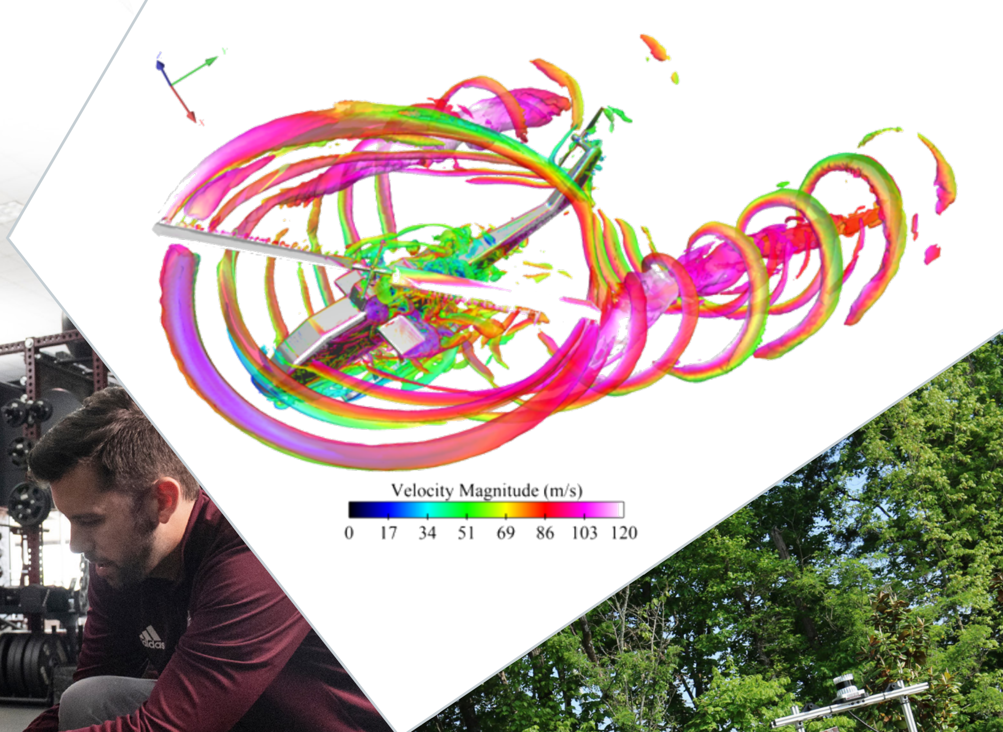


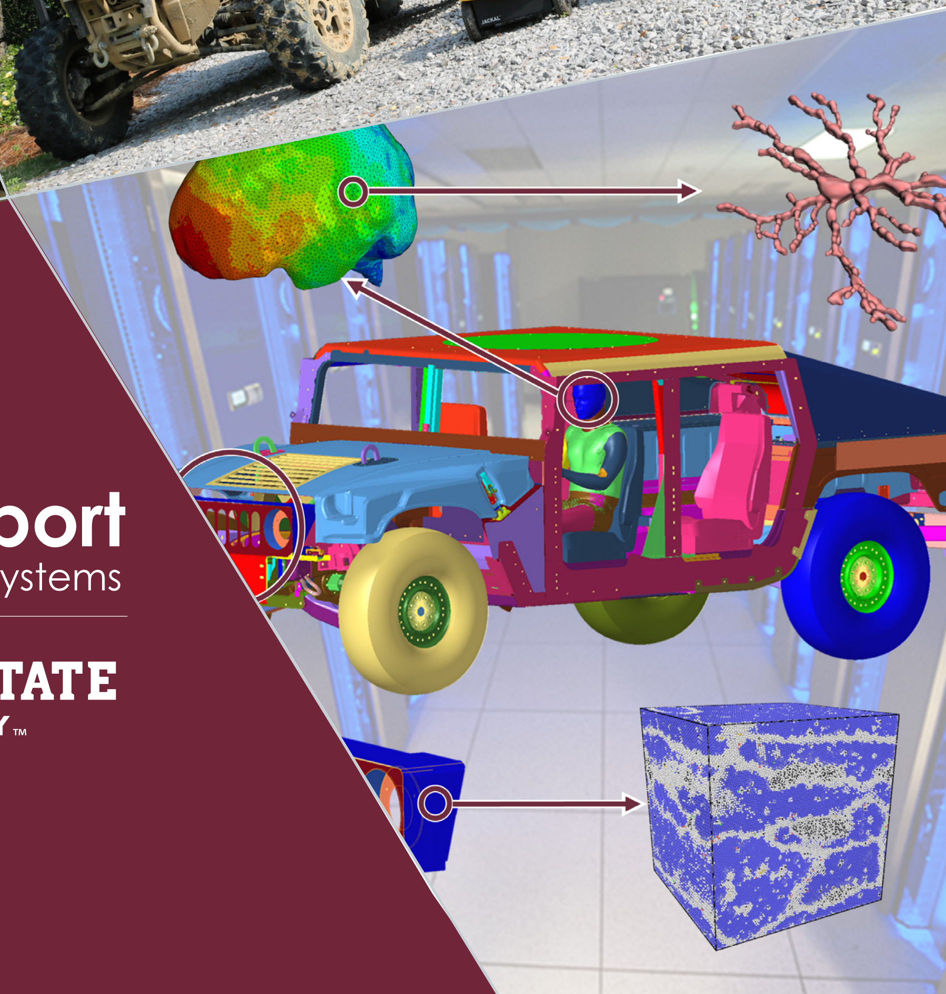

# CAVS Annual Report

## Center for Advanced Vehicular Systems

MISSISSIPPI STATE UNIVERSITY™

www.cavs.msstate.edu

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CAVS is an HPC2 member institute. CAVS is a member of MSU's Institute for Computational Research in Engineering and Science.

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CAVS

# FROM THE DIRECTOR

## Clay Walden / CAVS Executive Director

***"Over the course of the year, we have continued to work with some of our major partners and customers including the U.S. Army's Engineer Research and Development Center, Army Research Laboratory, Ground Vehicle Systems Center, Los Alamos National Lab, NASA, Nissan, Toyota, AM General, General Dynamics, Milwaukee Tools, and Steel Dynamics. These customers come to us with unique needs and goals, which has helped our leadership team establish CAVS as a multidisciplinary research organization."***

It has been my pleasure to lead the CAVS organization during this year. The four operating units of CAVS, CAVS Research, CAVS Extension, Institute for Systems Engineering, and the Institute for Imaging and Analytical Technologies highlight the diversity that is required to serve our variety of customers and their specific needs. This year's annual report captures this diversity by highlighting some of our widely varying projects and research efforts.

Over the course of the year, we have continued to work with some of our major partners and customers including the U.S. Army's Engineer Research and Development Center, Army Research Laboratory, Ground Vehicle Systems Center, Los Alamos National Lab, NASA, Nissan, Toyota, AM General, General Dynamics, Milwaukee Tools, and Steel Dynamics. These customers come to us with unique needs and goals, which has helped our leadership team establish CAVS as a multidisciplinary research organization with faculty engagement from over 40 faculty members from each of the 8 academic departments within the Bagley College of Engineering.

In addition, these faculty members directed the research of 77 graduate students, with well over half being PhD students.  The vast majority of these students are preparing applications-oriented dissertations and theses. These students are working on some of our nation's most challenging engineering problems, and we are proud of how they have risen to the occasion.

It's also been an exciting year serving the manufacturers around the state. As described in this report, CAVS Extension reported completing 80 projects with over 50 unique companies located all over the state. These clients have reported a total economic impact of over $170 million with over 500 jobs either created or retained.

Please keep track of our progress by following us on social media (Facebook, Twitter, and LinkedIn).

I am grateful to all those that contributed to the efforts throughout the year.

Clay T. Walden

Clayton T. Walden, Ph.D.
Executive Director
Center for Advanced Vehicular Systems



MISSISSIPPI STATE UNIVERSITY™
CENTER FOR ADVANCED
VEHICULAR SYSTEMS


## 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.

## 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.


**2018-2021**
TOTAL AWARDS
**$113,179,764**

# CAVS PARTNERS WITH ERDC TO LEAD $7.8 MILLION U.S. DEPARTMENT OF DEFENSE PROJECT TO ADVANCE MILITARY ENGINEERING CAPABILITIES

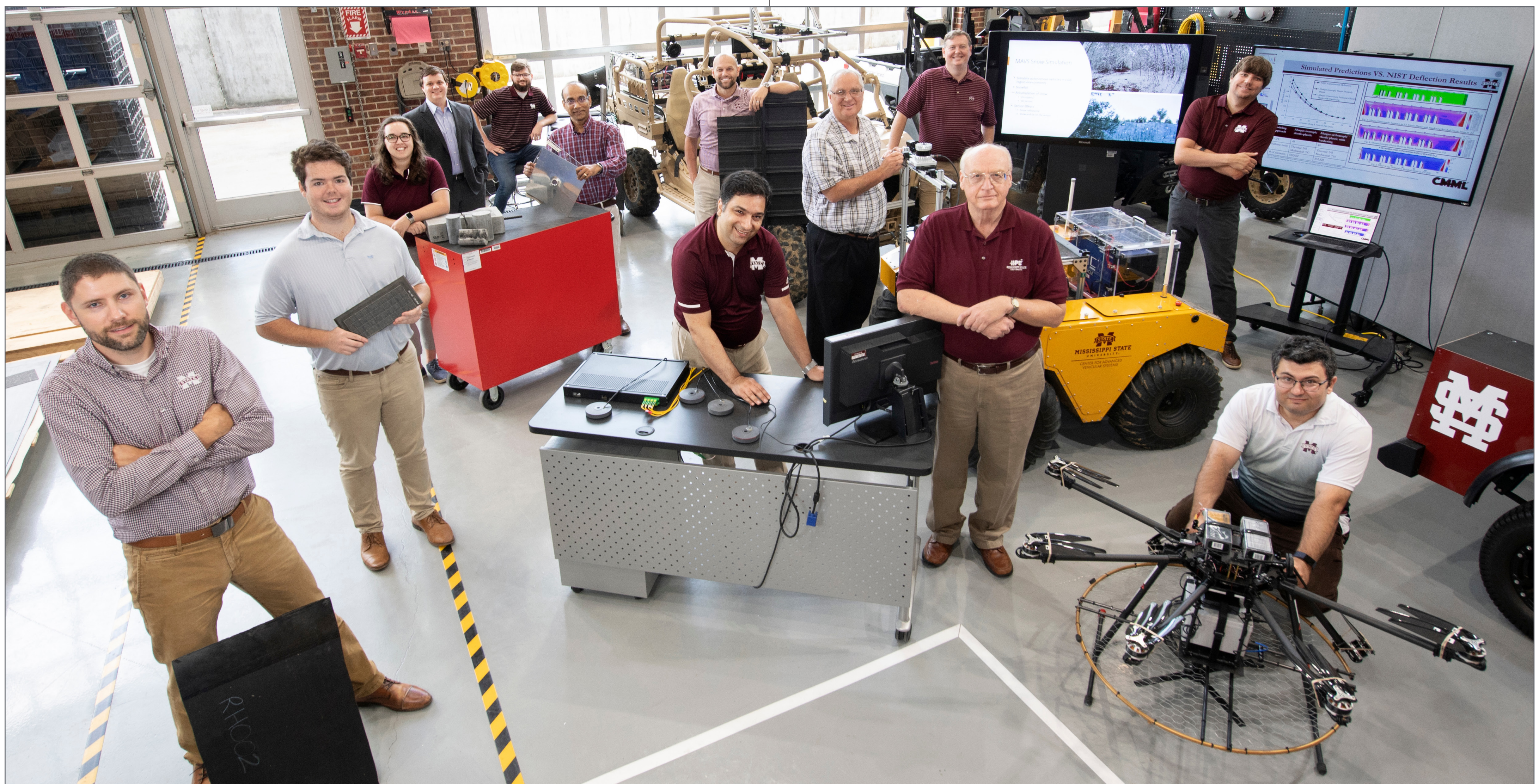
*By James Carskadon*

The multidisciplinary project is led by MSU's Center for Advanced Vehicular Systems and funded through the U.S. Army Engineer Research and Development Center in Vicksburg. Utilizing a wide-range of university research expertise, the three-year project focuses on remote sensing, developing the next generation of materials for force protection, force projection technologies and mobility modeling and simulation.

The research aims to develop new technologies to enhance ERDC's military engineering and force protection capabilities in support of national defense. Technical focus areas include sensor analytics and remote sensing, as well as the use of geo-materials, advanced, high-strength steels and future technologies for force protection and projection. MSU researchers will develop advanced materials and systems, garnering new insights into the protection capabilities of next generation materials used in military efforts. They also will conduct autonomous vehicle modeling and simulation for navigation in cold environments.

The 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 the 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. Both have extensive high-performance computing capabilities, which helps advance innovation and opportunities in Mississippi.




A MULTIDISCIPLINARY TEAM OF RESEARCHERS AT MISSISSIPPI STATE, LED BY THE UNIVERSITY'S CENTER FOR ADVANCED VEHICULAR SYSTEMS, IS WORKING ON A $7.8 MILLION PROJECT TO ENHANCE MILITARY ENGINEERING CAPABILITIES FOR THE U.S. DEPARTMENT OF DEFENSE.

In addition to CAVS personnel, principal investigators on the project represent multiple departments in MSU's James Worth Bagley College of Engineering, as well as its Advanced Composites Institute.

The new 3-year program, established as a result of MSU and ERDC's long-standing partnership, advances new materials, manufacturing, mobility, and modeling and simulation capabilities that will continue to transition advanced technologies in support of the Army's modernization priorities.

The ERDC is headquartered in Vicksburg, Mississippi, along with four of its seven laboratories: the Coastal and Hydraulics; Geotechnical and Structures; Environmental; and Information Technology laboratories. Additional laboratories include the Construction Engineering Research Laboratory in Champaign, Illinois; Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire; and the Geospatial Research Laboratory in Alexandria, Virginia. Its annual program exceeds $1 billion as it supports the Department of Defense and other agencies in military and civilian projects.

To learn more about the ERDC and its research and development activities, please visit https://www.erdc.usace.army.mil. For more information on CAVS, please visit https://cavs.msstate.edu.

# CROSS-COLLEGE COLLABORATION CREATES VR INITIATIVE TO HELP FUTURE GROWERS NAVIGATE HIGH RISK AG ENTERPRISE



*By Vanessa Beeson*

CHRISTOPHER HUDSON, CAVS RESEARCH ENGINEER, TESTS THE LATEST VERSION OF THE FGT VIRTUAL GREENHOUSE APPLICATION.

Learning how to maneuver the high-risk aspects of the agriculture industry is taking on a new meaning for MSU students through 3-D virtual reality and the university's Future Growers Technology Initiative.

