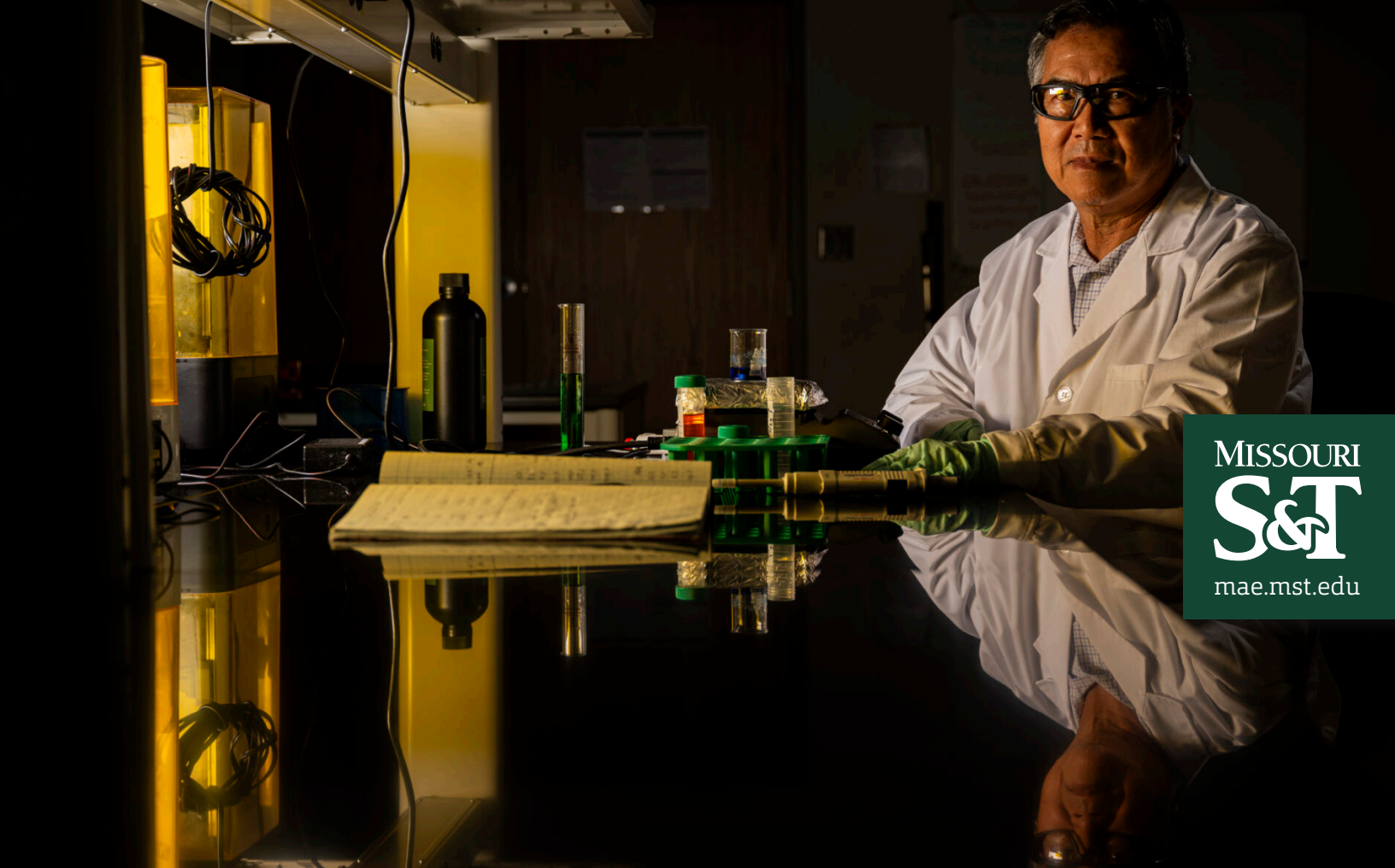


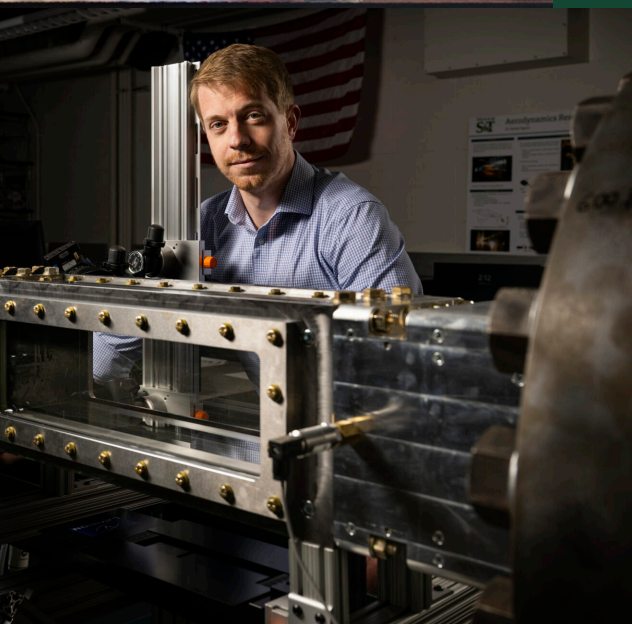


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GRADUATE PROGRAMS AND RESEARCH OPPORTUNITIES

Department of Mechanical and Aerospace Engineering



MESSAGE FROM THE CHAIR



Graduate school should change not only what you know, but what you are capable of doing.

In the Mechanical and Aerospace Engineering Department at Missouri S&T, we challenge our graduate students to take on difficult problems, create new knowledge, and transform ideas into engineering solutions that matter. In

the process, you will develop the technical depth, intellectual independence, creativity, and confidence to tackle challenging scientific and engineering problems few others can solve. You will be advised and work alongside accomplished faculty who are advancing the frontiers of mechanical and aerospace engineering. You

will have access to outstanding laboratories, facilities, and research infrastructure where ambitious ideas can be explored, tested, built, and demonstrated. Our goal is not simply for you to earn an advanced degree. It is for you to leave Missouri S&T with the ability to define important problems, conduct rigorous and innovative research, work across disciplines, communicate with confidence, and translate discoveries into technologies that make a real-world impact. **If you are ready to push the boundaries of what you can do, we are ready to provide the mentorship, resources, and opportunities to help you take the next major step—as an engineer, researcher, educator, innovator, and leader.**

Sincerely,
Jonghyun Park, Ph.D.
Professor and Interim Chair
Department of Mechanical and Aerospace Engineering
Missouri University of Science and Technology



Mechanical and
Aerospace Engineering
Department

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GRADUATE PROGRAM IN

MECHANICAL & AEROSPACE ENGINEERING

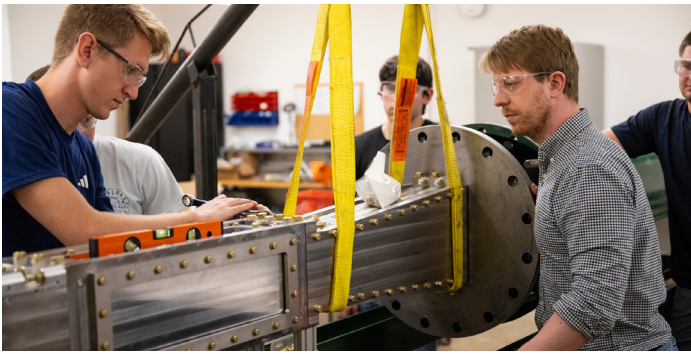
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GRADUATE PROGRAM AND FACULTY RESEARCH AT MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY

The graduate programs in the Department of Mechanical and Aerospace Engineering at Missouri University of Science and Technology (Missouri S&T) offer Master of Science and Ph.D. degrees in both mechanical engineering and aerospace engineering. Students may pursue a direct Ph.D. after earning a bachelor's degree, complete an M.S. degree through either thesis or non-thesis options, or enhance their expertise through a wide range of graduate certificate programs. All degree programs and certificates are also available to distance students through online delivery, providing flexible options for working professionals and students outside the Rolla campus.

In spring 2025, Missouri S&T achieved Carnegie R1 research institution status, reflecting the university's growing strength in high-impact research and innovation. In the MAE Department, graduate students work on challenging fundamental and applied research projects under the guidance of world-class faculty and in newly renovated, state-of-the-art facilities. The department also offers strong financial support opportunities: more than 97% of on-campus Ph.D. students and more than 83% of M.S. students conducting research receive support through assistantships, tuition and fee waivers, and fellowships. Distance students may also be eligible for support.





GRADUATE DEGREES OFFERED

The Mechanical and Aerospace Engineering graduate program at Missouri S&T offers multiple opportunities for research and education toward advanced degrees. Degree programs include:

- Doctor of Philosophy in Mechanical Engineering
- Doctor of Philosophy in Aerospace Engineering
- Master of Science in Mechanical Engineering
- Master of Science in Aerospace Engineering
- Master of Science in Manufacturing Engineering
- Graduate Certificates
 - » CAD/CAM and Rapid Product Realization
 - » Composite Materials & Structures
 - » Control Systems
 - » Energy Conversion & Transport
 - » Engineering Mechanics
 - » Manufacturing Automation
 - » Manufacturing Systems

For more information, please visit <https://mae.mst.edu/academic-programs/>

GET YOUR DEGREE ONLINE

The Mechanical and Aerospace Engineering graduate program also offers all graduate degree programs via distance education. For more information on distance graduate degrees, please visit <https://distance.mst.edu/distance-programs/>

RESEARCH EXCELLENCE

Our graduate program emphasizes advancing engineering knowledge through innovative research and the application of engineering principles to develop technologies and solutions with significant



real-world impact. You will learn and do research with our distinguished faculty in one of several areas, including advanced manufacturing, aerospace design, control systems and automation, energy systems, materials and structures, hypersonics, micro/nano systems, thermal science, space systems, and robotics and vehicle systems. For more information, please visit <https://mae.mst.edu/research/>

FACULTY EXPERTISE

Our award-winning mechanical and aerospace engineering faculty bring a wealth of expertise in areas such as advanced manufacturing, aerospace, energy, materials and structures, micro/nano systems, and robotics and vehicle systems, with years of experience in both basic and applied research and industry collaborations. They are constantly seeking bright and hard-working graduate students to join them in their research. To view a full list of faculty and their research areas, please visit: <https://mae.mst.edu/faculty-directory/>

HOW TO APPLY

To apply to a graduate program in the Department of Mechanical and Aerospace Engineering at Missouri S&T, students should submit their application through the university's Graduate Admissions portal. Applicants can explore available master's and Ph.D. programs in mechanical engineering and aerospace engineering, review admission requirements and priority deadlines, and track their application status online. Graduate assistantship and fellowship opportunities are available through the department for qualified applicants. Prospective students are encouraged to contact the department with any questions about the application process or program details. Early application is recommended to ensure full consideration for funding opportunities and timely admission decisions. Additional information about required application materials, such as transcripts, test scores, and letters of recommendation, can be found on the Graduate Admissions website.



CONTACT US

We invite you to contact us at 573-341-4661 or mae@mst.edu, or visit us online at mae.mst.edu.

RESEARCH AREAS

Through innovation and development, we do more than solve the problems of today; we prepare leaders of tomorrow to revolutionize the future. The MAE researchers perform basic research of engineering principles and advanced applications of these principles that create new discoveries to be implemented in impactful areas. From automating flight in space, studying fuels for propulsion to revolutionizing manufacturing of materials for efficiency, the MAE researchers are at the cutting edge of research and development in their fields including the following:

Energy: combustion, hydrogen fuel cells, advanced batteries, grid energy storage, alternative fuels, algae and algal bio-fuels, biodiesel, solar cells and thermophotovoltaic energy harvesting, fluid dynamics and thermodynamics of energy systems, control of alternative energy systems.

Advanced Manufacturing: additive manufacturing of metals, ceramics, polymers and composites, automation and control technologies for manufacturing process, advanced metrology solutions, advanced modeling for analysis and optimization of processing parameters, intelligent human-robot collaboration, cyber-physical sensing, modeling and control, micro/nano-fabrication and manufacturing, intelligent and sustainable machining.

Materials and Structures: fiber-reinforced composite materials engineering and science, theoretical, experimental, and numerical simulation approaches to solve mechanical behavior of materials and structures at multi-scale levels, structural health monitoring, corrosion and damage detection and assessment.

Control Systems, Machine Learning and Robotics: autonomous systems, adaptive and optimal control, reinforcement learning, human-robot interaction, swarm robotics, neural networks for control, robotic manipulation and locomotion, cyber-physical systems, sensor fusion, perception, and applications in aerospace, automotive, biomedical, and industrial systems.

Micro/Nano Systems: micro/nano-scale heat and mass transport, microfluidics and lab-on-a-chip, micro/nano-scale energy materials and advanced li-ion battery, dynamic modeling and control of micro- and nano-positioning systems,

optical microelectromechanical systems, nanoscale optical devices and metamaterials, photonic nanostructures, optical sensing and quantum optics.

Biomedical Engineering: biomaterials and tissue engineering, biomechanics and human movement analysis, biomedical imaging and signal processing, biosensors and wearable technologies, neural engineering and brain-machine interfaces, bioinformatics and computational biology, rehabilitation engineering, and medical robotics and assistive devices.

Aerospace: hypersonic flows and technologies, hypersonic propulsion systems, planetary entry/descent landing of spacecraft, active flow control, unmanned air vehicles (UAVs), composite materials, smart structures, nanocomposites, plasma aerospace applications, space propulsion, small satellite technology development, spacecraft orbit and mission design.



IMPULSIVE CONTROL FOR AGILE ROBOTIC SYSTEMS

“Rapid redirection of a dynamical system can be achieved through short, precisely timed control impulses that modify motion while preserving stability.”

Many robotic and mechanical systems must respond quickly to disturbances and perform agile maneuvers. Examples include mobile robots navigating cluttered environments, aerial vehicles executing rapid turns, and underactuated robotic systems that possess fewer actuators than degrees of freedom. Traditional control systems typically rely on continuous feedback, where actuator inputs vary smoothly over time to regulate system behavior. While this approach has been extremely successful in many applications, it can limit how quickly a system can react when large or rapid changes in motion are required.

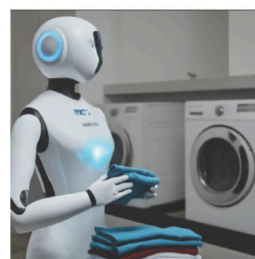
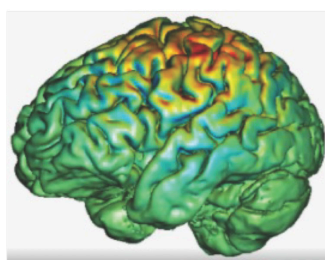
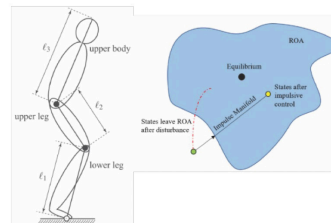
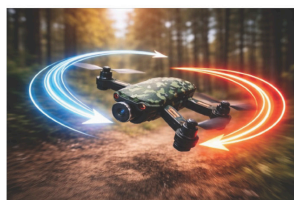
Dr. Nilay Kant’s research group investigates an alternative framework known as impulsive control, where the controller occasionally applies brief and carefully timed bursts of control effort that rapidly modify the system state. These impulses act like quick taps that redirect the system trajectory, while the natural dynamics of the system govern its motion between impulses.

