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School of Engineering
APRIL 21, 2025
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Preface

On behalf of the School of Engineering, we would like to share **Capstone Projects completed with Sponsor and Mentor support**. We had capstone projects completed in partnership with sponsors, advisers, and mentors for their support of our design teams and the entire program.

Senior design courses provide students with experience working on real-world projects that involve design constraints, budgets, reviews and deadlines. All the teams, sponsors, mentors, and everyone involved have experienced a year that created a challenging environment for collaborative design.

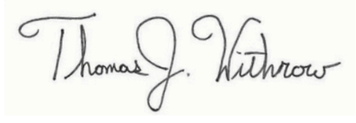
They will remember the adaptability and hard work to keep working from all corners of the globe. Students learned about professionalism, teamwork, entrepreneurship, and above all resilience.

As their projects take form, student teams interact with their industry and faculty advisers, hold meetings, write formal documentation and present their work. By the end of the academic year, the teams produce design processes, systems, prototypes, simulations, or demonstrations. This book is one of the tangible representations of Design Day, which has always been a celebration of all the lessons learned over four years of their engineering educations. As you read this book, know that those lessons were learned and demonstrated throughout all these projects.

We recognize the value of senior projects mentored and supported by external advisors—industry representatives, entrepreneurs, nonprofit mentors, as well as research and clinical faculty. This experience allows you to work with Vanderbilt engineering seniors and discover what makes our students stand out among other applicants when it comes to employment and postgraduate study. If you or your colleagues are interested in mentoring or sponsoring a project or to learn more, please contact me.

Be resilient, persevere, and work hard to make each other's world a little better each day. We are grateful for your support and guidance of our next generation of engineers and scientists.

With gratitude,



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Contents

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APRIL 21, 2025

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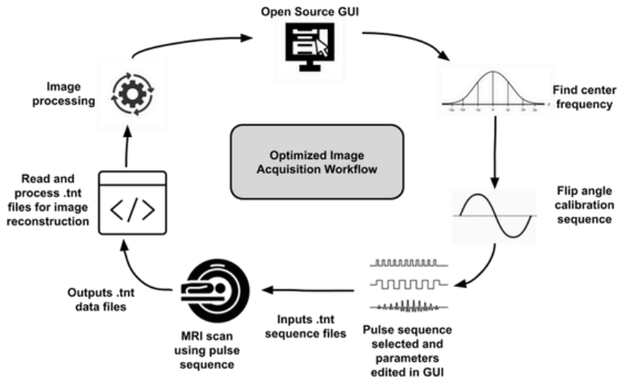
Open-source programming for low-field MRI user interface

MRI is an imaging technique that has revolutionized noninvasive diagnostics. However, MRI remains widely inaccessible worldwide. MRI costs are primarily due to the transportation and assembly costs associated with high strength magnets. To increase accessibility, low field MRIs are being developed. The goal of this project is to partner with an existing low field MRI group to develop an open-source graphical user interface (GUI) to edit pulse sequences and increase usability. The GUI will feature the ability to select from a library of pulse sequences, set spin echo parameters, and input FID parameters. Current MRI software requires proprietary and high expenses, limiting its adaptability for research and clinical applications in resource-limited settings. The new solution provides a user-friendly, customizable alternative that enables greater flexibility in low-field MRI technology. By supporting open-source development, our software will have the versatility to be utilized by various low-field MRI applications beyond our initial 47.5mT system.



This schematic represents the workflow of a low-field MRI system that reads data, processes the data using Python and displays representations within the GUI.

VUIIS

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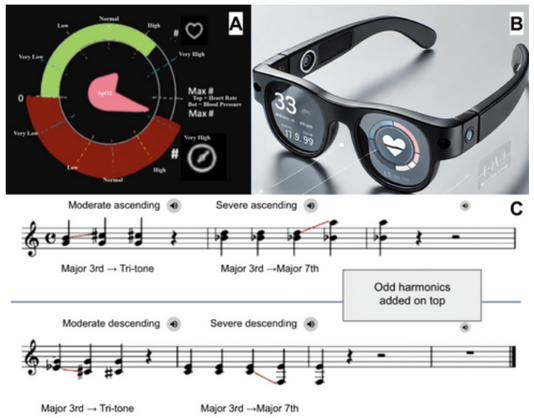
Eye tracking and pupillometry in the clinic

Alarm fatigue in critical care settings, such as the ICU and OR, is a complex issue that results in desensitization to patient alarms, leading to delayed responses and increased cognitive overload among health care providers. Existing alarm systems primarily rely on auditory signals that, in high-noise environments, are easily masked and ineffective. Our project introduces a novel multisensory alarm system integrated into physician-worn glasses with a heads-up display (HUD). The display visually presents real-time patient vitals, including heart rate, blood oxygen saturation (SpO_2), and blood pressure using dynamic, color-coded alerts. The system pairs these visual indicators with differentiated auditory cues delivered through bone conduction headphones. Testing conducted by our group on the novel auditory icons and visual display, examined independently of each other, has shown that they improve alarm detectability while reducing cognitive load and response times. Future testing of the fully integrated multisensory alarm system will validate its effectiveness in clinical settings, with the goal of mitigating alarm fatigue, improving reaction times, and enhancing patient safety.



(A) Real-time heart rate, blood pressure, SpO_2 levels. (B) Glasses integrate visual, auditory alerts. (C) Musical notation represents auditory alarm icons that signal high/low heart rates, high/low blood pressures.

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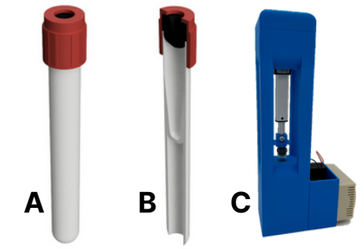
BIOMEDICAL ENGINEERING
BME-3

Pediatric blood collection tube improvement

This project addresses inefficiencies in pediatric blood collection by designing a new tube that is compatible with hospital automation devices. Current pediatric blood tubes do not fit standard automation systems, resulting in manual aliquoting, human errors, increased labor, contamination risks, and longer turnaround times. The proposed solution involves a dual-geometry blood collection tube that retains the internal capacity suitable for pediatric patients while adopting the external dimensions of adult-sized tubes to ensure compatibility with existing automation devices and vacuum caps. The pediatric blood tube will draw a specific amount of blood using the inner geometry and negative pressure created inside the tube. The tube will be compatible with existing adult vacuum seal caps and with automation devices. The caps are put onto our tubes in a vacuum chamber using a 3D printed device we designed. The capping device uses a linear actuator in a 3D printed shell that holds the tube in place as the linear actuator presses the cap onto the tube. The blood collection tube mitigates pediatric patient discomfort, improves workflow efficiency, and reduces economic burdens on health care providers.



A Blood collection tube exterior of adult blood collection tube that fits into the automation device. **B** Tube cross section with inner geometry that holds less blood for pediatric patient collection. **C** Linear actuator in 3D printed shell holds blood collection tubes and pushes rubber caps onto tubes inside a vacuum chamber to create a vacuum seal.

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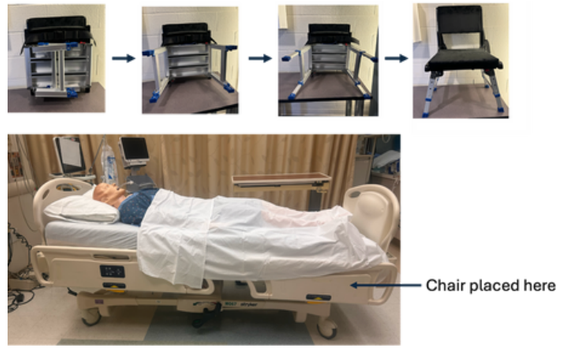
BIOMEDICAL ENGINEERING
BME-4

Clinical bedside chair to improve physician-patient interactions

The need for methods to improve patient-physician interactions is an important issue. Previous studies have suggested patient-physician interactions are improved when the physician sits at a patient's bedside. Our design aims to incorporate an easily storable, deployable, and attachable bedside chair in a hospital bed to allow physicians to sit eye level with patients. The chair will be hooked onto the foot side rail and when stored, it will remain folded by being buckled and having the chair's legs fold inwards on the bottom of the chair. When deployed, the chair will unfold to a 90 degree position and the chair's legs will open to reach the ground. Currently, other than a traditional stool, no solution exists to provide an easily collapsible and storable chair for physician use. The use of the hook along with the folding mechanism of both the chair and the chair legs are important and unique parts of this design. Overall, this chair offers an attachable, easily deployable, and usable chair for physicians to use when interacting with patients.



Back of chair attaches to bed's bottom side rail. Legs are unfolded, followed by a height-adjustment. Seat is unfolded after unbuckling a strap to reveal a functional chair.

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BIOMEDICAL ENGINEERING

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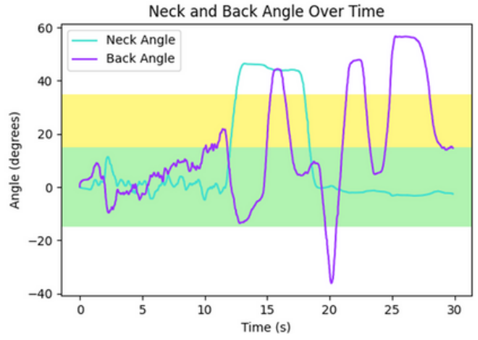
Biofeedback posture-monitoring system for surgeons

During operations, surgeons experience long hours and strenuous positions that contribute to ergonomic pain, chronic injuries, and at times, early retirement. To address these issues, our team designed ErgoSurg, a biofeedback posture-monitoring system for surgical procedures. The system uses two inertial measurement units (IMUs) to track the inclination angles of the lower back and head. The IMUs and their protective cases are secured by a pocket sewn into the scrub cap and an insert in an elastic belt worn by the surgeon. After pairing the IMUs to a computer via Bluetooth, the surgeon can record data for up to 8 hours, after which they can input pain levels and locations. The measured posture angles are used to generate interactive graphs that display these angles as well as posture statistics. ErgoSurg then provides insights into ergonomic risks, and it lists personalized exercise recommendations to mitigate long-term effects. Unlike traditional posture-tracking devices, this product focuses on tracking individual surgeons while also allowing for comparison between different surgeries or time periods. It seeks to improve posture and reduce pain, and we anticipate that ErgoSurg will advance ergonomic research and enhance provider and patient outcomes.



Above, Sample display of post-operative posture statistics.
Right, One IMUs in protective casing in a scrub cap pocket.

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BIOMEDICAL ENGINEERING

BME-6

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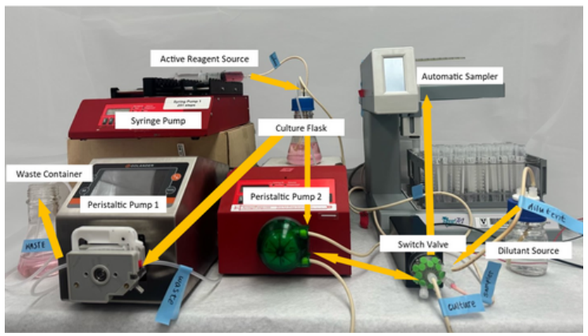
Automated cell culture instrument

Approximately 13 years and 1.8 billion USD are required for a new drug to reach the market, accounting for the fact that only 10% of formulations brought to trials succeed. An immense volume of resources (including animal subjects) and funds are wasted on projects that require numerous iterations of testing or fail all together. Our project goal is to create a cell culture instrument that better mimics the dynamic nature of the human body, leading to more accurate in vitro analysis of pharmaceuticals. Our device uses a series of pumps and proprietary code that can change the concentration of a drug that cell cultures are exposed to, allowing researchers to create a culture environment that matches the dynamic pharmacokinetics of the body. The device is capable of implementing any increasing and decreasing profile desired. As cells react differently to varying temporal concentration profiles, this device would allow researchers to perform more rigorous testing prior to entering animal and human trials, saving resources and funds by reducing failures caused by the inherent inaccuracy of current *ex vivo* research practices.



Cell culture device features a culture flask on a stir plate, a syringe pump that actuates the addition of a reagent, a peristaltic pump and a switch valve to alternate between the adding diluting agent and retrieving samples, and a second peristaltic pump that removes waste from the culture flask.