A one-of-a-kind simulated greenhouse, nearing completion and developed through the initiative's cross-college collaboration efforts, not only will give future farmers a safer state-of-the-art tool, but will redefine the time it takes to analyze crop production. The project is a partnership of MSU's Department of Plant and Soil Sciences in the College of Agriculture and Life Sciences and CAVS.

Funded through a federal grant, the principal investigator is Amelia Fox, clinical professor in plant and soil sciences, who said that unlike any conventional greenhouse on campus, this controlled condition system in 3-D will give students complete access to helm the environmental controls.

The team's prototype is being refined by Pulseworks, LLC, a world leader in motion simulators. Richard Harkess, a professor of plant and soil sciences, will use the technology in his greenhouse crops production course.

Students will grow spinach, lettuce and tomatoes in a virtual greenhouse from seed to market, setting up environmental controls and then checking on, feeding and watering their crops, while troubleshooting insect and disease pressure and more. The team also will test the efficacy of the system by measuring how much the students learn from it.

While students grow a crop from seed to market in a conventional greenhouse setting, everything they learn about the control system has been theoretical.

Plant and Soil Sciences' professors said in a college setting, students don't gain access to the controls in a conventional greenhouse because one small mistake can kill a large number of plants. In a commercial environment, the stakes are even higher with the potential to lose tens of thousands of dollars in a production environment.

This virtual technology uniquely positions students to garner hands-on experience manipulating greenhouse controls.

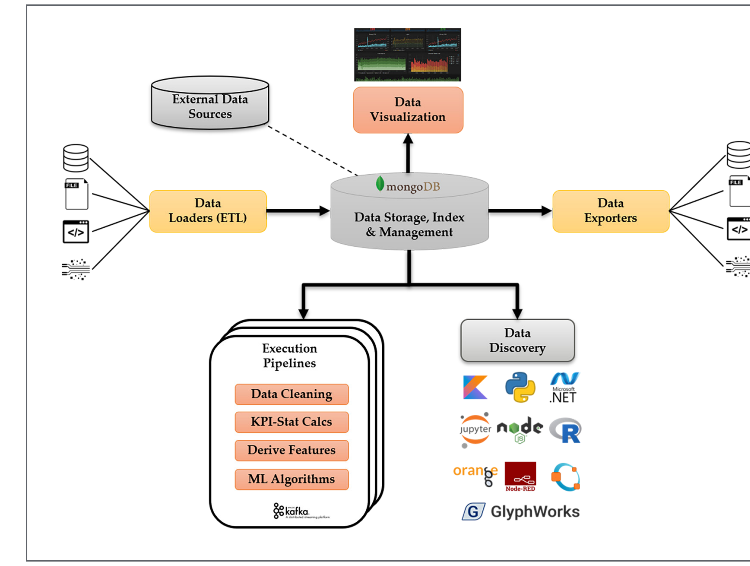
The project is funded by a three-year USDA National Institute of Food and Agriculture grant, which runs through 2023 and is from the organization's Food and Agriculture Cyberinformatics and Tools (FACT) initiative.



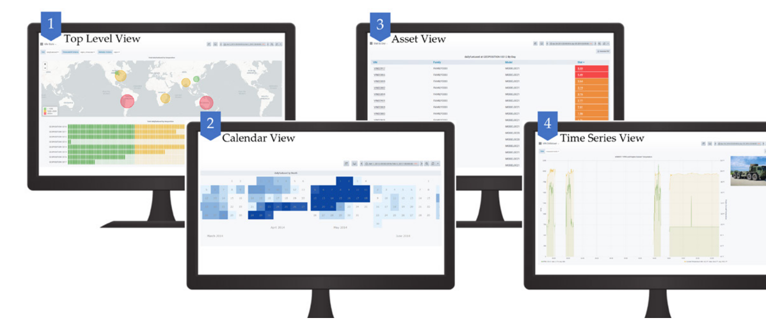


# VEPRO-A RESEARCH RESULTS EXPANDING TO OTHER RESEARCH ACTIVITIES

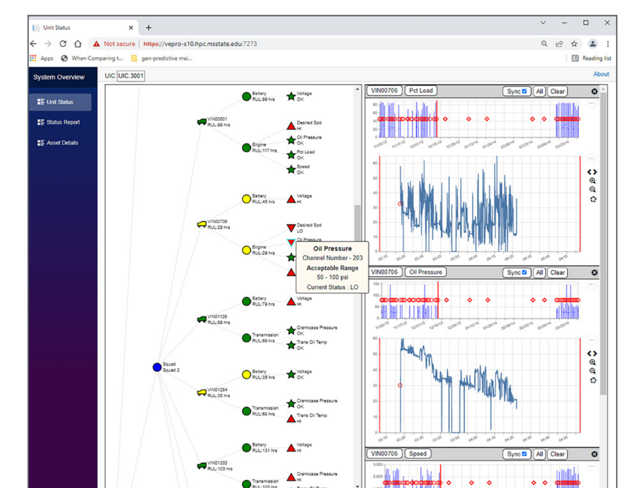
*By T. C. Falls*




The Institute for Systems Engineering Research (ISER) is working with with Hottinger, Bruel & Kjaer Solutions LLC and the U.S. Army Engineering Research and Development Center (ERDC), on the "Vehicle Performance, Reliability, Operations & Analysis" (VePRO-A), research project with the goal of providing an end-to-end solution to manage, analyze and visualize massive amounts of data per day from approximately 100 sensors for each of the 20,000 U.S. Army Vehicles per day. The research project supports the U.S. Army's Condition Based Maintenance (CBM) program for ground vehicles.




The result of the research, the Data Analysis and Visualization System (DAVS), consists of various software packages with clustered MongoDB and Apache Kafka providing the heavy lifting for the processing and storage of the data. The ability of DAVS to handle the massive amounts of data, as demonstrated during the VePRO-A project, led to the realization that DAVS was ideally suited to manage, visualize, and analyze other types of temporal data as well.

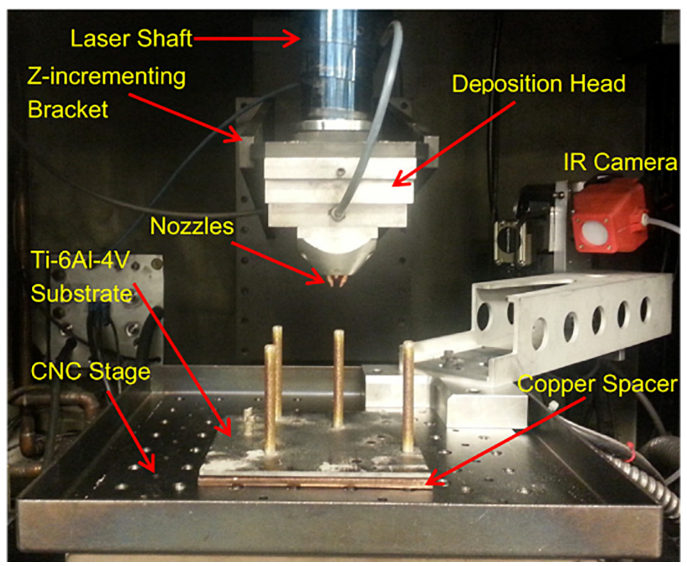


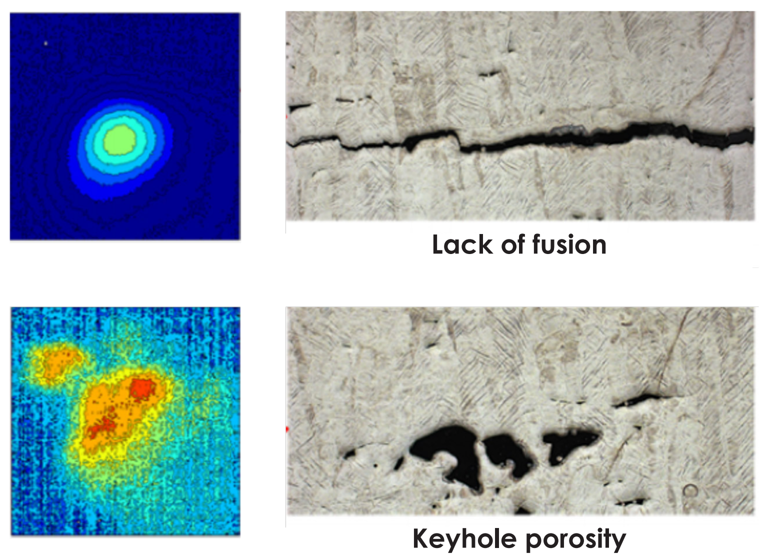
The success of this research is being leveraged by other big data applications. MSU is utilizing DAVS to support the Predictive Maintenance Lab at CAVS and is investigating the use of DAVS for autonomous vehicle testing and simulation studies. The U.S. Navy is investigating the use of DAVS for the Marine Corps CBM program and for non-ground vehicles temporal data to manage results collected during various test activities and the possibility of using it to monitor components aboard ships.

# FORECASTING MELT POOL TEMPERATURE DISTRIBUTION IN AN ADDITIVE MANUFACTURING PROCESS

*By Jonathan Storey*

In an additive manufacturing (AM) process, deficiencies in the printing process can lead to costly mistakes for the manufacturer if left unaddressed. Some of the more significant deficiencies that can occur, affecting the microstructural properties of a part, are porosity and lack of fusion within a part. Previous research has indicated defects in a part can occur from fluctuations in the melt pool temperature. The size of the melt pool and the scan pattern are key factors associated with part defects. Thus, it is critical to be able to adjust an AM process when certain criteria are met. To know when the criteria are met, we must anticipate when a process is tending towards an undesirable outcome in order that we might avoid damage to a part thereby saving time and reducing unnecessary expenses. This requires accurate forecasts of the process.

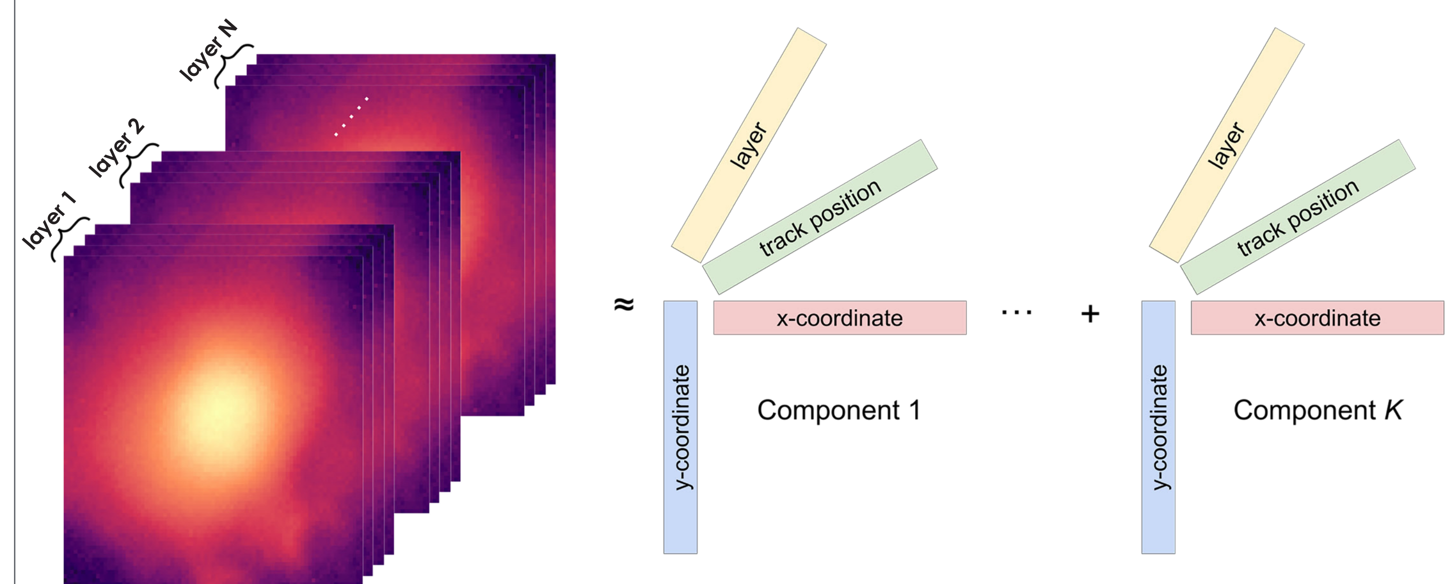


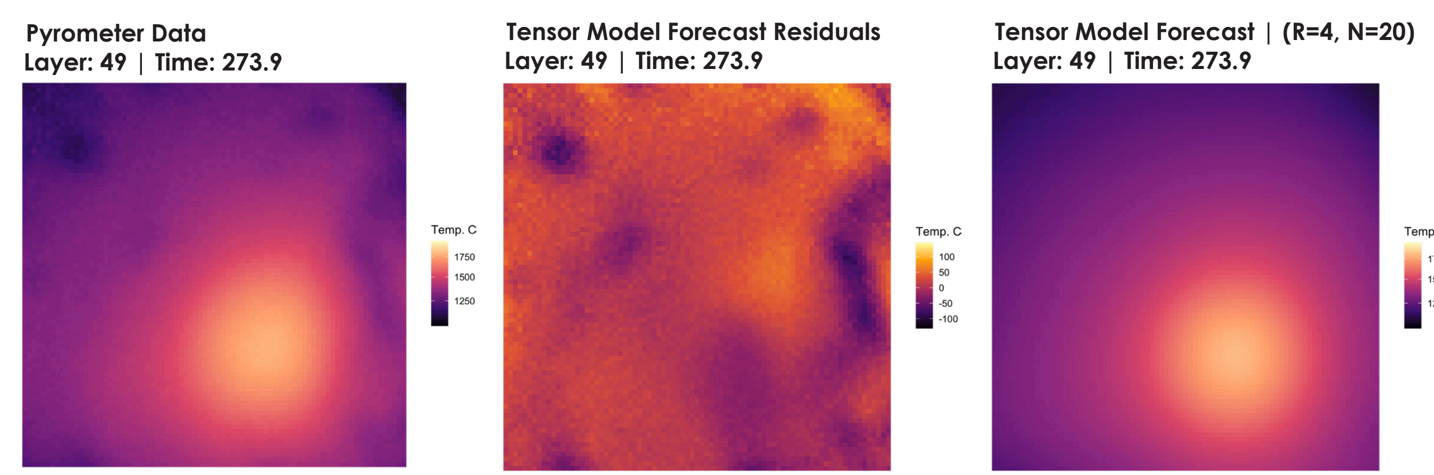

The dimensionality of the data, presence of noise within the data, and missing data, pose unique challenges in developing forecasting models. At the ISER, we are developing models of pyrometer sensor data using tensor rank decomposition and ensembling learning to forecast the melt pool temperature distribution. We structure the data as a fourth order tensor where stacks of images are grouped by layer.

The resulting decomposition enables us to produce forecasts by modeling the latent variables from the decomposition.