Over the past several years, our work has developed new theoretical tools for designing such control strategies. In particular, we have shown how periodic motions in underactuated mechanical systems can be stabilized using intermittent impulsive inputs that adjust the system’s energy in discrete steps. We have

also introduced control approaches based on impulse-controlled Poincaré maps, where impulses are triggered when the system trajectory crosses a designated surface in the state space. These methods enable stabilization of nonlinear systems such as cart-pendulum mechanisms and other robotic platforms. More recent work explores optimal impulsive control, where multiple impulses may be applied during each oscillation and their magnitudes are computed using a discrete Riccati equation to improve convergence speed and robustness.

Beyond applications in robotics and mechanical systems, we are also exploring how ideas from impulsive control can provide insight into oscillatory dynamics that appear in biological systems. In particular, ongoing research investigates whether controlled impulsive interventions can help analyze or regulate abnormal oscillations observed in neurological activity, including conditions such as epilepsy.

Together, this line of research contributes to the broader development of hybrid control frameworks that combine continuous dynamics with discrete control actions. Such approaches offer new possibilities for designing agile robotic systems while also providing a mathematical framework for understanding and influencing complex dynamical processes in engineering and nature.



HYPER-THICK ELECTRODES FOR NEXT-GENERATION LITHIUM-ION BATTERIES

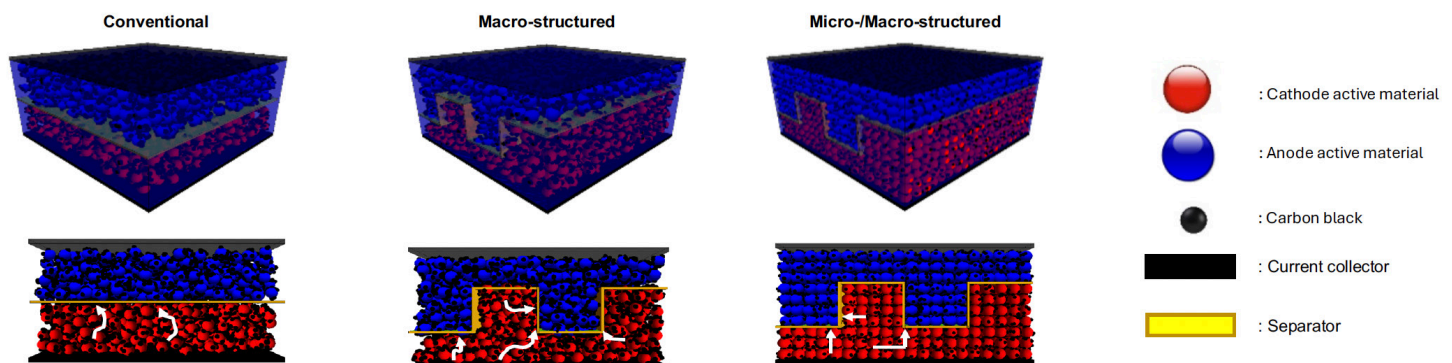
Electric vehicles, drones, phones, and renewable-energy systems all need batteries that store more energy without becoming too heavy, bulky, or expensive. One of the most direct ways to increase battery energy is to make the electrodes thicker, allowing more energy-storing material to be packed into the same area. However, thick electrodes usually suffer from slow ion transport, performance loss, and mechanical damage. In this research, we created a 700-micrometer hyper-thick lithium-ion battery electrode—far beyond the roughly 100-micrometer scale common in many commercial electrodes—while still maintaining strong power, long cycle life, and mechanical integrity.

This research is conducted in Dr. Jonghyun Park's laboratory and focuses on a new way to manufacture thick lithium-ion battery electrodes. Instead of only changing the battery chemistry, this work changes the internal architecture of the electrode. The central idea is to organize how battery particles are arranged so lithium ions can move efficiently through a much thicker structure.

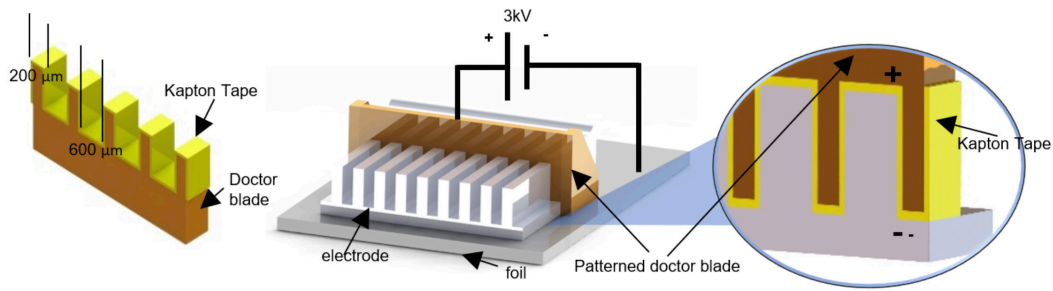
In a conventional electrode, particles are often randomly distributed. That randomness can create winding pathways, isolated particles, and inactive regions inside the battery. These problems become more serious as the electrode becomes thicker. To address this challenge, the team used a patterned blade to create a three-dimensional electrode structure and applied an electric field during fabrication to help guide the particles into a more organized arrangement.

This process, called the micro-electric-field process, combines manufacturing design with particle-level control. The patterned blade creates a larger-scale structure, while the electric field helps improve the internal particle arrangement. Together, these features create straighter pathways for lithium ions, reducing the transport limitations that normally make thick electrodes slow and inefficient.

Making a 700-micrometer electrode was also a major manufacturing challenge. When very thick electrodes are dried using ordinary heating, they can bend, crack, peel away from the current collector, or lose their structure. To solve this problem, the research team studied advanced drying strategies, including flash-sintering-influenced drying and laser-influenced drying. These processing studies were essential because a thick electrode is only useful if it can be fabricated reliably.



Organized pathways help lithium ions move through thick electrodes



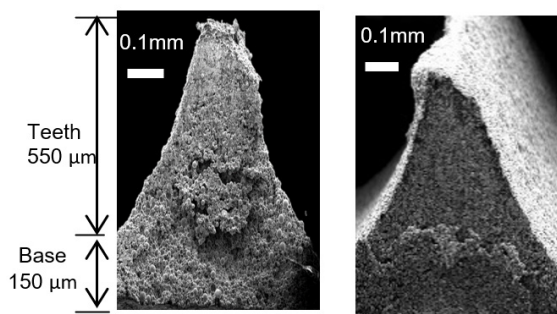
A custom blade and electric field shape the electrode during fabrication

The battery results show why this approach is exciting. The hyper-thick electrodes achieved an areal capacity of about 8 milliamp-hours per square centimeter, meaning they stored a large amount of charge in a given electrode area. Even under faster charging and discharging conditions, the electrodes continued to operate, showing that the design did not simply trade power for thickness.

electrodes made without electric-field-assisted particle organization. Mechanical testing also showed that the hyper-thick electrodes better resisted compression and maintained their structure.

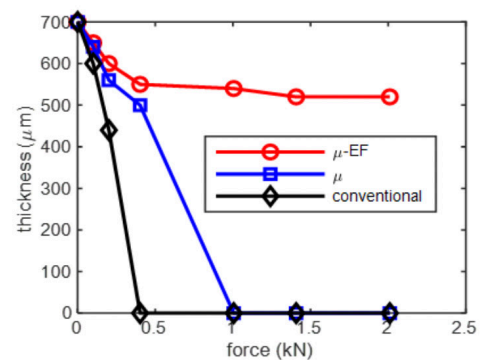
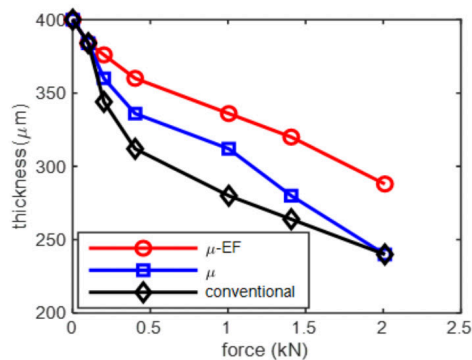
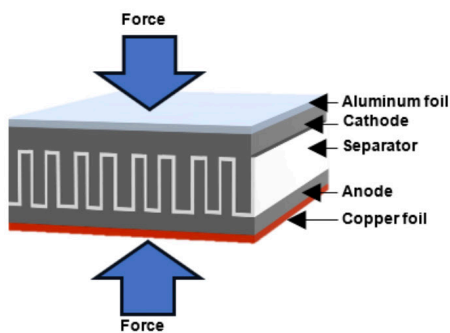
The broader impact is that this research provides a manufacturing-based pathway toward higher-capacity lithium-ion batteries. Rather than depending only on new battery materials, this work shows that electrode architecture, particle organization, and processing design can dramatically affect battery performance. For engineering students, it is a strong example of how materials science, manufacturing, mechanics, and electrochemistry can work together to solve a real energy problem.

Future research will focus on moving this idea closer to practical battery manufacturing. Important questions include how to improve particle organization further, how to dry large-area thick electrodes reliably, how to reduce processing time and cost, and how the approach performs in larger battery formats beyond laboratory coin cells. The long-term goal is to develop thick, high-capacity electrodes that are not only successful in the laboratory but also practical for electric vehicles, grid storage, and other real-world energy applications.



A hyper-thick electrode built with controlled internal structure

The electrodes also showed strong durability. They completed long-term cycling tests, including 1000 cycles under high-rate operation, without cell failure. After cycling, the structured electrodes showed fewer severe cracks and defects than



The structured electrode remains intact under mechanical pressure

COMPUTATIONAL MICRO/NANOSCALE HEAT AND MASS TRANSFER

Micro/nanoscale heat and mass transfer refers to the transport of thermal energy and mass in systems whose characteristic length scales range from micrometers (10^{-6} m) down to nanometers (10^{-9} m). At these scales, classical continuum descriptions of heat and mass transfer, such as Fourier's law for heat conduction and Fick's law for mass diffusion, often break down. In nanoscale systems such as carbon nanotubes and nanopores, thermal conductivity not only depends on temperature and pressure, but also system size.

The behavior of nanoscale systems is very different from that in macroscopic systems. For instance, due to the buoyancy force, the macrobubbles rise quickly to water surface and burst. However, as bubble size reduces to nanoscale, the buoyancy force is insignificant compared to Brownian motions. As a result, the nanobubbles can remain suspended in water for days or even months. Due to their unique properties, nanobubbles are extremely useful in a broad range of areas such as water treatment, bioremediation of groundwater pollution, surface cleaning, and the growth of plants and fish.

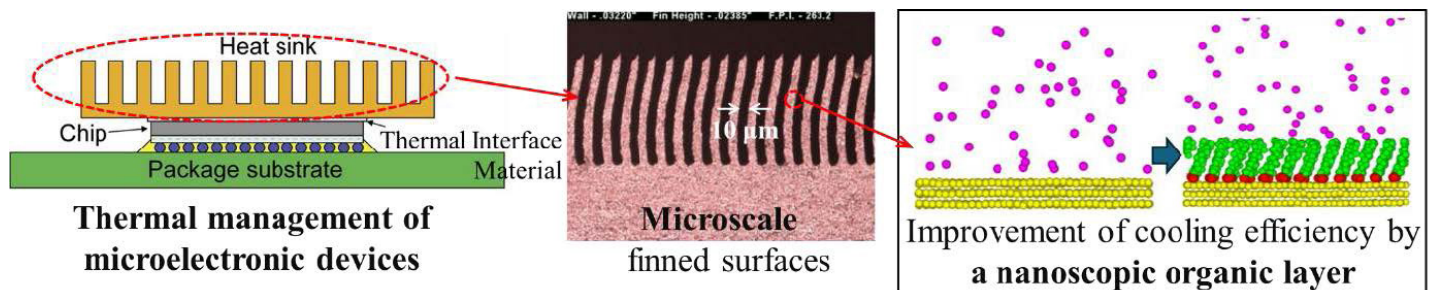
Understanding heat and mass transfer mechanisms in micro/nanoscale systems enables improved thermal management of high-power microelectronics, enhanced phase-change heat transfer in thin films and micro/nanodroplets, and optimized transport in porous and nanostructured materials. Dr. Zhi Liang's group mainly uses molecular dynamics (MD) simulations to study transport phenomena in micro/nanoscale systems. Molecular level modeling allows us to study microscopic details of micro/nanoscale transport phenomena, especially interfacial transport

phenomena, that are currently inaccessible by experimental means. Hence, MD simulation is very suitable for studying transport phenomena in micro/nanoscale systems. In the following, we show two specific research projects in Dr. Liang's group.

Thermal management in microelectronics

Microelectronic devices such as high-power LEDs and CPUs contain a variety of nanostructured semiconductor components. The main thermal barrier in these nanostructured components is not in the materials, but at the material interfaces. Generally, two kinds of interfaces need to be considered. One is solid-solid semiconductor interfaces within the nanostructured materials. The other is solid-gas or solid-liquid interface in the heat sinks since heat needs to be eventually dissipated to environment.

One of the tasks in Dr. Liang's research group is to use a variety of modeling techniques such as phonon wave packet simulations and MD simulations to study heat transfer mechanisms in nanostructured semiconductor



components and develop different strategies and design rules for enhancement of heat transfer efficiency. As shown in the following example, the size of heat sink for modern microelectronic devices could be in microscale (~ 0.1 mm or less). In microscale finned surfaces, the interfin spacing is as small as $10\text{ }\mu\text{m}$. For such microscale cooling devices, the cooling efficiency could be strongly affected by the heat transfer efficiency at the solid-gas interface. Using MD simulations, we provided a good understanding of heat transfer mechanisms at the solid-gas interface and developed a method to maximize the solid-gas interfacial heat transfer efficiency by functionalizing the solid surface with a nanoscopic organic layer.

Dynamics of micro/nanodroplets.

