



CENTER of
EXCELLENCE

Research to Standards

EXO TECHNOLOGY

ASTM INTERNATIONAL
Exo Technology Center of Excellence

2020/2021 ANNUAL REPORT

www.etcoe.org



Improving the quality of life and participation of all people through human-centric exo technologies

Now is the pivotal moment in the advancement of human civilization where we are moving from simply using technology to wearing it and pushing the limits of our capabilities beyond anything previously imagined. ASTM International (ASTM) has been helping the world work better since 1898 and is now leading other organizations to think and do more through initiatives like our Exo Technology Center of Excellence (ET CoE).

Exoskeletons are one of the many emerging technologies that will augment our abilities and enable people to have fuller high-quality lives. Through the work of the ET CoE, we've been able to leverage the world's top technical experts and professionals in government, academia, healthcare, and industry to accelerate safety and reliability standards for exoskeletons and their systems.

The ET CoE and its partners work to identify standards gaps, support strategic R&D, expand education and workforce development initiatives, and establish testing and certification programs.

This inaugural report includes detailed information on the ET CoE's scope, team, partners, current projects, accomplishments, and metrics. It documents the hard work of numerous individuals and organizations that are helping to move us toward the vision of the ET CoE where people of all ages are free to pursue a high-quality life and participate fully in work and society, thanks to safe, reliable, and effective exo technologies.

The ET CoE team is thankful to be a part of the exoskeleton community. We hope you enjoy the updates on the pages ahead.

William "Bill" Billotte, Ph.D.
ET CoE Executive Director



William "Bill" Billotte, Ph.D.
ET CoE Executive Director,
ASTM International



Katharine E. Morgan
President,
ASTM International



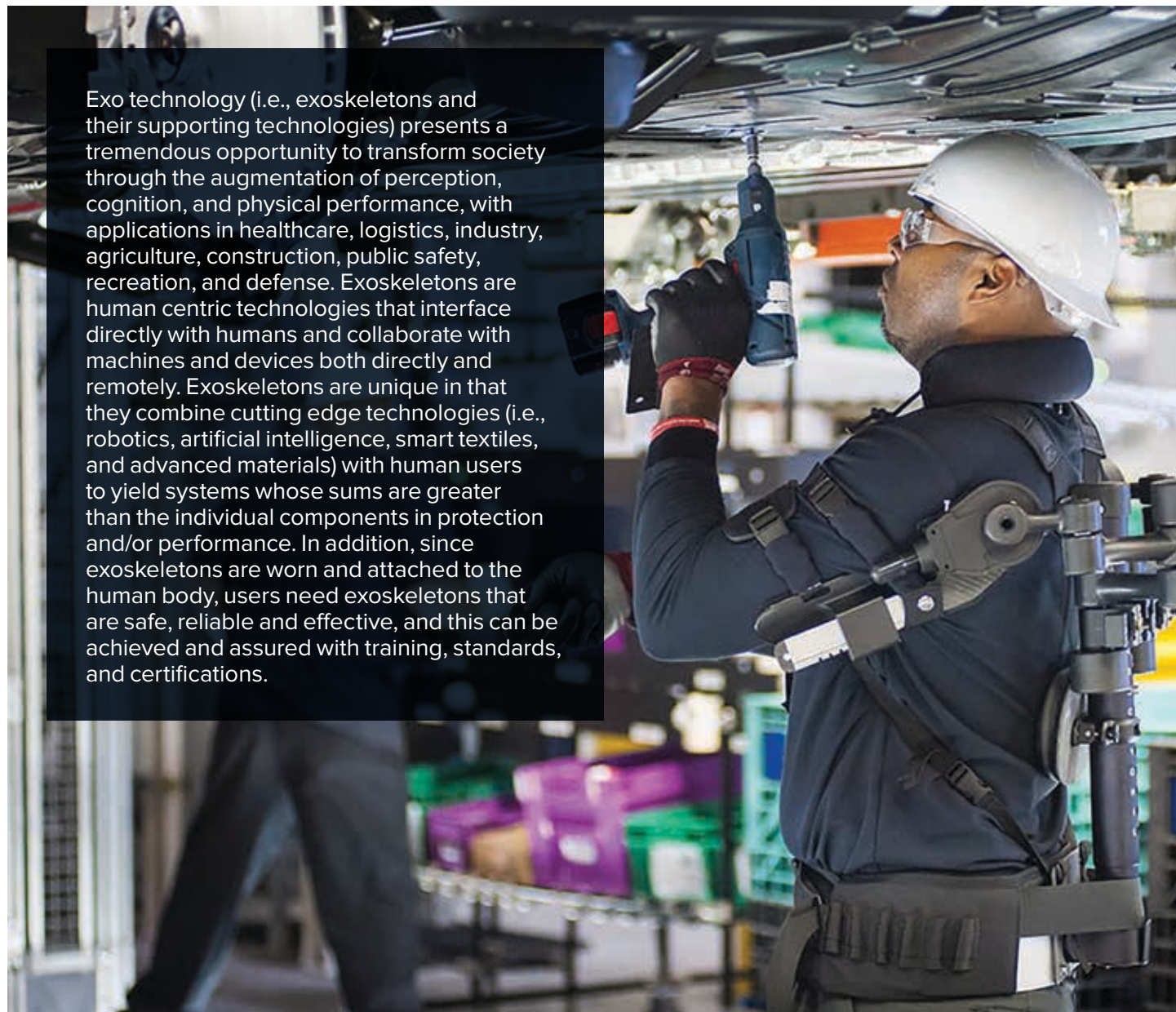
John Logar
2021 ASTM International
Chair of the Board