This formulation provides an effective means of reducing both dimensionality and noise, enabling accurate forecasts. Continuing efforts are focused on enhancing the methodology to account for less structure and more noise within the data.




**AN ILLUSTRATION OF THE TENSOR STRUCTURE FOR A PYROMETER DATASET. IMAGES WERE GROUPED BY LAYER FORMING A FOURTH ORDER TENSOR.**




**AN ILLUSTRATION OF THE OBSERVED PYROMETER DATA AND A ONE LAYER AHEAD FORECAST. THE LEFT IMAGE IS THE OBSERVED PYROMETER DATA. THE RIGHT IMAGE IS THE ONE LAYER AHEAD FORECAST. THE MIDDLE IMAGE ILLUSTRATES THE RESIDUALS (OBSERVED - FORECAST).**

# HELPING GOVERNMENT & AUTOMOTIVE INDUSTRY MEET $CO_2$ EMISSION STANDARDS FOR A BETTER GLOBAL CLIMATE



*By Diane Godwin*

CAVS researchers are conducting combustion research to reduce $CO_2$ emissions, supplement conventional fossil fuels with renewable alternative fuels and improve the fuel efficiency of combustion engines. The engine research is to help automakers meet the EPA's new and stricter efficiency and emission rules of 28.3% reduction in vehicle emissions through 2026 and a real-world average of about 40 mpg.

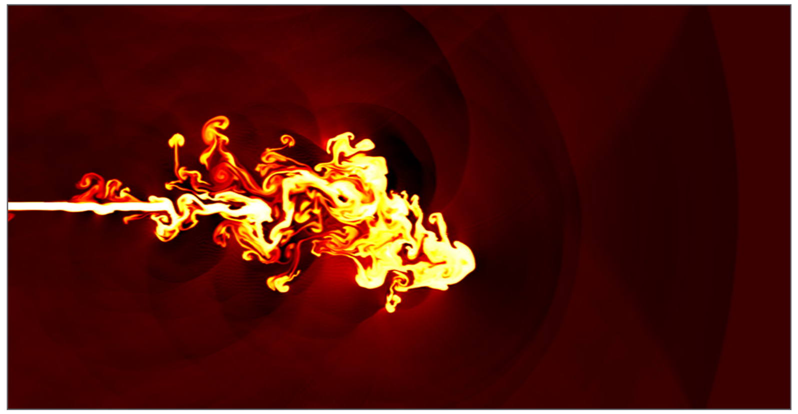
However, CAVS researchers are studying ways to have better fuel economy and emission performance that reach far beyond the 2026 emission standards. They are working on a three-level research process. **The first is the fundamental understanding of spray-combustion physics using a constant volume chamber that enables high-speed imaging under simulated engine conditions.** The 1.4L cubicle-shaped chamber, equipped with five quartz windows, provides wide optical access to capture the full process of spray combustion under engine-like ambient conditions. Results of high-speed optical diagnostics provide detailed information on mixture distribution, spray morphology, and soot emissions that is essential for understanding physics and validation of CFD simulations.

**The second process is linking the fundamental understanding of the research with an application by testing it on engines.** This is the direct path from fundamental research to application in real engines. Different from a constant volume chamber, real engines have turbulent flows due to valve and piston motions. Measurements on fuel efficiency, combustion, and emission characteristics add significant value in terms of the validation data set for CFD simulation. Finally, they use supercomputers at MSU's High-Performance Computing Center that convert the data into millions of algorithms that build models that run virtual simulations to test the experiments to get them close to producing real-world results, before moving to the last stage of testing it on an actual vehicle.

**The final stage is the ultimate goal of the research.** Conducting a real-vehicle test on the Chassis Dynamometer producing results that will help automotive industries go beyond meeting EPA standards now and in the future.

**RESEARCHERS:**
***Joonsik Hwang, Ph.D.***
Assistant Professor, Mechanical Engineering

***Charles Michael Gibson***
CAVS Research Engineer



INSTANCES OF 2D PLANAR TEMPERATURE DISTRIBUTION OF DODECANE (363 K, 600 M/S) TO NITROGEN (963 K, 110 BAR); THE PRESSURE GRADIENT, DENOTING SHOCK WAVES, IS REPRESENTED AS SHADING (VALUE 5 · 1010 PA/M).

DR. HWANG AND HIS GROUP DISCUSS THE COMPONENTS OF A SINGLE CYLINDER ENGINE DONATED BY HYUNDAI MOTOR COMPANY.





# THE EFFECTS OF ECOLOGICAL SIMULATION FOR GROUND VEHICLE MOBILITY FORECASTING

*By Christopher Hudson*

**Mississippi State University Research Engineer, Christopher Hudson** has designed a novel environment generation model based on forest ecology to generate realistic forested environments for off-road autonomous vehicle simulation. Vehicle mobility forecasting plays an important role in understanding how and where a vehicle can operate in a military setting. Unmanned ground vehicles (UGV) are being explored for use in military domains. Military UGVs must be able to operate in complex off-road environments.

Forecasting done through simulation, enables the repeated testing of UGVs in scenarios that would be difficult or dangerous to study in real world testing. To accurately capture UGV performance in simulation, the complex off-road operating environment must be accurately modeled. Current widely used methods for generating forested virtual environments rely on random methods. These methods result in forests that can appear to be realistic when visually inspected, but upon closer inspection the virtual forests lack the appropriate distribution of different sizes of vegetation.

**The size and distribution of vegetation plays a major role in the ability of a vehicle to successfully operate in a forested environment.** Therefore, there is a need for alternative forest generation algorithms that generate more realistic virtual forests. To address this need, a novel environment generation model based on forest ecology was implemented. This model accurately captures vegetation growth, disbursement, and competition.

When examining the distribution and frequency of different sizes of trees, the ecological scenes more closely match the distribution and frequency of trees that would be expected for real forested environments suggesting that the predictions for speed in ecological scenes better represent potential speeds for real environments.

# CAVS VEHICLE FLEET

## CLEARPATH WARTHOG

The **Clearpath Warthog** is a 610 lb. remote controlled amphibious robot. Clearpath is an industry leader in providing robot platforms for research and development. The Warthog comes equipped with basic autonomy software. CAVS researchers are developing and testing novel image processing and path planning algorithms for off-road navigation. The CAVS Warthog is equipped with LiDAR, cameras, GPS, IMU, and other sensors to gather data about the environment.

## POLARIS MRZR

The **Polaris MRZR** is a rugged, all-terrain four-person vehicle sometimes used by military special forces. The CAVS MRZR is equipped with an Applied Research Associates (ARA) drive-by-wire system with actuators for steering, braking, and acceleration. The drive-by-wire system allows remote control or autonomous navigation to GPS waypoints. The MRZR provides a platform for developing algorithms for fast autonomous navigation in complex, off-road environments.





## CLEARPATH JACKAL

The **Jackal** is an all-terrain driving platform developed by Clearpath. With a solid aluminum chassis, high torque four-wheel drive, and an IP62 weatherproof rating, the Jackal is well suited for challenging navigation scenarios both on and off-road. Due to its smaller size, the Jackal can be used to do initial experiments for algorithms or sensing hardware without the setup or space constraints of larger vehicles. The CAVS Jackal is equipped with an Ouster OS1 LiDAR and an Intel RealSense depth camera to test point-cloud-based autonomy.

## VEHICLE SENSOR KITS

Each of our off-road vehicles are equipped with **Ouster LiDAR units, Sekonix HD cameras, SwiftNav GPS and IMU sensors**, along with additional sensors selected to gather data and understand the vehicle's operating environment. Sensor data is processed in real-time by an Nvidia Drive AGX Pegasus and stored on a 17TB Quantum R3000 storage system. The Pegasus is our main compute system with two Nvidia Xavier system-on-a-chip and two Turing GPUs. In total, the Pegasus is capable of 320 Trillion operations per second.

Data collected with these vehicles provide CAVS researchers with an in-depth understanding of complex, off-road environments. CAVS researchers take that understanding and develop and test computer algorithms that will enable vehicles to make real-time, intelligent decisions about how to navigate in the complex, unstructured world that lies off the main roads.

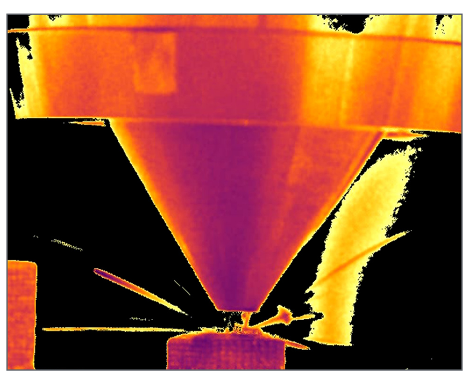
# CAVS ADDITIVE RESEARCH

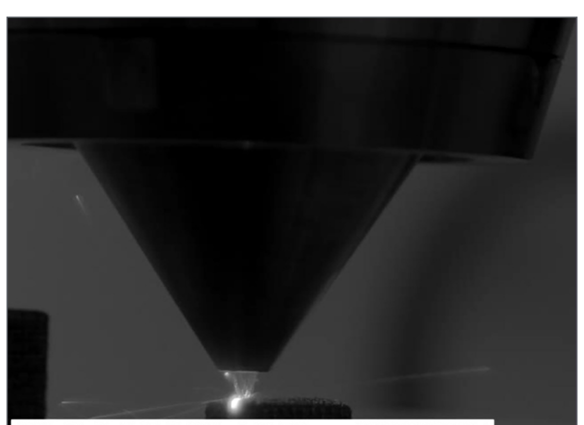
*By Haley Doude*




As our additive manufacturing (AM) research activities have expanded in recent years, multiple new systems and peripheral equipment were added to the lab. **In 2021, the lab was renovated to improve functionality and safety** to support the new and existing research programs. Over two months in 2021, the lab was decommissioned to install a conductive flooring material to reduce risk when handling metallic powders. After the installation, the lab equipment was reorganized to provide more dedicated workspace for each AM technology to prevent contamination, work interruption, and reduce the number of personnel in each equipment area. **These modifications have improved our workflow and safety**, allowing us to produce more impactful research results.

**The new laser-based directed energy deposition (DED) system** (BeAM Modulo 250) is a 5-axis blown metal powder additive manufacturing system with a 500W laser and dual powder hoppers. The DED system provides the capability to build in free space and to produce functionally graded chemistries. Because of the open build area, repair of existing parts is also possible. It is outfitted with BeAM-developed thermal monitoring system with a pyrometer for melt pool temperature, pyrocam for melt pool monitoring, a global infrared camera, and global camera for general imaging. Collaborative efforts between researchers at MSU and the University of Sao Paulo's LAPRAS team have used this system to refine temperature measurement capabilities for in-situ monitoring and modeling support.






**STAINLESS STEEL 316L VASE PRINTED ON THE BEAM MODULO 250.**


**THERMAL AND OPTICAL IMAGES SHOWING THE POWDER FROM THE DEPOSITION CONE (OPTICAL) AND SPLATTER (THERMAL) DURING THE PRODUCTION OF A CYLINDER.**





**Our Wire Arc Additive Manufacturing (WAAM) system** uses traditional welding technologies to quickly deposit large quantities of material for larger builds. The system uses an ABB manufacturing robot for motion control and Fronius weld units to provide multiple welding capabilities.

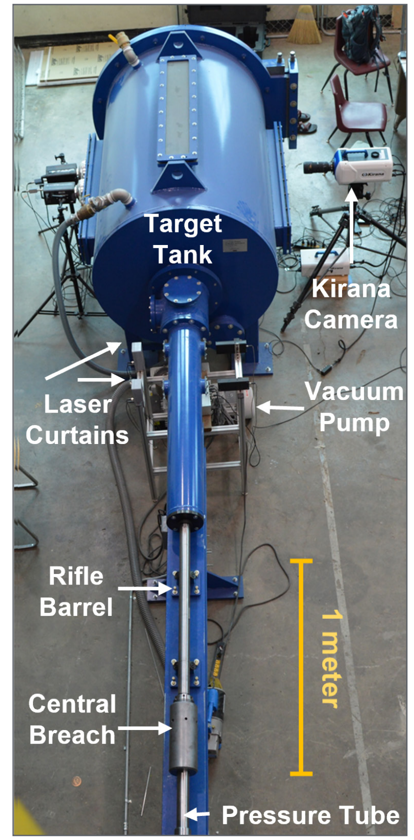
The integrated WAAM3D process monitoring end effector allows for gas shielding and temperature and arc monitoring during the process. The system was purchased to support research into process development for large scale manufacturing and repair for the Army Research Lab.

**MULTI-LAYER M250 STAINLESS STEEL ALLOY DEPOSITION USING THE CMT, COLD METAL TRANSFER, WELDING PROCESS PERFORMED ON THE WAAM. IT HAS BEEN SECTIONED FOR ANALYSIS.**

# GAS GUN TECHNOLOGY FOR MATERIAL FAILURE INVESTIGATIONS

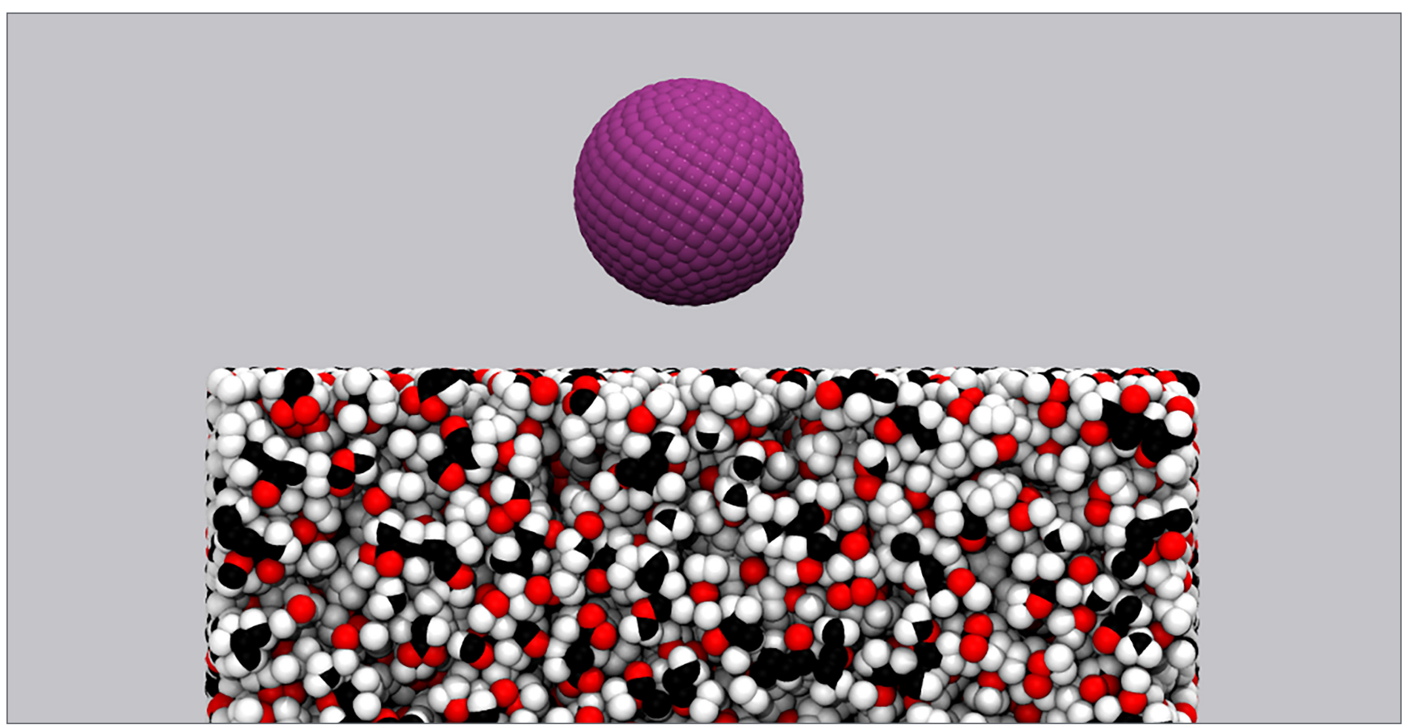
*By Diane Godwin*

Researchers use a **gas gun** with a unique capability to investigate material failure mechanisms subjected to hypervelocity impacts. The components of the two-stage light gas gun utilized by CAVS researchers are shown in the image on the right.