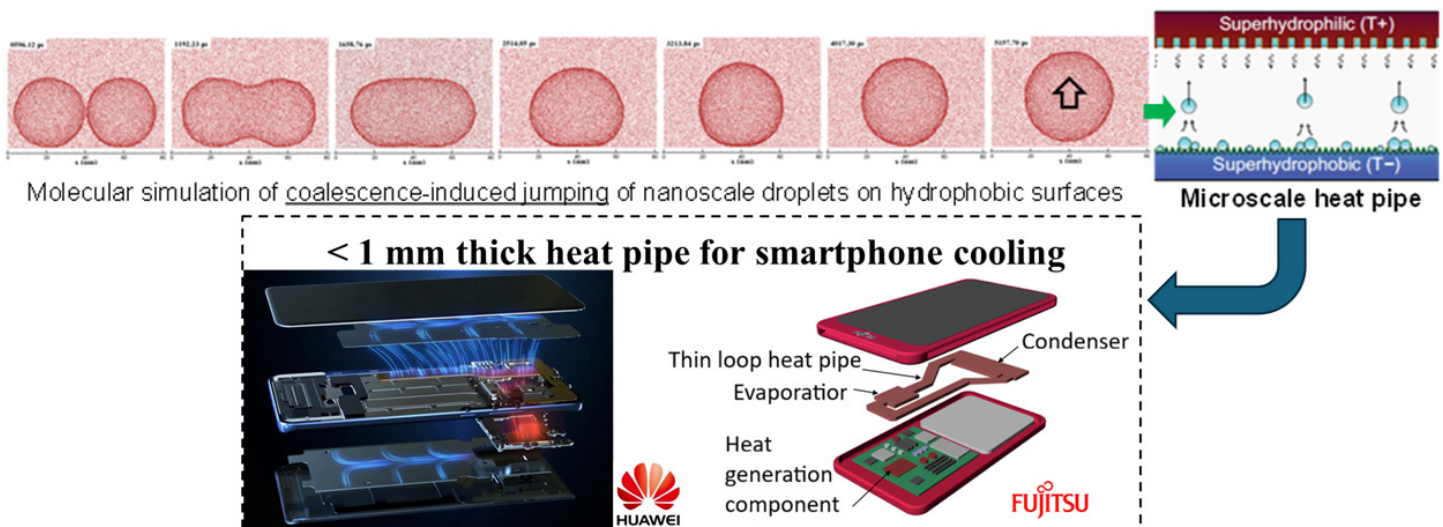
Micro/nanodroplets have very large surface-to-volume ratio. Surface energy and surface tension play a critical role in dynamics and phase change of these small droplets. This leads to a lot of interesting phenomena such as coalescence-induced jumping of micro/nanoscale droplets on super-hydrophobic surfaces. The molecular-level simulations can help fundamentally understand dynamics of nanodroplets and make use of these phenomena for a large number of applications including microscale heat pipes, water purification, self-cleaning surfaces and energy harvesting.

As shown in the following example, the CPU speed in smartphones is usually much lower than that in desktop/laptop computers since the smartphones do not have space to install a cooling device (i.e., finned surfaces+electric fan) that is widely used for cooling of CPUs in desktop/laptop computers. To avoid overheating, the CPUs in smartphones have to run at a low speed. If CPUs in smartphones can be cooled more quickly, the CPU speed in smartphones can be significantly enhanced to improve performance of smartphones.

Many smartphone companies are developing microscale heat pipes for smartphone cooling. One side of the heat pipe is in direct contact with the hot CPU surface. The coolant on the hot surface evaporates to cool the CPU. The evaporated vapor will condense on the cold surface on the other side of the microscale heat pipe to dissipate heat to the surroundings. To prevent the hot surface from drying out, one can make use of the coalescence-induced jumping of microdroplets to return the condensed liquid from the cold surface automatically to the hot surface as shown below. Our MD simulations provide fundamental understanding of how coalesced droplets jump and give design rules for development of a more efficient microscale cooling device for smartphones.

Our future work will be focused on dynamics and phase change of nanoparticles, nanodroplets, and nanobubbles with wide applications in interaction of airborne viruses (mostly nanoparticles) with liquid droplets, melt processing of nanoparticle-reinforced metal matrix composites, phase-change cooling of gas turbines, efficient combustion in high-performance engines, froth flotation of mineral particles, wastewater treatment, deinking of wastepaper, etc.

In all these applications with nanoscale systems, the transport phenomena at the solid-gas, solid-liquid, and liquid-gas interfaces could strongly affect the overall heat, mass, and momentum transport efficiency in the system. MD simulations are ideally suited to study interfacial transport phenomena. Our modeling results will enable us to develop strategies and design rules for various industrial, environmental, and biomedical applications with nanoparticles, nanodroplets, and nanobubbles.

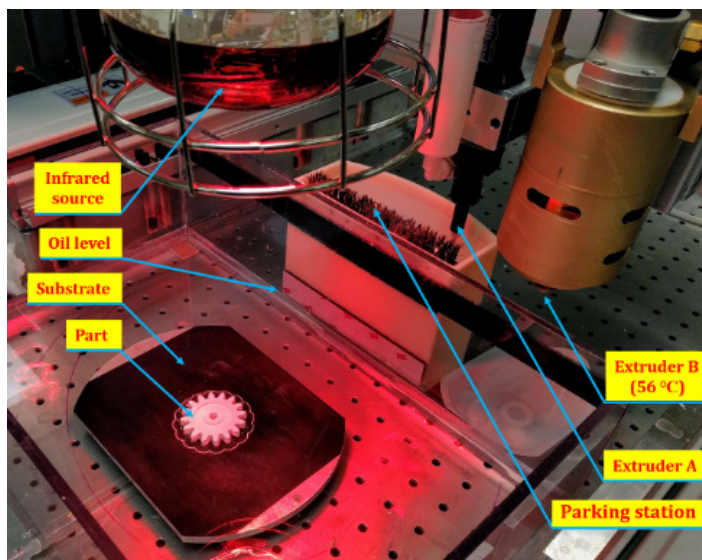


ADDITIVE MANUFACTURING OF ADVANCED CERAMICS

Ceramic materials exhibit a range of outstanding properties, including high hardness, excellent wear resistance, strong chemical and corrosion resistance, and superior creep resistance at elevated temperatures. These attributes make ceramics indispensable in numerous engineering applications across the aerospace, defense, electronics, biomedical, energy, and related industries.

Despite these advantages, fabricating complex ceramic components using traditional manufacturing methods remains highly challenging. Additive manufacturing (AM), or 3D printing, offers a promising alternative by enabling the efficient production of ceramic components with complex geometries. However, many AM approaches developed to date for ceramic fabrication have frequently resulted in defective or suboptimal components.

Material-extrusion-based additive manufacturing (MEX-AM) processes are among the most widely adopted methods for ceramic AM due to their relative process simplicity, low system cost, ability to fabricate high-density (low-porosity) parts, capability for multi-material fabrication, and minimal material waste during processing.



The Ceramic On-Demand Extrusion (CODE) system developed by Dr. Ming Leu's group at Missouri S&T

At Dr. Ming Leu's Innovative Smart and Additive Manufacturing (ISAM) Laboratory, extensive research has been conducted on the extrusion of high-solids-loading (>50 vol.%) aqueous ceramic pastes. To address the key challenges associated with MEX-AM processes, Dr. Leu's

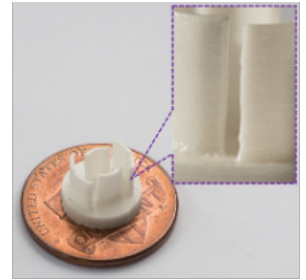
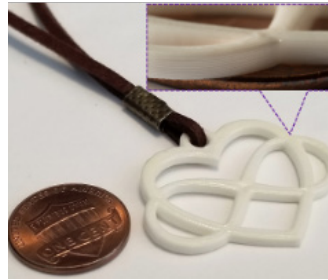
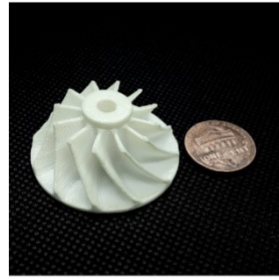
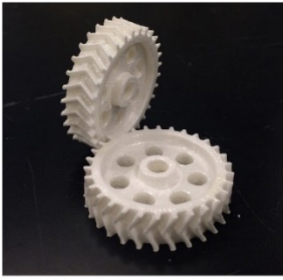
group developed the Ceramic On-Demand Extrusion (CODE) process for fabricating three-dimensional ceramic components with near-theoretical density.

In the CODE process, an aqueous ceramic paste with a very low binder content (<1 vol.%) is extruded through a traversing nozzle at room temperature. Following deposition, each printed layer is surrounded by a light oil to a level just below the top surface of the fabricated section, after which infrared radiation is applied to uniformly dry the exposed surface of the newly deposited layer. This sequence is repeated layer by layer until fabrication of the ceramic component is complete.

Manufacturing large, dense ceramic components with fine features using MEX-AM remains highly challenging due to the drying sensitivity of aqueous ceramic pastes, particularly when fabricating parts with large surface areas. The rheological properties of ceramic pastes—including viscoelasticity, shear-thinning behavior, and yield stress—play a critical role in process stability and part quality. Major technical challenges include uneven drying, part warping, and crack formation, while achieving an optimal balance between printing resolution and fabrication time is essential.

Our current research is strongly motivated by the need to develop a scalable methodology that enables high paste deposition rates, fine fabrication resolution, and controlled drying without introducing excessive system complexity. A primary objective is to establish on-demand optimization of printing parameters to facilitate the fabrication of large, dense ceramic components with fine features. To this end, various printing strategies are being evaluated, with particular attention to filament stretching behavior and its susceptibility to Rayleigh–Plateau instability.

The CODE process has also been extended to the fabrication of functionally graded ceramics through coordinated control of the volumetric flow rates of multiple ceramic pastes supplied from independent cylinders and homogenized using a



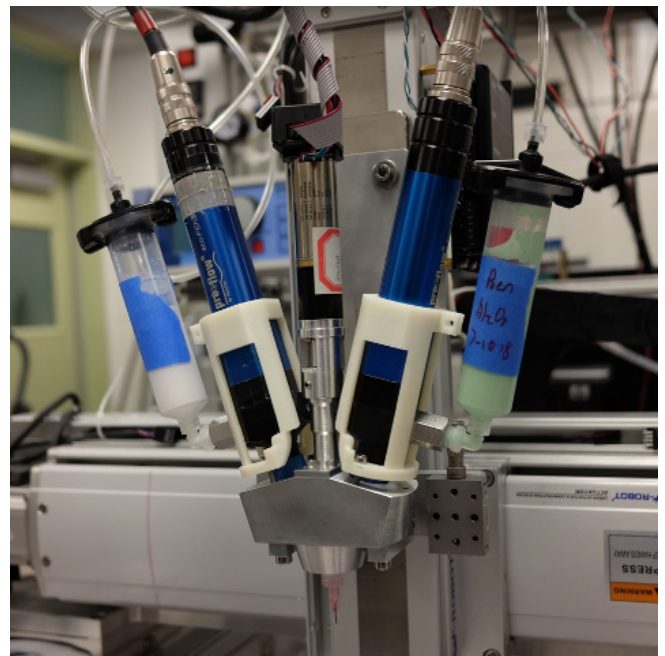
Sample parts fabricated by the CODE process

dynamic mixer. Using this approach, samples were printed, sintered, and mechanically characterized to evaluate the capability of the CODE process in producing functionally graded ceramic components.

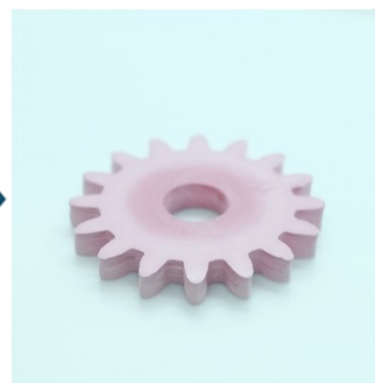
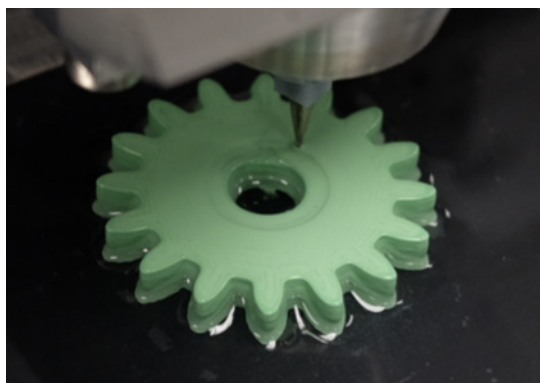
The target and actual material compositions of CODE-fabricated parts were compared using energy-dispersive spectroscopy. Dimensional changes in the sintered samples were analyzed to assess deformation of graded ceramic components during drying, debinding, and sintering. Vickers hardness was measured at multiple locations corresponding to different local material compositions. In addition, a case study demonstrated the capability of the CODE process to fabricate an $\text{Al}_2\text{O}_3\text{-ZrO}_2$ functionally graded ceramic gear.

Future work will focus on investigating interlayer and intralayer residual stresses arising from compositional grading both between layers and within individual layers, as well as evaluating the effects of these stresses on part warping, cracking, and delamination.

Fabrication of functionally graded ceramics is achieved through dynamic mixing of different ceramic pastes with coordinated control of their volumetric flow rates.



Part fabrication with graded materials by CODE with a dynamic mixer



Graded ceramic gear with 100% Al_2O_3 for the hub and 80% Al_2O_3 -20% ZrO_2 for the teeth

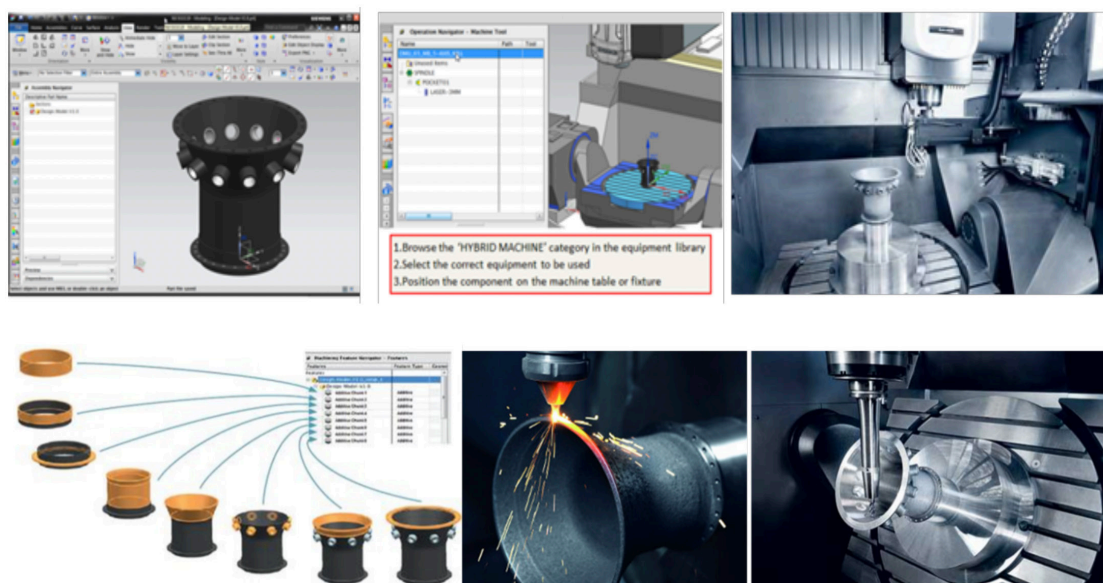
METAL ADDITIVE MANUFACTURING: BUILDING THE FUTURE OF INTELLIGENT PRODUCTION

Metal additive manufacturing (AM) has transformed how engineers design and produce complex components. However, additive manufacturing alone is often insufficient when high-dimensional accuracy, superior surface finish, material versatility, and production reliability are required. Missouri S&T researchers have pioneered Hybrid Metal Additive Manufacturing, an innovative approach that seamlessly integrates additive manufacturing with machining, laser processing, sensing, automation, and digital technologies to create a new generation of intelligent manufacturing systems.