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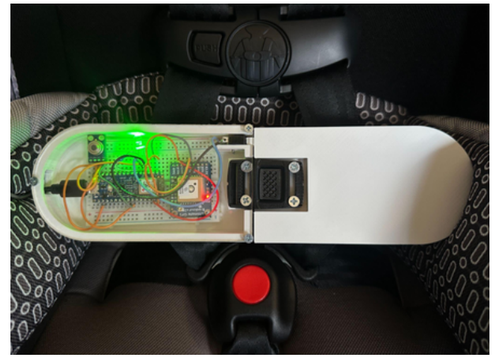
BIOMEDICAL ENGINEERING

BME-7

Smart safety clip to prevent child abandonment in vehicles

Each year, an average of 37 children in the United States die due to heatstroke after being left in hot cars. Many existing solutions are expensive and require professional installation, limiting accessibility for families of different socioeconomic backgrounds. Our project aims to create an affordable and user-friendly alternative to prevent child fatalities due to vehicular heatstroke. This device uses sensors built into a buckle to monitor the child's presence and the temperature within the car. These sensors are integrated with an Arduino Nano and a 3D-printed buckle attachment, which is currently made of PLA but will eventually utilize powder bed fusion to print out of Nylon 12. If a child is left behind in a vehicle and the conditions become hazardous, alerts will be sent to the caregiver and if necessary, emergency contacts. This device is designed to integrate into existing car seats, making it user-friendly, versatile, and cost-effective as compared to current smart car seats on the market. By providing caregivers with real-time alerts, this system has the potential to prevent tragic incidents and promote child safety.



Buckle includes a microcontroller, a battery pack, IR temperature sensor, limit switch, LED light, and GPS module. Pictured: Large version of buckle with clear lid for visualization purposes.

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BIOMEDICAL ENGINEERING

BME-8

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Heart valve bioreactor

Valvular endocarditis is a dangerous infectious disease of heart valves that affects more than 15,000 people annually in the US. Though endocarditis has a high rate of both morbidity and mortality, there has been little innovation in the treatment of this disease over the years with many instances needing risky surgical procedures. There currently exists no way to successfully model the development and sequelae of valvular endocarditis in the laboratory setting. This limits the ability to test new antimicrobial medications and therapeutic interventions prior to transitioning to the clinical setting. The pulsatile bioreactor system is capable of modeling the appropriate hemodynamic conditions experienced by a heart valve and subsequently model the development of bacterial endocarditis in this setting. The system includes a valve holder and chamber that secures the valve and ensures the one-way flow of blood through the valve. The proposed system will allow for the characterization of bacterial endocarditis development and progression in the mechanical and hemodynamic setting of the functioning heart valve, as well as potentially test new therapeutic strategies.

a) The bioreactor system includes two halves of a chamber with barbed fittings attached to tubing, a heart valve sutured to a holder, and a borescope attached to the inlet of the chamber. **b)** The holder fits into the hollow part of the chamber. **c)** The valve holder is secured by magnets that connect together the two halves of the chamber.

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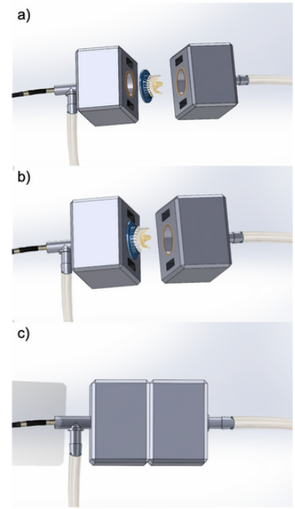

BIOMEDICAL ENGINEERING

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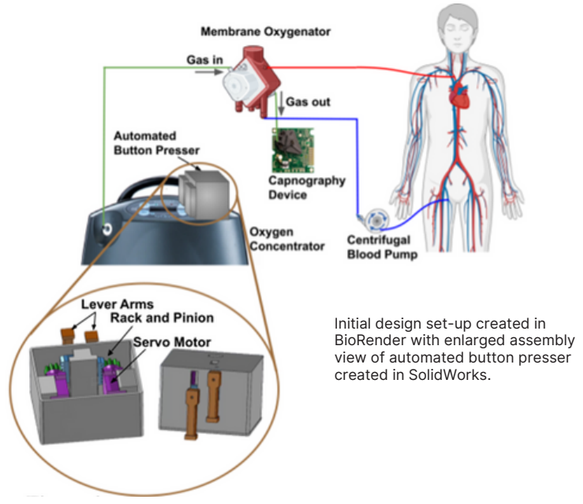
Automating sweep gas management for ECMO

Extracorporeal Membrane Oxygenation (ECMO) is a mechanical, cardiopulmonary support technology for patients with severe heart or lung dysfunction. ECMO is labor-intensive and requires constant monitoring and manual interventions for sweep gas regulation. Current systems rely on O2 tanks that restrict patient movement and limit accessibility. The team focused on a solution that improves patient mobility by incorporating an oxygen concentrator instead of O2 tanks (require refilling). The concentrator provides unlimited portable oxygen with just a recharge. To automate the sweep gas flow, an automated button presser with two servo motors is housed inside a 3D-printed PLA cube positioned above the buttons to control sweep gas flow from the oxygen concentrator. An Arduino receives continuous, real-time capnography metrics from the patient and commands the servo motors to raise or lower rectangular projections (arms) on the face of the PLA cube to increase or decrease sweep gas flow. Initial benchtop testing begins in March 2025 to evaluate system accuracy and responsiveness.



Initial design set-up created in BioRender with enlarged assembly view of automated button presser created in SolidWorks.

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BIOMEDICAL ENGINEERING

BME-10

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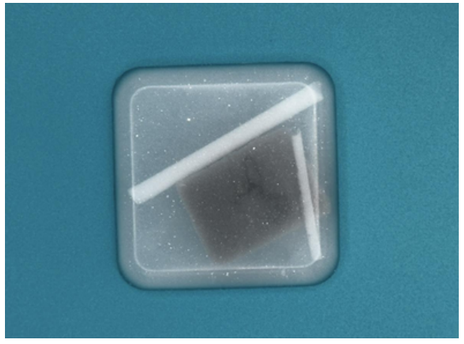
Yaya Scientific

Nerve phantom

Iatrogenic nerve injury is a medical complication caused by accidental damage to nerve tissue during surgery. To address this, Yaya Scientific created an imaging device to highlight the location of nerves in an open surgical field to aid doctors in avoiding operational mishaps. That said, Yaya Scientific lacks a way to calibrate its device to ensure safety and efficacy. Our team is accomplishing this goal through an epoxy-based nerve phantom, a physical model that mimics nerve tissue. This phantom must be small and long lasting. It must also emulate an open surgical field, mimicking the optical properties of nerve, muscle, and fat. Our model accomplishes this through different concentrations of light-scattering and light-absorbing materials embedded inside of a 3.0 x 3.0 x 1.5 cm epoxy mold. Yaya Scientific will be able to point its device at this phantom and calibrate to each tissue type. Though many biological phantoms exist, there are currently no nerve phantoms on the market. As such, this solution is advantageous in its novelty and ability to address a growing need in nerve imaging and surgical safety industries.



The resin based tissue phantom displays our nerve and fat replicas encased in muscle. Nerve is displayed as white cylinders, while fat is displayed as a dark grey rectangle.

YAYA SCIENTIFIC BIOMEDICAL SOLUTIONS

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BIOMEDICAL ENGINEERING

BME-11

Rollator walker extension

Many elderly individuals rely on rollator walkers for mobility but face challenges when transporting large or heavy items due to limited built-in storage. Carrying groceries, laundry, or personal belongings can destabilize the walker, increasing the risk of falls and reducing overall independence. The project goal is to design a rollator walker extension that provides a safe and convenient storage solution without compromising the walker's stability or ease of use. We developed a lightweight, foldable platform with a durable lattice structure, equipped with 360-degree ball-bearing wheels for smooth maneuverability. The platform securely attaches to the walker via a screw-on clip, ensuring universal compatibility and easy installation. Unlike existing storage solutions, the extension maintains balance and prevents tipping while supporting significant loads. An integrated electromagnet on the extension secures a detachable metallic basket, ensuring stability while allowing easy basket removal. By improving storage capacity and mobility, this solution empowers seniors to perform tasks independently, reducing reliance on caregivers while enhancing safety.

Preliminary prototype includes a lattice-structured platform with dual 360-degree ball-bearing wheel legs accompanied by current-induced magnets to hold the payload while the rollator walker is in motion.

GRANGER COBB
INSTITUTE FOR SENIOR LIVING

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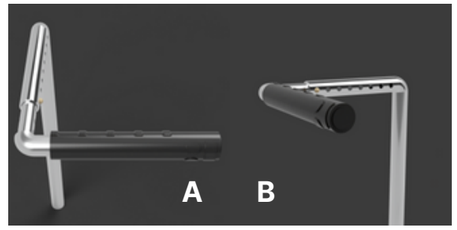
BIOMEDICAL ENGINEERING

BME-12

Attendant controller for wheelchair SmartDrive

Wheelchair attendants currently face significant challenges when maneuvering manual wheelchairs equipped with power assisted systems like the Permobil SmartDrive. Existing solutions lack intuitive proportional speed control, ergonomic handle integration, and seamless adaptability that can lead to muscle fatigue, inefficient maneuvering, and poor user experience for caregivers. Our project addresses these limitations with an attendant-specific SmartDrive controller featuring pin-locking telescoping handles that face inward toward each other with a gap in the middle, an ergonomic grip, and a modular control system. The telescoping feature and angling of the hand controls are aligned with standard measurement data to ensure neutral wrist posture and user comfort while minimizing physical strain. The controller incorporates a speed scroller, up/down speed buttons, pressure sensors on the grip (to eliminate the need for continuous finger activation), and a power button embedded on the end of the handle. This design improves existing solutions by enhancing adjustability, reducing wrist deviation, and integrating controls directly into the attendant's natural grip position.



The attendant controller features two telescoping handles equipped with pin-lock mechanisms. Handles face inward and both have 6" finger grips angled 8.5 degrees from the horizontal to support a neutral wrist posture. All of the integrated controls are housed on one dominant handle, pictured above in images A and B. These controls include up/down speed buttons and a power button.

permobil

BIOMEDICAL ENGINEERING

BME-13

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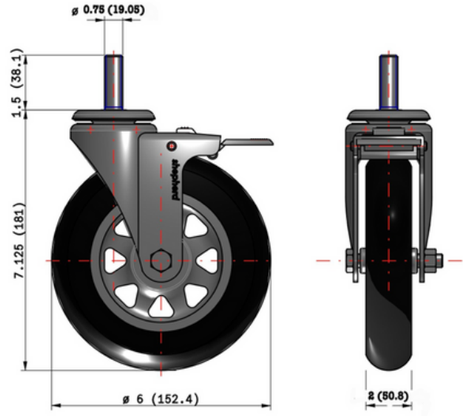
Minimizing adverse effects of neonatal transport

Vibrations during neonatal transport have been linked to an increased incidence of brain hemorrhages, raising both morbidity and mortality rates. This is particularly true for infants born before 32 weeks of gestation and weighing less than 1500 grams. Our team developed a wheel design that attaches to existing Giraffe incubators without compromising the machine's integrity. While our focus is on Giraffe incubators, this technology could be extended to other incubators used in the United States. This project is intended to reduce vibrations by increasing the wheel's diameter from 4 inches to 6 inches and its width to 2 inches. The solid rubber construction will also be replaced with a pneumatic tire, further dampening vibrations during transport. To ensure compatibility with Giraffe incubators, the top of the wheel will feature a 1-inch rod, mirroring the original design while allowing for easy replacement without needing a new attachment mechanism. The caster wheel will be constructed using a 3D printed ABS yolk paired with a metal swivel mechanism, ensuring that the device can handle a load of up to 250 lbs. This innovative design is expected to significantly reduce vibrations, improving cross-hospital neonatal transport safety.



The 6" castor wheel includes a pneumatic (air-filled) tire, circular swivel plate, stem mount, and total locking mechanism.

