DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

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The Department of Mechanical and Aerospace Engineering of the Case School of Engineering offers programs leading to bachelor's, master's, and doctoral degrees. It administers the programs leading to the degrees of Bachelor of Science in Engineering with a major in Aerospace Engineering and Bachelor of Science in Engineering with a major in Mechanical Engineering. Both curricula are based on four-year programs of preparation for productive engineering careers or further academic training.

Mission

The mission of the Mechanical and Aerospace Engineering Department is to educate and prepare students at both the undergraduate and graduate levels for leadership roles in the fields of Mechanical Engineering and Aerospace Engineering and to conduct research for the benefit of society.

The undergraduate program emphasizes fundamental engineering science, analysis and experiments to ensure that graduates will be strong contributors in their work environment, be prepared for advanced study at top graduate schools and be proficient lifelong learners. The graduate programs emphasize advanced methods of analysis, mathematical modeling, computational and experimental techniques applied to a variety of mechanical and aerospace engineering specialties including, applied mechanics, dynamic systems, robotics, biomechanics, fluid mechanics, heat transfer, propulsion and combustion. Leadership skills are developed by infusing the program with current engineering practice, design, and professionalism (including engineering ethics and the role of engineering in society) led by concerned educators and researchers.

The academic and research activities of the department center on the roles of mechanics, thermodynamics, heat and mass transfer, robotics, mechatronics, data analytics, sustainability in manufacturing, and engineering design in a wide variety of applications such as aeronautics, astronautics, biomechanics and orthopedic engineering, biomimetics and biologically-inspired robotics, energy, environment, mechanics of advanced materials, and nanotechnology. Many of these activities involve strong collaborations with the Departments of Biology, Electrical Engineering and Computer Science, Materials Science and Engineering, and Orthopedics of the School of Medicine.

The significant constituencies of the Mechanical and Aerospace Engineering Department are the faculty, the students, the alumni and the external advisory boards. The educational program objectives are established and reviewed continuously, based on the feedback from the various constituencies as well as archival information about the program graduates. The faculty engages in continuing discussions of the academic programs in the regularly scheduled faculty meetings throughout the academic year. Periodic surveys of alumni provide data regarding the preparedness and success of the graduates as well as guidance in program development. Archival data include the placement information for graduating seniors, which provides direct information regarding the success of the graduates in finding employment or being admitted to graduate programs.

Mastery of Fundamentals

- A strong background in the fundamentals of physics, mathematics and chemistry
- Methods of mechanical engineering analysis, both numerical and mathematical, applied to mechanics, dynamic systems and control, design, thermodynamics, fluid mechanics and heat transfer
- Methods of modern experimental engineering analysis and data acquisition

Creativity

- Ability to identify, model, and solve mechanical and aerospace engineering design problems
- Ability to design experiments to resolve mechanical and aerospace engineering issues
- Ability to perform an individual senior project that demonstrates original research and/or design content

Societal Awareness

- Issues of environmental impact, efficient use of energy and resources, benefits of recycling
- An awareness of the multidisciplinary nature of mechanical and aerospace engineering
- Impact of economic, product liability and other legal issues on mechanical and aerospace engineering manufacturing and design

Leadership Skills

- An ability to work in teams
- Ethical considerations in engineering decisions
- Proficiency in oral and written communication
- Professionalism
- Students are encouraged to develop as professionals through participation in the student chapters of the American Society of Mechanical Engineers (ASME) and the American Institute of Aeronautics and Astronautics (AIAA).
- Students are encouraged to augment their classroom experiences with the cooperative education program and the strong graduate research program of the department.
- Students are encouraged to take the Fundamentals of Engineering Examination as the first step in the process of becoming a registered professional engineer.
- The bachelor's candidate must complete an independent design or research project with an oral and written final report.
- The master's candidate on the thesis or project track must demonstrate independent research suitable for publication and/or presentation in peer-reviewed journals and/or conferences.
- The doctoral candidate must complete a rigorous independent thesis containing original research results that they must publish in archival journals.