For more than two decades, Dr. Frank Liou's research group at Missouri S&T Hybrid Manufacturing Laboratory has been advancing technologies that combine multiple manufacturing processes into a single, coordinated system. The vision is straightforward yet transformative: leverage the design freedom of additive manufacturing while incorporating precision finishing, real-time monitoring, and automated decision-making to produce high-quality components faster, more economically, and more sustainably than traditional manufacturing methods.

Many advanced engineering materials are difficult to process using conventional manufacturing techniques. Aerospace alloys, titanium components, tooling steels, and emerging multi-material systems often require extensive machining, long lead times, and expensive tooling.

Hybrid manufacturing addresses these challenges by integrating additive and subtractive processes within a unified manufacturing platform. Material can be deposited only where needed, followed immediately by machining or laser polishing to achieve precise

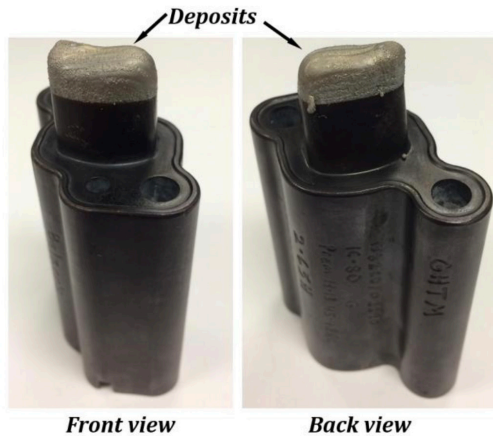


The hybrid manufacturing system, integrating additive manufacturing, machining, sensing, and automation, as developed by the Product Innovation and Engineering, Siemens (NX), DMG/MORI (Lasertec series), and Dr. Frank Liou's group at Missouri S&T.

dimensions and superior surface quality. The result is a manufacturing process that reduces material waste, shortens production cycles, and enables the fabrication of geometries that would otherwise be impossible or prohibitively expensive to produce.

The Missouri S&T research team has developed advanced hybrid manufacturing systems capable of combining directed energy deposition, machining, process monitoring, sensing, and automation into a single manufacturing environment. These systems provide a foundation for the intelligent factories of the future.

Industrial die repaired using metal additive manufacturing.



Molds and dies are costly and wear out very quickly, especially in high-volume production environments. Here shows a die repaired using the metal additive manufacturing process at Missouri S&T. The results show equal or greater performance than new dies.

One of the most impactful applications of hybrid manufacturing is component repair and remanufacturing. High-value industrial components such as molds,

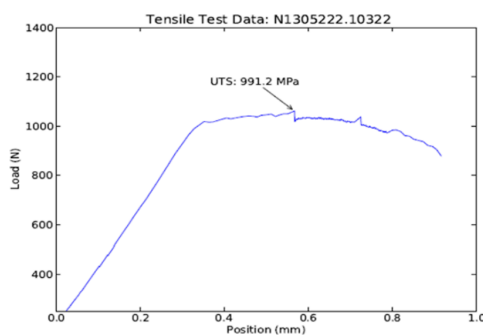
dies, aerospace structures, and energy-system components often fail only in localized regions while the majority of the component remains fully functional. Traditional replacement strategies can be costly, time-consuming, and environmentally inefficient.

Dr. Liou's research group has demonstrated that damaged components can be restored through additive manufacturing-based repair processes that rebuild worn or damaged regions with exceptional mechanical performance. Experimental studies on titanium alloys, steels, and industrial tooling materials consistently show that repaired interfaces often exhibit strengths equal to or greater than those of the original substrate material.

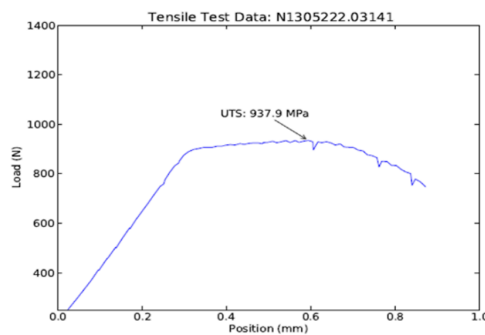
A particularly notable achievement involves the repair of industrial dies using the directed energy deposition technology. Testing results demonstrated that repaired dies achieved performance equal to or exceeding that of newly manufactured dies, significantly reducing replacement costs and downtime while extending component life.

These successes illustrate the enormous potential of hybrid manufacturing to support sustainable manufacturing practices by reducing material consumption, minimizing waste, and extending the useful life of critical industrial assets. The following are the planned future research: 1) Fabricating materials that are difficult, if not possible, using the traditional manufacturing processes, such as functionally graded materials and high entropy materials; and 2) Using the knowledge learned from hybrid processing to explore distributed digital factories that seamlessly integrate multiple manufacturing processes to form a digital supply chain.

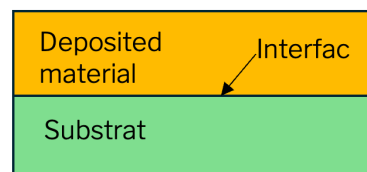
Sample#1
Specimen: **Interface**



Sample#2
Specimen: **Substrate**



Laser-based hybrid manufacturing repairs often achieve interface strengths greater than the original substrate material.

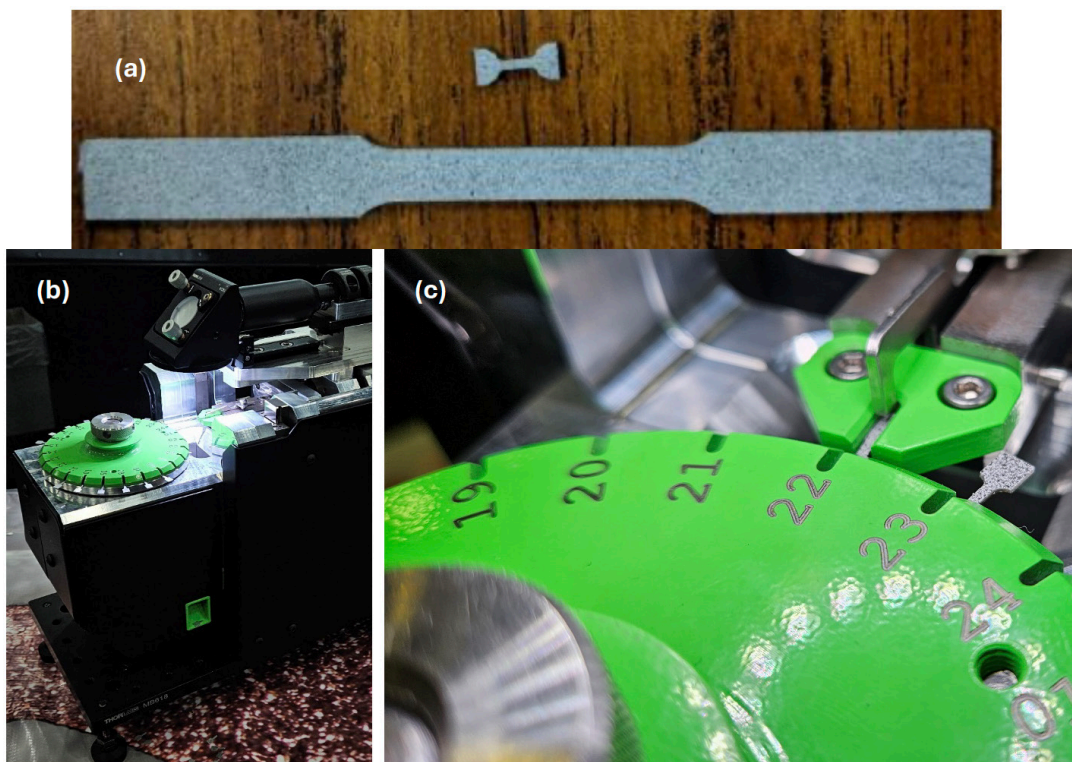


AUTOMATED HIGH-THROUGHPUT MECHANICAL TESTING USING MINIATURE SPECIMENS

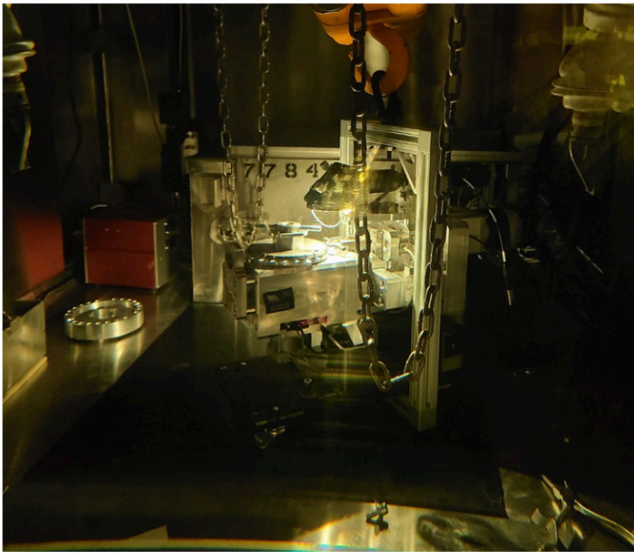
Conventional testing apparatus and their associated large-sized specimens were designed to measure the performance of conventional materials and their manufacturing processes. This is evident in their bulky design, need for high human interaction, slow test speeds, and the use of large amounts of material to perform these destructive tests. Hence, testing bulk quantities of cobalt, nickel, titanium, magnesium alloys, or even gold and rare earth materials can become prohibitively expensive. This problem is compounded when these materials are subjected to hazardous environments, such as radiation.

Larger specimens also pose challenges for quantifying multi-material systems, cellular structures, and manufacturing processes such as Additive Manufacturing (AM), as they do not provide relevant information on anisotropy and metallurgical bond strengths. There is a need to develop miniaturized test specimen designs and autonomous test systems that meet these research needs.

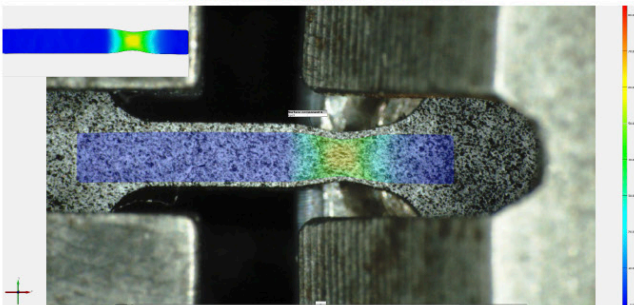
This is the core idea behind the development of miniature specimens in the meso-scale regime, which utilizes a sample size that is 1/230th the volume of the current smallest ASTM E8 dog-bone specimens. Such a system is coupled with the automation and associated Digital Image Correlation (DIC) achieved through this research's Advanced Mechanical Test System (AMTS). It allows rapid acquisition of large



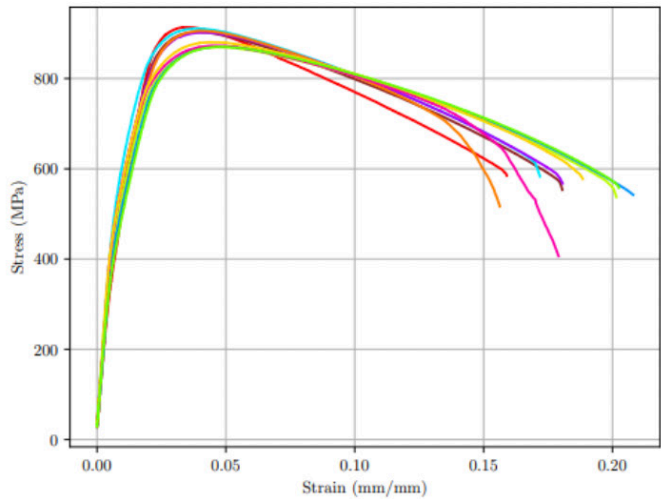
(a) Meso-scale miniature specimen design and comparison with ASTM E8 sub-size, (b) Research designed and built Advanced Mechanical Test System for high-throughput testing, (c) Close-up of autonomous miniature specimen tensile test



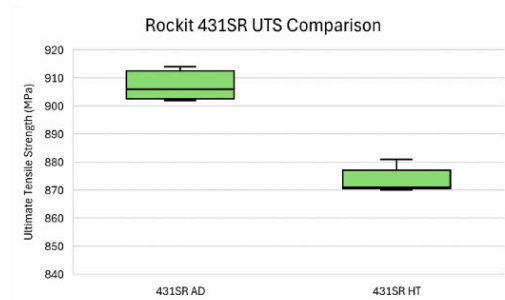
AMTS deployed at Idaho National Laboratory (INL) to test irradiated material



Mapping material behavior using DIC strain evolution



High-throughput and autonomously generated high fidelity data employed in numerical models and large language models (LLMs)



Quantifying strength changes in materials from manufacturing process effects and heat treatments

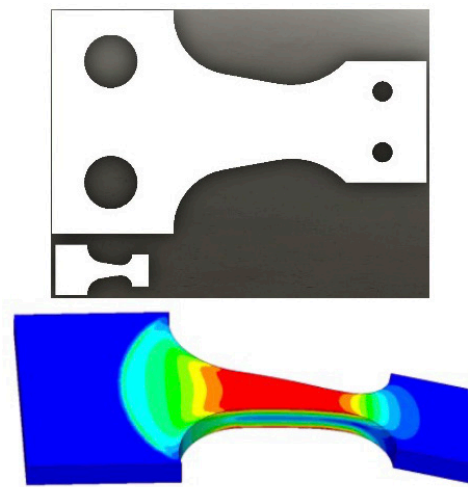
numbers of high-quality mechanical performance data for multiple alloys with minimal material, time, and cost.

The miniature tensile specimen design and AMTS have been successfully deployed to test a range of materials, manufacturing processes, heat treatment conditions, and more. Research has also been extended to a miniature single-Krause-type bending fatigue design to provide dynamic loading test results to complement static tensile testing.

Multiple avenues of future research have been identified to extend the capabilities and adoption of miniature meso-scale specimens and autonomous high-throughput testing.