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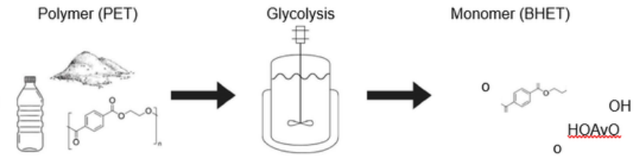
CHEMICAL AND BIOMOLECULAR ENGINEERING

ChBE-1

Chemical recycling of PET toward a circular plastics economy

Traditional mechanical recycling of polyethylene terephthalate (PET)—crushing and remolding plastic—degrades the quality of the polymer. Chemical recycling breaks down PET into its pure monomer with less energy than processing raw materials into monomer. Implementing circular plastic recycling worldwide could alleviate annual energy consumption by up to $176B. Our project focuses on modeling the chemical depolymerization of PET using triazabicyclodecene:trifluoroacetic acid (TBD:TFA), an efficient catalyst developed at Oak Ridge National Laboratory. We performed depolymerization reactions with varying temperature, impeller type, and mixing speed. Then, we developed a kinetic model in MAT LAB and an industrial-scale reactor in Aspen. We created a COMSOL model to optimize mixing efficiency. Finally, we conducted a life cycle analysis and capital cost estimate to evaluate the environmental and economic impacts of a pilot-scale process. By demonstrating the feasibility of TBD:TFA-catalyzed PET glycolysis, our work contributes to advancing scalable chemical recycling methods and achieving circular plastic recycling.



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The Vanderbilt Green Fund
OAK RIDGE National Laboratory
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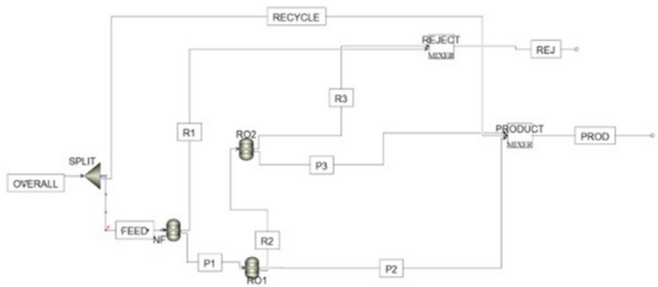
Sterling Ranch

CHEMICAL AND BIOMOLECULAR ENGINEERING

ChBE-2

Sterling Ranch water network design

Sterling Ranch is a community in Douglas County, Colorado, that prides itself on measures for water and energy sustainability. Through smart home water metering and onsite treatment facilities, Sterling Ranch has drastically decreased water consumption among residents. We developed a software tool in Microsoft Excel that aids in selecting water purification membranes (reverse osmosis, RO, and nanofiltration, NF) that allows Sterling Ranch to improve any of the many sources from which they obtain their water. Our motivation behind this goal is due to the array of parties involved in Sterling Ranch's water system. We found it to be more effective to develop a system that may be used to solve a variety of problems, rather than one problem that may not be relevant to Sterling Ranch's current goals. To accomplish this goal, we tested several RO and NF membranes, compiled their performances, and developed the software tool that uses these performance parameters.



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STERLING RANCH COLORADO

CHEMICAL AND BIOMOLECULAR ENGINEERING

ChBE-3

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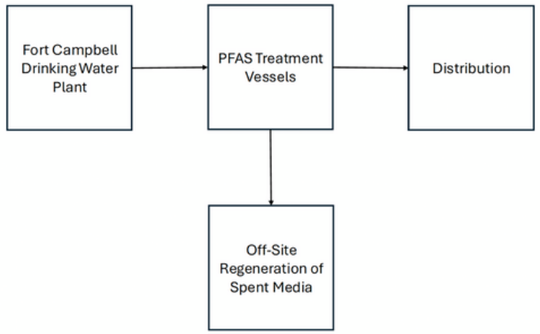
Design of a PFAS treatment system for Ft. Campbell

Per- and polyfluoroalkyl substances (PFAS) are synthetic chemicals with strong carbon-fluorine bonds, widely used since the 1950s for their non-stick properties. In 2025, the EPA regulated six PFAS in drinking water due to their harmful health effects. Ft. Campbell, a military base on the Kentucky-Tennessee border, has been designated an EPA Superfund site due to PFAS contamination from firefighting foam (AFFFs). Internal sampling confirms that its drinking water exceeds the EPA's new limits for all six regulated PFAS. The EPA recognizes four best available technologies (BATs) for PFAS removal, each varying in cost, effectiveness, and feasibility. Our goal is to design a cost-effective treatment system to reduce PFAS levels to meet or fall below EPA limits. We developed a Microsoft Excel-based tool to optimize the size and number of treatment vessels needed for normal and peak usage. Our analysis focused on granular activated carbon (GAC) and ion exchange (IEX) to determine the most efficient adsorbent. Additionally, we conducted a comprehensive economic and life cycle analysis to ensure a practical and sustainable solution, helping Ft. Campbell comply with regulations and improve water quality for the community.



Flow diagram of the designed process.

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CHEMICAL AND BIOMOLECULAR ENGINEERING

ChBE-4

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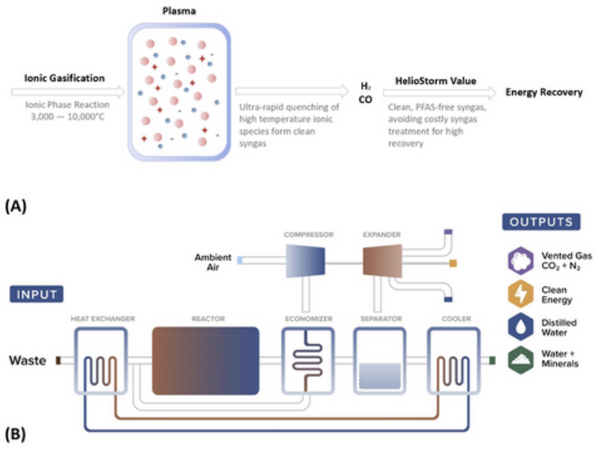
SCWO and plasma treatments for PFAS elimination in biosolids

PFAS/PFOS are long-lasting degradation-resistant contaminants linked to various health issues. Accumulation of PFAS/PFOS in biosolids, storage in landfills, and use in fertilizer creates a significant environmental risk. To determine the potential of supercritical water oxidation (SCWO) and plasma treatment technologies to reduce biosolid volume and eliminate PFAS, we performed mass balances and life cycle and cost analyses to determine the energy requirements and efficiency of both technologies. The SCWO and plasma treatment technologies models were based on data provided by 374Water Company in New York, Heartland Water Technologies in Tennessee, and Cedar Creek Park Waste Water Treatment Plant (WWTP) in Kansas. Life cycle analyses and mass balances on the PFAS-containing biosolids provided insight into the effectiveness of each technology. Economic considerations were evaluated, focused on potential cost savings related to reduced landfill usage, regulatory compliance, and long-term health benefits from destroying PFAS. The analysis indicates that while the initial capital investment for implementing these technologies may be large, the potential benefits outweigh the cost. With scaling and optimization, these technologies can offer an economically viable solution for WWTPs.



(A) The plasma treatment train at Heartland Technologies and (B) the Supercritical Water Oxidation (SCWO) treatment train from 374Water Company.

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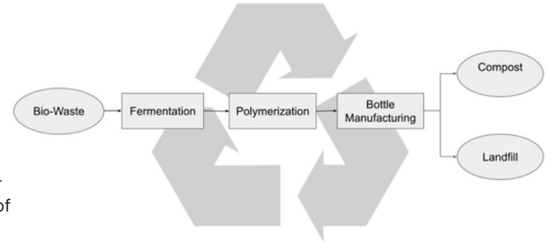
CHEMICAL AND BIOMOLECULAR ENGINEERING

ChBE-5

Life cycle analysis on PLA bottles to replace aluminum

While plastics are convenient, they are known to be environmentally harmful, with disposable PET bottles being one of the most visible culprits. Through Vanderbilt's FutureVU initiative, all PET bottles on campus were replaced with disposable aluminum bottles. While aluminum is easily recycled, its recycling rate is declining and its production from raw materials emits nearly three times the CO2 of plastic. We evaluated biodegradable polylactic acid (PLA) derived from renewable and waste feedstocks as an alternative. A cradle-to-grave life cycle analysis (LCA) is presented to assess the feasibility of replacing aluminum bottles with PLA bottles and delivers the cost, energy, and the CO2 equivalent per bottle. The feedstock procurement, fermentation, and polymerization were modeled through a literature review. The bottle manufacturing was designed and simulated as a stretch injection blow molding process to align with industry standards. A sensitivity analysis was performed to determine the recycling rate of aluminum where the replacement of Vanderbilt's aluminum bottles with PLA bottles is advantageous.



The life cycle of PLA water bottles: Bio-waste feed, fermentation, polymerization, bottle manufacturing, compost and landfill.

School of Engineering

CHEMICAL AND BIOMOLECULAR ENGINEERING

ChBE-6

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Microfluidic recalcification of citrated whole blood for point-of-care coagulation testing

Anticoagulants are chemical substances added to blood to prevent blood clotting-induced interferences. In many clinical assays that assess blood coagulation abilities, blood must be recalcified to restore coagulation function. We aim to design and fabricate a microfluidic device that recalcifies citrated whole blood and detects clot formation under flow conditions. The device mixes a calcium buffer with citrated whole blood before directing the fluid across various biomaterial surfaces coated with a thrombin sensor. The addition of a thrombin sensor provides real-time measurement of clot formation and allows for anticoagulant therapy monitoring. An economic analysis of our process was conducted to compare traditional blood testing methods to the novel microfluidic approach. After analyzing the requirements for FDA approval, we were able to gather the information necessary for documents such as a 510(k) Premarket Notification. This microfluidic device offers a more efficient and accurate method for clotting assessments.

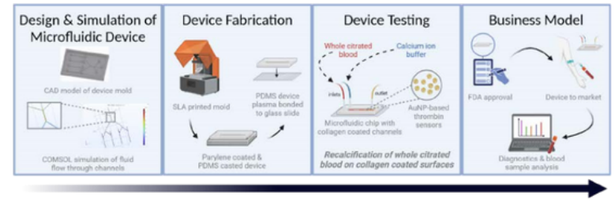

Diagram outlines the development process of a microfluidic device for blood diagnostics in patients with blood clotting disorders and covers design and simulation, fabrication, testing, and commercialization.

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CHEMICAL AND BIOMOLECULAR ENGINEERING

ChBE-7

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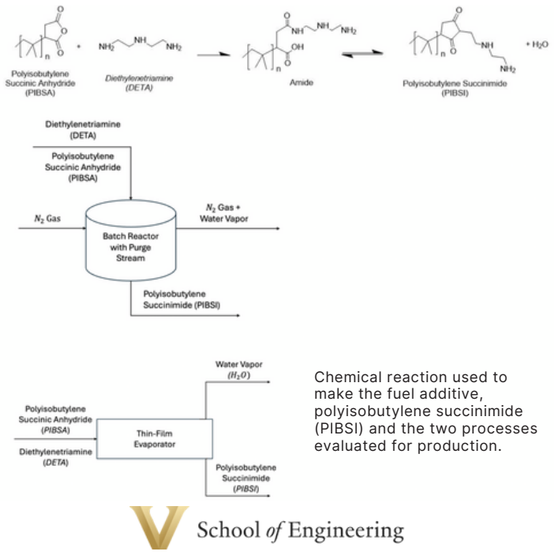
Batch manufacturing of a fuel additive

Polyisobutylene Succinimide (PIBSI) is a chemical dispersant used in engine oils that plays a key role in preventing sludge formation and ensuring engine longevity. Traditionally, PIBSI is synthesized using a two-step reaction in a jacketed batch reactor. Our team explored the economic and operational feasibility of transitioning PIBSI production from batch to continuous manufacturing. A critical challenge in both processes is water content, which compromises the lubricant's effectiveness. The processes are designed and simulated to maximize water removal to shift thermodynamic equilibrium and optimize energy consumption. In the batch process, water is purged using an overhead nitrogen stream, while continuous production employs a thin film evaporator to drive the reaction to completion. The financial analysis integrates real-world market data for raw material costs and PIBSI market size and pricing trend, alongside capital expenditure, utility, and labor costs derived from an existing factory's operational data. Key financial metrics—return on investment (ROI) and break-even analysis—are used to compare batch and continuous processes. This project highlights the potential benefits of switching to continuous manufacturing for a company seeking to penetrate the chemical dispersant market.



Chemical reaction used to make the fuel additive, polyisobutylene succinimide (PIBSI) and the two processes evaluated for production.