"Now is the right time to create a hub of collaboration among startups, companies, and other entities that are exploring how exoskeletons could support factory workers, patients, the military, and many other people."

ASTM International President
Katharine Morgan
June 2019

- 02 OVERVIEW
- 04 ORGANIZATION
- 06 PARTNERS
- 14 ACCELERATION PROJECTS
- 22 ACCOMPLISHMENTS & METRICS





Exo technology (i.e., exoskeletons and their supporting technologies) presents a tremendous opportunity to transform society through the augmentation of perception, cognition, and physical performance, with applications in healthcare, logistics, industry, agriculture, construction, public safety, recreation, and defense. Exoskeletons are human centric technologies that interface directly with humans and collaborate with machines and devices both directly and remotely. Exoskeletons are unique in that they combine cutting edge technologies (i.e., robotics, artificial intelligence, smart textiles, and advanced materials) with human users to yield systems whose sums are greater than the individual components in protection and/or performance. In addition, since exoskeletons are worn and attached to the human body, users need exoskeletons that are safe, reliable and effective, and this can be achieved and assured with training, standards, and certifications.

Established in 2019, the ASTM International Exo Technology Center of Excellence (ET CoE) is a collaboration between ASTM (and its more than 30,000 members) and consumers, industry, government, healthcare, and academia. The ET CoE seeks to improve the quality of life for all people through accelerating exo technology research, standards, testing, and training.

The ET CoE behaves as an exoskeleton for the global exo community. It augments, enables, assists, and enhances the exo community through initiatives that include:

- Identifying high priority needs and sponsoring research and development (R&D) through our groundbreaking Research to Standards (R2S) framework,
- Providing unbiased high value advice and counsel on exo technologies, including standards for technology around the globe
- Developing and delivering education, training, and workforce development (WD) products,
- Collaborating and partnering with other organizations passionate about exo technologies,
- Testing and evaluating exemplary products, processes, and laboratories to establish a trusted network of testing and certification organizations,
- Connecting people and organizations to promote innovation and collaboration,
- Providing a neutral venue for stakeholder groups to discuss common challenges,
- Curating and sharing knowledge, and
- Promoting exo technology through various outreach mechanisms.