LLMs can be leveraged to extract relevant data from high-throughput meso-scale testing to collate with other evaluations of material behavior. This will then be used to build and train models that use test and process data to support new materials discovery and manufacturing process qualifications. Additionally, there is a significant need to assess material properties at high temperatures to support various energy, defense, and space-based applications. The ability to generate high-throughput and

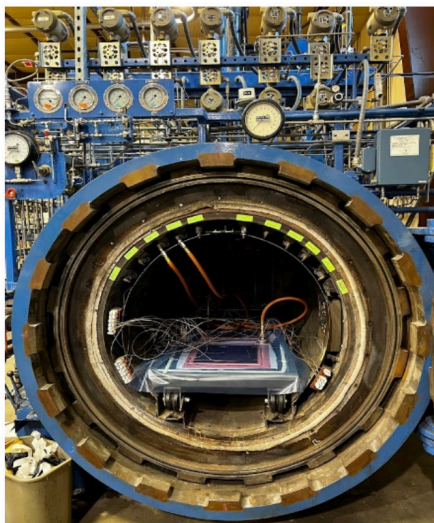
high-fidelity data at high temperatures using miniature specimens can be invaluable to address these needs.



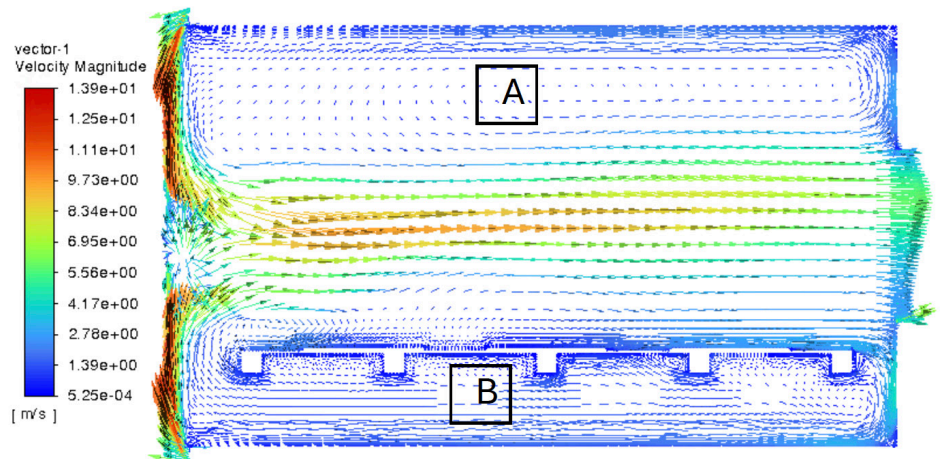
Development of miniature meso-scale bending fatigue specimen and comparison to ASTM, FEA-based analyses of Krause-type miniature bending test specimen

MANUFACTURING OF ADVANCED FIBER-REINFORCED POLYMER COMPOSITES

Composite materials are engineered systems consisting of two or more chemically distinct constituents, on a macroscale, having a distinct interface separating them. Fiber-reinforced polymer matrix composites are the most widely used composites. These composites have applications in many industries, such as automotive, construction, marine, electrical, aerospace, wind energy, biomedical, and recreation. The continued growth of polymer composites can be attributed to their outstanding properties such as high specific strength and stiffness, light weight, ease of fabrication, corrosion resistance, design flexibility, and high fatigue resistance.



Autoclave process



Flow pattern in autoclave chamber

Fiber is the primary load carrying component of the polymer composites while matrix binds the fibers together. Typical polymer composite fibers include glass, aramid, and carbon which may be continuous or discontinuous. Matrices can be polymers, metals, and ceramics. This research is focused on continuous fiber-reinforced polymer composites for high performance structural applications.

The composite manufacturing research led by Dr. K. Chandrashekhara encompasses a wide range of facilities which include pultrusion, filament winding, compression molding, injection molding, autoclave, resin transfer molding, and vacuum assisted resin transfer molding equipment. Recent research projects are focused on manufacturing complex composite parts using vacuum infusion, sandwich composite panels using out-of-autoclave process, pultruded bio-composite panels, and transparent composites using autoclave process. Autoclave is the most widely used method for producing high quality composites in the aerospace industry. The autoclave consists of a pressure vessel,

control system, electrical system, gas generation system and a vacuum system. Autoclave is pressurized with an inert gas (usually nitrogen). The autoclave facility at Missouri S&T has a sample size of 3 ft. diameter and 5.5 ft. in length. It can operate at temperatures up to 600°F and pressures up to 500 psi. Multiphysics/ multi-scale models have been developed for process optimization for the autoclave and to evaluate the structural performance of manufactured composite parts.

The ability of additive manufacturing process to reduce costs and lead times is of great interest to the composite manufacturing industry. The use of additive manufacturing process to produce complex end use parts with tailor made mechanical performance is currently being investigated. Both thermoplastic and thermoset composites are manufactured using Composite Based Additive Manufacturing (CBAM) facility at Missouri S&T. Technologies like machine learning and physics-informed neural networks enable real-time monitoring of complex additive manufacturing processes.



Additive manufacturing of composite structures



Hydrokinetic multi-turbine composite system

MULTIFUNCTIONAL MATERIALS AND ADVANCED MANUFACTURING FOR WEARABLE SENSING TECHNOLOGIES

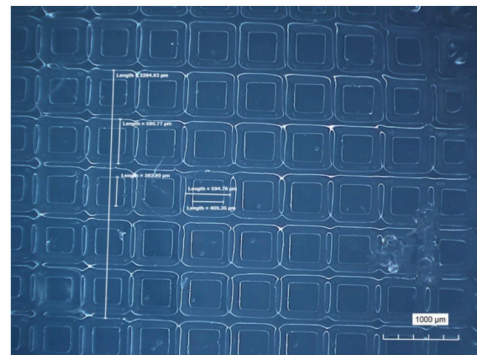
Wearable sensors are transforming how we monitor the human body and interact with surrounding environments. Applications ranging from healthcare monitoring and rehabilitation to sports performance tracking and human-robot interaction require sensing systems that can continuously capture physiological, chemical, mechanical, and motion-related signals in real time. Despite significant advances in recent years, many wearable sensors still rely on rigid electronic components, complex wiring, and onboard batteries. These elements increase device size and weight, reduce mechanical flexibility, and cause discomfort during long-term use.

Research in Dr. Bo Mi Lee's Intelligent Multifunctional Materials and Systems (IMMS) Laboratory addresses these challenges by using functional materials as the foundation for developing new types of sensors. Rather than relying on conventional electronic components to enable wearable sensing, Dr. Lee's group designs functional materials that can directly serve as sensing, conductive, and wireless signal-transducing components. This approach enables soft, lightweight, and mechanically compliant wearable sensing systems that are better suited for the human body.

One major research direction focuses on hydrogel-based wireless sensors. Hydrogels are attractive for wearable sensing because they are soft, stretchable, and tissue-like, allowing intimate contact with skin or other biological surfaces. Dr. Lee's group has successfully developed stimuli-responsive hydrogels that respond to mechanical inputs such as strain, pressure, and motion, as well as chemical or environmental changes including pH, temperature, and ionic concentration. These hydrogel materials have been integrated into



Conceptual illustration of a wearable hydrogel sensor patch for wireless physiological monitoring



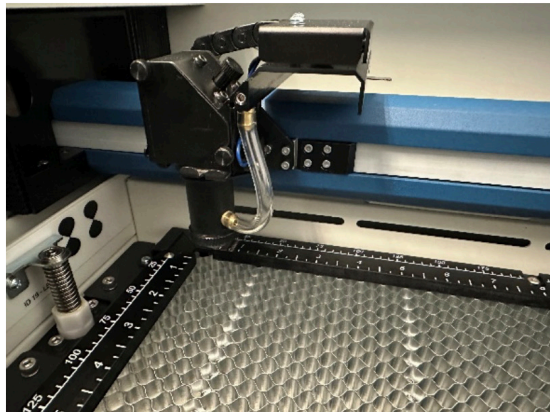
Optical microscopy image of an additively manufactured hydrogel sensor with engineered surface microstructures

passive wireless sensing platforms that operate without rigid electronics or onboard batteries.

To assemble these next-generation sensors, the IMMS Laboratory combines smart material design with advanced manufacturing strategies. Recent work has developed 3D-printable hydrogel inks that can be used to fabricate complex three-dimensional hydrogel microstructures.

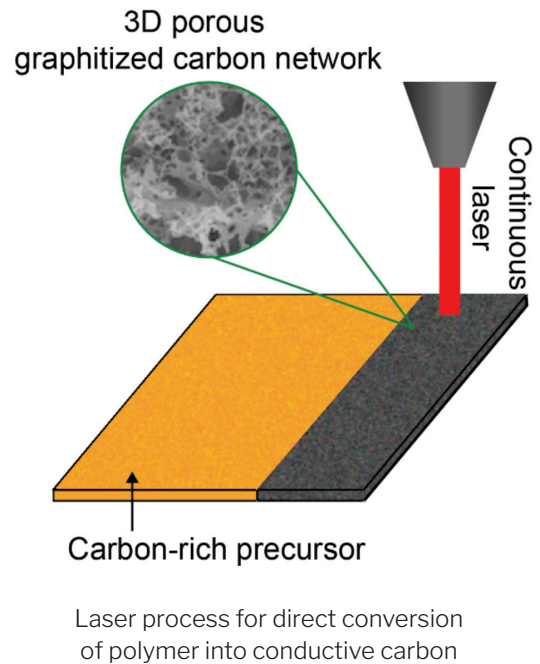
These engineered microstructures showed significantly improved pressure-sensing performance compared to non-structured hydrogel sensors, demonstrating how material architecture can be tailored to enhance sensing performance.

Beyond hydrogel-based sensors, next-generation wearable systems also require flexible conductive materials that can serve as sensing elements, electrodes, and interconnects. Conventional manufacturing of conductive structures on flexible substrates requires multiple fabrication steps, including conductive ink preparation, printing, curing, transfer, and post-processing. These methods involve complex material formulations, limited pattern resolution, and time-consuming and costly processing steps.



Laser processing equipment in the IMMS laboratory

Dr. Lee's group addresses these limitations by patterning conductive graphitized carbon directly on polymer using laser processing. Instead of depositing conductive

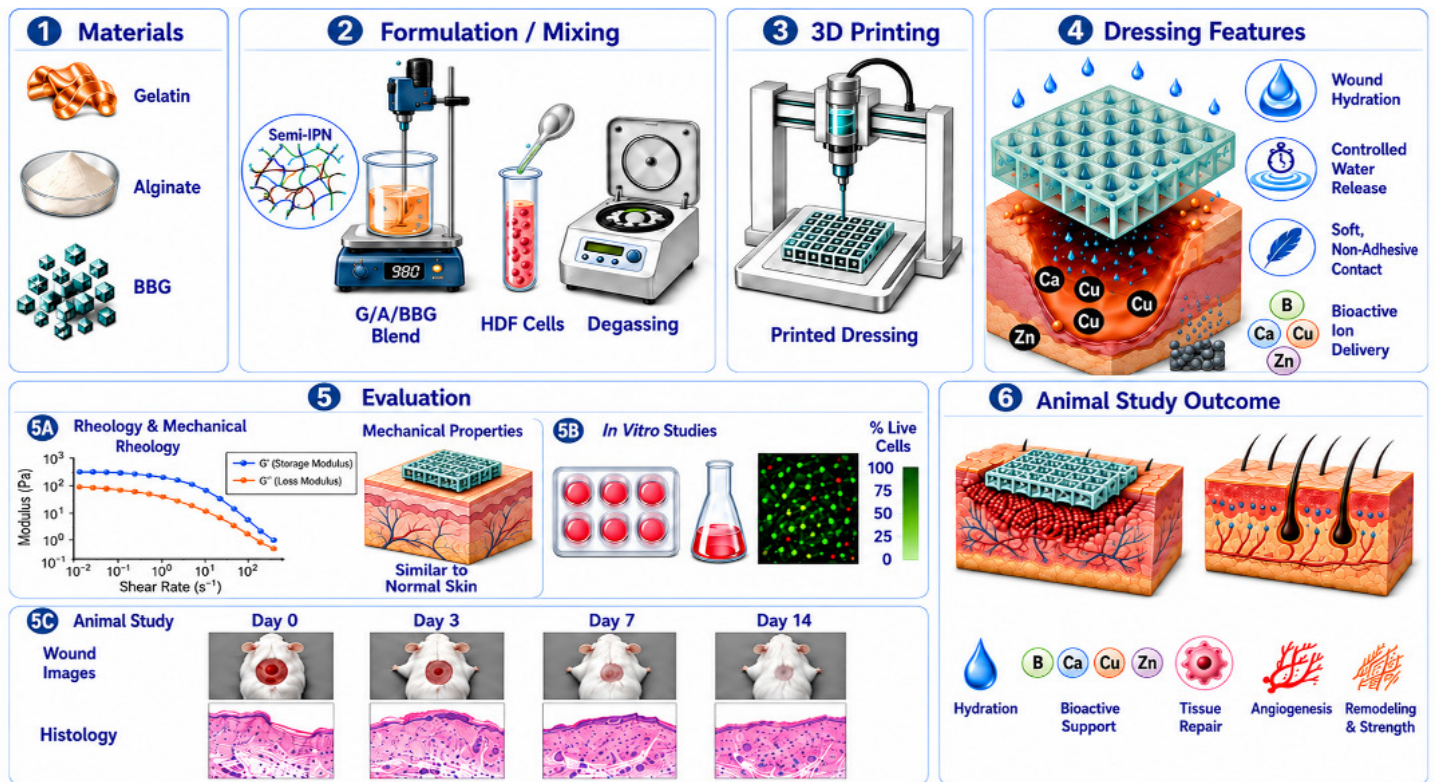


materials onto a surface, this approach converts selected regions of a polymer into conductive carbon using a focused laser beam. When the laser scans across certain carbon-rich polymers, intense localized heating rapidly transforms the material into a porous graphene-like carbon structure. This process enables conductive patterns to be written directly onto flexible substrates without inks, masks, or complex multi-step fabrication processes. By controlling laser parameters such as power, scanning speed, and beam focus, the structure and electrical properties of the resulting conductive materials can be tailored for sensing, flexible electronics, and energy-related applications.

Future research will investigate how laser processing parameters, such as laser power, scan speed, and focal conditions, affect the sensing properties of wearable electrochemical sensors fabricated using direct laser writing. In addition, the IMMS Laboratory will engineer microstructures of additively manufactured hydrogel to enhance sensing performance across multiple modalities including pH, temperature, and ion sensing.

BIOPRINTED SKIN FOR WOUND CARE, SKIN TISSUE MODELS, AND WEARABLE TECHNOLOGIES

Skin is the body's largest organ and its primary protective interface. It prevents fluid loss, protects the body against infection, senses the environment, regulates temperature, and supports communication between the body and its surroundings. When skin is damaged by burns, trauma, disease, or exposure to extreme environments, restoring these functions becomes a major clinical and engineering challenge. At the same time, there is a growing demand for wearable systems that can monitor health in real time without bulky electronics. Missouri S&T researchers address these challenges by developing advanced biofabrication approaches for skin repair, wound healing, skin tissue modeling, and intelligent biomedical interfaces.