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CHEMICAL AND BIOMOLECULAR ENGINEERING

ChBE-8

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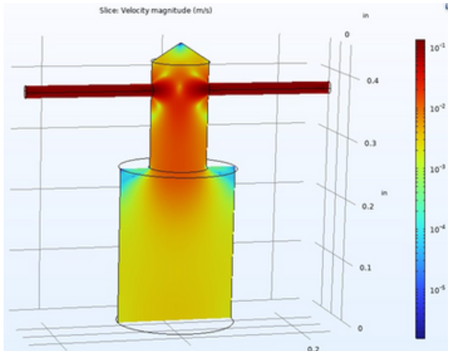
Scaling uniform LNP self-assembly in turbulent mixers

Lipid nanoparticles (LNPs) are critical drug delivery vehicles used in gene therapy, oncology, and vaccine applications—most notably in mRNA-based COVID-19 vaccines. Despite the growing impact of LNPs, optimizing their production remains difficult. The size of produced nanoparticles must be accurate and narrowly distributed for effective drug delivery. Achieving precise control over particle size at different manufacturing scales is challenging with current technologies. Our project, in collaboration with Helix Biotech, aims to enhance the understanding of LNP synthesis through computational modeling of an impinging jet mixer (IJM) using COMSOL Multiphysics software. Using an accurate CAD model of Helix's Nova IJM in COMSOL, we analyzed fluid dynamics and mixing behavior under varying operating conditions. By integrating the model results with existing knowledge regarding LNP self-assembly kinetics, the team produced useful scaling correlations for Helix Biotech that will allow them to iterate rapidly on new mixer designs and ensure uniform nanoparticle size distributions. Further, these correlations are independent of the mixing system used, meaning that a uniform size distribution can be achieved in a wide range of LNP synthesis mixers by aligning physical system properties (Reynolds number, solvent properties) with the generic system guidelines.



The velocity profile for a confined impinging jet mixer, showing the dispersion of momentum at the impingement plane.

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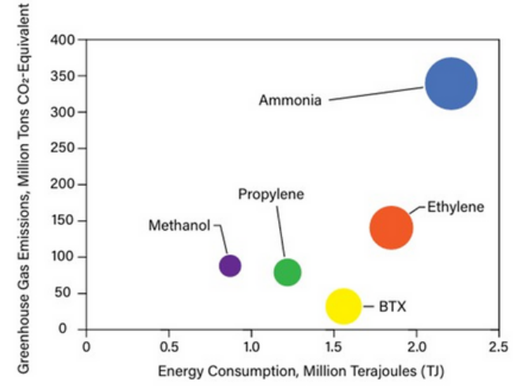
CHEMICAL AND BIOMOLECULAR ENGINEERING

ChBE-9

Decarbonization and optimization of ammonia production

Ammonia plays an important role in fertilizer production, energy storage, and industrial applications. However, ammonia production through steam methane reforming (SMR) for the Haber-Bosch process relies heavily on fossil fuels, subsequently emitting significant carbon into the atmosphere. This project explores the feasibility of sustainable ammonia production through electrolysis-based hydrogen production and the use of renewable energy sources to lower the carbon footprint. ASPEN simulations are used to model plant efficiency, energy consumption, and economics of a full scale production facility. The model is designed to meet 2050 emission targets as defined by the Climate Bonds Initiative. The model evaluated the economic and environmental viability of the proposed process and compared it to traditional SMR plants. A cost analysis considered capital expenditures (CAPEX), operational expenditures (OpEX), and the cost of hydrogen and ammonia. The study also assessed the use of carbon credits, grid supply costs, and return on investment (ROI) to determine competitiveness. The environmental footprint of the process was evaluated by analyzing carbon emission reductions, energy consumption reductions, and water usage compared to traditional ammonia production plants.



Greenhouse gas emissions vs energy consumption demonstrates that ammonia is currently the highest producer of greenhouse gas emissions compared to methanol, propylene, BTX, and ethylene.

School *of* Engineering

CIVIL AND ENVIRONMENTAL ENGINEERING

CEE-1

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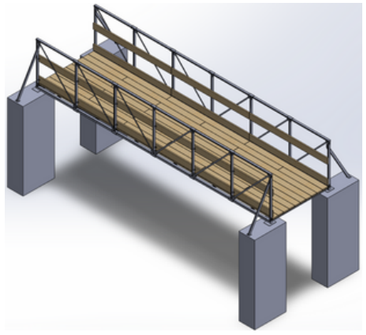
Pedestrian bridge design-build project in Costa Rica

An elderly woman in a community near San José, Costa Rica, faces challenges accessing her property due to a stream separating her home from the rest of the community. The project goal is to design and construct a pedestrian bridge that improves safety and accessibility and fosters community connectivity. The bridge will include foundation, superstructure, and substructure components, using a modular construction process that facilitates efficient on-site assembly. Hydraulic and seismic considerations are incorporated into the design, ensuring compliance with AASHTO LRFD Guide Specifications and AISC steel standards. By fabricating the modular components at Vanderbilt, the project offers advantages in cost, transport, and installation speed compared to traditional construction methods. The design also considers local cultural norms to create a solution that is both functional and culturally appropriate. Upon completion, the bridge is expected to provide a durable and safe passage, enhancing the resident's quality of life and strengthening community ties.



Pratt truss bridge design includes concrete foundations, steel superstructure, and composite wood decking.

CIVIL AND ENVIRONMENTAL ENGINEERING

CEE-2

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Kimley-Horn

Traffic calming design for two Nashville streets

The project goal is to improve pedestrian and cyclist safety on several Nashville streets using various traffic calming measures to reduce vehicle speeds. The team first analyzed traffic data across multiple streets in Nashville using NDOT's Neighborhood Street Calming Prioritization framework, adjusting the formulas to assign scores. After collecting and researching the top scoring streets, the team chose Albion Street and Lock 2 Road to redesign. Albion Street is a 0.59-mile, two-lane residential road with flat, wide lanes contributing to high speeds. The illustration shows the team's redesign of Albion Street, which includes speed cushions (C) and bulb-outs (B). Shoulders also were added by marking 4 inches of white pavement on both sides, narrowing the travel lanes to 11 feet and improving pedestrian/cyclist accessibility. Lock 2 Road is a 0.74-mile-long residential road whose 85th percentile speed is almost double the posted speed limit of 25 miles per hour. The team redesigned this road by adding several speed cushions throughout the corridor and by narrowing the lanes from 13 to 10 feet. Overall, these designs aim to reduce vehicle speeds and enhance safety for users of Nashville roads.

This traffic calming plan for Albion Street aims to enhance pedestrian safety and reduce vehicle speeds through the implementation of speed cushions (C), bulb-outs (B), and lane narrowing.

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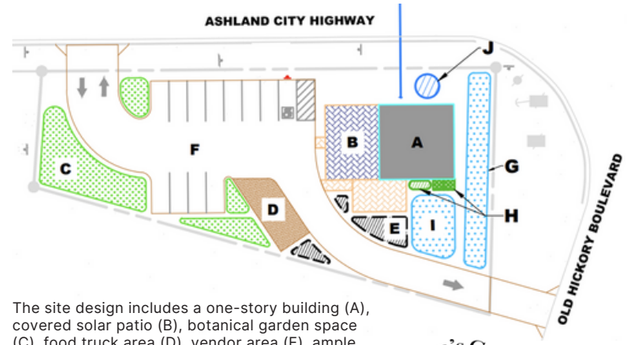
CIVIL AND ENVIRONMENTAL ENGINEERING

CEE-3

Living Building project at Farmer's Corner at Bells Bend

Farmer's Corner at Bells Bend is the first living building project in Tennessee. Site development will happen at the intersection of Ashland City Highway and Old Hickory Boulevard and will feature the Bells Bend Bistro, a community center honoring the Bells Bend Conservation Corridor non-profit organization, a botanical garden, and areas for local farmers or vendors to sell goods. The Living Building Challenge (LBC) is a certification program that defines today's most advanced measure of sustainability in the built environment. The LBC's key performance areas for a sustainable and regenerative project include net-positive energy, responsible water use, green materials, and social equity. After meeting with regional officials and regulating bodies (LBC Council, Metro Water Services, Nashville Electric Service, and others), we finalized the construction drawings for site layout, utilities, land grading, and more. We also have constructed a technical report detailing the site's "living" features. At Farmer's Corner, site systems for rainwater collection, wastewater reclamation, and energy generation will be met by a passionate community eager to fellowship, learn, grow, and give back to local culture and the environment.



The site design includes a one-story building (A), covered solar patio (B), botanical garden space (C), food truck area (D), vendor area (E), ample parking (F), storm bioretention area (G), composting toilets (H), a constructed wetland for wastewater treatment (I), and a cistern for rainwater capture (J).

CIVIL AND ENVIRONMENTAL ENGINEERING

CEE-4

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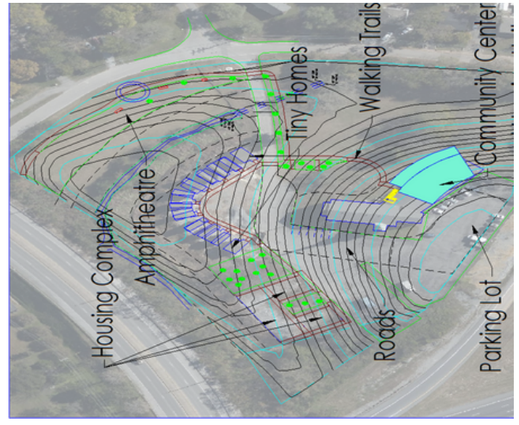
Thomas and Hutton
The Village at Glencliff

Affordable housing site design for The Village at Glencliff

The Village at Glencliff is a nonprofit medical respite program that provides medically vulnerable, unhoused individuals in Nashville with a safe and dignified place for recovery. Following the success of its first phase, which introduced 12 tiny homes in 2017, the program is expanding to use its full 8-acre site. This project aims to develop a comprehensive site layout that optimizes land use, enhances accessibility, and improves stormwater management. The project involves the design of residential complexes, a multi-story building that houses a community center and additional residential units, a redesigned road and parking system, and green spaces with walking trails for physical rehabilitation. The design also features an amphitheater to foster community engagement and an advanced stormwater management system to mitigate existing flooding issues on the site.This project prioritizes long-term resilience and affordability by integrating sustainable drainage solutions and ADA-compliant pathways to ensure accessibility for all residents. . By expanding housing capacity and improving infrastructure, the design enhances the quality of care provided by The Village at Glencliff. The anticipated outcome is a well-planned, comfortable environment that supports the organization's mission to serve and empower vulnerable populations with stability.



Site layout shows placement of residential units, multi-story community center, green spaces, parking lot and walking trails.

CIVIL AND ENVIRONMENTAL ENGINEERING

CEE-5

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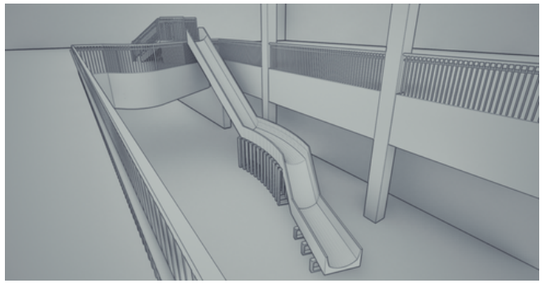
DPR Construction

A slide for Featheringill Hall"s Adams Atrium

The environment in which we live, work, and play shapes our success and satisfaction. The team designed a slide for Adams Atrium in Vanderbilt's Featheringill Hall to increase student and faculty enjoyment while providing an alternative movement route. The aim is to create a fun and innovative structure accessible to the Vanderbilt community, showcasing the possibilities of civil engineering. The one-story-tall slide consists of three main components: a free-standing acceleration zone, a 30-degree curve supported by superelevated wedges, and the exit zone. Riders reach a thrilling speed of up to 25 feet per second. The team adhered to national standards for both wood and playground design while collaborating with various compliance departments at Vanderbilt to ensure safety. Using structural analysis and material testing, the team optimized the slide's design for durability and performance. They employ modular construction and oversee the slide's life cycle from conception to demolition.



The 17.5-foot-tall slide spans over 35 feet, using superelevation to safely deliver riders from the second to first floor in a fast and exciting manner.