The **gas gun** operates by first igniting a powder charge for compressing a column of pressurized hydrogen gas in the pressure tube. This gas stream is subsequently driven through the central breech into the rifle barrel, where the projectile is launched at hypervelocity. A high-speed camera captures footage of the impact event occurring within the target tank for further analysis.

Researchers also use **molecular dynamics simulations** to get molecular-level insights into the high-strain rate failure mechanism. A simulation snapshot of such a system is shown below.



**SIMULATION SNAPSHOT OF A HIGH-VELOCITY PROJECTILE APPROACHING A POLYMER TARGET.**





# HYPERVELOCITY IMPACT AND SUPERCOMPUTER SIMULATION RESEARCH

*By Diane Godwin*

The result of ballistic and hypervelocity impacts can be catastrophic, resulting in the loss of military personnel and expensive military platforms. That is why CAVS researchers are working with the U.S. Engineering Research and Development Center to test and understand the reactions of various materials, including polycarbonates, a high-performance plastic, of different thicknesses when impacted by projectiles moving at different velocities ranging from ballistic to hypervelocity. The research is part of the U.S. Simulation-Based Reliability and Safety project that tests the reliability of materials used to protect soldiers and military equipment.

MSU's state-of-the-art two-stage light gas gun can launch 4 mm millimeters in hypervelocity speeds, as high as 6,000 meters per second or over 3.7 miles per second. The resulting information aids CAVS researchers and ERDC engineers in understanding the failure behavior of polycarbonates and other materials subjected to hypervelocity impacts.

The next step involves investigating materials failure at the molecular level by using supercomputers located at MSU's Malcolm A. Portera High Performance Computing Center. Researchers use the experimental data to develop models and theoretical understanding that eventually will help design safer armor packages or create new armor technologies or techniques.

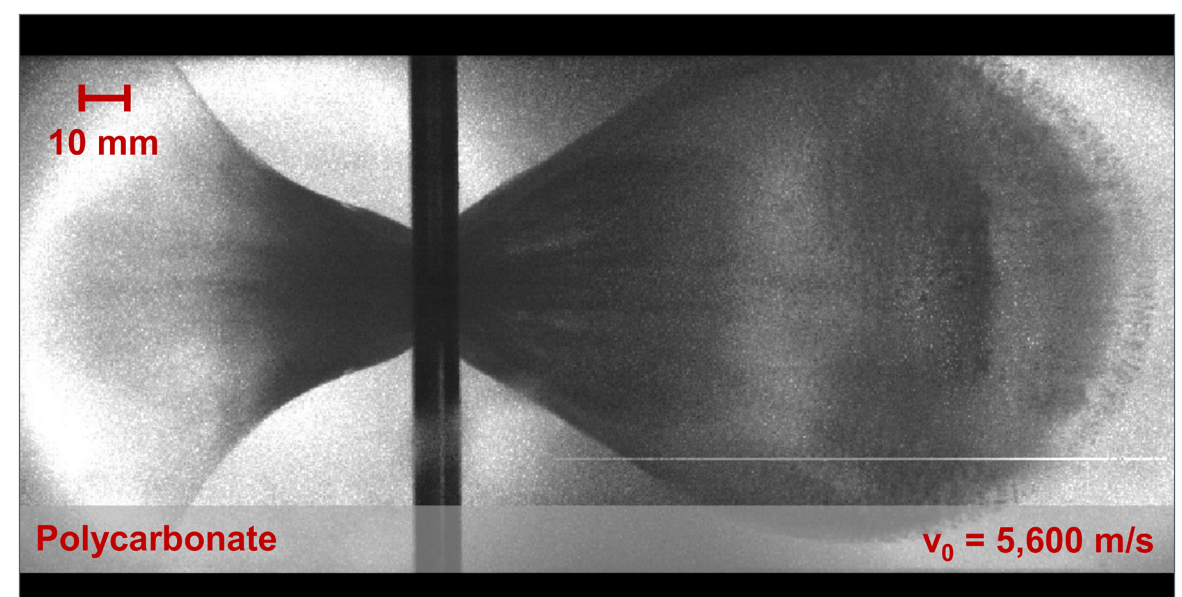
## RESEARCHERS:

***Kyle Callahan & Woodrow Wilson***, Dave C. Swalm School of Chemical Engineering and graduate researchers with Center for Advanced Vehicular Systems

***John Michael Lane***, Dave C. Swalm School of Chemical Engineering and undergraduate researcher with Center for Advanced Vehicular Systems

***William Heard***, U.S. Army Engineer Research and Development Center

***Santanu Kundu, Ph.D. & Neeraj Rai, Ph.D.***, Dave C. Swalm School of Chemical Engineering and the researchers with Center for Advanced Vehicular Systems

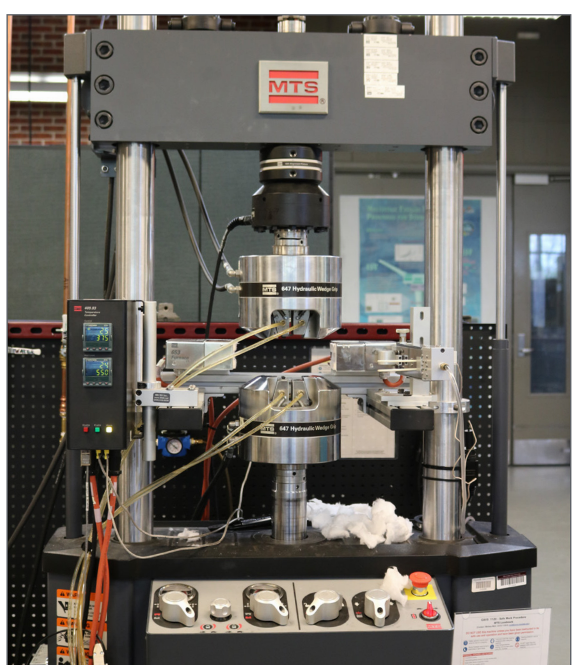



**THE IMAGE (LEFT) SHOWS A POLYMER DEBRIS-CLOUD DUE TO HYPERVELOCITY PROJECTILE IMPACT.**

# MECHANICAL TESTING



The Center for Advanced Vehicular Systems (CAVS) at Mississippi State University is a premier research facility in the areas of mechanical testing, characterization, manufacturing, and material modeling. Within this body, the Engineering Mechanics and Materials Science (EMMS) group performs experiments to reduce uncertainty in processing and design, qualify materials, and validate component performance. The experimental capabilities of EMMS group include obtaining thermo-mechanical behavior of metallic and non-metallic materials from different stress states at strain rates on the order of quasi-static to high strain rates while controlling temperatures.

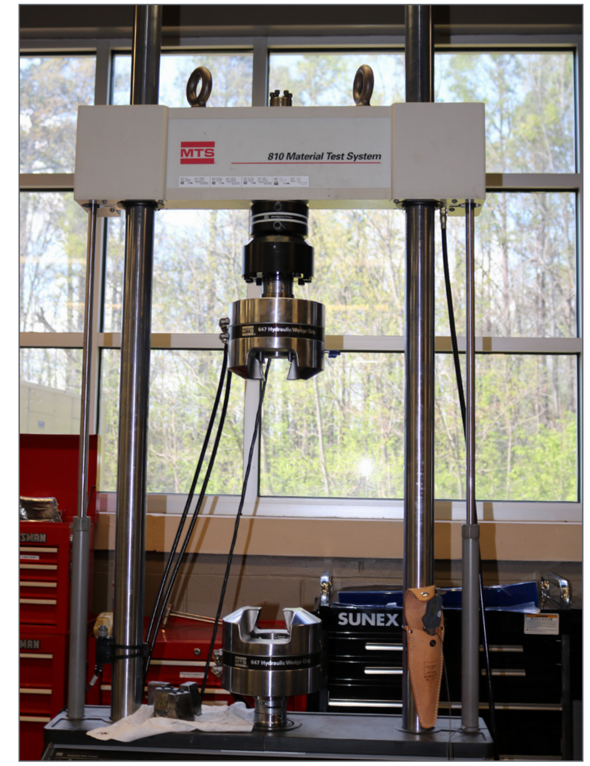



## MTS LANDMARK

**The MTS Landmark system** delivers a broad array of testing capabilities for both low and high force static and dynamic testing. It can test materials ranging in strength from plastics to aluminum, composites, and steel, and perform a wide variety of tests including tensile, high- and low-cycle fatigue, fracture mechanics, and durability of components. The CAVS Landmark system has a load capability of 100 kN.







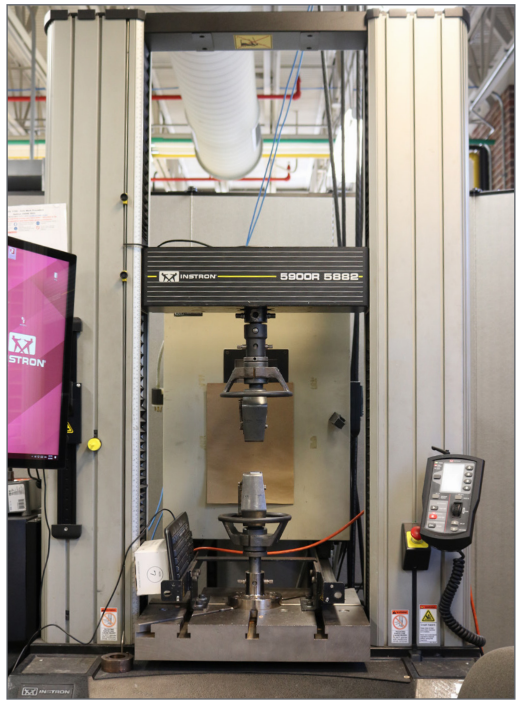

## MTS 810

**The MTS 810 system** is a uniaxial servo-hydraulic static and dynamic test system capable of extensive testing capabilities for fatigue, fracture, and monotonic tests with featuring a load capacity of 100 kN and a corrosive environmental chamber.


## MTS 858

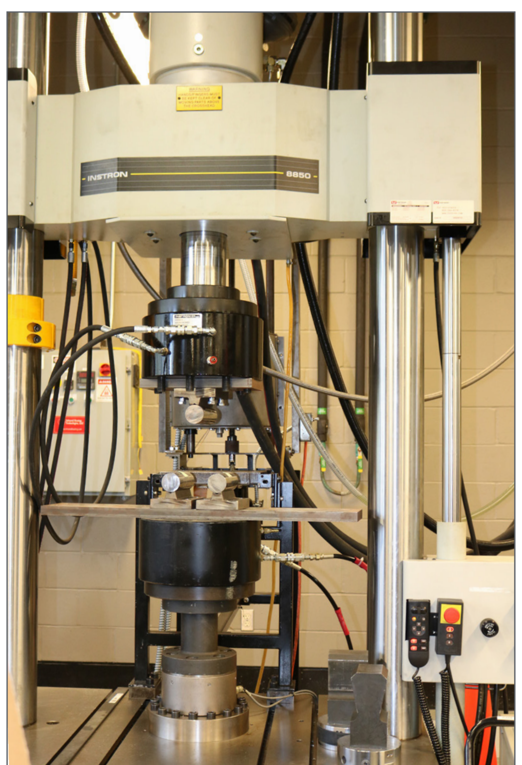
**The MTS 858 tabletop** system is a servo-hydraulic fatigue, torsion, tension, and compression test machine. This system has a load capacity of 25 kN and a 250 N-m torsional capacity with a corrosive environmental chamber for corrosion-fatigue analysis.

# MECHANICAL TESTING



## INSTRON 5882 & 5869

**Instron electromechanical testing systems** are used to test a wide range of materials in tension, compression, or bending (flexure tests) at various strain rates and temperatures. CAVS possesses a 11 kip Instron 5869 frame with load cells of 5 kN and 50 kN and a 22.5 kip Instron 5882 frame with load cell of 100 kN.



## INSTRON 8850

**The Instron 8850** is a biaxial servo-hydraulic dynamic test system that provides axial and torsional load on the specimen in an integrated biaxial actuator. The CAVS Instron 8850 system has an axial load capacity of ±300 kN (±67.4 kip) and a torque capacity of ±3000 N-m (±2212.7 ft-lb) with an infrared clamshell oven for elevated temperature testing.

ENGINEERING MECHANICS & MATERIALS SCIENCE





# CFD SIMULATIONS TEST CLEAN, EFFICIENT, INNOVATIVE & SAFER NUCLEAR TECHNOLOGIES

*By Diane Godwin*

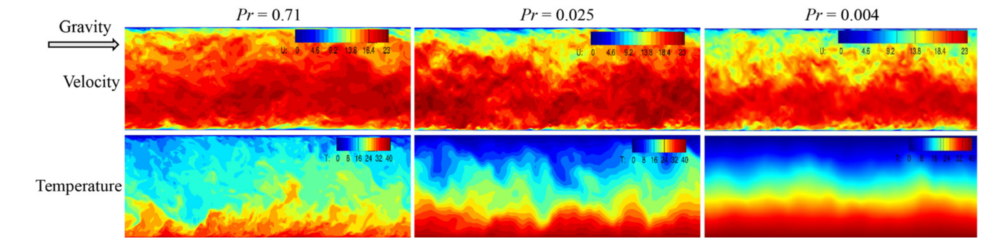
Mississippi State University researchers along with scientists at the University of Arkansas, Fayetteville, Texas A&M, Pennsylvania State University and the U.S. Argonne National Lab are developing Computational Fluid Dynamic simulation tools that show advantages, identify problems or provide solutions in using liquid metal cooling for advanced, nuclear reactor systems.