Aerospace Engineering

Aerospace engineering has grown dramatically with the rapid development of the computer in experiments, design and numerical analysis. The wealth of scientific information developed as a result of aerospace activity forms the foundation for the aerospace engineering major.

Scientific knowledge is being developed each day for programs to develop reusable launch and interplanetary vehicles, the International Space Station (ISS), supersonic and hypersonic flight vehicles, crewed and robotic space missions, and micro-electro-mechanical sensors and control systems for advanced flight. New methods of analysis and design for structural, fluid, and thermodynamic applications are required to meet these challenges.

The aerospace engineering major has been developed to address the needs of those students seeking career opportunities in the highly specialized and advancing aerospace industries.

Mechanical Engineering

Civilization, as we know it today, depends on the intelligent and humane use of our energy resources and machines. The mechanical engineer's function is to apply science and technology to the design, analysis, development, manufacture, and use of machines that convert and transmit energy, and to apply energy to the completion of useful operations. The top ten choices of the millennium committee of the National Academy of Engineering, asked to select the 20 top engineering accomplishments of the 20th century, was abundant with mechanical engineering accomplishments, electrification (large scale power generation and distribution), automobiles, air travel (development of aircraft and propulsion), mechanized agriculture, and refrigeration and air conditioning.

Research

Aerospace Technology and Space Exploration

Pressure gain combustion, hypersonic aerodynamics, shock wave boundary layer interactions, two phase flow, supersonic combustion and propulsion, thermoacoustic refrigeration, in-situ resource utilization from space. Gravitational effects on transport phenomena, fluids and thermal processes in advance life support systems for long duration space travel, interfacial processes, g-jitter effects on microgravity flows, two phase flow in zero and reduced gravity. Aerospace vehicle design and mission analysis.

Experimental Fluid Dynamics

Turbulence, transition, separated flows, imaging diagnostics for fluids, advanced velocimetry techniques, biological flows.

Combustion and Fire Engineering

Solid pyrolysis, ignition, flame spread, material flammability, wild land fire, battery fire, fire dynamics, fire modeling, combustion in micro- and partial gravity.

Data Analytics

Multi-domain signal decomposition and analysis, wavelet transform and other transformation methods, multi-scale analysis, data fusion, stochastic modeling and statistical methods for defect detection, root cause diagnosis, and remaining service life prognosis.

Electromechanical Systems

Fundamental and applied research on physics-based sensing for improved observability and controllability of dynamic systems, vibration analysis, artificial intelligence and machine learning for data analytics, energy harvesting, smart materials and structures, and energy-efficient wireless communication methods based on radio frequencies, acoustic waves, and magnetic field coupling.

Engineering Design

Optimization and computer-aided design, feasibility studies of kinematic mechanisms, control systems, experimental stress analysis, failure analysis, development of biologically inspired methodologies.

Heat Transfer

Analysis of heat transfer in complex systems such as biological organisms, multi-functional materials and building enclosures.

Sustainable and Additive Manufacturing

Modeling, characterization and manufacturing of next-generation lithium ion batteries for electric vehicles and perovskite solar cells for low-cost solar power generation, multiphysics electrochemistry modeling, atomic layer deposition, scalable nano-manufacturing, life cycle assessment of lithium ion batteries on environmental sustainability, agile manufacturing work cells based on coordinated, multiple robots, additive manufacturing, in-process sensing and control.

Advanced Materials

Development of advanced materials with unprecedented properties and functionality for extreme environment conditions. Modeling of nonlinear deformations, instability, and failure of multi-functional materials and structures. Design, fabrication, and optimization of advanced composite materials, bio-inspired materials, and meta-materials. 3D/4D printing of functional materials and structures.