CIVIL AND ENVIRONMENTAL ENGINEERING

CEE-6

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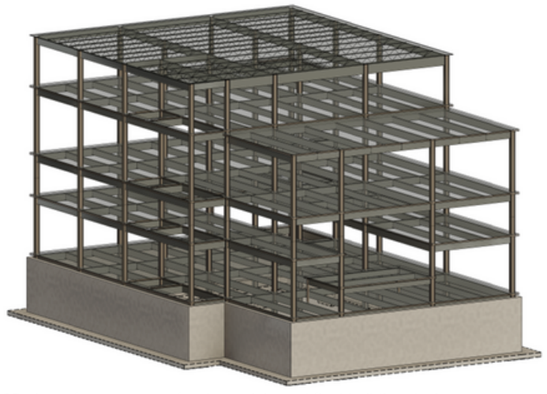
KPFF

Honky-Tonk steel structure

The Honky-Tonk Steel Structure team designed a structure to withstand all weather anomalies and deliver a safe and functional space for Nashville tourists. This project balances safety, durability, and efficiency—key challenges in designing steel structures for high-occupancy spaces. We applied industry-proven methodologies to develop a comprehensive structural system that meets IBC 2018, ASCE 7-16, and AISC 360-16 standards. We conducted detailed gravity and lateral load analysis, considering dead, live, snow, wind, and seismic forces. Structural components—including beams, girders, columns, and footings—were optimized for both material efficiency and constructability. A comparative analysis of bracing systems led to the selection of an effective lateral force-resisting system, ensuring stability under dynamic loads. The completed project includes construction-ready drawings, 3D-rendered visualizations, and a scaled 3D-printed model showcasing key structural connections.



3D view of components for the anticipated final building design.

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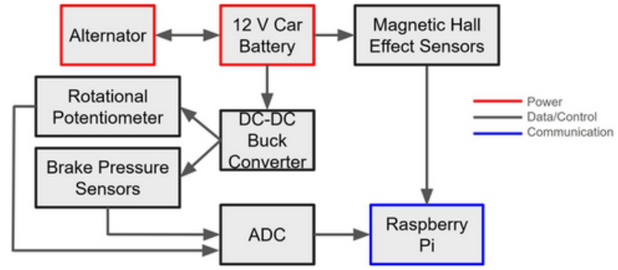
Vanderbilt University Motorsports

ELECTRICAL AND COMPUTER ENGINEERING

ECE-1

Formula SAE racecar data acquisition system

The Vanderbilt University Motorsports team is a student-led engineering organization that designs and builds a Formula Society of Automotive Engineers (SAE) racecar to compete against 120+ teams worldwide. In May 2024, the team achieved 3rd place in the efficiency event and 27th overall in the Formula SAE Internal Combustion competition. To enhance future competition performance, the Motorsports team sponsored our senior design team to develop a data acquisition system to collect data from this year's car. The data acquisition system integrates multiple sensors, all connected to a Raspberry Pi, to collect performance data. Key data points include steering angle, speed, traction loss, shock displacement, and brake usage. These metrics will help validate the suspension design and guide improvements in the vehicle's design. This project provides a data-driven approach to performance tuning. The Motorsports team will make informed design decisions by integrating the senior design team's sensor technology into their competition strategy.



The data acquisition system integrates magnetic Hall Effect sensors, rotational potentiometers, and brake pressure sensors, all mounted onto the vehicle and connected to a Raspberry Pi. These sensors monitor key performance metrics, including wheel spin, traction loss, steering angle, shock displacement, and brake usage, providing meaningful data for Vanderbilt University Motorsports.

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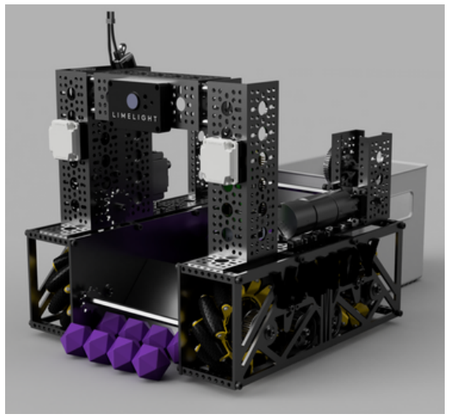
ELECTRICAL AND COMPUTER ENGINEERING

ECE-2

IEEE SoutheastCon 2025 hardware competition robot

SoutheastCon 2025 Hardware Competition teams must develop an autonomous robot to navigate a playfield while collecting, transporting, and sorting small "astral materials" into designated "cosmic shipping containers" (CSCs). The robot then delivers them to rendezvous pads along the playfield perimeter. Our robot is built on a custom parallel plate chassis with omnidirectional wheels, providing precise maneuverability while optimizing internal space for material storage. The material acquisition system employs a high-RPM brush-style intake with surgical tubing for efficient collection, complemented by a dumping hopper mechanism for seamless transfer into the CSCs. For localization and object recognition, the robot integrates a Limelight Smart Camera, with real-time processing handled by Python programs running on a Raspberry Pi. Motor control and electromechanical actuation are managed by C programs running on an ESP microcontroller, ensuring efficient real-time operation of the drivetrain and material handling subsystems. Through advanced automation, precision control, and strategic design, the robot maximizes point collection by placing as many astral materials as possible into its designated CSC.



CAD model of robot with example game pieces in front.

ELECTRICAL AND COMPUTER ENGINEERING

ECE-3

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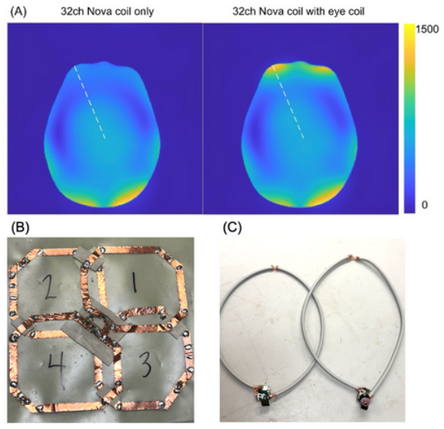
SPONSOR
Vanderbilt University Institute of Imaging Science (VUIIS)

Inductively coupled wireless detector for MRI

High-field MRI (≥3T) offers improved signal-to-noise ratio (SNR) and higher spatial resolution, yet traditional RF coils often struggle to provide optimal imaging for specific anatomical structures. This project seeks to develop wireless RF detectors, referred to as wireless coils, to enhance imaging quality for 3T and 7T MRI systems, with a focus on the optic nerve and lumbar spinal cord. The team is conducting electromagnetic simulations in Ansys HFSS to optimize sensitivity, designing PCB and housing components using KiCad and SolidWorks, and assembling and testing the detectors at VUIIS. By eliminating cables, wireless coils reduce motion artifacts, enhance patient comfort, and improve workflow efficiency compared to conventional wired designs. Although final validation is still in progress, the anticipated outcome is a set of wireless detectors capable of significantly improving MRI performance for targeted regions. This advancement has the potential to benefit both clinical diagnostics and research applications, contributing to the next generation of RF coil technology.



A Measured SNR comparison without (left) and with (right) the wireless coils around eye region.
B Circuit schematic of lumbar spinal cord.
C Circuit schematic of optic nerve.

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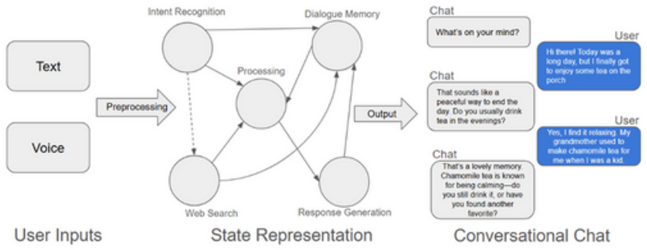
SPONSOR
Granger Cobb Institute for Senior Living

ELECTRICAL AND COMPUTER ENGINEERING

ECE-4

Conversation Buddy

Our team developed Conversation Buddy, a tool that will use generative AI to provide a supplemental form of social interaction for senior adults experiencing social isolation. Conversation Buddy will build and maintain a representation and knowledge base about the user for a personalized conversation. The service uses GPT-4 as the large language model (LLM), and integrates the latest technologies in text-to-speech, speech-to-text, and web browsing to deliver a natural conversation with access to the latest news. Conversation Buddy also has finely configured and tested prompts to extract the most conversation-like and appropriate response from the LLM. The anticipated product will converse with senior adults in a way that feels natural and engaging. Furthermore, it offers a solution that can be used at home, making it accessible to seniors with limited mobility.



The system processes text or voice input, adds information about the user, passes it to the large language model, and outputs a natural conversation response.

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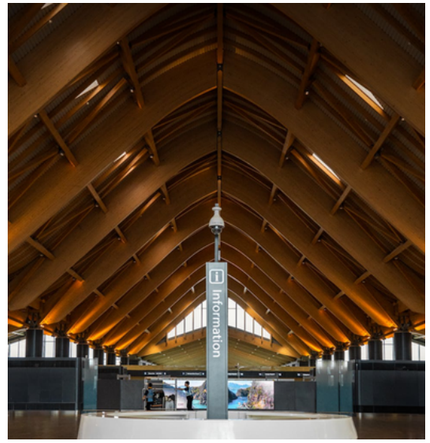
SPONSOR
Airport Cooperative Research Program (ACRP)

ENGINEERING SCIENCE AND MANAGEMENT

ESM-1

Reducing carbon emissions in airports through timber use

Airports inherently are major emission contributors due to the nature of plane fuel requirements, 24/7 operations, and resource-intense systems. However, this also offers the potential of small changes making a big impact on resource and energy usage, as demonstrated through various successful sustainable design projects across the airport industry. Our team's solution explores how the use of timber in terminal construction can reduce emissions. Wood, as a construction material, has a significantly lower environmental impact compared to steel and concrete. Replacing conventional building materials with mass timber in 50% of new urban construction could contribute up to 9% of the 2030 global emissions reduction targets to keep global warming below 1.5 °C. Timber has a global warming potential (GWP) ratio of less than that of 60% of steel and 90% of that of concrete. The proposal includes a cost-benefit analysis and implementation plan for timber use in the airside of airports.



Timber terminal in Clark International Airport, the Philippines.

ACRP AIRPORT COOPERATIVE RESEARCH PROGRAM

ENGINEERING SCIENCE AND MANAGEMENT

ESM-2

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SPONSOR
Airport Cooperative Research Program (ACRP)

Reducing wheelchair mishandling in airports

The ACRP sponsors an annual university competition to address challenges related to airports and the National Airspace System. One pressing issue is wheelchair mishandling. By 2050, the number of individuals aged 60 and older is projected to double to 2.1 billion, many of whom will require mobility assistance while traveling. Despite existing regulations, wheelchair mishandling remains a significant challenge as U.S. airlines reported more than 800 mishandled wheelchairs in 2023, and the Department of Transportation received 1,494 disability-related complaints. Systemic failures in staff training and inconsistent enforcement of accessibility standards continue to impact passenger mobility and safety. This project aims to develop a solution that integrates best practices from health care and assistive mobility industries. By emphasizing proper lifting, transport, and storage techniques—along with passenger dignity and legal compliance—the solution seeks to minimize damage to mobility devices and reduce complaints.

Luggage chute with elevator for safe wheelchair transport, a recent infrastructure addition missing at most jet bridges.

ACRP AIRPORT COOPERATIVE RESEARCH PROGRAM

ENGINEERING SCIENCE AND MANAGEMENT

ESM-3

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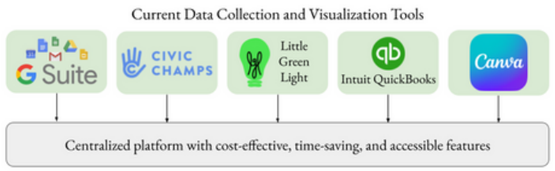
SPONSOR
The Aloe Family, Inc.

Development of a data and file management system for The Aloe Family, Inc.

The Aloe Family supports resilient communities facing poverty or limited family support by providing resources, education, and support services in Nashville and Mexico. Their data is currently compiled across five different platforms, requiring significant manual data entry and workup. This project aims to develop a centralized system for data collection and management that facilitates efficient grant reporting, data analysis, and performance tracking. It also will be user-friendly to streamline data access and analysis for staff members. By centralizing their data, the Aloe Family will gain better insights into their impact, streamline grant applications and reporting, and better harness data to inform decisions. This system will reduce administrative burdens like managing spreadsheets. Implementing this solution has potential to help them improve programs, expand reach, and secure more funding to continue their mission.