Most reactor designs use highly pressurized water at a raised boiling point to cool the systems, which presents safety and maintenance issues. ***The team is advancing the U.S. Department of Energy's Nuclear Advanced Modeling and Simulation program*** to study if liquid metal can be used to produce vapor at higher temperatures than in a water-cooled reactor, leading to higher thermodynamic efficiency.

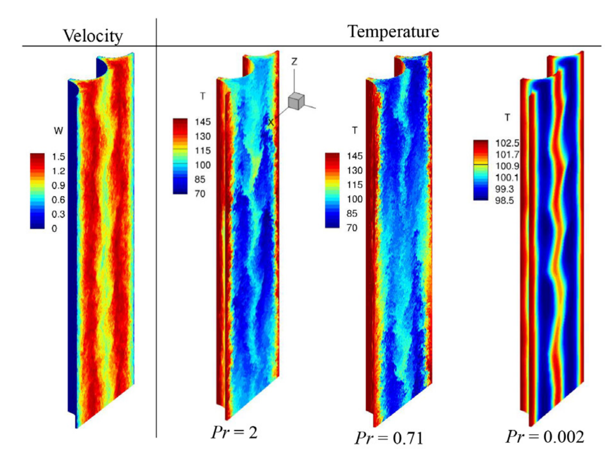
The simulations can handle complex, multi-physics flows like high-temperature reacting flows—giving researchers information that is almost impossible to calculate analytically, and much safer than conducting expensive physical tests. Currently, the team is assessing liquid metals' corrosive nature of the molten salt on the structural integrity of the nuclear reactor systems.

***The goal is to build simulations that prove liquid metals can be used to properly manage the heat transfer and reduce heat loss,*** which in turn saves energy and promotes a more stable cooling process. This innovative system is expected to be cleaner, safer and more efficient than previous generations.

COMPUTATIONAL FLUID DYNAMICS




DIRECT NUMERICAL SIMULATION (DNS) PREDICTIONS OF INSTANTANEOUS STREAMWISE VELOCITY (TOP) AND TEMPERATURE FOR MIXED FORCED AND CONVECTIVE FLOW IN A PLANE CHANNEL WITH HEATED BOTTOM WALL AT $RE_\tau$ = 640, PR = 0.71, 0.025 AND 0.004 AND GR = 17.4 X $10^6$. THE ARROW SHOWS THE GRAVITY DIRECTION.




LARGE EDDY SIMULATION PREDICTIONS OF INSTANTANEOUS STREAMWISE VELOCITY (ALONG Z DIRECTION) (LEFT) AND TEMPERATURE FOR FORCED CONVECTIVE FLOW IN A ROD BUNDLE ASSEMBLY WITH CONSTANT HEAT FLUX FROM THE WALLS AT $RE_D$ = 40341 FOR PR = 2.0, 0.71, 0.002 AND GR = 0. THE VELOCITY PROFILE (LEFT PANEL) IS SAME FOR ALL PR CASES, BUT THE TEMPERATURE PROFILE CHANGES.

# ATHLETE ENGINEERING



ATHLETE ENGINEERING AT MSU™

Athlete Engineering recognizes that human performance isn't limited to sports. The repetitive motion workers in industrial facilities within Mississippi and neighboring states, as well as the military warfighters at home and abroad are all athletes and can therefore utilize the capabilities of the Athlete Engineering team. For this reason, research team expertise includes former industry and military human performance experts. CAVS' primary function is to serve industry and military partners and, while the sports athletes receive much of the attention from this program, everything done through Athlete Engineering is completely transferable to everywhere that human movement and performance needs evaluation.

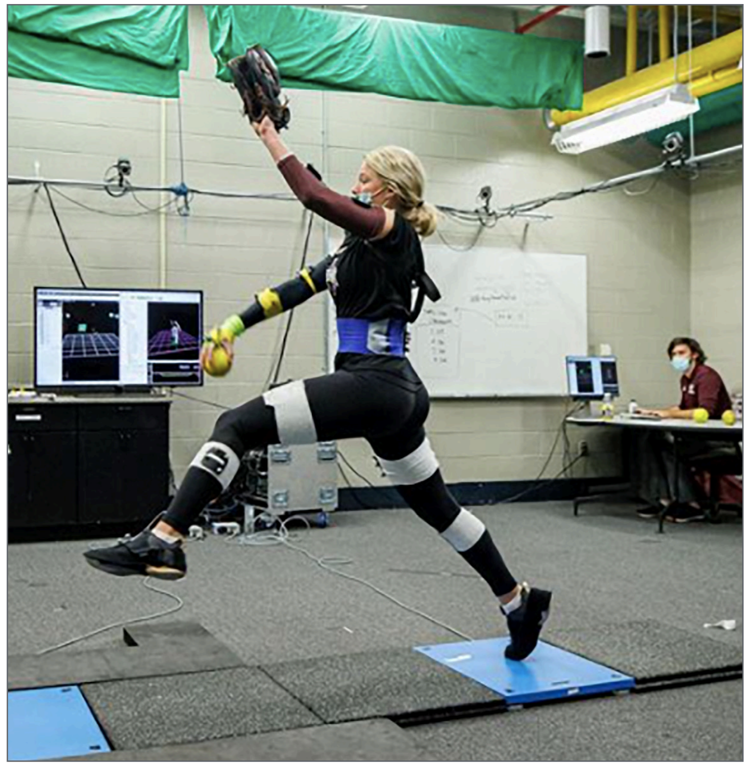

## SPORTS ATHLETE

**Working with the sports athlete requires gold standard laboratory equipment** to capture precise movements during critical competitive movements for aiding in performance enhancement. The Human Performance Lab partners with sports teams to quantify and report human performance in ways that are actionable to coaches and others concerned with the health and safety of our student athletes.

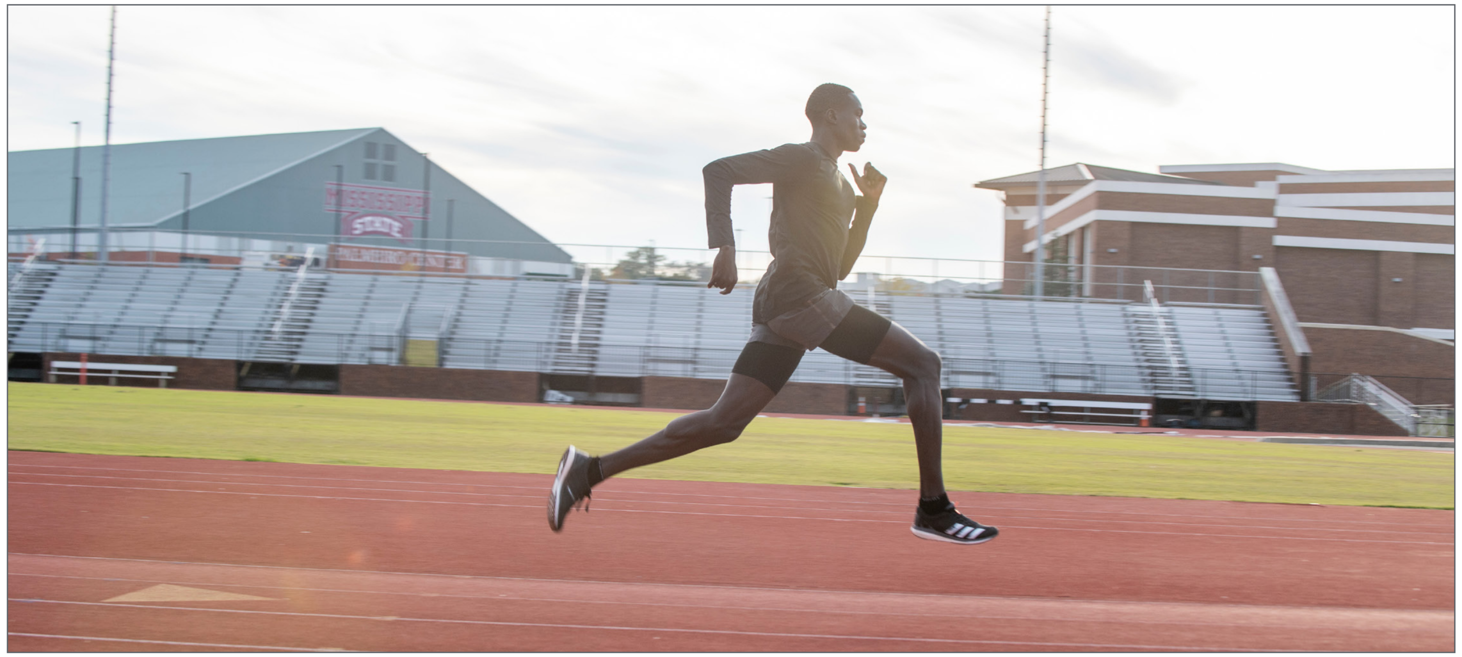





AN EARLY VERSION OF THE "SMART SOCK" PROTOTYPE THAT EVOLVED OUT OF NATIONAL SCIENCE FOUNDATION RESEARCH FUNDING LED BY FACULTY AND STUDENTS ON THE ATHLETE ENGINEERING TEAM.



A SOFTBALL PITCHING STUDY BEING CONDUCTED IN THE HUMAN PERFORMANCE LABORATORY TO ASSES FULL-BODY, BIOMECHANICAL MOVEMENTS AND GROUND REACTION FORCES DURING THE PITCHING MOVEMENT.

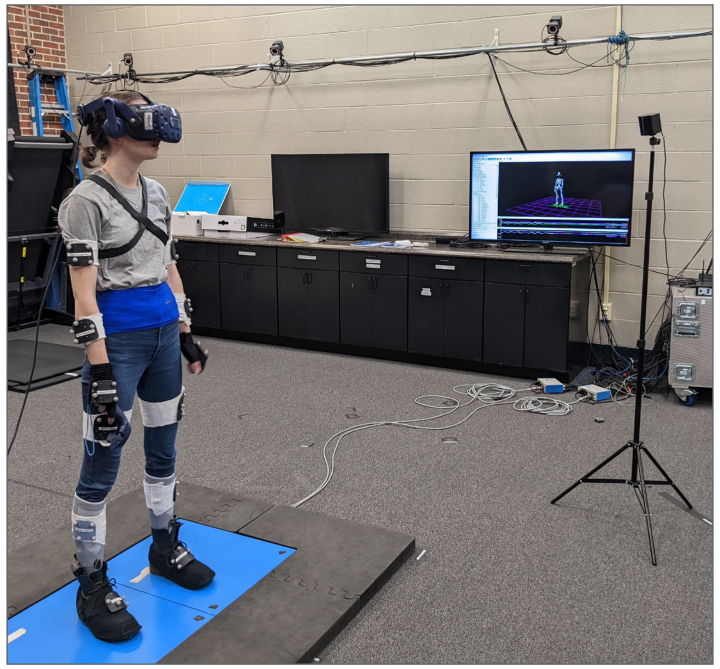


TRACK STUDENT-ATHLETE, MARCO AROP, RUNNING AFTER HAVING CONDUCTED HIS STRENGTH TRAINING IN THE SHIRA FIELDHOUSE WHERE MANY OF THE ATHLETE ENGINEERING RESEARCH STUDIES ARE CONDUCTED.

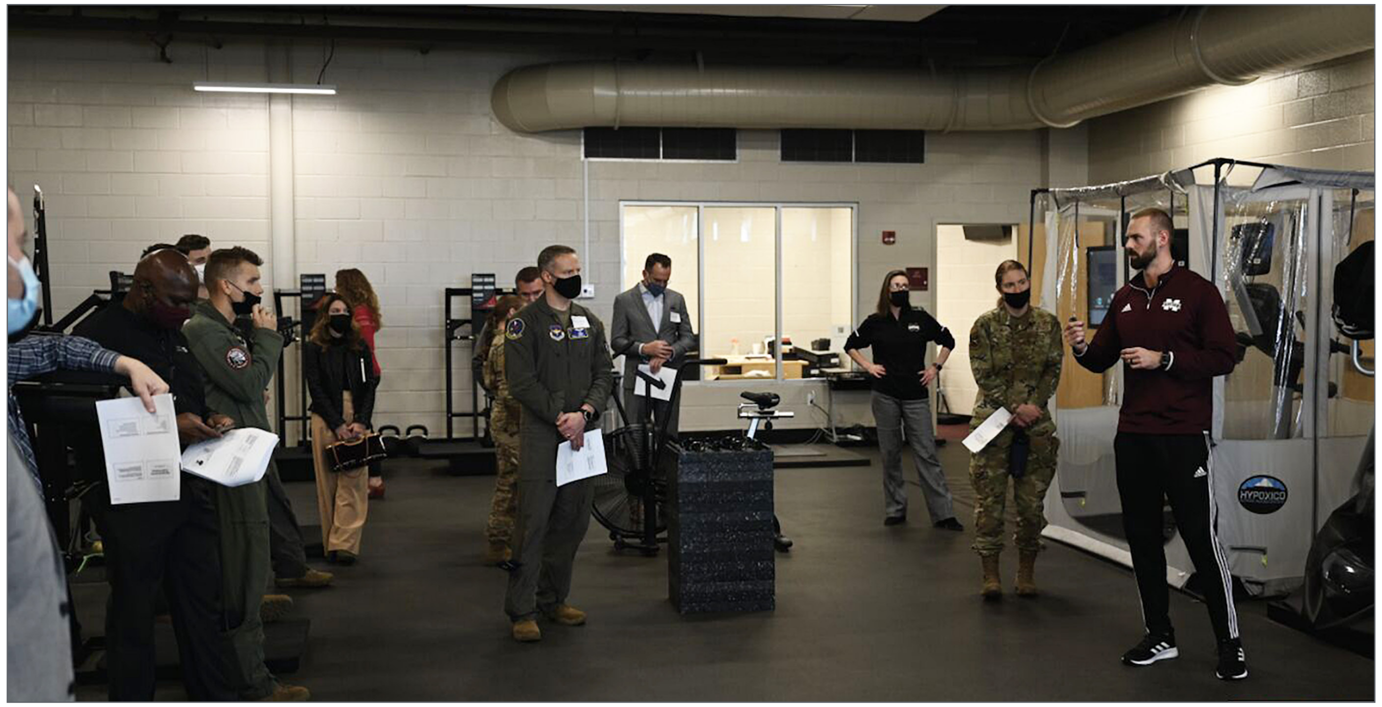
# ATHLETE ENGINEERING



## AT-RISK ATHLETE



**Regardless of the sector where we work or the task we perform, we may find ourselves at risk of or recovering from injury.** Thanks to our partnership with the University of Mississippi Medical Center, we are involved in projects that utilize virtual reality and postural stability to assess the physical and cognitive impacts from concussions and COVID-19.