Multiphase Flow and Laser Diagnostics

Application of non-intrusive laser based diagnostic techniques and ultrasound techniques including pulsed ultrasound Doppler velocimetry to study solid-liquid, solid-gas, liquid-gas and solid-liquid-gas, multiphase flows encountered in slurry transport and bio-fluid mechanics.

Nanomaterials and Nanotechnology

Nanomaterials and nanotechnologies for high-performance nanoelectronics (transistors, sensors, photodetectors, memristors, etc.), energy conversion/generation/storage devices (batteries, supercapacitors, nanogenerators). Nanostructured materials and nanocomposites. Mechanical, thermal, optical, and electrical properties of nanomaterials. Surface and interface properties of nanomaterials. Solution processing and printing of novel nanomaterials.

Musculoskeletal Mechanics and Materials

Design, modeling, and failure analysis of orthopaedic prostheses and material selection; mechanical properties of, and transport processes in, bone and soft tissue; tribology of native and tissue engineered cartilage; nondestructive mechanical evaluation of tissue engineered cartilage.

Robotics

Biologically-inspired and biomimetic design and control of legged robots, crab-like robots, and soft worm-like robots. Controls via synthetic nervous systems, motion primitives and stable heteroclinic channels. Autonomous robots. Small fixed-wing drones. Dynamics, control and simulation of animals and robots.

Sensing and Metrology

Signal transduction mechanisms, design, modeling, functional characterization, and performance evaluation of mechanical, thermal, optical, and magnetic-field sensors, multi-physics sensing, and precision instrumentation.

Soft Machines and Electronics

Development of soft/hybrid robotics for broad applications, such as biomedical treatment, elderly care, rehabilitation, prosthetics, agriculture harvesting, and infrastructure inspections. Development of self-powered soft electronic systems for wearables, implantable, prosthetics, artificial skins, and smart agriculture systems. Printed electronics and technologies. Scalable manufacturing technologies for flexible/stretchable electronic system.

Faculty

Robert X. Gao, PhD
(Technical University of Berlin, Germany)
Cady Staley Professor of Engineering and Department Chair
Multi-physics sensing and stochastic modeling methods for improving observability in dynamical systems

Ozan Akkus, PhD
(Case Western Reserve University)
Leonard Case Jr. Professor of Engineering
Biologically active and mechanically functional tissue repair systems, and chemical imaging instrumentation for noninvasive biomedical and hazard diagnostics

Richard J. Bachmann, PhD
(Case Western Reserve University)
Associate Professor
Biologically inspired robotics

Paul Barnhart, PhD, PE
(Case Western Reserve University)
Professor and Associate Chair for Undergratuate Education
Aerospace system design, propulsion, gas dynamics, shock wave boundary layer interactions and fluid/thermal systems modeling

Changyong (Chase) Cao, PhD
(Australian National University)
Assistant Professor
Mechanics, designs, and manufacturing of smart multifunctional materials, soft robotics, soft electronics, and self-powered sensing systems

Sunniva Collins, PhD, FASM
(Case Western Reserve University)
Professor and Associate Dean of Professional Programs
Metallic surfaces for improved performance, material and design manufacturing processes for innovative outcomes

Kathryn Daltorio, PhD
(Case Western Reserve University)
Assistant Professor
Robots that can traverse and operate in new environments, inspired by biological models of smart physical systems

Umut A. Gurkan, PhD
(Purdue University)
Professor
Human health via research in cell mechanics to develop biosensors and point-of-care systems

Steve Hostler, PhD
(California Institute of Technology)
Assistant Professor
Development and characterization of novel thermal management materials

Chirag Kharangate, PhD
(Purdue University)
Assistant Professor
Thermal management of electronics and computational fluid dynamics

Ya-Ting T. Liao, PhD
(Case Western Reserve University)
Associate Professor
Computational models of combustion, fire behavior and fire-resistant structures

Brian Maxwell, PhD
(University of Ottawa, Canada)
Assistant Professor
Next-generation propulsion systems and advanced theory of supersonic and reactive systems