VISION

People of all ages free to pursue a high-quality life and participate fully in work and society, thanks to safe, reliable, and effective exo technologies.



MISSION

The ET CoE's mission is to accelerate exo technology research, standards, testing, and training.



GOALS & OBJECTIVES

- Education and sharing knowledge with the broader exoskeleton community, including users, implementors, producers and researchers
- Conducting and accelerating research to standards
- Testing and certifying the safety, performance, and reliability of exoskeletons
- Increasing the capability of the CoE to help the community through partnerships and collaborations

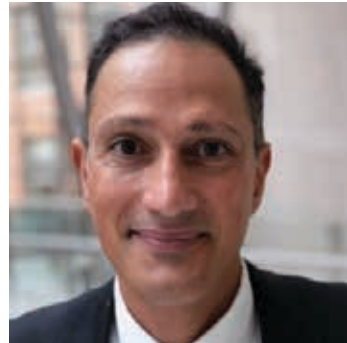
By attracting the world’s top exoskeleton experts who have a passion to serve the entire exo community, the ET CoE is structured to strategically support all stakeholders, including government, industry, healthcare, and more.

Exo Technology Advisory Board

The exoskeleton community looks to the CoE to create a technical foundation of high-quality standards and related programs that support continued growth, innovation and commercialization. The CoE’s Advisory Board was chartered to provide vision and direction of the CoE to ensure that it remains current with the existing and future drivers of the exo technology industry.



David Audet
U.S. Army Combat Capabilities Development Command Soldier Center



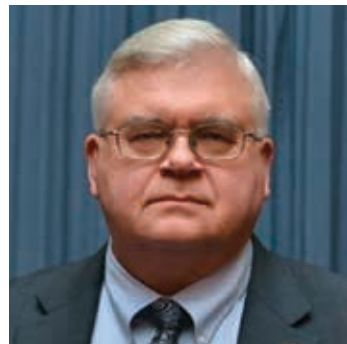
Hany Demian
U.S. Food and Drug Administration



Hugh Herr, Ph.D.
Massachusetts Institute of Technology



John Howard, MD, MPH, JD, LLM, MBA
U.S. Department of Health and Human Services



Philip Mattson
U.S. Department of Homeland Security



Jim Miller
Sarcos Defense



Samuel Reimer, Ph.D.
Ottobock Industrials



Connor Walsh, Ph.D.
Harvard University



The ET CoE Team

A world-class ASTM International team coordinates the day-to-day management of the ET CoE and coordinates across ASTM’s departments, technical committees, testing organizations, centers of excellence, and other groups.

William “Bill” Billotte, Ph.D.
ET CoE Executive Director

Nora Nimmerichter
Staff Manager and ET CoE Liaison

Len Morrissey
Director, Global Business Development & Strategy

Tessa Sulkes
Program Manager, Business Development

Lissy Velez
Program Manager, Business Development

Tricia Hock
Director, Certification Operations

Pat Picariello
Director, Developmental Operations

Brian Meincke
Vice President, Global Business Development and Innovation Strategy



PHOTO COURTESY OF THE BOEING COMPANY



ET CoE partners provide technical and business expertise while connecting the CoE to exo users, developers, and producers. Our partners provide relevant data and exo knowledge, and conduct projects including outreach, research to standards, training, and testing. These efforts support the priorities of the exo community by accelerating standards development, raising awareness and knowledge of exoskeletons, and supporting ASTM Committee F48 on Exoskeletons and Exosuits.