3D printed hydrogel dressings reinforced with bioactive glass for burn wound healing

Dr. Fateme Fayyazbakhsh's research integrates mechanical engineering, biomaterials, biomedical science, and biofabrication to design skin-inspired systems that are soft, functional, and responsive. Rather than viewing wound dressings as passive coverings, our work aims to engineer them as active platforms that can support dynamic tissue regeneration and eventually monitor and respond to changes in the wound environment. This vision is especially important for burn wounds, where dehydration, pain, short-term wound coverage, infection risk, and scarring remain significant challenges.

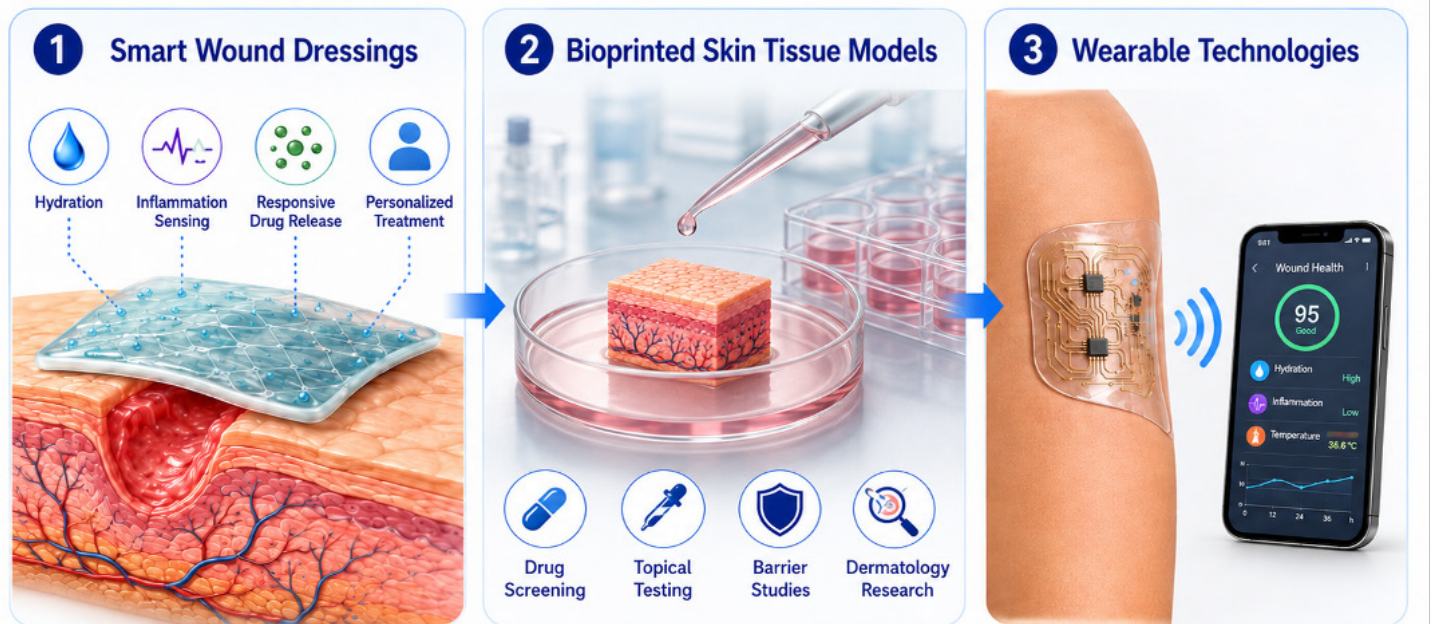
Our recent work has focused on the fabrication and characterization of 3D-printed hydrogel dressings for burn wound healing (Figure 1). Using gelatin and alginate as clinically relevant hydrogel materials, our group designed printable dressings with porous architectures that can maintain wound hydration while providing soft, non-adhesive contact with injured tissue. We further incorporated bioactive borate glass into these hydrogels to create hydrogel-BBG dressings with improved mechanical stability, controlled water release, and bioactive ion delivery. Through in vitro testing and preclinical burn wound animal models, this work showed that 3D printing can improve dressing structure and wound interaction, while the bioactive formulation can support long-term hydration, tissue repair, and regeneration of skin features such as hair follicles.

Building on this foundation, our lab is expanding toward the next generation of smart and adaptive

wound care systems (Figure 2). One direction is the development of personalized wound dressings that can be fabricated based on wound size, shape, depth, and patient-specific needs. By combining printable hydrogels, bioactive materials, and controlled porous architectures, we aim to create dressings that better match the mechanical and biological requirements of different wound types, including burns, chronic wounds, and injuries in austere or extreme environments.

A second direction is the integration of sensing capability into soft wound platforms. Future wound dressings should not only protect the wound but also provide information about the healing process. Our group is exploring conductive hydrogels, wearable sensors, and soft bioelectronic interfaces that can detect changes related to hydration, inflammation, infection risk, and tissue regeneration. These systems could eventually help clinicians monitor healing progress while reducing the need for frequent dressing removal and visual inspection.

Beyond wound care, our broader vision is to develop bioprinted skin tissue models and wearable technologies that support regenerative medicine, drug testing, disease modeling, and space health research. Students in our lab gain hands-on experience with 3D printing, bioprinting, hydrogel formulation, biomaterials characterization, cell studies, sensor fabrication, and preclinical research. Through this interdisciplinary training, they learn to translate engineering principles into biomedical technologies that address urgent healthcare needs.



Future directions

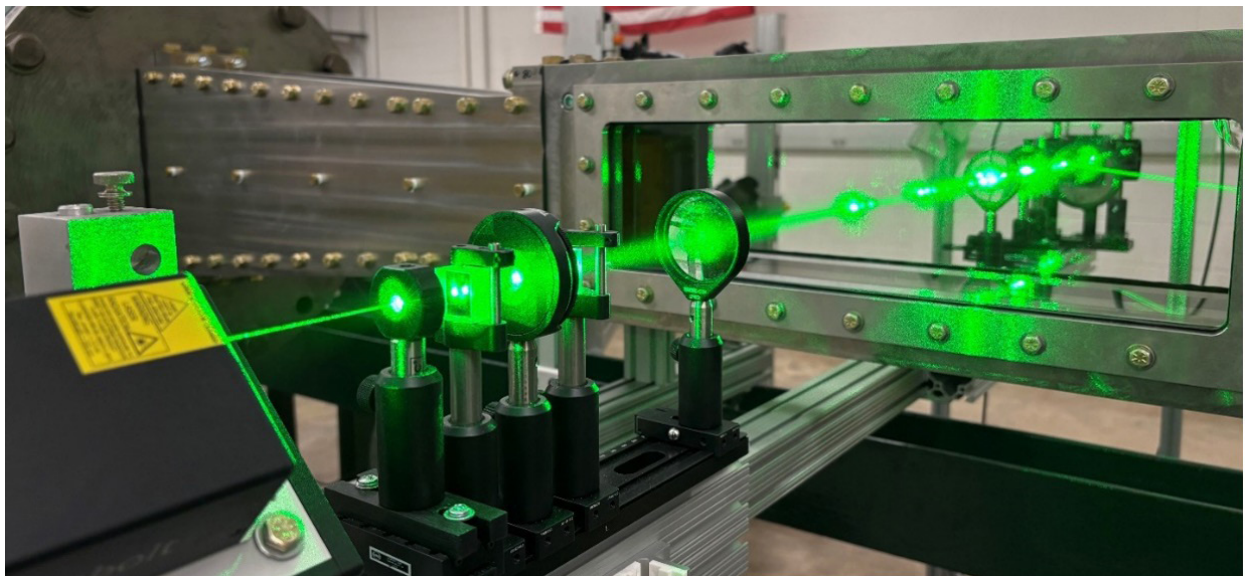
HIGH-SPEED TURBULENT FLOW RESEARCH

The study of high-speed turbulent flows remains a central challenge in advancing supersonic and hypersonic flight technologies. At Missouri S&T, this challenge is addressed through an integrated approach combining facility development, diagnostic innovation, and fundamental investigations of compressible flow physics. A major milestone has been the reactivation and continued upgrade of the campus Mach 3 wind tunnel, which now serves as the cornerstone of a growing experimental research program. This capability is complemented by a range of intrusive and non-intrusive measurement techniques that enable investigations into mixing in supersonic flows, vortex dynamics, and flow phenomena relevant to high-speed air-breathing propulsion. Together, these efforts support a research program focused on expanding experimental capability while advancing understanding of complex compressible flow behavior.

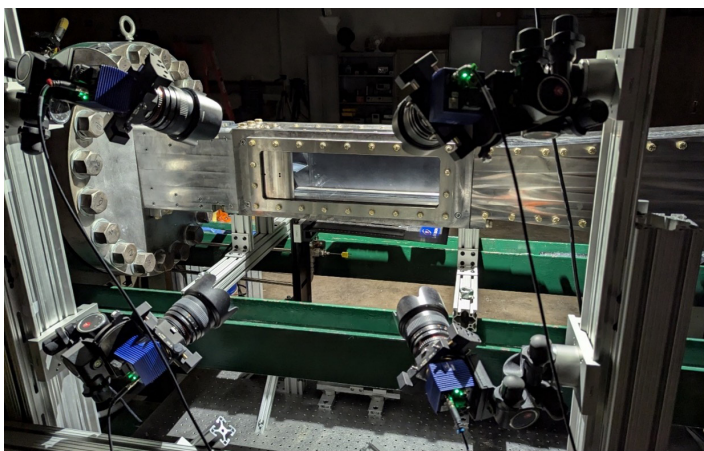
A central research thrust of Dr. Davide Vigano's Aerodynamics Research Laboratory focuses on understanding the role of turbulence in compressible flows and its impact on high-speed mixing processes relevant to air-breathing propulsion. While turbulence is often associated with performance losses, its inherent unsteadiness and three-dimensional structure can be leveraged to enhance fuel-air

mixing in supersonic combustion environments, where rapid mixing is a primary limiting factor.

Supported by funding from the National Science Foundation, ongoing work investigates the mechanisms governing turbulence generation, evolution, and mixing efficiency at high convective Mach numbers. Experiments



Focused Laser Differential Interferometry system used for high-frequency turbulence measurements in supersonic flows



Tomo-PIV system installed in the Mach 3 facility

conducted in the Missouri S&T Mach 3 wind tunnel combine controlled flow configurations with advanced laser-based diagnostics to resolve the structure and dynamics of turbulent mixing layers and vortex-dominated flows. These measurements aim to establish quantitative links between flow instability, coherent structure formation, and scalar mixing performance.

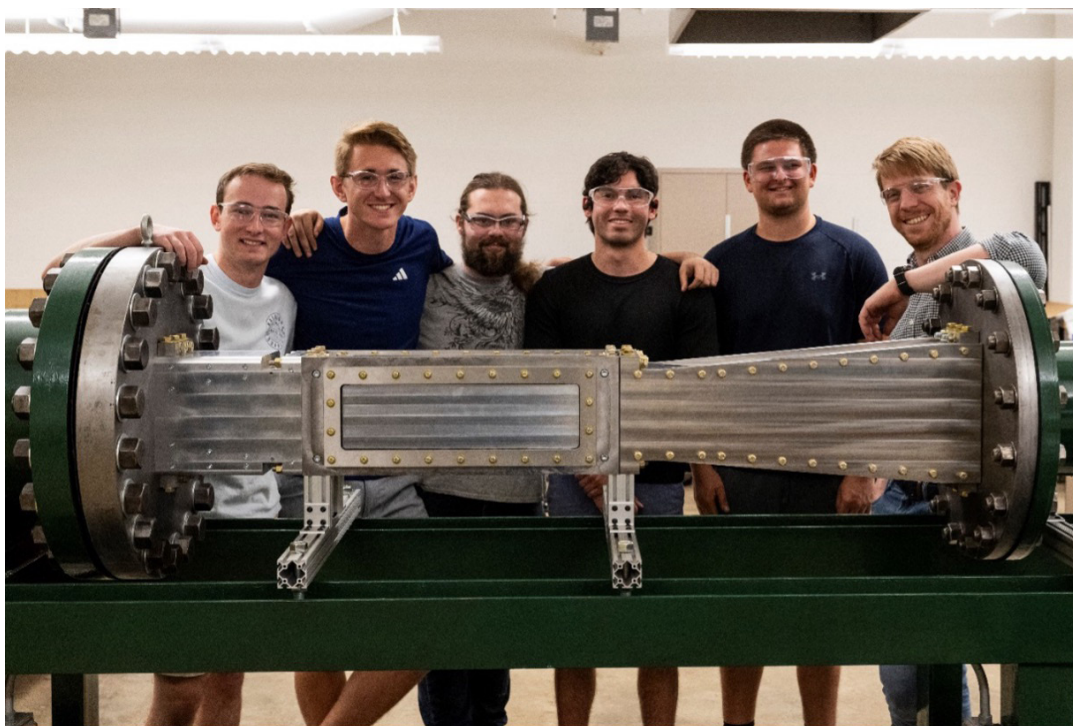
Beyond advancing fundamental understanding, this effort contributes to the development of improved experimental datasets for model validation and provides a framework for designing flow control strategies that exploit turbulence rather than suppress it.

To investigate the compressible flow, the laboratory is also advancing the use of Tomographic Particle Image Velocimetry (Tomo-PIV) as a tool for volumetric flow reconstruction in compressible environments. Applied

to the recently upgraded Missouri S&T Mach 3 wind tunnel, this approach enables three-dimensional, time-resolved measurements that provide a more complete assessment of complex, compressible, three-dimensional flows. The second technique used in our laboratory is Two-Point Focused Laser Differential Interferometry (2-FLDI). This laser-based diagnostic is unique as it allows simultaneous measurements of velocity and density fluctuations in compressible turbulent flows. Together, these techniques provide a unique experimental capability at the Aerodynamics Research Laboratory.

The laboratory continues to grow as a collaborative research environment supported by an expanding student team with a strong undergraduate component. Many undergraduate researchers transition into graduate roles within the group, creating continuity across projects and enabling sustained progress in both scientific investigations and facility development. Students contribute directly to experimental campaigns, instrumentation development, and wind tunnel upgrades, gaining hands-on experience while strengthening the laboratory's research capability.

While our current work is addressing the issue of compressibility in cold flows, future research efforts will focus on studying the effects of heat addition. This particularly challenging problem is highly relevant for the development of supersonic combustors that can, in turn, enable efficient high-speed flight. Furthermore, we will continue to develop new cutting-edge wind tunnels and novel diagnostics to be able to replicate, and measure, on the ground the extreme conditions found in hypersonic flight.