Roger D. Quinn, PhD
(Virginia Polytechnic Institute & State University)
Arthur P. Armington Professor of Engineering
Neural and mechanical models of animals and data to design and control robots and exoskeletons

Majid Rashidi, PhD, PE
(Case Western Reserve University)
Professor
Machine and medical device design

Bryan E. Schmidt, PhD
(California Institute of Technology)
Assistant Professor
Turbulent and unsteady flows from low-speed to hypersonic using advanced imaging methods

Yingchun (Chris) Yuan, PhD
(University of California at Berkeley)
Professor
Design, manufacturing and sustainability science of lithium ion batteries, solar cells and nanotechnologies

Research Faculty

R. Balasubramaniam, PhD
(Case Western Reserve University)
Research Associate Professor
Enables the development and understanding of thermal and fluid systems to advance space exploration

Uday Hegde, PhD
(Georgia Institute of Technology)
Research Associate Professor
Develops supercritical water oxidation technologies for waste management and water reclamation for extended duration space missions

Olga Kartuzova, PhD
(Cleveland State University)
Research Assistant Professor
Studies and develops computational models for cryogenic storage tanks, and investigates zero boil-off tanks

Mohammad Kassemi, PhD
(University of Akron)
Research Professor
Researches microgravity fluid physics and combustion research, including ZBOT, cryogenic fluid management, propellant tank models and gravity's impact on systems

Jun Kojima, PhD
Research Associate Professor
Laser diagnostics and combustion code validation

Kenneth Moses, PhD
(Case Western Reserve University)
Research Assistant Professor
Project manager for NSF NeuroNex Network grant on Communication, Coordination and Control in Neuromechanical Systems

Vedha Nayagam, PhD
(University of Kentucky)
Research Associate Professor
Low gravity combustion and fluid physics

Associated Faculty

Alexis Abramson, PhD
(University of California, Berkeley)
Adjunct Professor
Macro/micro/nanoscale heat transfer and energy transport

Jennifer W. Carter, PhD
(The Ohio Stage University)
Associate Professor of Materials Science and Engineering
Processing-structure-property relationships of crystalline and amorphous materials, multi-scale material characterization methods

M. Cenk Cavusoglu, PhD
(University of California, Berkeley)
Professor of Electrical, Computer, and Systems Engineering
Robotics, systems and control theory, and human-machine interfaces; with emphasis on medical robotics, haptics, virtual environments, surgical simulation, and bio-system modeling

Mario Garcia Sanz, DrEng
(University of Navarra)
Professor of Electrical, Computer, and Systems Engineering
Systems and control, spacecraft controls, automated manufacturing

John J. Lewandowski, PhD
(Carnegie Mellon University)
Professor of Materials Science and Engineering
Mechanical behavior of materials, fracture and fatigue, micromechanisms of deformation and fracture

Kenneth Loparo, PhD
(Case Western Reserve University)
Professor of Electrical, Computer, and Systems Engineering
Control, robotics, stability of dynamical systems, vibrations

João Maia, PhD
(University of Wales Aberystwyth, U.K.)
Associate Professor of Macromolecular Science and Engineering
Polymer rheology: extensional rheology and rheometry, micro- and nano-rheology, bio-rheology

David Matthiesen, PhD
(Massachusetts Institute of Technology)
Associate Professor of Materials Science and Engineering
Microgravity crystal growth

Wyatt S. Newman, PhD
(Massachusetts Institute of Technology)
Professor of Electrical, Computer, and Systems Engineering
Mechatronics, high-speed robot design, force and vision-bases machine control, artificial reflexes for autonomous machines, rapid prototyping, agile manufacturing

Ravi Vaidyanathan, PhD
(Case Western Reserve University)
Adjunct Associate Professor
Robotics and control

Xiong Yu, PhD, PE
(Purdue University)
Professor of Civil and Environmental Engineering
Geotechnical engineering, non-destructive testing, intelligent infrastructures