Founding Partners

- Exoskeleton Report
- New Stone Soup
- Prime Performance

Research to Standards Partners

- Smart HLPR
- SwiftMotion
- Texas Tech University (TTU)
- The University of Massachusetts Lowell (UMass Lowell)
- University of Michigan
- University of Michigan – Dearborn
- Vanderbilt University
- Virginia Tech

Collaboration Partners

- Automotive Exoskeleton Group (AExG)
- Human Factors and Ergonomics Society
- U.S. National Institute of Occupational Safety and Health (NIOSH)
- National Institute of Standards and Technology (NIST)
- National Safety Council

Training Partners

- Boston Engineering
- LIUNA TriFund
- U.S. Army Combat Capabilities Development Command, Soldier Center (DEVCOM SC)

Technical Committees

- Robotics, Automation, and Autonomous Systems (F45)
- Exoskeletons and Exosuits (F48)

Advisers

- Innovation & Research (F48.90.05)
- R&D Team
- Advisory Board

Founding Partners



Exoskeleton Report (ExR) LLC: Headquartered in San Jose, California, ExR is a volunteer-based organization focused exclusively on exoskeletons, exosuits, and wearable devices that exert a force on the user. ExR publishes “hype-free” articles concerning only the exoskeleton industry and is the leading source for reporting related news of interest. ExR staff serve as ASTM F48 secretary; ASTM F48 terminology committee member; WearRA standards and opportunities committee member; and as a contributor on exoskeletons and related topics on manufacturing for Forbes.com.



New Stone Soup (NSS) VT LLC: Headquartered in Hudson, Massachusetts, NSS is an 8a Certified Woman Owned Strategic Management and Outreach, Business Development, Program Management, Product Development and Strategic Engagement Firm. NSS has over 25 years of experience in cross-industry and government and multi-disciplinary team building and project management. NSS is a member of the ASTM F48 terminology committee; National Defense Industrial Association - Women in Defense; Massachusetts Technology Leadership Consortia (MassTLC); and WearRA standards and opportunities committee, among others.



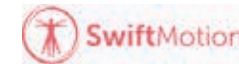
Prime Performance LLC: Headquartered in Portland, Oregon, Prime Performance LLC provides rehabilitation, coaching, and consulting services. Its CEO and founder is a Physical Therapist, Certified Professional Ergonomist, Certified Workers

Compensation Healthcare Provider, Certified Strength and Conditioning Specialist, Tactical Strength and Conditioning Facilitator and Six Sigma Black Belt among other related and relevant certifications and skills. Prime Performance LLC is a recognized practitioner and educator in the fields above as well as the exoskeleton and wearable technology fields. Prime Performance LLC is a participating member in the ASTM Committee on Exoskeletons and Exosuits (F48), Washington State Department of Labor and Industries Exoskeleton Advisory Committee, and Wearable Robotics Association.

R2S Project Partners

Smart HLPR

Smart HLPR
Roger Bostelman, Ph.D. formed Smart HLPR LLC in 2018 to contract to government and other organizations upon retiring from the U.S. National Institute of Standards and Technology (NIST). Bostelman currently contracts through Smart HLPR with NIST in his same role through July 2022. Bostelman’s role at NIST during his 41 year career included developing and updating ASTM, International Standards Organization (ISO), and American National Standards Institute (ANSI) standards and leading exoskeleton and autonomous vehicle projects for measurement science research and standards developments. He chairs ASTM committee on Robotics, Automation, and Autonomous Systems (F45), F45.01, F45.91, and F48.03 and is an expert on ANSI ISTDF B56.5 and ISO TC299 WG2 and WG4. He holds a B.S. in Electrical Engineering from George Washington University; an M.S. in Technology Management - University of Maryland University College; and a Ph.D. in Computer Science – University of Burgundy, France. He holds seven patents and has published over 120 chapters/papers in books, journals, and conference proceedings. Dr. Bostelman holds two ASTM awards: 2018 James A. Thomas President’s Leadership Award; 2016 Robert J. Painter Award from SES: The Society for Standards Professionals and ASTM International for his exceptional standards development and he has received many NIST awards.



SwiftMotion

SwiftMotion is an innovative company based in the San Francisco Bay Area, California which focuses on developing products for the improvement of occupational health. The company was founded by a team of experienced engineers from places such as Apple and is advised by some of the leading experts in the field of ergonomics and occupational health.

