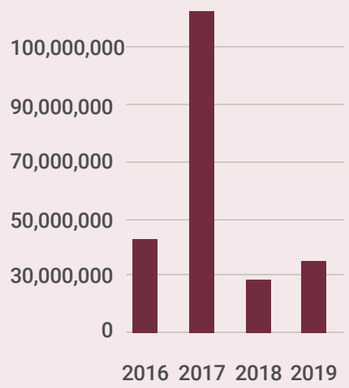
TOTAL CAVS AWARDS 2016-2019

2016	$16,830,669
2017	$19,613,004
2018	$25,448,355
2019	$33,686,980

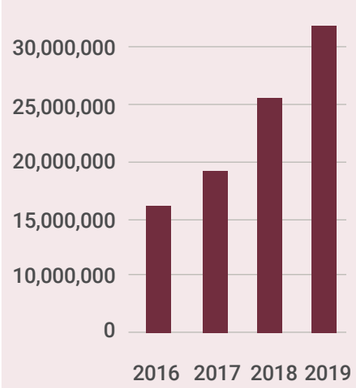
TOTAL CAVS RESEARCH EXPENDITURES 2016-2019

2016	$20,410,848
2017	$24,891,284
2018	$25,802,557
2019	*$31,844,198

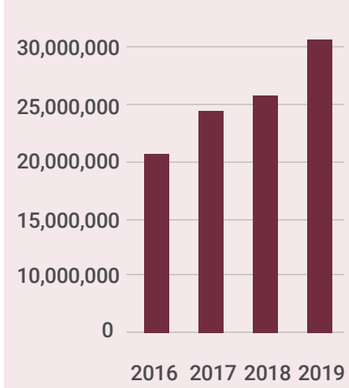
TOTAL CAVS PROPOSALS 2016 - 2019



TOTAL CAVS AWARDS 2016- 2019



TOTAL CAVS RESEARCH EXPENDITURES 2016 - 2019



*Does not include state appropriation dollars

CAVS 2019 TOP TWEETS

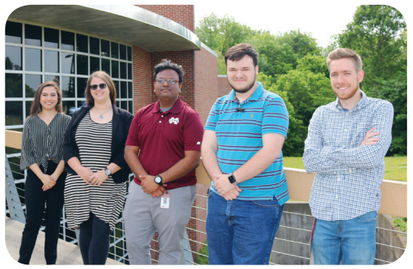
Center for Advanced Vehicular Systems - CAVS @CAVS_MSSTATE Jun 17

Meet the CAVS Crew: Elaine Turner

Administrative assistant Elaine Turner has a heart for people, which is continually demonstrated through her work with the Advanced Vehicle Systems (AVS) and Human Factors groups at CAVS.

Center for Advanced Vehicular Systems - CAVS @CAVS_MSSTATE May 3

To all of our @msstate students who are turning the tassel this weekend, we are so proud of you! The long hours, hard work and valuable contributions to our research efforts at CAVS have not gone unnoticed. Whether you're sticking around CAVS after graduation, or starting a new venture, we wish you the best on your future endeavors! #HailState #WeRingTrue



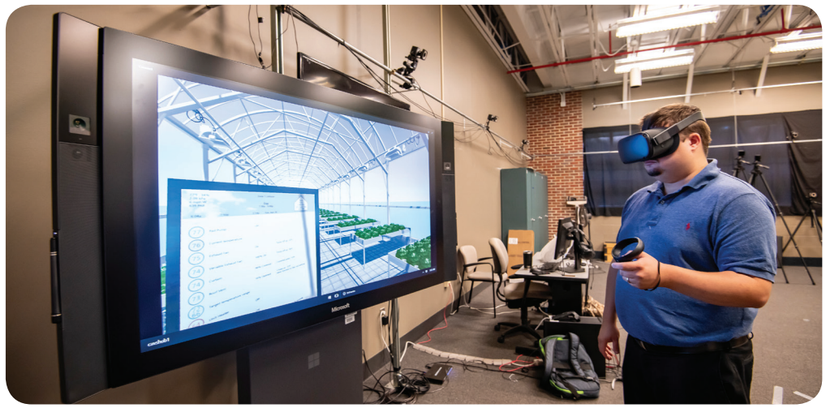

Center for Advanced Vehicular Systems - CAVS @CAVS_MSSTATE Jul 5

From America → Australia!

CAVS researchers recently traveled alongside teams from @ArmyERDC and the U.S. Naval Research Laboratory to collect and analyze Australian soils data for quantifying military maneuvers.

Center for Advanced Vehicular Systems - CAVS @CAVS_MSSTATE Jul 22

CAVS researchers are helping @msstate students master environmental controls through hands-on technology, cultivating a crossover between virtual reality and agriculture training.



Center for Advanced Vehicular Systems - CAVS @CAVS_MSSTATE Dec 18

One of the country's top supercomputers can now be found in Starkville, Mississippi. CAVS research will utilize the capabilities provided by the new Orion system at @msstate's @HPC2MSU. #STATEPROUD

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