Christian A. Zorman, PhD
(Case Western Reserve University)
Professor of Electrical, Computer, and Systems Engineering
Materials and processing techniques for MEMS and NEMS, wide bandgap semiconductors, development of materials and fabrication techniques for polymer-based MEMS and bioMEMS

Emeritus Faculty

Dwight T. Davy, PhD, PE
(University of Iowa)
Professor Emeritus
Musculo-skeletal biomechanics, applied mechanics

Isaac Greber, PhD
(Massachusetts Institute of Technology)
Professor Emeritus
Fluid dynamics, molecular dynamics and kinetic theory, biological fluid mechanics, acoustics

Jaikrishnan R. Kadambi, PhD
(University of Pittsburgh)
Professor Emeritus
Experimental fluid mechanics, laser diagnostics, bio-fluid mechanics, turbomachinery

Yasuhiro Kamotani, PhD
(Case Western Reserve University)
Professor Emeritus
Experimental fluid dynamics, heat transfer, microgravity fluid mechanics

Joseph M. Mansour, PhD
(Rensselaer Polytechnic Institute)
Professor Emeritus
Biomechanics and applied mechanics

Eli Reshotko, PhD
(California Institute of Technology)
Kent H. Smith Emeritus Professor of Engineering
Fluid Dynamics, heat transfer, propulsion, power generation

Clare M. Rimnac, PhD
(Lehigh University)
Wilbert J. Austin Emeritus Professor of Engineering
Biomechanics, fatigue and fracture mechanics

Fumiaki Takahashi, PhD
(Keio University)
Professor Emeritus
Combustion, fire science and engineering

James S. Tien, PhD
(Princeton University)
Professor Emeritus
Combustion, propulsion, and fire research

Programs

- Aerospace Engineering, BSE
- Aerospace Engineering, MS
- Aerospace Engineering, PhD
- Mechanical Design and Manufacturing, Minor
- Mechanical Engineering, BSE
- Mechanical Engineering, MS
- Mechanical Engineering, MS (Online)
- Mechanical Engineering, PhD

Dual Degrees

- Undergraduate Programs toward Graduate or Professional Degrees

Facilities

The education and research philosophy of the Department of Mechanical and Aerospace Engineering for both the undergraduate and graduate programs is based on a balanced operation of analytical, experimental, and computational activities. All three of these tools are used in a fundamental approach to the professional activities of research, development, and design. Among the major assets of the department are the experimental facilities maintained and available for the faculty, students, and staff.

Introductory undergraduate courses in computer aided design and manufacturing are taught in both the fabrication lab and the Reinberger Design Studio that are housed within Sears think[box], the university's 7 story, 50,000 square feet, innovation center and makerspace. The Robert M. Ward '41 Laboratory is modular in concept and available to students at regularly scheduled class periods to conduct a variety of prepared experimental assignments. The lab is equipped with a variety of instruments ranging from classic analog devices to modern digital computer devices for the collection of data and the control of processes.

Advanced departmental facilities described below are available for more specialized experimental tasks. Every undergraduate and most graduate degree programs involve a requirement, i.e., Project, Thesis or Dissertation, in which the student is exposed to a variety of departmental facilities. In addition, think[box] facilities are available to all undergraduate and graduate students for these requirements and for other projects.

The following is a listing of the major laboratory facilities used for advanced courses and research in the department.

Biorobotics Facilities

The Biorobotics Complex (http//biorobots.cwru.edu/) consists of 8 labs, shops and office spaces on the 8th floor of the Glennan Engineering Building. Facilities include a fully equipped machine shop with CNC and manual machines for fabricating robot components. An Aerostructures Lab allows for construction of components using carbon fiber matrix composites. The Biorobotics Complex also includes labs for building worm robots and crab-like robots, with a small wave tank, dedicated 3D printers, wet working area and hood.