The company’s first product, called Fuze, launched in 2018; it allows users to estimate risks of low back and shoulder injury in work places based on sensor data. It is currently used by a few large insurance companies in the United States. Recently, this product has been upgraded by including foot insoles to measure loads in addition to posture tracking.

The team has developed standards for mobile telecommunications, smartphone industry, focusing on smartphone performance measurements, testing of phones and for the safety of end users. The team has participated in several industry standards bodies meetings such as the 3rd Generation Partnership Project (3GPP) as well as the Cellular Technologies Industries Association (CTIA).

SwiftMotion has experience building and shipping hardware products, and provides all tools necessary for R&D and data collection efforts. The company has performed several successful field assessments using Fuze and presented findings that have helped employers reduce injury-related costs or make process improvements. Such assessments have been performed at warehouses, airports, and at large hospital facilities, among others. The company has presented findings from their field assessments at leading expos and conferences with the goal of disseminate knowledge to the broader ergonomics community.

SwiftMotion is also actively collaborating with researchers at California State University at Sacramento in their biomechanics labs. This joint study will focus on exposure assessment systems and their validation with plans to publish some of these results in the near future.



Texas Tech University (TTU)

As a public research university, TTU advances knowledge through innovative and creative teaching, research, and scholarship. It is dedicated to student success by preparing learners to be ethical leaders for a diverse, globally competitive workforce. TTU is a Carnegie R1 research institution with more than \$190 million USD in annual research expenditures, as well as being a Hispanic Serving Institution, offering 150 undergraduate, 100 graduate, and 50 doctoral degrees across the colleges of Agricultural Sciences & Natural Resources, Architecture, Arts and Sciences, Business Administration, Education, Engineering, Human Sciences, Media & Communication, Visual & Performing Arts, Law, and Veterinary Medicine. The TTU system includes campuses in Amarillo, the Permian Basin (Odessa/Midland), and El Paso, as well as Angelo State University (San Angelo) and facilities in Costa Rica and Spain. Its service area is larger than 46 of the 50 states. Midwestern State University (Wichita Falls) has recently accepted an invitation to join the TTU.



The University of Massachusetts, Lowell (UMass)

UMass Lowell is a nationally ranked, public research institution located in Lowell, Massachusetts just outside of Boston, Massachusetts. UMass Lowell, one of five campuses in the UMass system, has about 1,100 faculty members and over 18,000 students, and is the second-largest public institution in the state.

The New England Robotics Validation and Experimentation (NERVE) Center of UMass Lowell is a 10,000 sq. ft. interdisciplinary robotics testing, research, and training facility that evaluates robotic capabilities, human performance, and human-robot interaction. The mission of the NERVE Center is to improve the development of robotic systems by enabling evaluation across many domains, including industrial automation,

exoskeletons and wearable robots, and disaster response. NERVE houses many overground test environments and equipment for measuring human and robot performance. The center provides test and evaluation services and consultation for developing test protocols, provision of sensors, data collection and analysis, personnel support, and logistics, which are available on-site, in the field, and remotely. These services are provided through grant-funded work as a research center and as a Core Research Facility (CRF). NERVE faculty have backgrounds in computer science, mechanical engineering, physical therapy and kinesiology, and biomedical engineering, providing the comprehensive expertise needed for exoskeleton and human factors evaluation. The NERVE Center's research has been supported by the U.S. Army CCDC-SC, Office of Naval Research, NIST, National Science Foundation, ARM Institute, U.S. Department of Energy, Defense Advanced Research Projects Agency (DARPA), and NASA.