Members of the research team celebrating the completion of the facility upgrade they designed

EXPLORING MARS WITH INTELLIGENT ROVERS

Mars is hundreds of millions of kilometers away from Earth. When a rover on Mars sends a signal home, it usually takes about 20 minutes to arrive, and another 20 minutes for a response to return. This means every instruction, every warning, and every decision is separated by nearly 40 minutes of silence. If the rover approaches a steep slope or soft sand, there is no one on Earth who can react in time. By the time engineers see the danger, it has already happened. Alone on a distant planet, the rover must rely on its own intelligence. It must look at the terrain ahead, recognize potential risks, and decide where to go next. Every move matters.

A wrong decision could trap the rover permanently, ending a mission that took years to plan and millions of miles to reach its destination. Yet these robotic explorers are humanity's eyes and hands on Mars. They cross ancient landscapes, climb rocky hills, and search for clues about the history of another world. To succeed, they must do more than follow instructions. They must learn to think, adapt, and explore on their own.

Our current knowledge of the Martian surface remains very limited. Although orbiting spacecraft have captured many images, only a small portion of Mars has been imaged in high enough resolution to clearly reveal terrain details. Many areas remain poorly understood, and the rover itself can only see a small region around it. As a result, the rover must make decisions even when complete information is not available.

The Martian surface is full of challenges. Beneath the rover's wheels may be solid rock, loose sand, or steep slopes. Some areas may appear safe but can trap the rover permanently. Once trapped, the mission could come to an early end. Helping the rover understand its environment and choose safe paths is therefore a critical challenge in space exploration.

In Dr. Chaoying Pei's laboratory, researchers are developing new intelligent technologies that allow rovers to make decisions using only a very small amount of prior data, combined with real-time information from onboard cameras and other sensors. Even in an unfamiliar terrain, the rover can evaluate risk and select safer and more efficient routes. As shown in the figure, the rover can actively avoid hazardous regions instead of moving blindly. Importantly, the rover is often



NASA's Perseverance rover exploring Mars



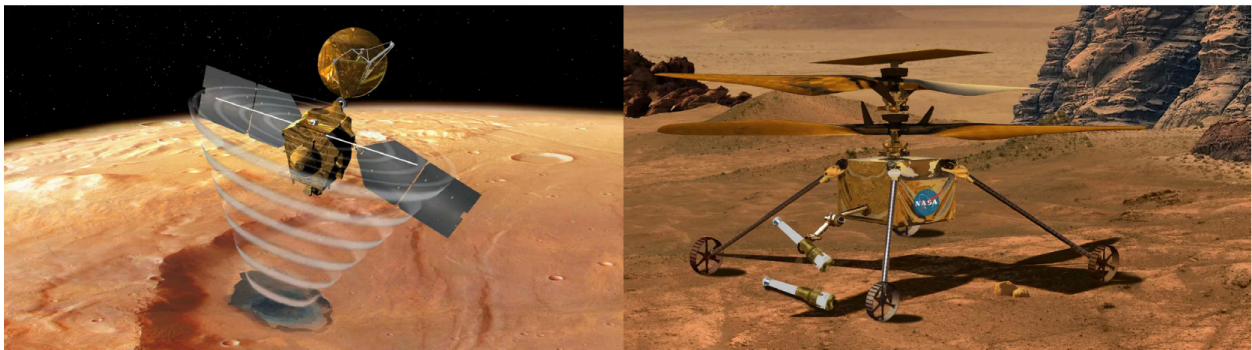
Martian terrain with rocks, sand, and slopes

not alone. Orbiters such as the Mars Reconnaissance Orbiter and aerial scouts such as the Ingenuity helicopter can observe the environment from above and send back valuable information. These teammates provide a broader, global view of the terrain that the rover cannot see from the ground. By combining this global information with its own local sensor data, the rover can make better decisions, plan safer routes, and avoid hidden dangers. This capability allows the rover to operate more reliably, travel farther, and explore regions that would otherwise be too risky to reach.

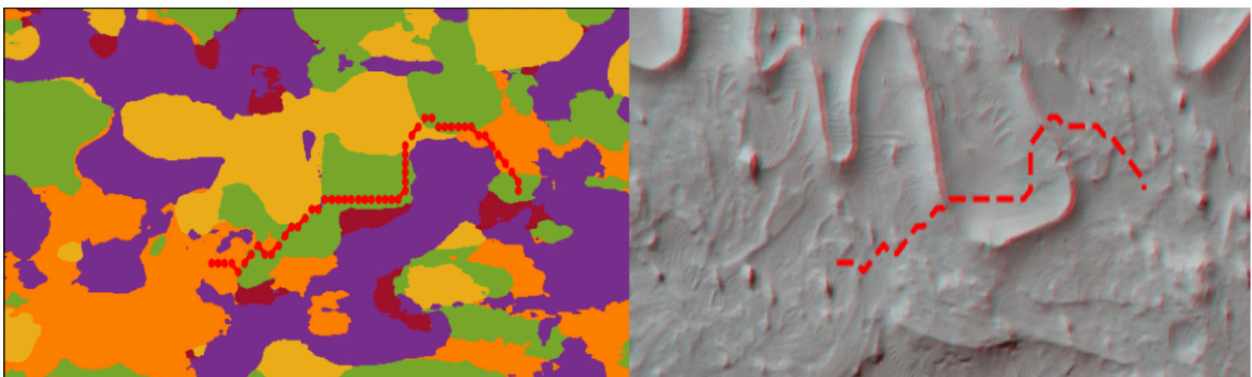
This research allows robots not only to see their surroundings, but to understand them, make decisions, and explore independently. Instead of relying entirely on instructions from Earth, the rover can operate more independently. This level of autonomy is essential for future space missions, where communication delays and unknown environments make real-time human

control impossible. By increasing robotic autonomy, future missions will be able to explore more challenging regions and achieve greater scientific discovery.

In the future, these technologies will be tested using real robotic systems in laboratory environments that simulate Martian terrain. These experiments will help verify the safety and reliability of autonomous navigation and prepare robotic explorers for real planetary missions. This work will support the next generation of Mars and Moon rovers, enabling them to travel farther, operate longer, and explore regions that have never been reached before. By giving robots the ability to make their own decisions, this research helps extend human exploration beyond Earth. These intelligent explorers will venture deeper into space, uncover new environments, and bring us closer to answering one of humanity's most fundamental questions: Are we alone in the universe?



Teammates of the Perseverance rover: orbiters and the Ingenuity helicopter



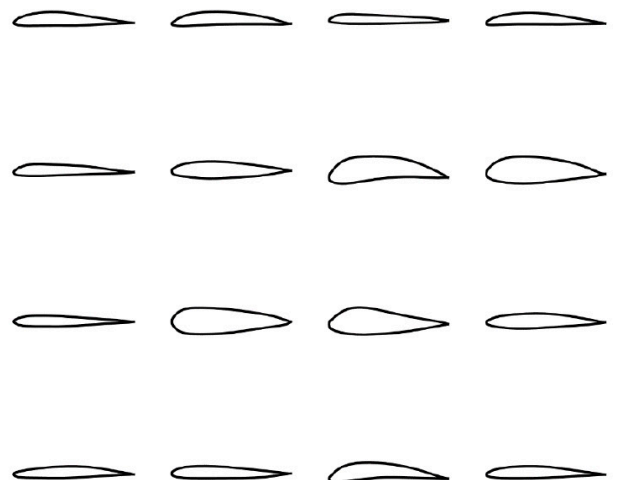
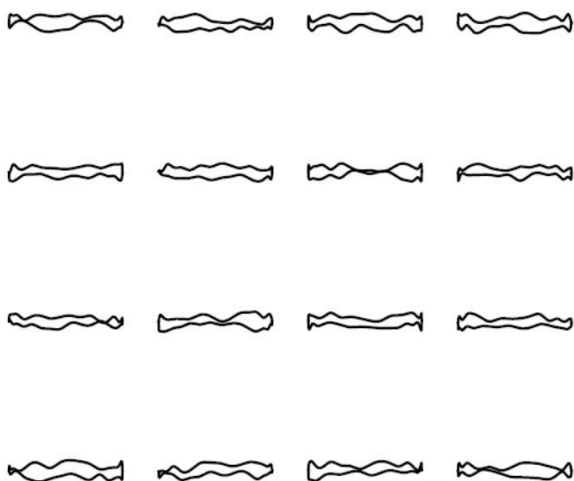
Autonomous rover trajectory avoiding hazardous terrain

GENERATIVE ARTIFICIAL INTELLIGENCE FOR AIRCRAFT DESIGN

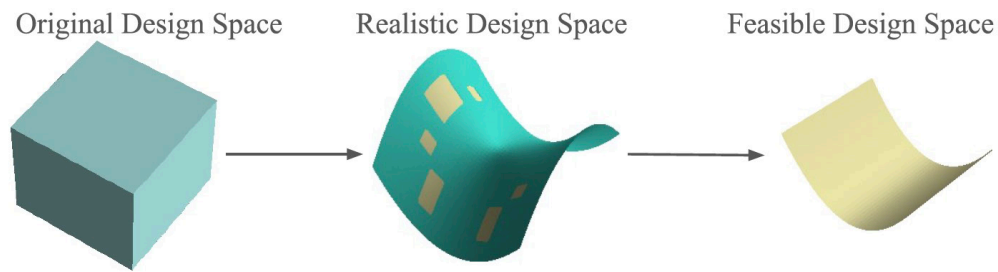
Aircraft design optimization plays an essential role in aerospace engineering for improved performance such as enhanced fuel efficiency and reduced emissions. Conventional aircraft design optimization adopts high-fidelity simulation models to automate the design process and shorten the design cycle compared with human-supervised aircraft design. However, iteratively evaluating high-fidelity simulations typically results in excessive computational cost, even with the support of high-performance computing resources. This challenge prohibits fast, even real-time, decision-making that is highly desired in modern aircraft design.

Artificial intelligence (AI) has emerged as a revolutionary game-changer in human society, ranging from daily life (such as smartphone face recognition) to engineering applications (such as drones and autonomous vehicles). Among these advancements, AI has enabled aircraft design by leveraging prediction models, in lieu of computationally expensive simulation models. Broad success has been demonstrated; however, training AI prediction models could cost significant computational resources, especially in high-dimensional aircraft design optimizations. This bottleneck is often referred to as the “curse of dimensionality.”

Dr. Xiaosong Du’s research lab addresses these challenges by using generative AI (genAI) and physics-informed (physical) AI. GenAI is used to generate geometrically realistic designs while physical AI integrates governing physics or physical constraints into data-driven AI models for improved performance. GenAI was originally developed to generate human-like content including text, images, and code. The prominent large language models such as ChatGPT, Gemini, and DeepSeek represent a subset of genAI. Dr. Du’s lab has successfully applied genAI to generate realistic aircraft-related geometries and trajectories,



Randomly generated “airfoils” by conventional methods (left) compared to randomly generated airfoils by genAI (right)



Design space transformation using physics-constrained genAI

including airfoil shapes and takeoff profiles for electric autonomous drones. The realistic shapes generated by both genAI and physical AI provide a guide for AI prediction models to focus on realistic shapes and corresponding quantities of interest, which simplify the modeling complexity and computational burden. This feature is particularly attractive considering that the filtered-out unrealistic shapes (such as airfoils with wiggles) almost never make the optimal design.

Funded by the National Science Foundation, the recent work integrates physical constraints into data-driven genAI, termed physics-constrained genAI, such that a trained genAI produces designs that automatically satisfy all physical constraints. The physics-constrained genAI aims to transform the original design space using

a data-driven genAI to a “feasible” space that satisfies all physical constraints. Thus, complex constrained aircraft designs can be reformulated as unconstrained optimizations, significantly reducing optimization complexity and enhancing optimization efficiency. This approach has been successfully demonstrated in the optimization of drones, airfoils, and wings. There is almost no visible difference between the simulation-based optimal design and the physics-constrained, genAI-based optimal design. Moreover, the physics-constrained genAI method completes the optimal takeoff design in 1~2 seconds while the conventional optimization approach takes 20~30 minutes with the same desktop computer. Dr. Du’s research lab is currently using real drones to validate the AI-driven optimal designs.



An electric takeoff and landing is modeled to demonstrate the optimal takeoff trajectory design based on physics-constrained genAI.

FRACTURE, FATIGUE AND IMPACT DAMAGE IN AEROSPACE COMPOSITES

Modern aerospace structures increasingly utilize advanced composite materials to achieve lightweight and high-performance designs. Contemporary passenger and military aircraft incorporate more than 50% composites by weight; however, their structural integrity is influenced by complex damage mechanisms, including debonding at heterogeneous interfaces, fracture resistance, and barely visible impact damage or delamination (BVID). These failure modes develop through strong interactions among geometry, material heterogeneity, environmental exposure, and loading history, which present significant challenges for certification and safe structural design.

The Composites Aerostructures Laboratory, established by Dr. Arief Yudhanto in Fall 2025, conducts research programs that address critical challenges in composite materials. The laboratory employs an integrated experimental and computational framework to advance fracture-mechanics-based modeling, data-reduction methodologies, and multi-physics testing protocols for aerospace composite structures.

Progressive fracture in face-core interface of sandwich composites with honeycomb core

Sponsored by the NASA Missouri Space Grant Consortium, this research aims to simulate progressive face-core interfacial fracture (debonding) in sandwich composites and to quantify the associated energy release rate (ERR). Unlike conventional approaches that resort to 2D models, we develop 3D single-cell and multi-cell finite element models developed in ABAQUS that explicitly represent the honeycomb cell geometry, directly enabling an in-depth study of geometric nonlinearity and competing failure modes at the microscale. Cohesive Zone Modeling (CZM) and Continuum Damage Mechanics (CDM) simulate distinct mechanisms: adhesive failure (pure face-core debonding), cohesive failure within the core, mixed-mode failure, and local core kinking. The models specifically decouple the influences of geometric nonlinearity and competing failure modes on ERR. Validation against in-house experiments is also performed to verify the modeling strategies' outcomes. This work is expected to clarify the uncertainty in

debonding characterization and enhance models for predicting the behavior of aerospace sandwich panels.