Visit https://engineering.case.edu/research/labs/Daltorio/ for more details.

A compressed air facility has been installed to operate pneumatic robots. In addition, an automated treadmill (5 feet by 6 feet) is available for testing walking robots. The Complex includes computers and software for designing, analyzing and testing mobile robots. Dozens of legged, wheeled and worm-like robots have been constructed with funding from ONR, NSF, DARPA, AFOSR and NASA.

Center for Applied Raman Spectroscopy

The Applied Raman Spectroscopy Center provides services to both trained and untrained users in acquiring Raman spectra and spectral data processing. Raman spectroscopy provides information on identities and amounts of chemical species, crystallinity/purity and molecular alignment.

Liquid, gas or solid phase specimens can be analyzed with Raman. Pharmaceuticals, polymers, coating, additives, biological samples and tissues, graphene, diamond, carbon nanotube, and inorganic species are a few of the many samples that can be analyzed.

The center is equipped with specialty Raman systems that use green, NIR and IR lasers. Explore the center's full array of equipment. All systems are accessible as a service center to individuals within Case Western Reserve University and from outside the university. The Applied Raman Spectroscopy Center also provides services in the processing and interpretation of spectral data.

Electromechanical Systems (EMS) Laboratory

The EMS Lab, approximately 1,200 square feet in space, is housed in the Glennan Engineering Building of the Mechanical and Aerospace Engineering department. Since its founding in 1995, faculty and students in the EMS lab have been conducting fundamental and applied research on physics-based sensing for improved observability and controllability of dynamic systems, vibration analysis, machine learning for data analytics, energy harvesting, smart materials and structures, and energy-efficient wireless communication methods based on radio frequencies, acoustic waves, and magnetic field coupling. More than 70 projects have been conducted over the past 20 years, under the sponsorship of NSF and other federal agencies, as well as the industry. Research topics involved the monitoring, diagnosis, and prognosis of manufacturing and oil drilling equipment and processes, digital manufacturing, machine learning methods, wearable sensing for human physical activity assessment, computational algorithms for reconfigurable information acquisition, energy-efficient and wireless sensor networks, etc.

The Lab is equipped with state-of-the-art electronic instruments for the design, modeling, simulation, prototyping, and experimental evaluation of miniaturized and wireless sensors and sensor networks, e.g. logic analyzer, spectrum analyzer, arbitrary waveform generator, high speed digital oscilloscopes, instrument for high speed electrical capacitance tomography, etc. It also has equipment and related software for FPGA and microcontroller-based embedded computing, multiple sensor nodes for adaptive wireless sensor communication, vibration shaker for sensor reliability testing, active vibration suppression and control test bed, etc. It also has two machine fault simulators for rotary machine systems (including bearings, spindles, and gearboxes) diagnosis and prognosis, as well as a Makerbot Replicator 3D printing machine.

Flow Physics and Imaging Laboratory

The Flow Physics and Imaging Laboratory consists of 1600 square feet of research space and a dedicated student office. The primary flow facility in the lab is a water tunnel with a test section of 30 cm x 30 cm x 1 m capable of flow speeds up to 1 m/s. The lab is also equipped with equipment for high speed stereoscopic PIV and other imaging applications, including a Photonics DM-527-DH Nd:YLF PIV laser, a Nd:YAG laser, two Photron Nova S12 high speed CMOS cameras capable of 1 MP imaging at 12,800 frames per second, an Imperx Cheetah 31 MP CMOS camera, two Nila Varsa flicker-free LED lamps, and Insight4G PIV acquisition and processing software.

Visit https://case.edu/engineering/labs/fpi/ for more details.

Laboratory for Sustainable Energy Manufacturing

The Laboratory for Sustainable Energy Manufacturing is equipped with state-of-the-art manufacturing and testing facilities for lithium ion batteries, and is capable to fabricate various sizes of lithium ion battery cells, ranging from small coin cells to large EV battery cells. Arbin battery testers are available to test the batteries from a single individual battery cell to a battery module pack on their electrochemical performance, internal impedance, rate capability, etc. Environmental chamber can support the testing of lithium ion battery cells and modules under various temperature and humidity conditions.