## TACTICAL ATHLETE

**Whether the athlete competes on a sports team or is putting their life on the line to protect the rest of us,** we all want the same training outcome: happy, healthy, and effective team members. Our work with the Air Force has demonstrated that the same principles of human performance that we learn from our strength and conditioning partners immediately applies to pilots and all other men and women of service.

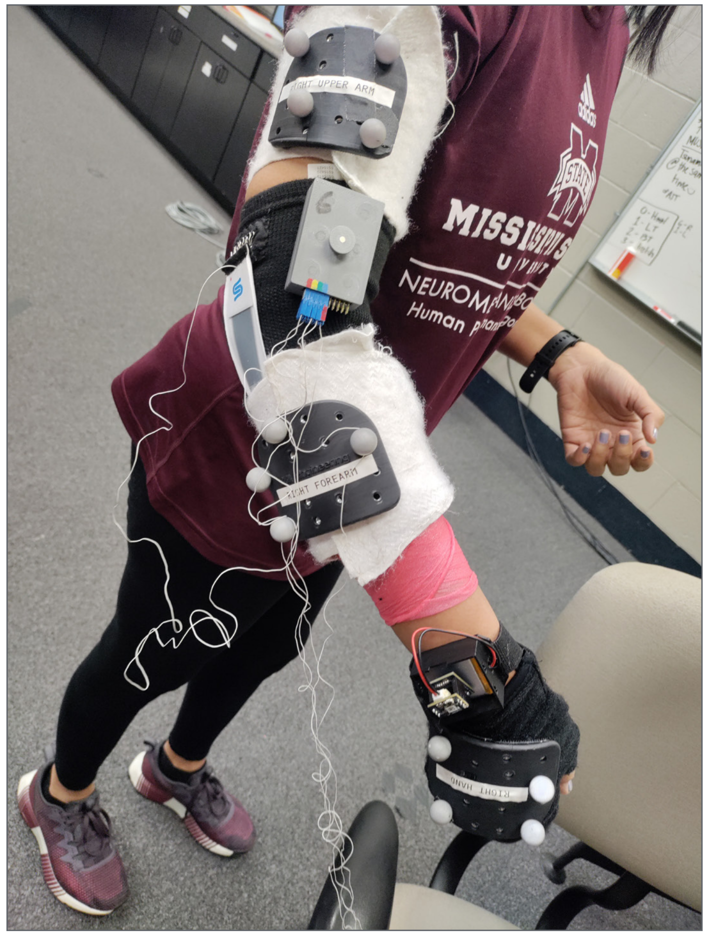




## INDUSTRIAL ATHLETE

**Wearable technology is moving forward, providing real-time data and allowing immediate feedback to workers and employers about a potentially hazardous condition or situation.** The wearable sensor technologies are already in use for monitoring workers post-injury, but wearable sensors for preventing injuries and treatments are still in the proof-of-concept stage. Unlike conventional approaches, wearable sensor systems enable convenient, continuous, and unobtrusive monitoring of a users' behavioral signal. Even though wearable haptic interfaces are now widely used in laboratories and research centers, their use still remains underexploited. The current study provides spatiotemporal grip force analysis, which can monitor health data, industrial or exercise activities, and several other performance data involving grip force measurements. In any given industry, the determination and measurement of hand-handle interface forces are vital for assessing the hand transmitted contact stress and musculoskeletal loads. The low-cost and flexible sensors could be conveniently applied to the curved surfaces of real tool handles in the field to measure the handgrip and the forces exerted on the palm and the fingers. The most significant benefit of the sensors lies with their minimal costs and applicability of the actual tool handles. Using the data signals collected from the sensors, employers may also be able to predict hazardous situations and enhance accident/injury prevention measures. One essential goal of workers' compensation is to prevent an injury before it occurs. **If wearables can identify and mitigate risks in real-time—before a worker is injured—it could transform the world of loss control and, most importantly, change workers' lives.**

A merit of using capacitive sensing is the stability of sampling rates largely independent of experimental setup conditions. When implemented in an array of individual sensor units, the capacitive soft sensors are suitable for large and arbitrary area sensing, even for surfaces that can change dimensions. The simple



and robust sensor system is very convenient for integrating/onto instruments and wearable garments to monitor human body activities and parameters. **The sensors provide an efficient and cost-effective alternative to large-scale setups designed to use in laboratory settings.** A system equipped with non-invasive, lightweight, and unobtrusive capacitive wearable sensors can be a viable diagnostic tool for monitoring important physiological and kinematic activities in real-time, allowing prompt computerized feedback and data acquisition. The project's long-term goal includes developing sensorized gloves and compression sleeves that can be used to easily detect human kinetics and kinematics in an out-of-lab setting, just like the compression socks being developed currently at MSU. Data viewed in real-time can be beneficial to get insights into an individual's biomechanical data, help assess performances and provide valuable guidelines for coaching and injury prevention.

# COMPUTATIONAL MODELING RESEARCH

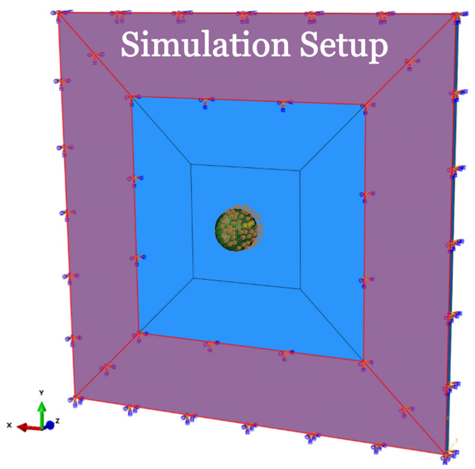
CEM

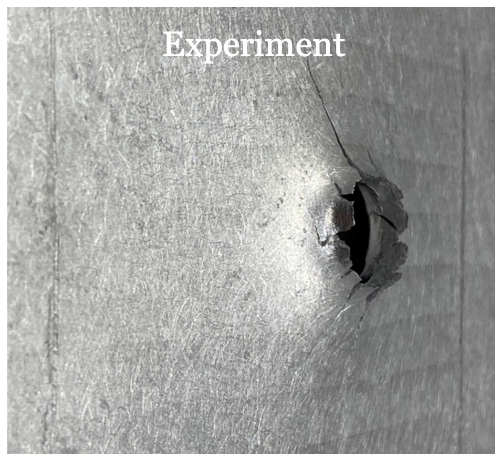
COMPUTATIONAL ENGINEERING MECHANICS

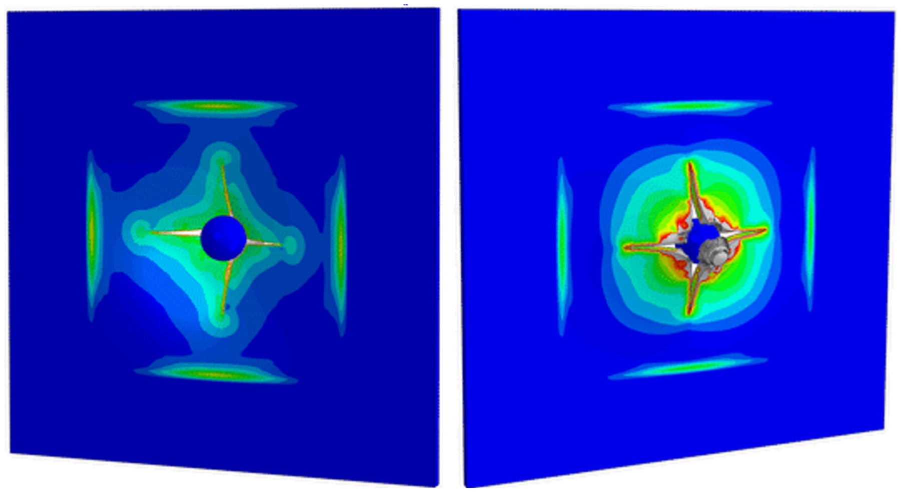
Computational Engineering Mechanics (CEM) is the intersection of mechanics, applied mathematics, and computer science, aimed at developing new methods for solving computationally challenging problems in science and engineering. Computational modeling research at CAVS covers a variety of emerging engineering problems by using state-of-the-science numerical algorithms and high-performance computing technology from resources at HPCC. Our researchers are developing solutions in relevant high-impact research areas, such as vehicular lightweighting and crashworthiness analysis, multiscale materials model development, traumatic brain injury and vibration injury mechanisms, hypersonic materials, ballistic impact studies, surrogate modeling, and machine learning and optimization.

## BALLISTIC IMPACT STUDIES

**CAVS researchers are developing machine learning-based surrogate models for dynamic ballistic impact studies.** Surrogate models provide a low-cost alternative to predicting outcomes of ballistic impact and penetration scenarios, as well as allow the failure mechanisms of armor and material plates to be optimized to better protect vehicles, structures, and personnel.



BALLISTIC SIMULATION TESTS CAPTURE THE REAL-WORLD PHYSICS OF EXPERIMENTS AND ENABLE PROTECTIVE GEAR OPTIMIZATION.

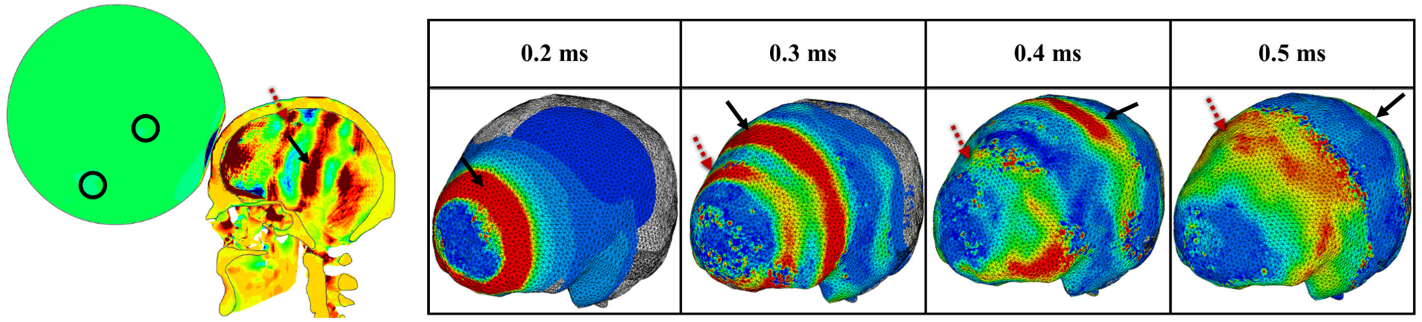




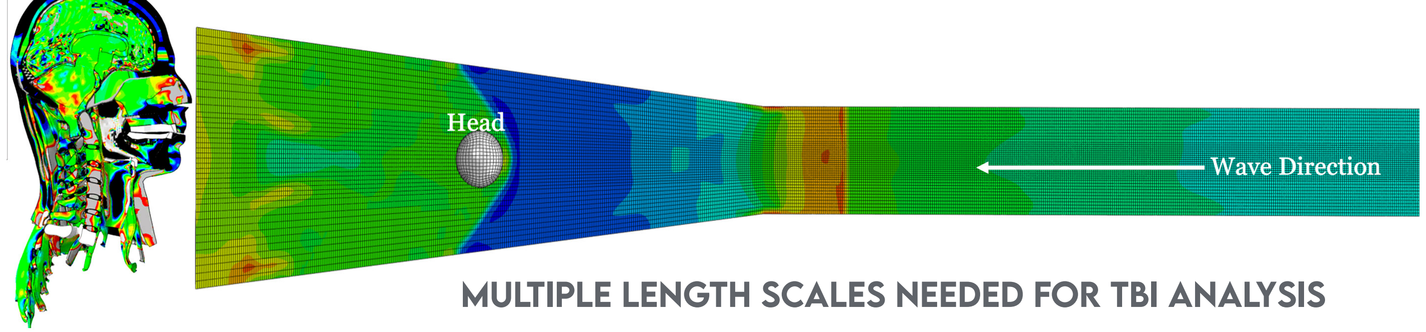
## BRAIN INJURY BIOMECHANICS

**CAVS researchers are leading novel research in brain injury biomechanics.** Multiscale material models and simulations are being developed to study human injury scenarios, such as traumatic brain injury (TBI) during soccer header impacts and blast exposure, that cannot be tested in living subjects. These models enable scientists to view the effects of injury scenarios at the different length scales to examine different damage mechanisms. Further, they allow a better understanding of these underlying mechanisms, which aids in developing improved treatment methods.

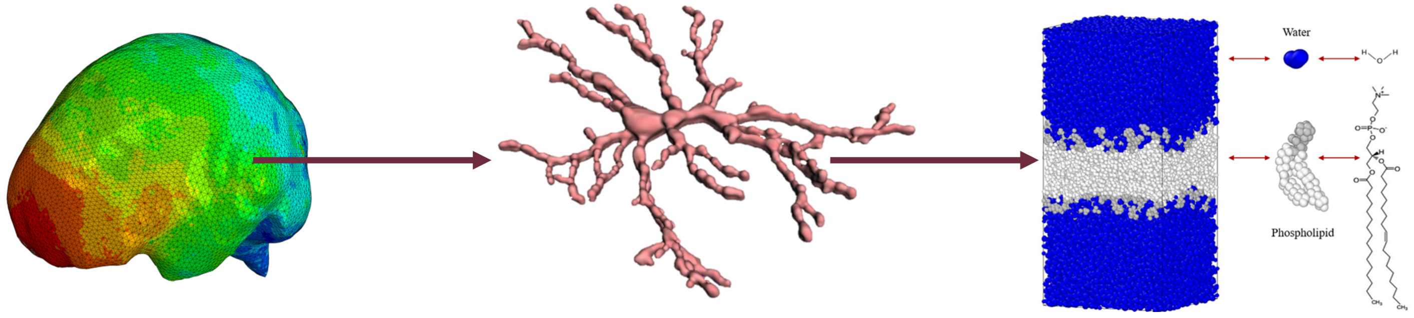
SOCCER HEADER CAUSING WAVES IN THE BRAIN




BLAST TUBE SIMULATING MECHANICAL STRESS AND INJURY IN THE BRAIN



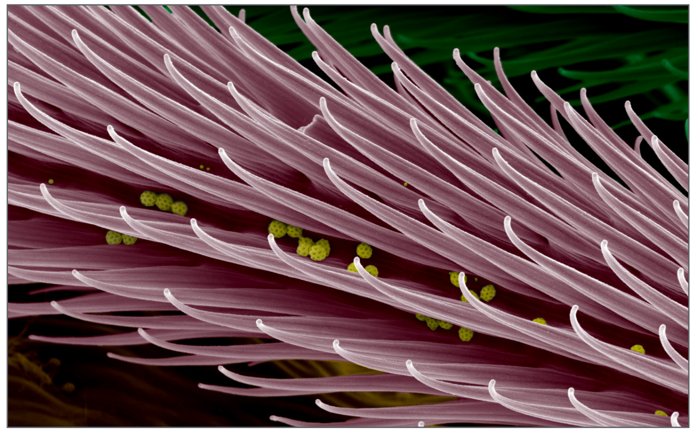

MULTIPLE LENGTH SCALES NEEDED FOR TBI ANALYSIS



# THE INSTITUTE FOR IMAGING AND ANALYTICAL TECHNOLOGIES IS FOCUSED ON WHAT MATTERS

*By Diane Godwin*

The Institute for Imaging & Analytical Technologies is relocating to a new centralized facility where researchers will have improved access to the cutting-edge instrumentation necessary to accelerate scientific discovery in a wide array of research areas including materials science, cell and tissue morphogenesis, nanoparticles, and biomedicine.