University of Michigan
The University of Michigan is a top-ranked public university with a tradition of excellence in research, learning, and teaching. The team consists of three faculty members from the Robotics Institute. In addition to the faculty leads, the team recruited undergraduate students from across the College of Engineering to support the effort. Michigan Robotics is a collaborative community of roboticists who work together to create smart machines that serve society. The principal investigator is also a core faculty member within the Center for Ergonomics (C4E), which operates within the Department of Industrial and Operations Engineering in the College of Engineering. There is a long-standing history and distinguished record of work in the areas of cognitive ergonomics, biomechanics, and work physiology and safety. C4E also provides continuing education courses to graduate students in various departments as well as to professional ergonomists, engineers, and designers in private industry.

University of Michigan – Dearborn

Dearborn is one of the three regent campuses of the University of Michigan. Slightly different from Ann Arbor's theoretical and fundamental research focus, the Dearborn campus mainly promotes applied research that has clear application potential in the field. With grants and financial support received from industry and government agencies, Dearborn faculty conduct transdisciplinary, translational, and transactional research that could have specific applications and direct impacts in multiple research fields.

The University of Michigan - Dearborn has two human factors and ergonomics research laboratories (HPEC 1000 and ELB 3042) and one vehicle ergonomics laboratory (IAVS 1080).



Vanderbilt University
The Vanderbilt University Center for Rehabilitation Engineering and Assistive Technology (CREATE) is co-directed by Profs. Karl Zelik, Ph.D. and Michael Goldfarb, Ph.D. (co-PIs), and their colleague Prof. David Braun, Ph.D. The 3000 sq. ft. state-of-the-art motion analysis lab contains the following equipment for experimental testing: 10 Vicon T40 motion capture cameras, 10-camera Opti-Track System, portable Xsens motion capture system, Bertec split-belt force-instrumented treadmill, six AMTI in-ground force plates, 16-channel Delsys Trigno EMG (muscle activity) measurement system, Cosmed K4b2 portable respirometry system (to measure metabolic energy expenditure), two Telemed Echo Blaster ultrasound systems, as well as a variety of other smaller measurement sensors and tools.

The lab also contains two HuMoTech robotic actuation systems (off-board motor, controller, real-time input/output) for high-bandwidth control and device

emulation. There is an additional 3000 sq. ft. of engineering space in CREATE that includes dozens of computers for data analysis (with all necessary biomechanical analysis software for this proposed research), student desks, electrical/mechanical design, and fabrication workspace. The Vanderbilt University School of Engineering has a breadth of additional resources available to the research team, including two machine shops (with manual and CNC mills, lathes, laser cutters, 3D printers, etc.) for fabrication, and substantial computing resources and administrative support.



Virginia Tech
As the Commonwealth of Virginia's most comprehensive university and a leading research institution, Virginia Tech offers about 280 undergraduate and graduate degree programs to more than 37,000 undergraduate, graduate, and professional students and manages a research portfolio of more than \$556 million USD. The university fulfills its role as a land-grant institution by fostering a collaborative environment that integrates technology into all disciplines. The Virginia Tech community can serve as a force for positive change around the state, the country, and the world. Through experiential learning, future-focused research, and an inclusive, spirited culture, Virginia Tech strives to accomplish the charge of its motto *Ut Prosim* (That I May Serve).

The research team has a strong collaboration with broad areas of expertise and experience involving multiple faculty members from the Department of Industrial and Systems Engineering (ISE). Each of these faculty are members of the Virginia Tech Occupational Ergonomics and Biomechanics (OEB) Laboratories. The OEB Laboratories conduct work in theoretical and applied ergonomics, occupational biomechanics, and work physiology, primarily relating to worksite, workstation, and equipment evaluation and design.

Collaboration Partners



Automotive Exoskeleton Group (AExG)
AExG is a Wearable Robotics Association sponsored and industry-inclusive group that supports the evolution of exoskeletons for industry. It began with members from the automotive industry but has since expanded to include members from other industries, exoskeleton producers, and other interested stakeholders. Its vision is to promote quality of life through wearable technologies. AExG works create a forum where the exoskeleton community may openly exchange information.