In situ micro-scale fracture characterization of composite under hygro-thermo-mechanical loading

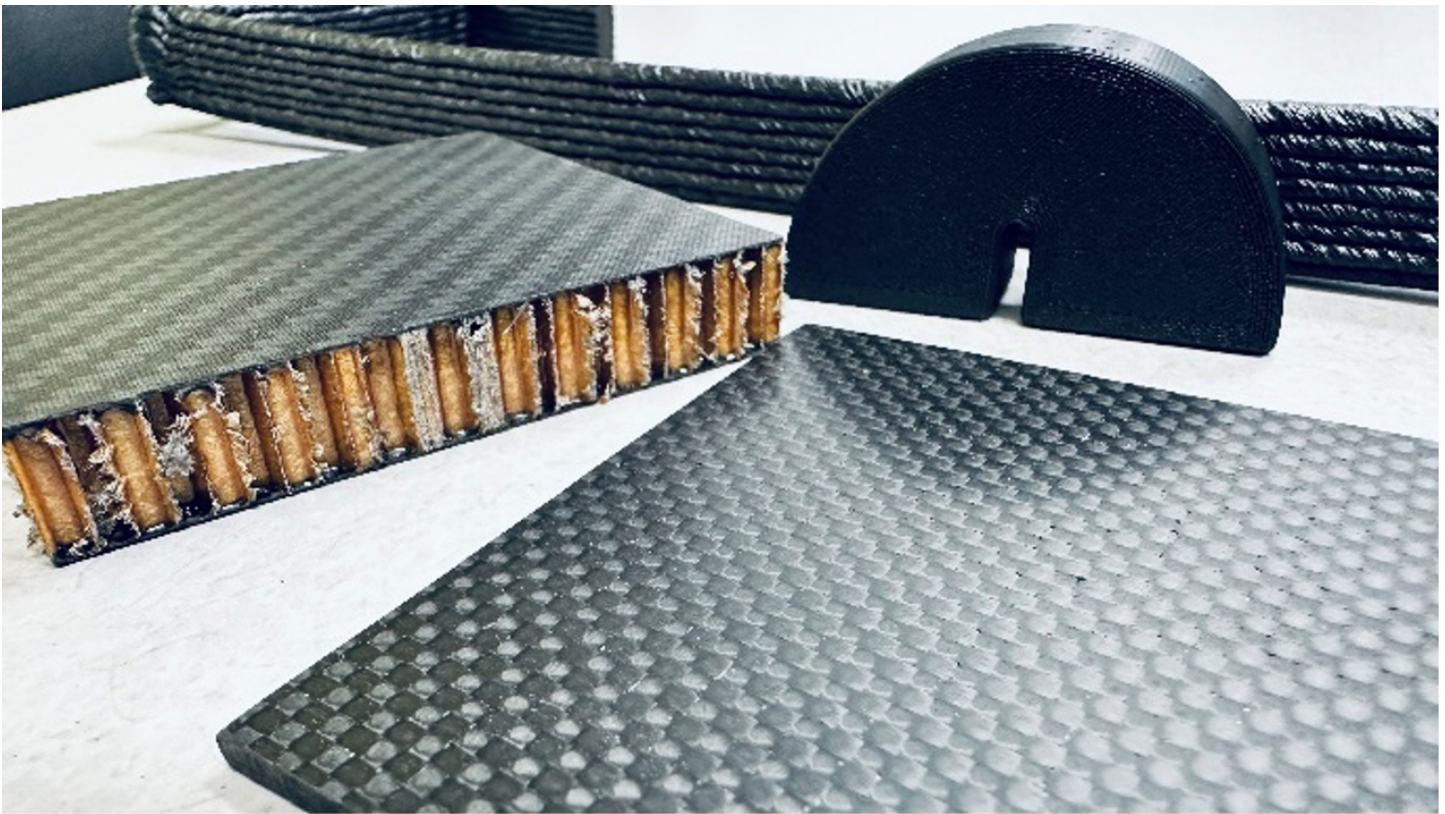
Sponsored by Missouri S&T's Kummer Institute, this research seeks to advance the understanding of carbon fiber-reinforced polymer (CFRP) degradation under combined moisture, heat, and mechanical stress. In aerospace and energy applications, structures are routinely exposed to these conditions, which accelerate damage at the fiber-matrix interface and lead to cracking, delamination, and fiber breakage. However, comprehensive knowledge of fracture initiation and progression in such environments remains limited due to the lack of experimental setups capable of simultaneously applying mechanical loads, controlling environmental conditions, and enabling real-time observation. To address this limitation, the project utilizes X-ray microcomputed tomography to establish a novel experimental methodology and a closed test system that applies controlled mechanical loads at specified temperatures while capturing high-resolution images. This methodology is expected to generate a dataset on crack initiation and propagation, along with variations in energy release rates under realistic service conditions. Furthermore, a new fracture model is being developed to incorporate these combined effects. The ultimate objective is to elucidate multiphysics fatigue-induced fracture in composites, reflecting their realistic use under cyclic loading.

This project provides a foundation for evaluating the durability of composites in extreme environments.

Multi-site impacts and residual strength of composite panels

This research seeks to characterize impact-induced damage, including transverse cracking, delamination, and fiber rupture, in composite materials under realistic geometries and loading conditions. Current certification practices rely almost exclusively on single-impact tests, despite the fact that aircraft structures are frequently subjected to repeated low-velocity impacts from debris, hail, and maintenance operations, which can occur at the same or different locations. The accumulation of such events results in barely visible impact damage (BVID), which significantly reduces the residual strength of composites. This project will develop a hybrid approach

that integrates the cohesive zone modeling (CZM) and continuum damage mechanics (CDM) to simulate delamination initiation and progressive growth in CFRP laminates subjected to multiple impacts. A study is also conducted to understand the BVID in sandwich composites. The effect of damage interaction on mode-mixity is accounted for by applying the Virtual Crack Closure Technique. The effect of panel geometry is studied by incorporating curvature-induced mode coupling, strain-rate effects, and sequential impact histories. The proposed framework advances beyond conventional single-impact modeling. The methodology is validated through experiments using an in-house movable setup on flat and curved plates, providing a computationally efficient and physically consistent approach for predicting impact-driven interlaminar damage in representative aerospace structures.



Advanced structural materials: sandwich composites with honeycomb structures, carbon fiber woven composites, semi-circular fracture test specimen, and the beads of large-area additive manufactured carbon/ABS (in the background)

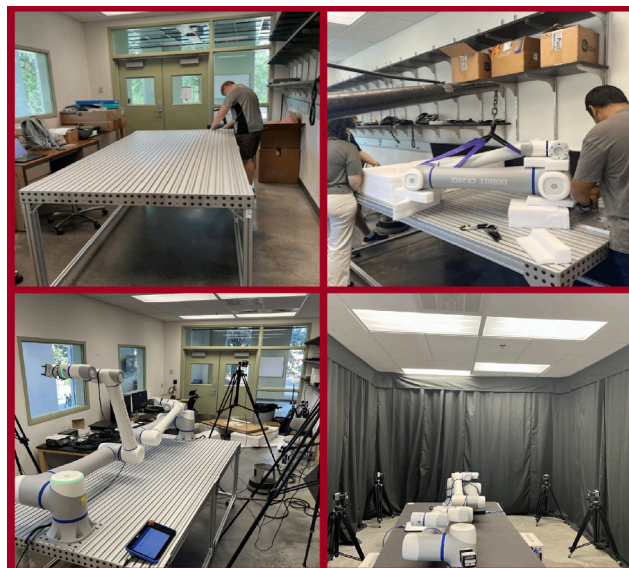
MULTI-AGENT RENDEZVOUS FRAMEWORK FOR ADVANCED SPACE AUTONOMY

With the rapid growth of the resident space object population in near-Earth space, traditional passive space domain awareness (SDA) capabilities must be complemented by active measures, such as space debris removal and on-orbit servicing, to ensure the safety and sustainability of the near-Earth space environment. Achieving this objective requires reliable and intelligent autonomous systems capable of safe, coordinated guidance, navigation, and control during close-proximity operations with non-cooperative space objects.

The Dynamics, Control, and Computer Vision for Space Sustainability and Missions (DCV-Space) group, led by Dr. Smriti Nandan Paul, conducts experimental and computational research at the intersection of SDA, space weather-astrodynamics coupling, space autonomy, and applications of stochastic machine learning techniques. One active and experimentally driven focus of the group is autonomous rendezvous and proximity operations (RPO) with direct relevance to active space debris removal, on-orbit state modification, and In-space Servicing, Assembly, and Manufacturing (ISAM). The core capability of DCV-Space is a hardware-in-the-loop RPO testbed, currently under development, that enables controlled experiments involving multiple-agent systems. The lab is currently equipped with two

6DoF Dobot robotic arms for complex manipulation, eight Vicom cameras for high-fidelity tracking, four RGB-D Femto Bolt cameras for navigation, two Jetson TX₂ computers for real-time operations, one Godox LED lamp for simulating various lighting conditions, and two state-of-the-art workstations.

The DCV-Space RPO testbed is designed using multi-agent, single-target architecture. Two intelligent agents, each mounted on 6DoF robotic arm, simultaneously approach a common non-cooperative target mounted on a third fixture. This configuration represents future debris removal and orbit modification scenarios, where multiple servicing spacecraft



Different phases of the multi-agent RPO testbed construction

coordinate their motion to safely interact with a large (known or unknown) non-cooperative target.

The target mockup currently under consideration is a scaled physical model of NASA's Aura satellite. The robotic arms emulate relative translational and rotational motion between each agent and the target, allowing a systematic study of coupled multi-agent proximity dynamics under realistic system and safety constraints.

Calibration is performed using robot kinematics and a combination of onboard camera and external motion-capture measurements to enable accurate transformation between different frames of interest. These calibrated measurements from multiple sources are fused to generate reliable pose labels used for training and evaluating a vision-based (navigation) network.

The machine learning-based navigation network relies on both laboratory-generated imagery under controlled illumination and synthetic imagery produced by using a digital twin of the agents, target, and the operating environment. This combined dataset increases the system's robustness and reliability.

The DCV-Space testbed is used by Dr. Paul's group to study cooperative, learning-based guidance strategies for multi-agent RPO. Reinforcement learning models are trained to generate desired acceleration guidance signals for each agent while respecting safety and coordination constraints inherent to multi-agent proximity operations. A safety-aware controller, based on Control Barrier Functions (CBFs), is currently being developed for tracking the desired guidance signals.

On-ground validation experiments focus on scenarios in which both agents simultaneously approach the target, iteratively refine their state estimates, and coordinate their motion until terminal proximity conditions are satisfied. Each robotic agent is equipped with two monocular RGB-D cameras that provide imagery for 6DoF relative pose estimation of the non-cooperative target.

The DCV-Space multi-agent RPO testbed provides a distinctive experimental capability for studying safety-aware autonomous space applications. The lab is currently also investigating sensor fusion techniques to help with RPO under extreme lighting conditions and modification of the testbed for non-space applications.



Synthetic image of the Aura satellite generated using Blender

SMALLSAT/CUBESAT ASSEMBLY, INTEGRATION, TEST, LAUNCH, AND OPERATIONS

Missouri S&T's Satellite Research Team (M-SAT) designs, assembles, and tests small satellites in their Space Systems Engineering Lab. One of these satellites, M3, was launched into Earth orbit on March 6, 2024, and more are to follow. Mission concepts are synthesized by team members with relevance to NASA, DoD, and commercial spaceflight priorities.

Currently, the team led by Dr. Hank Pernicka is focused on developing its DEXSTR mission (Doppler Experiment for Search, Tracking, and Rescue) in support of search and rescue of civilian, military, and NASA assets that



are in some level of distress. DEXSTR will host a specialized payload onboard a single cubesat capable of detecting and locating a beacon (carried by a user in need of rescue). DEXSTR will also be capable of messaging to/from the beacon during its orbit pass to assist the user with their search and rescue. In current search and

rescue operations, satellite constellations such as the Doppler-based Cospas-Sarsat system search for distress signals from emergency beacons that are downlinked to a ground station for analysis. While this type of architecture uses techniques that reduce the number of satellites required, the Doppler calculations are typically performed on the ground to generate a location result. This reliance on ground stations for the Doppler calculations increases the response time to the victims and the cost of an already expensive constellation. Additionally, Cospas-Sarsat does not have the ability to communicate with the users' beacons using its Doppler-based satellites. The DEXSTR mission seeks to improve this process.

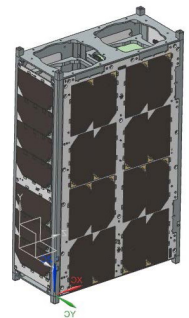
One key enabling technology DEXSTR uses is a chip-scale atomic clock (CSAC) to provide the short-term time stability required for this Doppler-based approach. The onboard, real-time processing removes the latency of traditional systems like Cospas-Sarsat and eliminates the need for multiple satellite passes, reducing time-to-rescue and infrastructure costs. Unlike current solutions that require separate constellations for geolocation and communication, this payload delivers both functions



through a single, low-cost platform, transforming how emergency beacons operate in unfavorable environments. This method of geolocation has the potential to support both civilian and DoD operations by providing an alternative to the often heavily relied upon GPS/GNSS constellation while providing the additional capability of bidirectional communications to gather crucial incident information. As a scalable proof of concept, DEXSTR lays the foundation for a next-generation, real-time geolocation constellation that could offer persistent global coverage, significantly enhanced situational awareness, and life-saving responsiveness in even GPS-denied environments. This approach will benefit both NASA and DoD end users by enabling geolocation in environments where this is not currently possible, including possible future applications with lunar exploration. Additionally, the combination of geolocation and bidirectional communication enables more information to be efficiently processed to decrease response time in time critical situations such as a downed aircraft or a capsized ship.

Spacecraft Design and Development

The DEXSTR mission is sponsored by the Air Force Research Lab's University Nanosatellite Program. As shown in the figure, DEXSTR is a 6U cubesat including its payload that includes a software-defined radio (SDR) capable of dual-band UHF transmission and reception and a computer. DEXSTR will be powered by solar panels affixed to the spacecraft (except where the UHF antennas will be located). DEXSTR will use a UHF antenna to receive ground commands from Missouri S&T's ground station, send telemetry, detect broadcasts at 406 MHz (the standard frequency used by search and rescue beacon devices) and communicate bidirectionally with the beacon.



The payload will collect beacon UHF signals to measure the Doppler shift processed by an algorithm integrated into the payload computer to compute its location. Test beacons with known locations will be used to assess the accuracy of the payload's algorithm.

Concept of Operations

The experiment begins when DEXSTR receives a command from the ground station through UHF communications that specifies which experiment phase to enter. The cubesat then turns on the payload radio that then listens for a beacon signal on the UHF frequency and measures the frequency shift caused by the relative speed between the beacon and the satellite. DEXSTR will collect other data from the beacon as well, such as the nature of the emergency, the number of people involved, etc. via a series of multiple-choice questions and the responses from the beacon. DEXSTR will then use its onboard algorithm to geolocate the beacon, and the results will be downlinked to the ground station.

The spacecraft will be operated in four mission modes after being launched into low Earth orbit. M-SAT students are developing all flight software for the mission with collaborative assistance from the WarpWare company and their software products.

Next Steps

A prototype version of DEXSTR will soon begin its assembly, integration (AIT), and test phase in the campus Space Systems Engineering lab. The M-SAT team will then present the prototype DEXSTR to AFRL personnel in a formal Flight Selection Review. With a positive outcome from this design review, the DEXSTR mission will proceed to Phase B of the program and, following a final design review, proceed with the AIT of the flight version of DEXSTR. After successful testing of DEXSTR at AFRL's facilities, DEXSTR will be provided a launch into low Earth orbit. The mission will be commanded from the M-SAT ground station on the Missouri S&T campus. All data downlinked will be analyzed to assess mission success levels and determine the indicated future applications for the associated technologies.





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