Centralization of the Aloe Family's five primary data collection and visualization tools into a more accessible and comprehensive platform.

The ALOE Family

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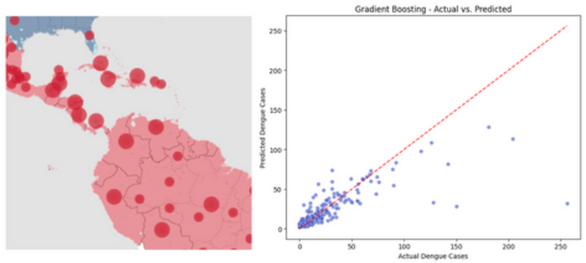
SPONSOR
Vanderbilt School of Engineering
Division of Engineering Science and Management

ENGINEERING SCIENCE AND MANAGEMENT

ESM-4

Data-driven approach with machine learning to predict dengue fever

The dengue fever prediction project integrates dengue fever transmission data with environmental and climate variables to develop an accurate model capable of forecasting weekly cases in San Juan, Puerto Rico, and Iquitos, Peru. The project host is DrivenData, an online platform that hosts competitions to drive social impact through data science and engineering. There is the growing prevalence and spread of dengue fever, driven by factors like environment, disease incidence, and climate change. Current predictive models are often inaccurate and cannot incorporate real-time climate and environmental data, resulting in reactive rather than proactive public health measures. This project will leverage advanced machine learning and environmental datasets to improve predictive accuracy, allowing for timely interventions and better public health outcomes. This project provides potential benefits by aiding public health agencies with actionable insights to mitigate the impact of dengue epidemics. Accurate predictions can guide resource allocation, research initiatives, and public health interventions.



A heatmap of dengue cases in Central and South America alongside actual vs. predicted values from a gradient boost model we developed.

VANDERBILT
School of Engineering

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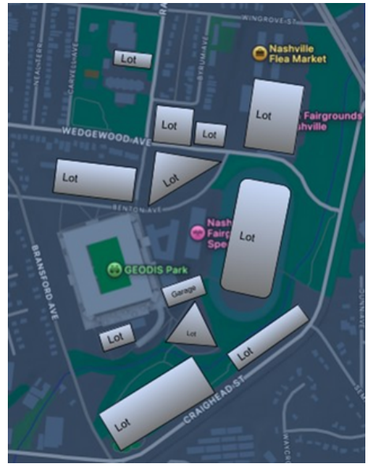
SPONSOR
Nashville Metropolitan Council's Transportation & Infrastructure Committee

ENGINEERING SCIENCE AND MANAGEMENT

ESM-5

Nashville parking locator technology

The project addresses the growing need for real-time parking locator technology and improved traffic management around Geodis Park in Nashville. Existing tools, including interactive maps, provide static parking location data and lack live updates on availability. The goal is to develop a website and parking app skeleton prototype that integrates real-time parking data that improves accessibility, reduces traffic congestion, and supports Nashville's Smart City initiatives. The app will leverage user-reported data and sensor-based vehicle detection in the long term to track parking lot capacities and available spots. As attendants and lot owners add their lots and count parking spots available via our app, drivers will be able to visualize the capacities of the lots via our website. The solution exceeds existing systems by providing up-to-date parking insights, enhancing urban mobility, and promoting alternative transportation by integrating WeGo bus service options. By allowing drivers to visualize lots, the app is expected to decrease parking search times, improve event traffic flow, and reduce unnecessary vehicle emissions. The anticipated result is a scalable, user-friendly parking solution that can extend beyond Geodis Park and potentially benefit other high-traffic areas across Nashville.



Lots surround key venues of GEODIS Park Stadium and the Nashville Fairgrounds.

ENGINEERING SCIENCE AND MANAGEMENT

ESM-6

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SPONSOR
Vanderbilt Career Center

Vanderbilt Career Center visitor assistance program

Our project creates a personalized navigation program designed to enhance visitor experiences at Vanderbilt University, and specifically supports industry visitors attending Career Center and engineering school events, as well as emergency personnel, students, faculty, and other guests navigating the campus. The university's complex layout, ongoing campus construction, and limited signage, often causes visitors to struggle to find destinations efficiently. Our solution aims to streamline wayfinding by integrating adaptive navigation tools that accommodate real-time changes in construction, event locations, and accessibility requirements. Unlike existing solutions, our system will be adaptable to campus modifications and scalable for future enhancements. By implementing this system, we anticipate improved visitor satisfaction, reduced staff burden at the Career Center, and better emergency response efficiency. Industry professionals and recruiters will also benefit from a more seamless experience, strengthening Vanderbilt's commitment to innovation and accessibility.

The program will expand upon existing campus maps to create a more inclusive navigation experience.

VANDERBILT
Career Center

ENGINEERING SCIENCE AND MANAGEMENT

ESM-7

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Facilities Department,
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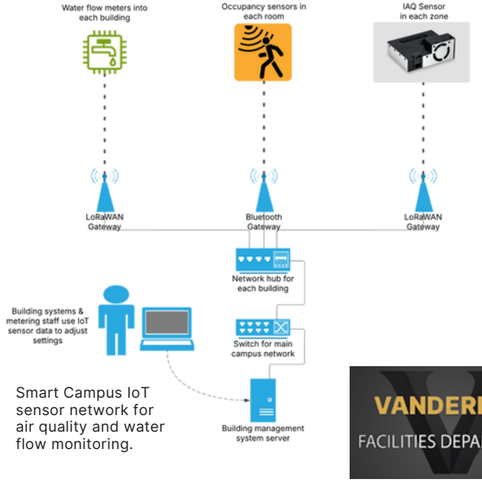
SPONSOR
Vanderbilt University Facilities Department

Implementing smart-campus initiatives at Vanderbilt

This project aims to measure, optimize, and reduce energy waste on Vanderbilt's campus by integrating smart technologies, such as advanced HVAC and water metering technologies, to better track and manage energy consumption. These technologies counteract problems of delayed water-leak detection, wasteful recycling of indoor air, and overspending on natural gas by use of indoor air quality (IAQ) sensors, mesh-enabled Bluetooth interoperable networks, and smart water metering. The design includes the application of Bluetooth LED lights, IAQ sensor installation, natural gas and water metering systems, and real-time monitoring interfaces. These systems will be integrated into a smart-campus platform that enables real-time detection of wasted resources to reduce energy and water usage. This approach facilitates real-time data collection, faster detection of inefficiencies, and lower operational cost, with the added benefit of a more sustainable and energy-efficient campus.



Smart Campus IoT sensor network for air quality and water flow monitoring.

VANDERBILT
FACILITIES DEPARTMENT

ENGINEERING SCIENCE AND MANAGEMENT

ESM-8

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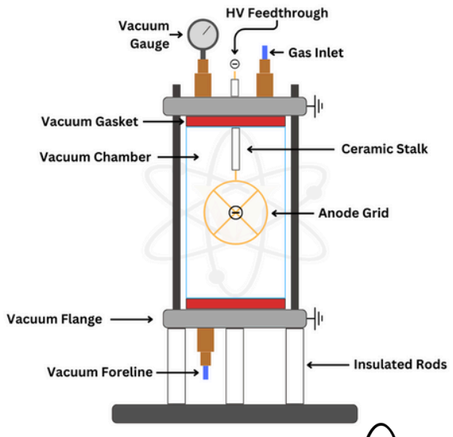
Department of Physics
and Astronomy

SPONSOR
The Vanderbilt Fusion Project

Vanderbilt Fusion Project institutionalization plan and nuclear fusion curricula

The Vanderbilt Fusion Project (VFP) is the only undergraduate-led organization in the country dedicated to the construction and operation of a functional miniature nuclear fusion reactor. VFP's goal is to promote interdisciplinary, hands-on engineering at Vanderbilt and develop future engineers and leaders through practical research on cutting-edge technology. As the founding members of VFP graduate, the organization seeks to both clarify its own future as a student group and expand nuclear fusion's presence in an educational capacity at Vanderbilt. To assist VFP in achieving its aims, the goal of this project is twofold. First, the team plans to provide VFP with transition materials on organizational scope and structure, recruitment planning, and member education. Second, we are working to launch an introductory course on nuclear fusion as the starting point for a future minor program. Overall, this project hopes to improve student engagement and outcomes in both their extracurricular and academic activities, as well as to maintain VUSE's status as an engineering program committed to multidisciplinary innovation.



The project component to an introductory fusion course will be a virtual anode plasma demonstrator that simulates an inertial electrostatic confinement fusion device.

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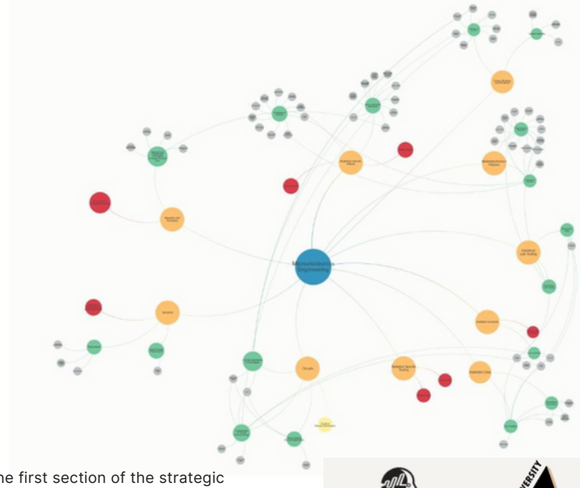
SPONSORS
Institute for Space and Defense Electronics (ISDE)
Scalable Asymmetric Lifecycle Engagement (SCALE)

ENGINEERING SCIENCE AND MANAGEMENT

ESM-9

Strategic knowledge mapping for radiation-hardened microelectronics

The Strategic Knowledge Map (SKM) project tackles a critical challenge in the space and defense industry: training the future workforce for designing, developing, and manufacturing radiation-tolerant (hardened) electronics. Gaining expertise in the effects of radiation on semiconductor electronics requires deep specialization in highly technical fields. However, as technology advances and experienced professionals retire, identifying where critical expertise resides and ensuring workforce replenishment becomes increasingly difficult. Strategic Knowledge Mapping offers a solution by displaying the relationships and connections within the RadHard electronics sector. Using network visualization technology, the proposed system will map key entities—such as essential skills, academic institutions teaching those skills, and industrial or government partners applying them—enabling deeper exploration of workforce dynamics. The platform may expand to other semiconductor disciplines and incorporate machine learning to automate knowledge categorization. Ultimately, the SKM will be a vital tool in training and educating the next generation of radiation-hardened electronics professionals.



The first section of the strategic knowledge map outlines Vanderbilt courses that align with Knowledge, Skills and Abilities (KSA's) in the field of radiation-hardened microelectronics.

SCALE
SCalable Asymmetric Lifecycle Engagement

VANDERBILT UNIVERSITY ISDE

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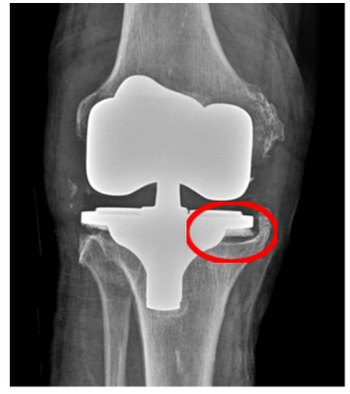
ENGINEERING SCIENCE AND MANAGEMENT

ESM-10

Piezoelectric sensing for early detection of TKR loosening

Orthopedic implant loosening is a major complication in total knee replacement (TKR) implants, leading to pain, reduced mobility, and costly revision surgeries. X-rays and CT scans often detect loosening only after significant damage has occurred and limit the ability for early intervention. Our project aims to develop a sensor-integrated total knee replacement implant that uses piezoelectric force sensors to provide real-time monitoring of implant stability, allowing for early detection of loosening. The primary objective is to create a proof-of-concept prototype that embeds piezoelectric force sensors around the implant to track force distribution over time. These sensors will generate a force map that offers detailed spatial and temporal data to identify where and when loosening occurs. By continuously monitoring changes in force patterns, our system will enable proactive intervention before major implant failure occurs. This approach provides a significant advantage over traditional diagnostic techniques, which rely on periodic imaging and subjective clinical assessments. By delivering continuous, real-time data, our solution has the potential to improve patient outcomes, extend implant lifespan, and reduce health care costs associated with revision surgeries.