Human Factors and Ergonomics Society (HFES)
Founded in 1957, HFES is the world's largest scientific association for human factors/ergonomics professionals. HFES serves the needs of members and the public by promoting and advancing the discovery and exchange of knowledge concerning the characteristics of human beings that are applicable to the design of systems, products, tools, and environments of all kinds.

ASTM International and HFES cooperate with the following goals:

1. Promote communication between the two organizations,
2. Promote knowledge of ASTM standards and the benefits of ASTM membership to HFES members,
3. Promote knowledge of HFES and the benefits of HFES membership to ASTM members,
4. Increase expert input into the development of ASTM exo technology standards and other areas of common interest from HFES,
5. Pursue safe and reliable exo technologies through awareness and education activities such as workshops, symposia, training events, and conferences.



U.S. National Institute of Occupational Safety and Health (NIOSH)

The Occupational Safety and Health Act of 1970 established NIOSH as a research agency focused on the study of worker safety and health, and empowering employers and workers to create safe and healthy workplaces. NIOSH is part of the U.S. Centers for Disease Control and Prevention, in the U.S. Department of Health and Human Services. NIOSH has the mandate to assure “every man and woman in the nation safe and healthful working conditions and to preserve our human resources.” NIOSH has more than 1,300 employees from a diverse set of fields including epidemiology, medicine, nursing, industrial hygiene, safety, psychology, chemistry, statistics, economics, and many branches of engineering.



National Safety Council (NSC)

NSC is America’s a leading nonprofit safety advocate; it has been for over 100 years. As a mission-based organization, it works to eliminate the leading causes of preventable death and injury, focusing efforts on the workplace, roadway and impairment. NSC creates a culture of safety to not only keep people safer at work, but also beyond the workplace so they can live their fullest lives.

NSC wishes to encourage quality, safety, innovation, and trade in advanced and emerging technology areas through development of technical standards, enhancing technical knowledge, and facilitating conversations and constructive information exchange among stakeholders.

Training Partners



Boston Engineering

Boston Engineering Corporation (Boston Engineering) provides product design and engineering consulting throughout the entire product development process, from concept through connected product capabilities. Certified for ISO 9001 and ISO 13485, the company’s industry expertise includes defense & security, medical devices, robotics, and commercial products. Founded in 1995, Boston Engineering is headquartered in Waltham, Massachusetts. Since 2018, Boston Engineering has been serving as DEVCOM SC’s third-party independent engineering analysis agent under an "Other Transaction Authority" agreement from the Army Contracting Command – Aberdeen Proving Grounds (ACC APG).



LIUNA TriFund

The Laborers’ International Union of North America (LIUNA) is a powerhouse of workers who help build the United States and Canada. A half-million strong, LIUNA provides the opportunity to earn a living wage, receive benefits, including health care and pensions, and attend life-long education and training for career advancement and better lives. LIUNA members are the first on the job and the last to leave, possessing a wide range of skill sets covering new building construction, demolition and deconstruction, environmental remediation, renewable energy, and all areas of infrastructure, including roads, bridges, dams, and utilities. They are certified to install rainwater catchment systems and trained to build water and sewer systems, solar plants, wind farms, natural gas and oil pipelines, while also performing maintenance and decommissioning of nuclear and coal powered facilities.

Playing a critical role in achieving these opportunities are LIUNA’s TRI-Funds: LIUNA Training and Education Fund (LIUNA Training), the Laborers-Employers Cooperation and Education Trust (LECET), and the Laborers’ Health and Safety Fund of North America

(LHSFNA). Each provide a labor-management approach to training, marketing, and health and safety programs.

LIUNA Training provides accredited curriculum and instructor training, registered apprenticeship, standards development, and portable industry credentials to a North American network of world-class training centers. The LHSFNA ensures workers are safe on the job and at home while providing expertise to ensure the best healthcare benefits in the industry. LECET keeps the vision of labor-management cooperation by providing a competitive edge in tracking work opportunities. The TRI-Funds’ goals are to ensure LIUNA’s journey-workers and apprentices remain a skilled, safe, and productive experienced union workforce, enabling union contractors to gain more work by bringing projects in on time and on budget.