**ECODANDRUFF: A COLORIZED SCANNING ELECTRON MIRCROGRAPH OF POLLEN ON THE TINES OF A MESH WEB WEAVER SPIDER HAIR. THE POLLEN GRAINS (YELLOW) MAY OFFER A CLUE AS TO WHERE THE SPIDERS HUNT THEIR PREY. MARKER BAR = 1 MICRON.**

Interim Director Tonia Lane stated that relocating I2AT to its new home at 301 Research Boulevard gives her team an opportunity to better leverage resources and expertise to the benefit of MSU's faculty and students.

"Centralizing the Institute will lead to improved access to instruments that might normally be out of reach [often due to cost], improved technical support, and provide greater opportunities for collaboration," said Lane.

"Our technical staff have science and engineering backgrounds. The team is dedicated to supporting the students and collaborating with researchers," Lane said. "The association to the research for them is more than being service providers, they have a passion to actively contribute to discovery and innovation."

To keep up with the rapid advancements in research and technology, core facilities must be able to stay relevant. Lane along with her team are working to develop a more comprehensive service package based on researchers' changing needs.

"Shared research facilities such as I2AT leverage major research instrumentation and technical expertise in a cost-effective way and provides a charge back mechanism for offsetting the maintenance expenses."

MSU's investment in critical research infrastructure also benefits Mississippians by supporting mid-to large-sized companies that benefit from sought-after capabilities or expertise at the university. By cultivating and maintaining relationships between university researchers and industry, including startups, there is an added economic development benefit of continued career path growth for a skilled workforce.

Lane concluded with, "We want people saying, 'We want to collaborate with Mississippi State to get access not only to the equipment but to the expertise. We want to plug into their network of scientists and researchers because they have the equipment and the expertise to back that up"'

I2AT facilitates interdisciplinary research, education and outreach in the life and materials sciences. These technologies provide MSU, the state of Mississippi and the local community with state-of-the-art resources that facilitate scholarly research, grow competitive funding, foster project completion, enable high-quality undergraduate and graduate education, enhance the impact of outreach, and promote economic development. For more on I2AT, visit www.I2AT.msstate.edu.





# OSWEGO GRAIN BULK STORAGE

**OSWEGO EMPLOYEE TESTS THE ORIGINAL PROTOTYPE WAGON DESIGN.**

*By Debbie Miller*

CAVS-E is well known for providing manufacturing solutions, technical assistance and professional development training; however, they also have the capability to work with entrepreneurs to create innovative solutions to address needs outside of manufacturing. In this particular case, a Mississippi farming community needed a solution to address a real-world problem associated with grain storage products.

The storage of grain is essential to the success of selling quality products. Storing quality grain relies on silos, or elevators, with proper temperature, drying, and air flow techniques. This requires precise timing and transportation to harvest grain, which limit the flexibility for harvest times and the ability to sell at the best price. James Killebrew, a local farmer in the Tchula, MS community recognized this problem and developed Oswego Joint Venture to provide the necessary flexibility in grain storage to the farming industry.

CAVS-E engineers helped Oswego Joint Venture to design a Grain Bulk Storage System consisting of a grain storage bag and mobile filling station. The resulting design includes a cost-effective prototype of a polypropylene bag that provides a new and improved storage solution, and a mobile grain wagon used to fill and store grain in the field allowing for the flexibility needed in today's market. Work is in progress to move this storage system into production.

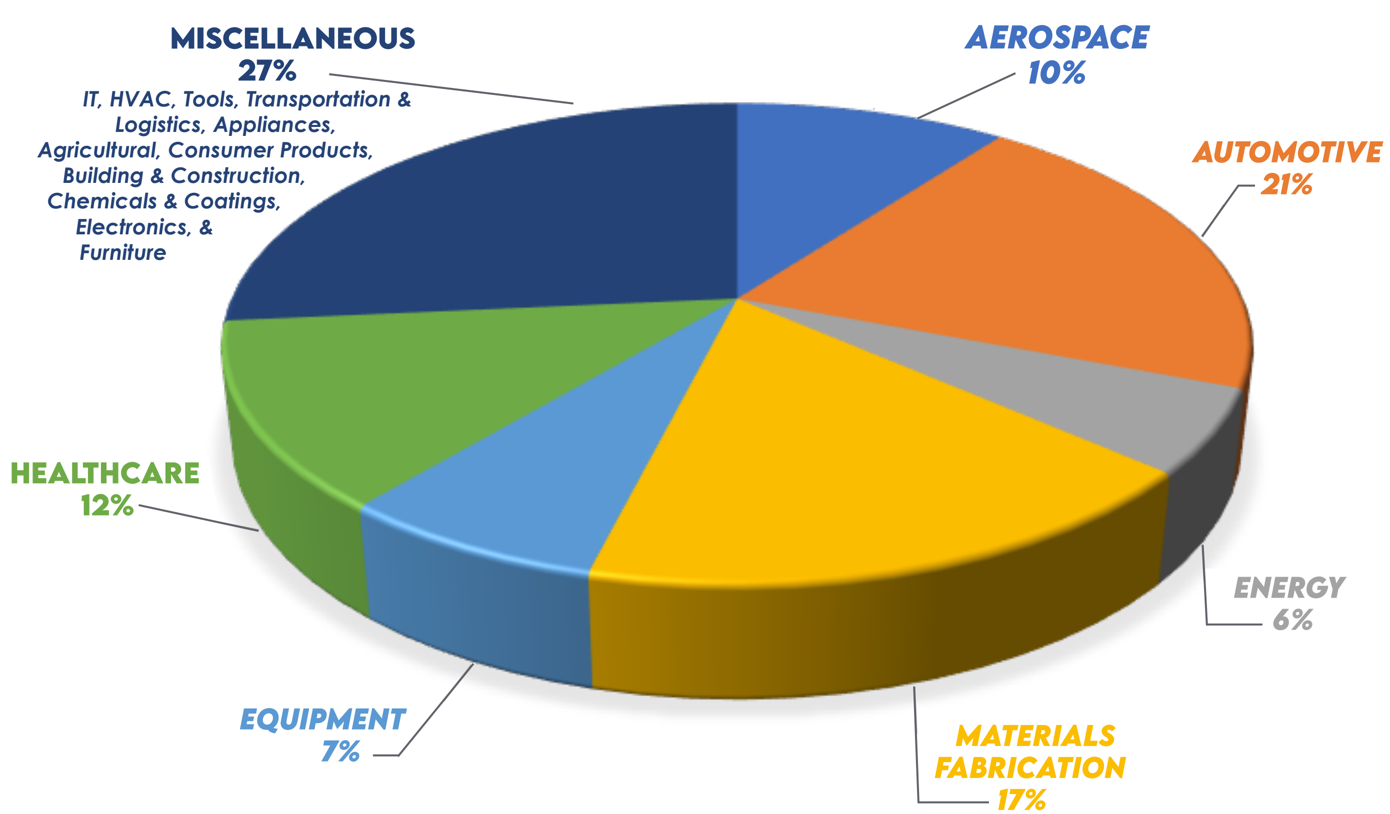
**RESEARCHER:**
***Jonathan Howell***
MSU Project Leader, Center for Advanced Vehicular Systems Extension

**RIGHT: MSU'S JONATHAN HOWELL IS PICTURED WITH THE OPTIMIZED PROTO-TYPE WAGON DESIGNED BY CAVS EXTENSION.**

# CAVS EXTENSION

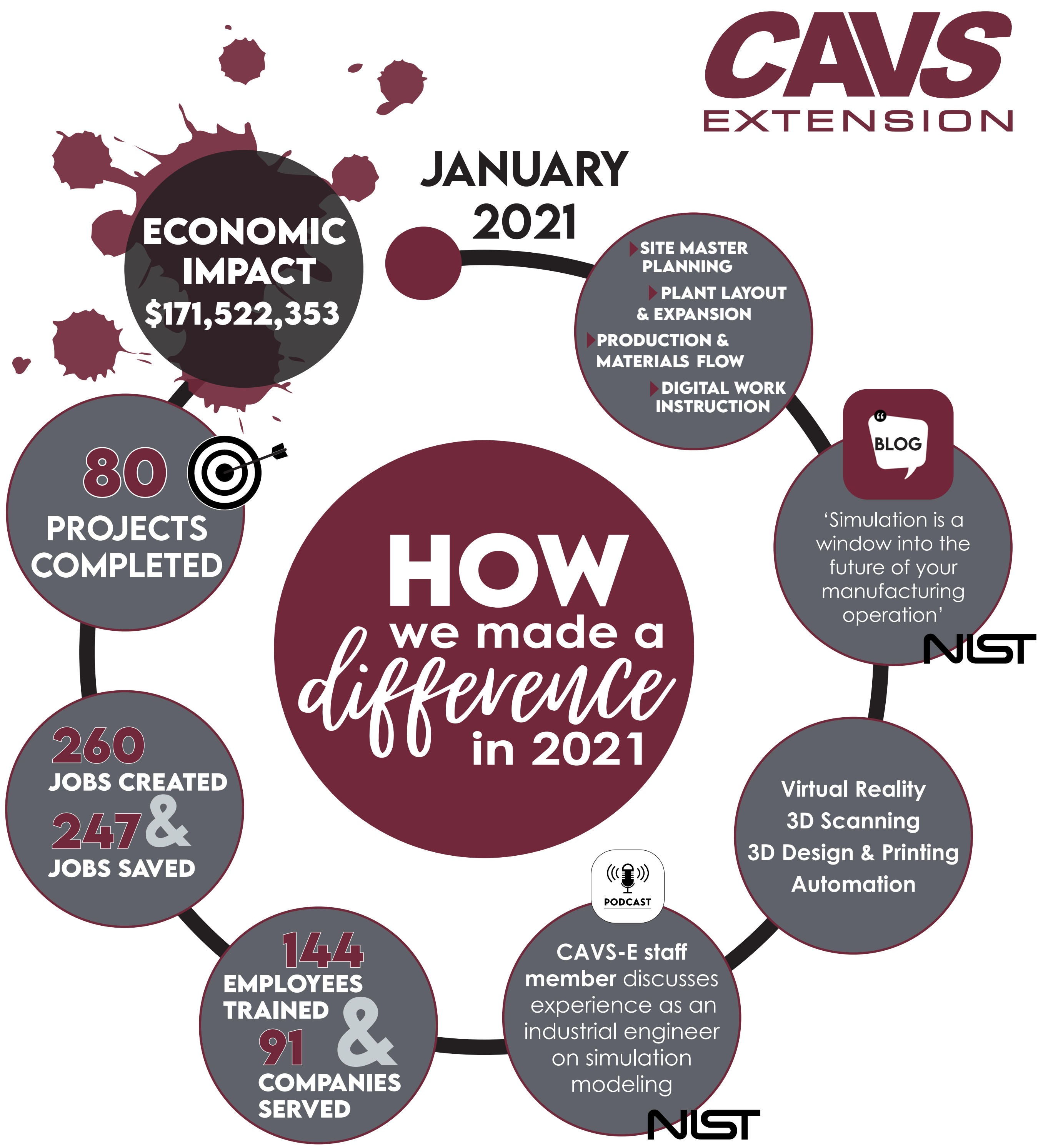
People often associate **CAVS-E** with the automotive industry and do not realize the extent of the work being done within other sectors. Between 2006 and 2021, CAVS-E completed 656 projects for companies in various industries as shown in the chart. The top five industries that CAVS-E serves has been automotive, materials fabrication, healthcare, aerospace, and equipment manufacturers. In addition to the top automotive OEMs such as Nissan and Toyota, this list also includes such companies as Hol-Mac, Superior Optical, Viking Range Corporation, Franklin Furniture, Huntington Ingalls, Taylor Machine Works, Milwaukee Tool, and Yokohama Tire. No matter the sector, CAVS-E is committed to providing programs and services to help companies grow and prosper in Mississippi.