When loosening occurs in the tibial stem of a TKR, our device—integrated at the inferior surface of the tibial baseplate (in red)—uses piezoelectric sensors to detect micro-movements and interface separation at both the bone-cement and implant-cement junctions, enabling early diagnosis of implant instability.

VANDERBILT UNIVERSITY
MEDICAL CENTER

MECHANICAL ENGINEERING
ME-1

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Professor Thomas Withrow, ME

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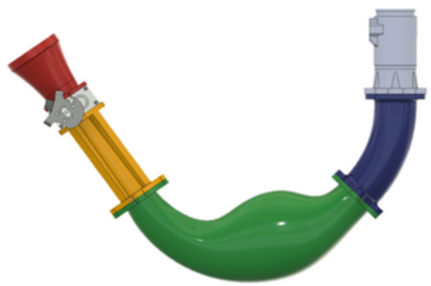
Vanderbilt University School of Engineering
Vanderbilt University Motorsports

Aerodynamic induction system for a high-performance SAE racecar

The Vanderbilt Motorsports team designs and builds a single-seat, open-wheeled vehicle that is optimized for short-course autocross-style tracks and conforms to Formula SAE rules. The goal of this project is to design, build, and test a high-performance air intake system that will replace the baseline system for the Vanderbilt Motorsports 2025 Formula SAE vehicle. The complete air intake system for a naturally aspirated Formula SAE car typically consists of five main components (air filter, throttle, venturi, plenum, runner) – all are combined to meet three main goals: Maximize airflow into the engine, increase responsiveness to throttle inputs, and be robust while minimizing weight. With fluid dynamics simulation, computer-aided design, flow testing, and materials analysis, the team optimized an induction system that can be quickly disassembled for maintenance and maximizes the volumetric efficiency of the engine, resulting in higher vehicle performance and ultimately a more competitive vehicle.



The "full-stack intake assembly" features (from left to right) the air filter housing (red), throttle body (silver), venturi (yellow), plenum (green), and runner (blue).

School of Engineering

VANDERBILT MOTORSPORTS

MECHANICAL ENGINEERING
ME-2

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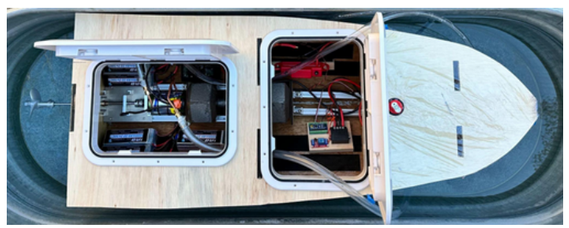
SPONSORS
Vanderbilt University School of Engineering
American Society of Naval Engineers

Electric powered boat to compete at Promoting Electric Propulsion (PEP) 2025

The American Society of Naval Engineers hosts the Promoting Electric Propulsion competition annually to encourage students to explore electric propulsion solutions in maritime engineering. The competition is a time trial race in open water. Teams must complete two 1-mile laps while carrying a 30-pound payload. The fastest boat to finish wins. We competing in the unmanned vessel division with a 4-foot V-shaped hull designed to optimize stability, buoyancy, and drag reduction while accommodating the required payload. The propulsion system features a 7-hp motor powered by a 12S (50V) battery configuration with a custom drivetrain. A cooling system that uses bay water prevents critical electrical components from overheating. The remote-controlled vessel uses a dual rudder system with servo actuation for steering and a dual hatch system for improved sealing and access during in-water adjustments. The goal is to complete the two-mile course in under eight minutes.



The top-down view shows a dual hatch system of the boat in a water tank. An electric drivetrain connects a propeller to the motor, which is powered by rechargeable batteries. An external water-cooling system is included and a dumbbell serves as the required 30-lb payload.

School of Engineering

AMERICAN SOCIETY NAVAL ENGINEERS · 1888 ·

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SPONSOR
NISSAN North America

MECHANICAL ENGINEERING
ME-3

Nissan full-scale reconfigurable interior buck demonstrator

The project objective is to develop a full-scale reconfigurable interior buck, which is a physical model used to simulate the interior dimensions and cargo space of a vehicle. The reconfigurable buck improves upon static mock-ups and digital simulations by offering a full-scale, interactive experience, allowing a user to sit inside the vehicle, evaluate roominess, visibility, ease of entry and exit for both the first and second rows, and assess cargo areas for loading, unloading, and overall usability. Its adjustable design provides realistic assessments of comfort and usability, helping Nissan gather insights on optimal layouts, ergonomics, and space efficiency for future vehicle platforms. To achieve these goals, the buck is constructed to be robust, visually aligned with Nissan's interior concepts, and designed to maximize the ability to demonstrate new configurations. The structure incorporates materials such as aluminum extrusions for the vehicle's framework. Upon completion, the buck is being used in a consumer research event this spring where Nissan will investigate new vehicle platforms for the future.

A full-scale reconfigurable interior buck designed to show a vehicle interior and cargo space. The system can adjust frame configuration, length and width of the vehicle, seating locations, and raise or lower the roof line. Wheels provide easier transportation and car-like appearance.

NISSAN

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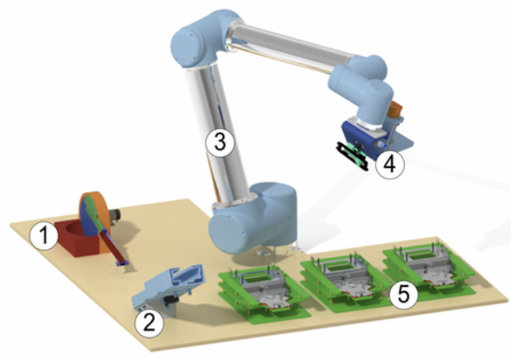
David Blaylock, Nissan North America

MECHANICAL ENGINEERING
ME-4

Robotically maneuver and secure an Intelligent Cruise Control Module

This project automates the assembly process of Intelligent Cruise Control Modules (ICCM) on Nissan's production line. The system uses a Universal Robotics, UR10e, robotic arm to efficiently pick up ICCMs, place them onto mounting brackets, and securely fasten them with nuts. The key components of the design include a bracket nest, ICCM nest, custom robot end effector, bowl feeder, delivery system, and the control of the UR10 robot. The project offers significant advantages over existing solutions by improving efficiency, reducing operator workload, and ensuring consistent quality. The system employs custom subsystems like a rotary bowl feeder and an integrated magazine-style delivery system to maintain proper nut orientation, providing a more cost-effective and reliable solution compared to traditional systems. The anticipated results include streamlined operations on the assembly line, reduced operator fatigue, and improved production throughput. With rigorous testing and iteration, the project is expected to meet Nissan's operational standards while also enhancing safety and integration with human operators in the workspace.



The automated ICCM assembly station features a custom bowl feeder system (1), ICCM nest (2), UR10e robotic arm (3), end effector (4), bracket nests (5), and magazine-style nut delivery system (6), all working in sync to optimize the assembly process.

NISSAN GROUP OF NORTH AMERICA

MECHANICAL ENGINEERING

ME-5

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SPONSORS
Vanderbilt Aerospace Design Laboratory
National Aeronautics and Space Administration

Extraterrestrial lander for data collection and R.F. transmission.

For the 2025 NASA Student Launch Challenge, VADLdeveloped the STEMnaut Capsule Radio Frequency Transmitter (STEMCRaFT), a lander tasked with carrying four analog astronauts (STEMnauts) and transmitting flight data via Radio Frequency (R.F.) over the 2-meter band. The STEMCRaFT is stowed in the fore section of a 6" diameter rocket, which launches to an apogee within 5% of 4200 feet above ground level and descends under drogue and main parachutes. At 300 feet, the Lander Separation Mechanism (LSM) jettisons the STEMCRaFT fvia two electronic rotary latches. The STEMCRaFT reorients from a vertical to horizontal configuration while its parachute unfurls, triggering the Leg Deployment Mechanism (LDM) to passively deploy the lander's four aluminum legs. The STEMCRaFT, under parachute, achieves a smooth and upright landing for the four STEMnauts housed in the STEMnaut Crew Module (SCM). Once the onboard algorithm detects landing, the Parachute Detachment Mechanism (PDM) releases the parachute via an electronic latch. The Antenna Extension Mechanism (AEM) then extends three spring-loaded tape antennas that transmit a suite of flight data, including landing site temperature, apogee, and crew survivability metrics, to the NASA ground station, thus completing the mission.

STEMCRaFT, upon landing, shows deployed legs and antennas following parachute detachment.

MECHANICAL ENGINEERING

ME-6

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Optimizing ALICE-type military backpack frame for comfort and adjustability

The MOLLE-4K rucksack currently used by U.S. Army soldiers has been criticized for discomfort and durability issues, particularly on long-distance rucks with heavy loads. Soldiers report frame cracking, poor weight distribution, and limited adjustability, leading to fatigue and inefficiency in the field. This project optimizes the ALICE-type backpack frame, the backpack frame standard prior to the MOLLE, to enhance comfort and adjustability while maintaining the strength and modular system required for military operations. Our kit contains all the pieces needed to modify an existing ALICE frame and a detailed instruction guide for complete clarity. Soldiers can customize the fit based on their height, ensuring better weight distribution and reduced strain. The design also includes a removable hygiene pouch for convenient access to personal items. Compared to the current MOLLE-4K frame, this kit solution offers superior durability, improved ergonomic fit, and easy customization. Unlike the brittle plastic of the MOLLE-4K, the aluminum frame resists cracking and can be manually adjusted without specialized tools. Currently, there are no customizable frames on the market, making the kit solution novel and versatile. Through testing with soldiers from the 101st Airborne Division at Fort Campbell, Ky., our modifications have shown promising results in comfort and performance.

Customization kit provides materials and instructions to modify an after-market ALICE frame to soldier preferences.

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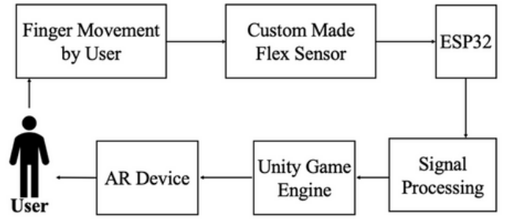
MECHANICAL ENGINEERING

ME-7

Wearable finger tracking device for augmented reality integration

This project addresses limitations in current augmented reality (AR) hand-tracking technologies. Specifically, it targets issues with computer vision-based hand tracking related to optical occlusion and inaccuracies in detecting hand and finger movements within complex environments. We propose a wearable solution employing resistive flex sensors designed specifically for precise and reliable hand tracking. This approach promises high precision in tracking hand and finger joint angles. The customizable flex sensor translates physical finger bending into measurable resistance changes by using a meandering structure, enhancing material flexibility and allowing conductive particles within to separate further when flexed, thus increasing resistance and sensitivity. The signals from the sensor are captured and processed by an ESP32 microcontroller that digitizes and transmits the data wirelessly to a dedicated signal processing module. The sensor data is further refined and formatted to be compatible with a Unity Game Engine environment. Unity interprets this processed signal to generate interactive digital elements or responses in the AR device. The AR device provides visual, auditory, or somatosensory feedback directly back to the user.



Project flow chart

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MECHANICAL ENGINEERING

ME-8

Enhanced braking for a Permobil manual wheelchair

Power-assist devices in wheelchairs increase the need for dedicated braking systems to ensure user safety. Wheelchairs powered by Permobil's SmartDrive system can benefit from an integrated brake mechanism to mitigate hazards at high speeds or during turns. This project aims to develop a braking system that enhances safety and control by ensuring reliable stopping power in various conditions. The system must be easily removable for storage and designed for accessibility. The design features a brake disc mounting system that attaches to the wheel hub via a 3D-printed nylon clamp and adapter. A caliper mount secures the system to the wheelchair's axle, while braking force is applied through custom 3D-printed paddles on Shimano brake levers. These paddles increase contact area, making activation easier for users with limited hand function. Hall effect sensors detect braking input, enabling SmartDrive motor adjustments. This adaptable system improves braking accessibility across wheelchair models. The anticipated outcome is a seamlessly integrated braking system that provides both general stopping power and differential braking for steering control.

Wheelchair braking system integrates hydraulic brakes and an adapter to mount a brake disc on the wheel, while a removable caliper remains stationary on the wheelchair frame. Sensors underneath each brake level communicate via a microcontroller to decrease an external propulsion motor accordingly.