The lab has instruments for research and development of battery materials and testing of the materials properties. The Lab also houses a THT EV+ Calorimeter as a safety testing instrument for thermal runaway testing of lithium ion batteries under various charging/discharging conditions. The lab also has modeling tools and established professional databases for life cycle assessment (LCA) and sustainability studies of lithium ion batteries, solar cells, fuel cells, etc. Energy efficiency of industrial manufacturing processes is also studied with digital energy meters, current transducers and data loggers to measure the real-time energy consumption of a single equipment and/or an individual process.

Multiphase Flow and Laser Diagnostics Laboratory

A laser diagnostics laboratory is directed toward investigation of complex two-phase flow fields involved in energy-related areas, bio-fluid mechanics of cardiovascular systems, slurry flow in pumps and thermoacoustic power and refrigeration systems. The laboratory is equipped with state-of-the-art Particle Image Velocimetry (PIV) equipment, Pulsed Ultrasound Doppler Velocimeter, Ultrasound concentration measurement instrumentation and modern data acquisition and analysis equipment including PCs. The laboratory houses a clear centrifugal slurry flow pump loop and heart pump loop. Current research projects include investigation of flow through microchip devices, CSF flow in ventricles, investigation of solid-slurry flow in centrifugal pumps using ultrasound technique and PIV, thermo-acoustic refrigeration for space application.

Musculoskeletal Mechanics and Materials Laboratories

These laboratories are a collaborative effort between the Mechanical and Aerospace Engineering Department of the Case School of Engineering and the Department of Orthopaedics of the School of Medicine that has been ongoing for more than 40 years. Research activities have ranged from basic studies of mechanics of skeletal tissues and skeletal structures, experimental investigation of prosthetic joints and implants, measurement of musculoskeletal motion and forces, and theoretical modeling of mechanics of musculoskeletal systems. Many studies are collaborative, combining the forces of engineering, biology, biochemistry, and surgery.

The Biomechanics Test labs include Instron mechanical test machines with simultaneous axial and torsional loading capabilities, a non-contacting video extensometer for evaluation of biological materials and engineering polymers used in joint replacements, acoustic emission hardware, and software, and specialized test apparatus for analysis of joint kinematics.

The Bio-imaging Laboratory includes microscopes and three-dimensional imaging equipment for evaluating tissue microstructure and workstations for three-dimensional visualization, measurement, and finite element modeling.

An Orthopaedic Implant Retrieval Analysis lab has resources for characterization and analysis of hard tissues and engineering polymers, as well as resources to maintain a growing collection of retrieved total hip and total knee replacements that are available for the study of implant design.

The Soft Tissue Biomechanics lab includes several standard and special test machines. Instrumentation and histology facilities support the activities within the Musculoskeletal Mechanics and Materials Laboratories.

Soft Machines & Electronics (SME) Laboratory

The Laboratory for Soft Machines & Electronics (SME) has approximately 600 square feet in space with a diverse set of facilities for the development, characterization, manufacturing and testing of multifunctional materials, soft robotics, flexible and stretchable electronics. The following resources are available for research: Olympus Microscope (BX51), HI-TEMP Vacuum Oven (MDL 281), Analytical Balance (Mettler AE160), Hotplates, Planetary Centrifugal Mixer (Thinky AR-100), Ultrasonic Cleaner (Fisher Scientific FS30D), Spin Coater, Potentiostat for electrochemistry measurements, complete materials chemistry wet lab, Goniometer for measuring surface wetting properties (contact angles, surface energy, surface tension, etc.) of materials, Model 6514 Electrometer (Tektronix Inc.), Experimental gas-flow setup for sensor testing, Aerosol Jet Printer (Nanojet Desktop) for printed nanomaterial-based electronics & sensors, 3D bioprinter (BIO-X6, Cellink Inc.) capable of printing six kinds of materials simultaneously and can perform coaxial printing of core-shell structures for a variety of soft materials and biomaterials. 3D printers include One Flash Forge Adventurer 4 3D Printer and one Prusa MK3S for fast prototyping of curing molds and complex structures and devices.