## CAVS-E INDUSTRY PROJECTS 2006-2021







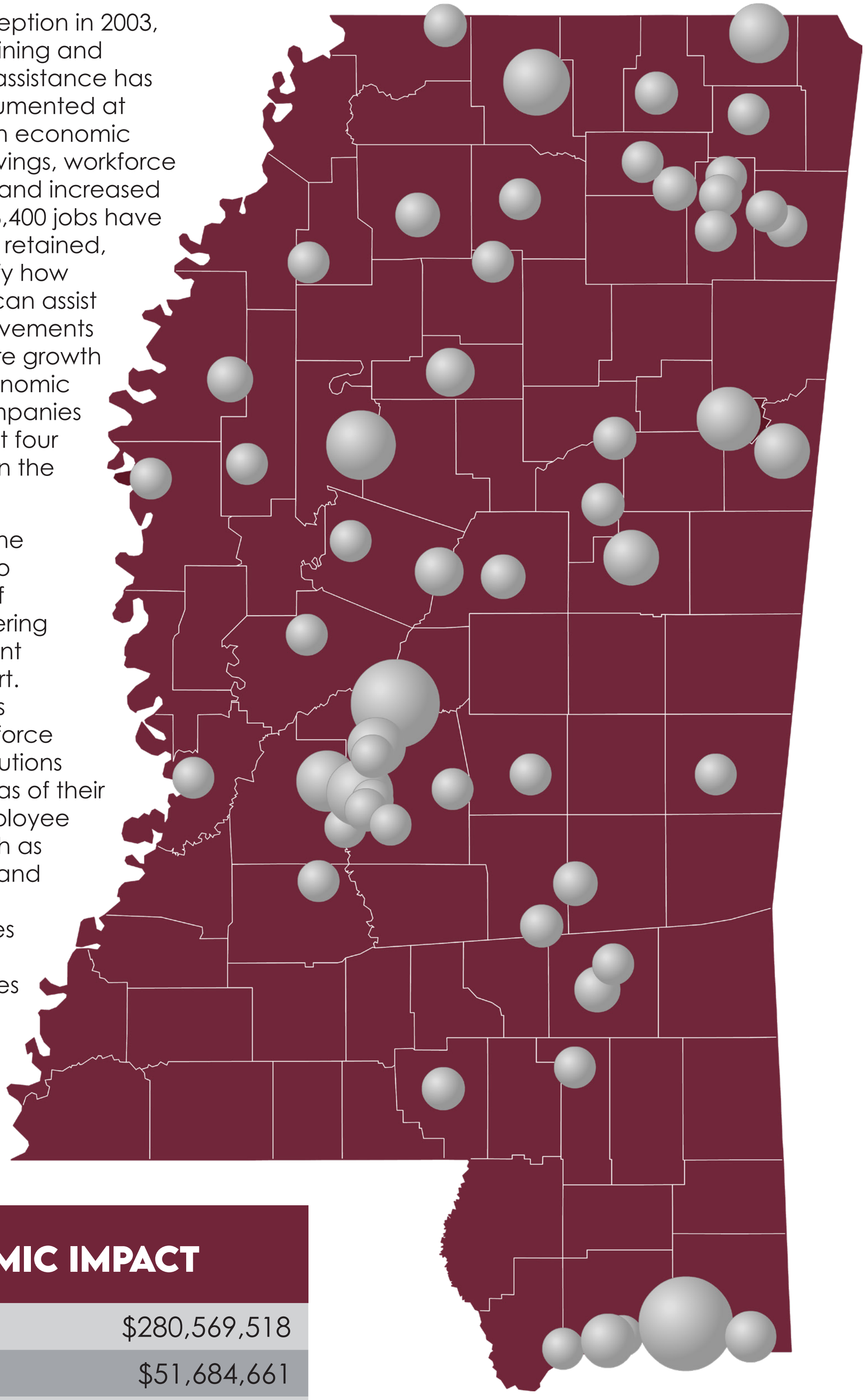
CAVS-E

# ECONOMIC IMPACT

CENTER FOR ADVANCED VEHICULAR SYSTEMS EXTENSION

Since its inception in 2003, CAVS-E training and technical assistance has been documented at over $6.3 billion in economic impacts (cost savings, workforce skills investment, and increased sales) and over 6,400 jobs have been created or retained, all of which signify how CAVS-Extension can assist in business improvements that lead to future growth in Mississippi. Economic impacts of CAVS-E services for companies throughout the state during the last four years, 2018 – 2021, are illustrated on the following map.

CAVS-E provides companies with the competitive advantage needed to meet and exceed the demands of today's economy through engineering outreach, professional development training, and on-site project support. CAVS-E's team of industry experts is uniquely qualified to address workforce issues and help companies find solutions that allow for improvements in areas of their manufacturing processes and employee skills training using technology, such as Virtual Reality, 3D Laser Scanning, and 3D Design. The extent of CAVS-E's impact is recognized by companies throughout the state, from aerospace and furniture companies in North Mississippi, to automobiles, tooling, and appliances in the Mississippi Central and Delta regions, and to shipbuilding and steel fabrication on the Mississippi coast.



## 2018 - 2021 ECONOMIC IMPACT

| | |
|---|---|
| Increased/Retained Sales | $280,569,518 |
| Cost Savings/Avoidance | $51,684,661 |
| Total Company Investments | $83,499,655 |
| **Total Overall** | **$415,753,834** |
| Jobs Created/Retained | 1,808 |





# FINANCIAL HIGHLIGHTS

### CAVS PROPOSALS 2018-2021

| | |
|---|---|
| 2018 | $29,803,120 |
| 2019 | $35,833,495 |
| 2020 | $159,133,105 |
| 2021 | $76,809,489 |

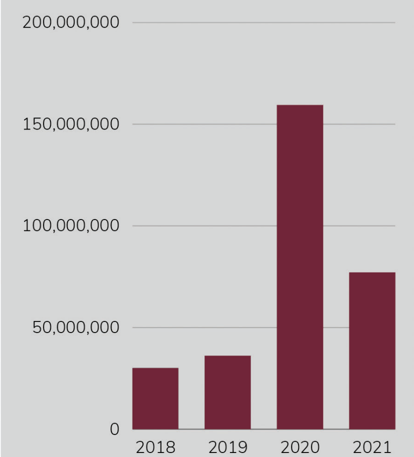
### CAVS AWARDS 2018-2021

| | |
|---|---|
| 2018 | $25,448,355 |
| 2019 | $33,686,980 |
| 2020 | $34,674,692 |
| 2021 | $19,369,737 |

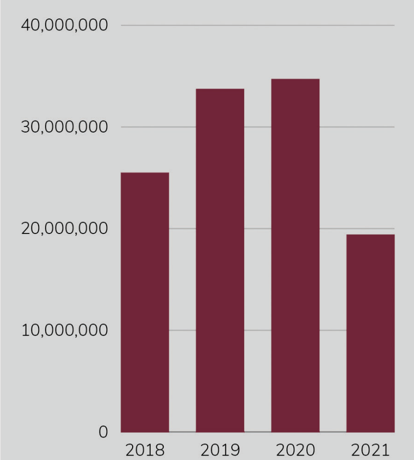
### CAVS RESEARCH EXPENDITURES 2018-2021

| | |
|---|---|
| 2018 | $25,802,557 |
| 2019 | $31,844,198 |
| 2020 | $29,976,106 |
| 2021 | $33,104,019 |

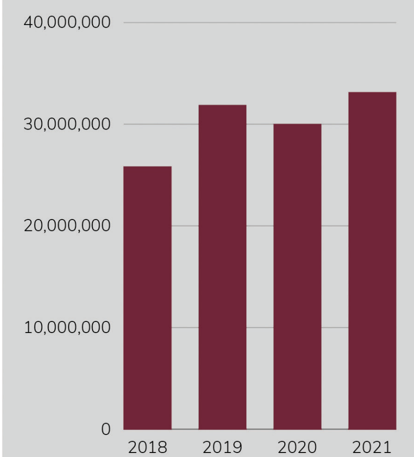
TOTAL CAVS PROPOSALS
2018-2021




TOTAL CAVS AWARDS
2018-2021




TOTAL CAVS RESEARCH EXPENDITURES
2018-2021



# AWARDS & ACCOMPLISHMENTS

JOHN BALL

**John Ball,** associate professor and Robert Guyton Endowed Faculty Chair in Teaching Excellence with the Department of Electrical and Computer Engineering in the Bagley College of Engineering, was honored with the **MSU Alumni Association Graduate Teaching Excellence Award**. "Exceptional teaching by world-class faculty is at the core of Mississippi State's mission. Our outstanding award winners this year exemplify excellence across a variety of disciplines, and they excel at everything from making our newest students feel welcome to helping our most advanced graduate students attain the highest levels of success," said MSU Provost and Executive Vice President David Shaw.

**Reuben Burch,** a Center for Advanced Vehicular Systems researcher and an associate professor of industrial and systems engineering, recently earned the **2021 New Faculty Researcher Award from the Southeast Section of American Society for Engineering Education**. The highly competitive award honors a faculty member who has fewer than six years of teaching or research experience but who has demonstrated excellence in both areas. "I'm very honored to receive this award from the Southeast Section of ASEE," Burch said. "I appreciate that they recognize the importance of applying real world problems to what we teach in the classroom." Burch was recognized primarily for his work with the Athlete Engineering research program. The multi-disciplinary team includes faculty and staff from such on-campus areas as engineering, athletics, textiles, kinesiology and sociology, as well as researchers from CAVS and NSPARC.

REUBEN BURCH

ASHLEY CAREY

**Ashley Carey,** a Research Engineer with the Center for Advanced Vehicular Systems has been inducted into the **Bagley College of Engineering Student Hall of Fame**. Ashley is a Ph.D. candidate in Mechanical Engineering and is a graduate teaching assistant with Civil & Environmental Engineering. Ashley is the co-author of three published journal articles with four others in review. She has over 1,000 hours of lab experience.





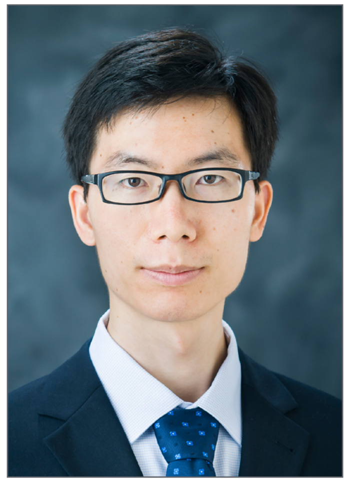
**David Failla,** a mechanical engineering student pursuing both a master's and Ph.D. in the Bagley College of Engineering, is the recipient of the **Science, Mathematics, and Research for Transformation Scholarship as part of the DoD's SMART Scholarship-for-Service-Program**. The scholarship provides recipients with full tuition for up to five years, summer internships, a stipend and full-time employment with the Department of Defense after graduation. The unique opportunity offers students hands-on experience at one of over 200 of the nation's most innovative laboratories across the Army, Navy, Air Force and larger Department of Defense. During summer internships, SMART Scholars work directly with an experienced mentor, gaining valuable technical skills.

DAVID FAILLA

ALI GURBUZ

**Ali Gurbuz,** a CAVS and GRI researcher and an assistant professor in MSU's Department of Electrical and Computer Engineering, is being recognized for his early career success and impactful research with a prestigious **National Science Foundation CAREER award**. Gurbuz is receiving $500,000 to support his research developing sophisticated smart sensing systems, which have the potential to improve the data collected and processed by everything from autonomous vehicles to precision agriculture to medical imaging machines. Gurbuz is co-director of the Information Processing and Sensing (IMPRESS), which conducts basic and applied research in sensing systems and information processing.

**Like Li,** a researcher with the Center for Advanced Vehicular Systems and assistant professor of mechanical engineering at Mississippi State, **will receive nearly $170,000 from the National Science Foundation** to help study the thermochemical reactions that occur during solar thermal energy storage. The grant is one of just 35 awarded nationwide as part of the NSF's EPSCoR Research Infrastructure Improvement Track 4 program. The 2-year project is titled "RII Track-4: Understanding Reaction-Transport Coupling in High-Temperature Thermochemical Energy Storage Systems." The goal of the project is to understand and quantify the fundamental reaction-transport coupling in high-temperature solar thermochemical energy storage (TCES) materials and structures.



LIKE LI

# CAVS AWARDS & ACCOMPLISHMENTS

CENTER FOR ADVANCED VEHICULAR SYSTEMS

TONYA MCCALL

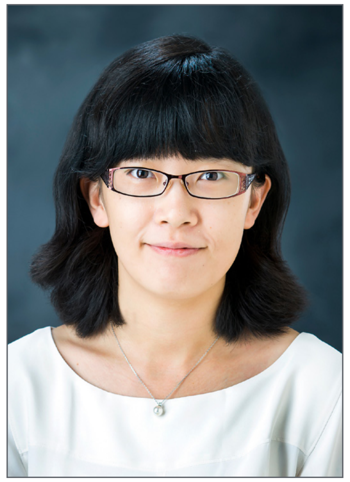
## Tonya McCall now **leads MSU CAVS Extension, a center that supports the state's manufacturing industry.**

McCall brings 25 years of combined engineering experience in the aerospace, plant construction, home appliance and automotive industries. She previously served as associate director for CAVS Extension, which has created a $6.2 billion economic impact in Mississippi since 2006. Based in Canton, CAVS Extension serves as the outreach arm of the CAVS research facility located on MSU's Starkville campus. CAVS Extension helps meet the needs of Mississippi's manufacturers by providing technical expertise, industry-focused professional development, and on-site project support.

## Tonya Stone & Qian "Jenny" Du,

were among 24 MSU professors who completed the **MSU Faculty Leadership Development Institute**. The leadership program, which is sponsored by the Office of Research and Economic Development and the Office of the Provost and Executive Vice President, includes lessons on leadership styles, organizational change, diversity, building winning research teams, and organizational evaluation and assessment. MSU President Mark E. Keenum commended the faculty on completing the program.

TONYA STONE & QIAN "JENNY" DU
PICTURED FRONT ROW THIRD & FOURTH RESPECTIVELY



WENMENG TIAN

## Wenmeng "Meg" Tian, an assistant

professor in the Department of Industrial and Systems Engineering, recently **received $515,000 from a National Science Foundation CAREER award**. The prestigious early career award will help Tian advance her research, funding her project aimed at strengthening additive manufacturing processes for small and medium sized manufacturers while protecting confidential design information. Tian's research focus is on using machine learning and data mining to improve the quality of products made using the additive manufacturing process, which builds products layer by layer. Advanced and expensive equipment is often needed to make the required high-quality metal parts, and facilities at CAVS give Tian and other researchers the ability to digitally model, optimize and produce products using these methods.



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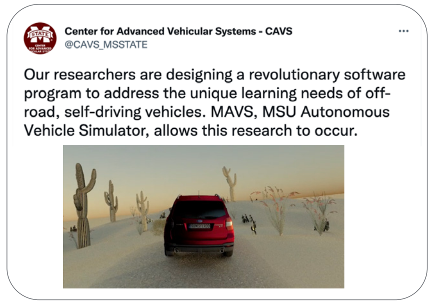
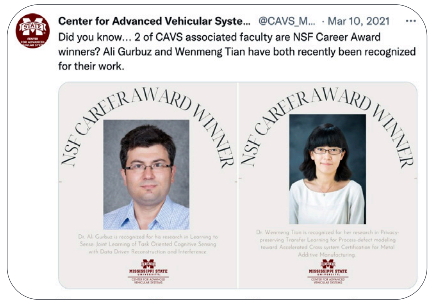
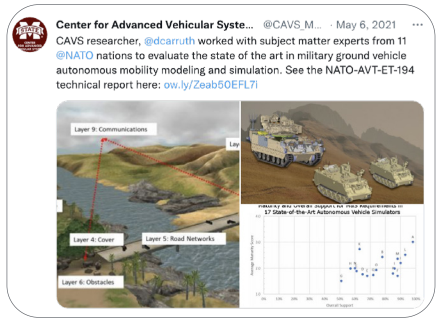
# TOP TWEETS OF 2021



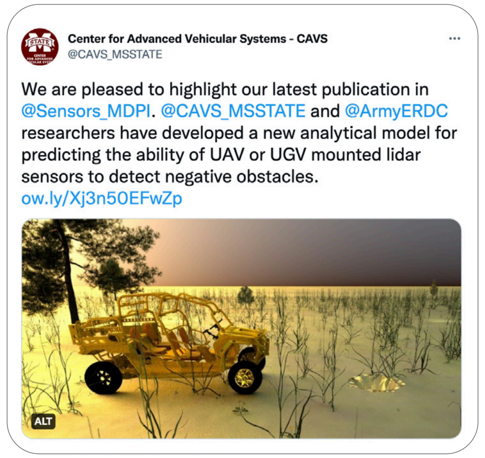












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