MECHANICAL ENGINEERING

ME-9

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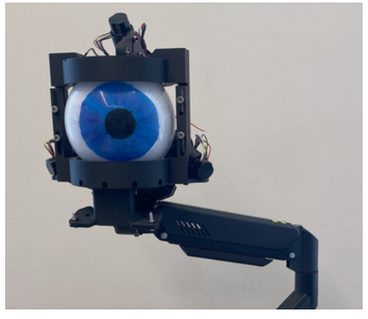
Eyeball rotation and tracking mechanism with Animax

The project goal is to develop an animatronic eyeball mechanism that can reliably rotate a sphere to show any face to the front. To be successful, the final prototype must be capable of precise tracking and recalibration. Our design allows an animatronic to change the appearance of its eyes or exhibit a large range of motion, which improves upon the limitations of the current, half-shell designs. Our prototype consists of three main subsystems: the external drive system, the internal tracking system, and the algorithmic control system. The external system holds the eyeball and constrains it to smooth rotational motion. The three motors and omni-wheels attached to the housing drive the rotation of the eyeball about any axis. The low volume profile and fully constrained housing are designed to integrate easily with full-scale animatronics. The eyeball itself contains a sensor system that tracks the rotation and provides orientation feedback to the control algorithm, as well as an induction coil for wireless charging and magnets for calibration. The algorithmic control system acts as the main input and dictates the motion and calibration sequences for the eyeball. With these features, the project is highly versatile and can be adapted to numerous different characters.



The animatronic (shown here with no character-specific costuming) fully constrains the eyeball within the housing for smooth motion. Interior sensors provide orientation feedback, and motors mounted to the back drive precise orientation changes.

ANIMAX

MECHANICAL ENGINEERING

ME-10

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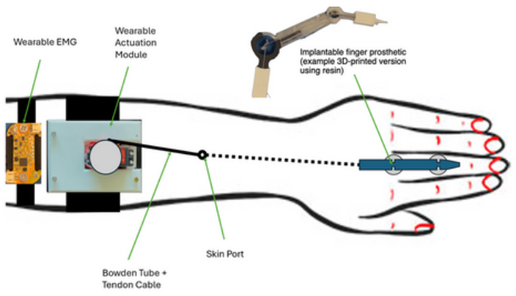
Implantable finger prosthesis

We developed an implantable finger prosthetic that replaces the metacarpophalangeal (MCP) and proximal interphalangeal (PIP) joints, providing active movement control for patients with arthritis or traumatic injury to finger joints. There are three integrated components: an EMG sensor worn on the forearm, a wearable actuation module, and an implantable flexure mechanism. The design uses wireless communication between the EMG sensor and a compact wearable module that houses a DC motor, battery, and control electronics. When activated, the module pulls on “tendon" cables that enter the body through a skin port and connect to the implanted flexure device. Users can alternate between flat hand and flat fist positions through intuitive control based on forearm muscle activity. The implantable component features a flexure design with independent rotating segments that mimic natural finger joints. The mechanism includes both flexor and extensor cables routed through internal channels to provide bidirectional movement. Currently tested at 1.5x scale with a response time of 248ms, we are transitioning to a 1:1 scale implementation and addressing critical biocompatibility requirements. This system restores functional control and strength of finger joints while maintaining the sensory advantages of an internal solution.



Schematic demonstrates the complete system in action: the wearable actuation module (white box) receives signals from the EMG sensor to pull tendon cables, causing the implantable finger prosthetic to alternate between flat hand and flat fist positions. This integrated system allows intuitive control of the prosthetic MCP and PIP joints through natural muscle movements.

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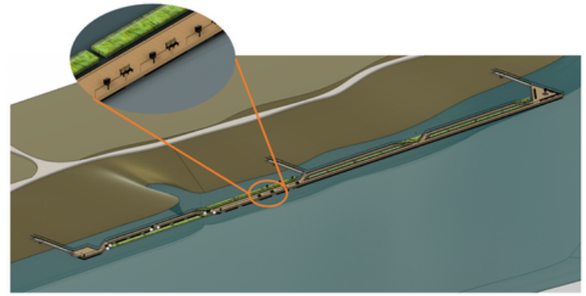
Cumberland River Compact

MECHANICAL ENGINEERING

ME-11

Cumberland River floating boardwalk

Nashville residents have limited opportunities to engage with the Cumberland River, learn about its ecology, and develop an appreciation for the water quality. Our team has created a comprehensive plan and feasibility study for a floating boardwalk at the Shelby Bottoms Greenway. Spanning 1,000 feet, the boardwalk features two gathering platforms, strategically placed benches, designated fishing stations, and a kayak launch to encourage outdoor activity. To support local biodiversity, artificial floating vegetation will be integrated along the structure, enhancing ecological education opportunities. The boardwalk is designed to withstand the river’s currents and water level fluctuation. An elastic mooring system will secure it to the riverbed, allowing it to rise and fall with changing water levels. Additionally, three gangways will connect the boardwalk to the bank, ensuring safe and stable access for visitors. This project aims to create an engaging public amenity where the community can interact with the Cumberland River in new and meaningful ways, promoting environmental awareness and recreation.



This CAD rendering of the 1,000-foot-long boardwalk includes features such as benches, gangways, and floating vegetation. A zoomed-in section provides a detailed view.

CUMBERLAND RIVER COMPACT
OUR WATER. OUR FUTURE.

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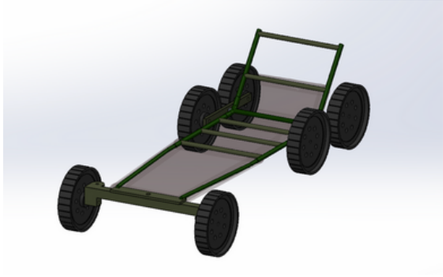
MECHANICAL ENGINEERING

ME-12

Heavy weapons transportation system for the Civil Military Innovation Institute

The heavy weapons transportation system addresses the challenge of efficiently transporting heavy military equipment, specifically the M2 .50 Cal Machine Gun system that can weigh up to 200 lbs. Assistant Gunners (AGs) often face significant fatigue and mobility limitations when moving these weapons across rugged terrain. Existing solutions, such as artic sleds, are terrain-specific and lack adaptability for broader environments. The project goal is to develop a pull cart that minimizes physical strain, enhances maneuverability, and increases overall functionality across various terrains. Inspired by Mars Rover wheel systems and deer carts, the design features a double-wheel rocker configuration that optimizes weight distribution and stability. It includes a collapsible aluminum-steel frame for lightweight durability, an efficient steering system utilizing 80/20, and a reinforced plastic netting system with D-hooks and bungee straps to securely hold parts in place without risk of tearing. The design improves upon previous solution designs by expanding terrain adaptability, reducing entanglement risks, and optimizing weight distribution for increased payload capacity. The expected outcome is a transport system that enhances soldier efficiency, reduces injury risks, and improves overall mission readiness in demanding field conditions



CAD model of the complete heavy weapons transportation system, featuring a collapsible aluminum-steel frame, a passive steering system with a high-strength needle bearing, and a reinforced moisture-resistant polyethylene plastic sheet for the cargo 'netting' with integrated hooks and straps to secure weapon components during transport across rugged terrains.

CIVIL-MILITARY INNOVATION INSTITUTE

MECHANICAL ENGINEERING

ME-13

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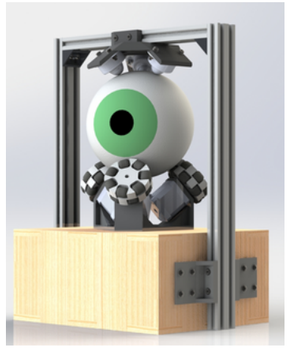
Universally rotating animatronic eyeball

Traditional animatronic eyeballs typically are limited to movement along two axes, restricting their range of motion and functionality. This design uses a three omni-wheel system with 360-degree rotation, each wheel powered by a stepper motor. A removable multi-processing unit, combined accelerometer and gyroscope, continuously monitors the eyeball's orientation and records absolute position data that is transmitted via Wi-Fi to an external microcontroller, enabling real-time feedback for precise control. The system features a 3D-printed motor mount and a custom-fabricated eyeball to incorporate internal electronics. This approach eliminates the need for things like complex magnetic systems while ensuring seamless, unrestricted movement. By integrating omni-wheels for continuous motion and internal sensors for reliable position tracking, this project advances the capabilities of animatronic eyes. A final prototype will demonstrate natural, fluid motion, with future improvements focusing on refining control algorithms, enhancing surface traction, and improving overall aesthetics.



SolidWorks rendering of animatronic eyeball assembly. External electronics, including power supplies and stepper motors circuitry, are housed inside the base; internal electronics, including the MPU and supporting circuitry, are in an electronics compartment inside the eyeball.

ANIMAX

MECHANICAL ENGINEERING

ME-14

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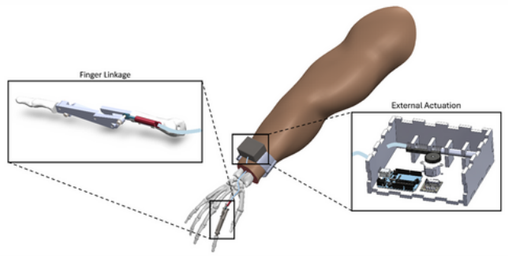
Implantable multi-joint powered finger prosthesis

Arthritis affects over 50 million people in the U.S., often leading to joint pain and loss of finger mobility. Current artificial finger implants replace damaged joints with passive non-actuating hinges that have limited functionality, unpredictable success rates, and low patient acceptance. Our team in collaboration with surgeons and hand therapists is developing a highly functional, implantable finger prosthesis. The prosthesis is designed to restore the full range of motion and provide comparable strength to that of a natural finger. The prosthesis use a hydraulic-driven linkage mechanism. The hydraulic line facilitates force transmission while the linkage is designed to maintain a compact, non-electronic design. Both features are designed with a focus on biocompatibility, as they would be implanted into a person's body. Next steps for this project include sourcing hydraulic and linkage components, continuing to scale down components to a 2:1 maximum ratio, and testing different configurations focused on minimizing size while maximizing force and functionality. This proof of concept aims to pave the way for advanced prosthetic solutions and future funding opportunities.



The implantable finger prosthesis consists of a hydraulic actuation system (left) along with a finger linkage mechanism (right), working in tandem to move the finger through its range of motion.

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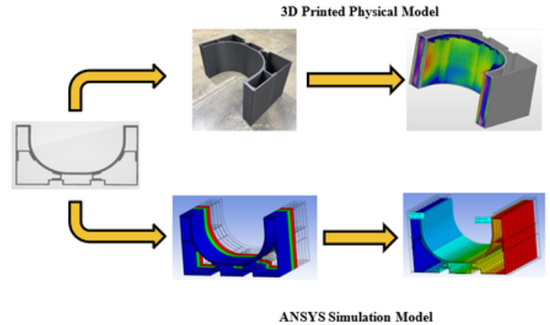
MECHANICAL ENGINEERING

ME-15

Prediction of warping in large-scale additively manufactured aerospace components

In aerospace manufacturing it is common practice when using carbon fiber materials to first machine a negative mold of the intended part out of metal. However, these molds are heavy and relatively expensive to machine. Additively manufactured thermoplastics offer a cheaper and lighter alternative to these metal molds but have lower dimensional accuracy due to manufacturing tolerances and thermal cooling. Companies like Airtech use rule-of-thumb and trial-and-error methods to mitigate deformations in the additively manufactures parts, which results in time, money, and resources wasted on non-quantitative methods. The team created a thermal-structural finite element model in ANSYS to simulate the process of additively manufacturing a component. The model uses orthotropic materials properties, time-based layering, and temperature dependent properties to mimic the additive manufacturing process. A low-cost, computationally inexpensive, and quick running model is not currently presented in literature for additive manufacturing applications and has the potential to save companies time, money, and resources in the current rule-of-thumb workflow.



Workflow for evaluating ANSYS simulation fidelity for sample 3D printable component.

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Design and Project Faculty

Biomedical Engineering
Chemical Engineering
Civil and Environmental Engineering
Electrical and Computer Engineering
Engineering Science and Management
Mechanical Engineering

We take great pride in recognizing these faculty members who are the core of our design program in their respective departments. Their outstanding contributions and excellence as instructors, advisers, and mentors have led to the work demonstrated on Design Day, April 21, 2025

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