UL Fire and Combustion Laboratories

UL Fire and Combustion Laboratories was founded in 2015 at Case Western Reserve University. The mission of the labs is to support both the science community and industry to advance knowledge in material and fire dynamics with an ultimate goal to improve fire safety and save lives. The 2,200 square feet laboratory contains the following equipment: cone calorimeter, smoke density chamber, micro-combustion calorimeter, Fourier Transform Infrared Spectroscopy (FTIR) gas analyzer, Thermal Protective Performance (TPP) tester, analytical balances, fume hoods, various environmental chambers, and high-pressure gas supply systems. Imaging equipment includes infrared (FLIR) cameras, high-definition video camcorders, and SLR digital cameras.

Other Facilities

The department facilities also include several specialized laboratories.

Engineering Services Fabrication Center offers complete support to assist projects from design inception to completion of fabrication. Knowledgeable staff is available to assist Faculty, Staff, Students, Researchers, and personnel associated with Case Western Reserve University.

Sears think[box] is a university facility housed in a 7-story building near the Glennan Building that the Department of Mechanical and Aerospace Engineering gains many benefits from for teaching and research.

Sears think[box] is a 50,000 square feet innovation center and makerspace that is open to the entire campus community as well as users from the public. The makerspace area, inclusive of metal and wood fabrication, welding, 3D printing, laser cutting, and other capabilities inhabits half of the total area and is distributed across four adjacent floors.

The Reinberger Design Studio is located on the fifth floor of think[box]. It is outfitted with 20 thin clients running Citrix and connected to a dedicated server with high-end GPU support for demanding CAD and other applications. A host of design software is installed locally, including Solidworks, MasterCAM, Abaqus, COMSOL, and MATLAB. This lab is used for many design classes, student design clubs, and is also open to public users of think[box].

The Robert M. Ward Laboratory on the 4th floor of the Glennan Engineering Building is the primary undergraduate teaching laboratory within the Department of Mechanical and Aerospace Engineering. Featuring a wind tunnel, Instron universal testing machines, and National Instruments data acquisition systems this laboratory is capable of supporting advanced engineering measurements. This laboratory is also utilized for department research, senior projects, and support for student engineering design clubs.

High Performance Computing Resources at CWRU enable researchers to solve large-scale, data-intensive, advanced computational problems on topics across the disciplinary spectrum faster, more accurately and more efficiently. The HPC cluster at CWRU provides immediate, cost-effective access to a supercomputer capable of supporting the work of researchers in all departments, across all disciplines at the university. Computationally intensive research is supported through the continuously growing (currently at 976-processors) high performance computing cluster based on Dell PowerEdge servers with Intel processors and Red Hat Enterprise Linux. The ITS HPC cluster currently consists of 187 compute nodes with Intel Xeon EM64T processors, with the following different node types such as 64 Dell PowerEdge 1950 nodes with two 3.0 GHz quad-core "Harpertown" CPUs, 16 Gbytes of main memory, and a 146 Gbyte SAS hard drive; 42 Dell PowerEdge 1950 nodes with two 3.0 GHz dual-core "Woodcrest" CPUs, 8 Gbytes of main memory, and a 146 Gbyte SAS hard drive; 72 Dell PowerEdge R410 nodes with two 2.66 GHz six-core "Westmere" CPUs, 24 Gbytes of main memory, and a 300 Gbyte SAS hard drive. In addition to high performance computing, the Research Technologies group provides data visualization and graphics processing; data storage; database creation, management, and consultation; a high-speed network; and application consultation.