U.S. Army Combat Capabilities Development Command, Soldier Center (DEVCOM SC)

DEVCOM SC ensures the dominance of Army capabilities by creating, integrating, and delivering technology-enabled solutions to our soldiers. Soldier Center follows a simple mandate: to ensure that American soldiers are the best fed, the best protected, and the most highly mobile military in the world.

The U.S. Army has provided modern Soldiers with greater capability than has existed at any time in the history of warfare. The average soldier’s load has doubled since World War II despite efforts to reduce the load, increasing fatigue and musculoskeletal injuries and decreasing soldier readiness. Soldier speed, endurance, and range all decrease with load, and they are also impacted by the nature of many of the required repetitive motion maneuvers. Until now, there have been limited choices in dealing with the effects of load and motion: Carry the load and accept the negative consequences or go without a critical piece or pieces of the Soldier kit. These choices have consequences that

impact the effectiveness of Soldiers and can potentially limit options for commanders. The future will call for warfare for even greater maneuvering in dense urban terrain, subterranean and vertical, and over 72-hour operations carrying only organic supplies, as well as experiencing complex maneuver operations.

The Army is interested in exoskeleton technology to assist in addressing the soldiers’ physical and cognitive load challenges to improve their readiness and operational effectiveness. Due to advancements in technology and large investments from industry, exoskeleton technology has the potential to provide a significant advantage for warfighters. Many organizations, including the Program Executive Office Soldier, the Maneuver Center of Excellence, and collaborations with the Special Operations Command, U.S. Navy, and U.S. Air Force are working to investigate and eventually deploy such devices.



National Institute of Standards and Technology (NIST)

The National Institute of Standards and Technology (NIST) was founded in 1901 and is now part of the U.S. Department of Commerce. NIST is one of the nation’s oldest physical science laboratories. Congress established the agency to remove a major challenge to U.S. industrial competitiveness at the time—a second-rate measurement infrastructure that lagged behind the capabilities of the United Kingdom, Germany, and other economic rivals.

From the smart electric power grid and electronic health records to atomic clocks, advanced nanomaterials, and computer chips, innumerable products and services rely in some way on technology, measurement, and standards provided by the National Institute of Standards and Technology.

Today, NIST measurements support the smallest of technologies to the largest and most complex of human-made creations—from nanoscale devices so tiny that tens of thousands can fit on the end of a single human hair up to earthquake-resistant skyscrapers and global communication networks.



Identify

Identify need/gap (standard, training, testing, qualification, etc.)



Market

Market research and landscape analysis



Develop

Develop a project overview and problem statement



Consult

Consult with F48.90.05, R&D Team, Advisory Board and others as appropriate



Acquire

Acquire optimal project team (i.e. Request for Proposals/ RFP, current partners and/or combination)



Manage

Manage project and execute



Deliver

Deliver product, standard, or service that addresses need/gap

RESEARCH

A systematic study directed toward fuller scientific knowledge or understanding of the subject studied. "Development" is the systematic use of knowledge and understanding gained from research directed toward the production of useful materials, devices, systems, or methods, including design and development of prototypes and processes. Source: 2 CFR 200.87

Research to Standards (R2S) Projects

Towards the Development of Test Methods and Measures for Evaluating Cognitive Fit of Exoskeletons

Texas Tech University

- Exoskeletons may affect the wearer's attentional and cognitive performance due to the added weight, restrictions on mobility, and augmented physical strength.
- The current research aims to investigate the potential effects of wearing an exoskeleton on the wearer's cognitive loads and attentional distribution, using a multifaceted approach of self-reported, behavioral performance, and eye-tracking measures.
- The current study design and expected research findings will be used to develop a standard guide for how to assess exoskeleton users' cognitive performance while performing load handling tasks.



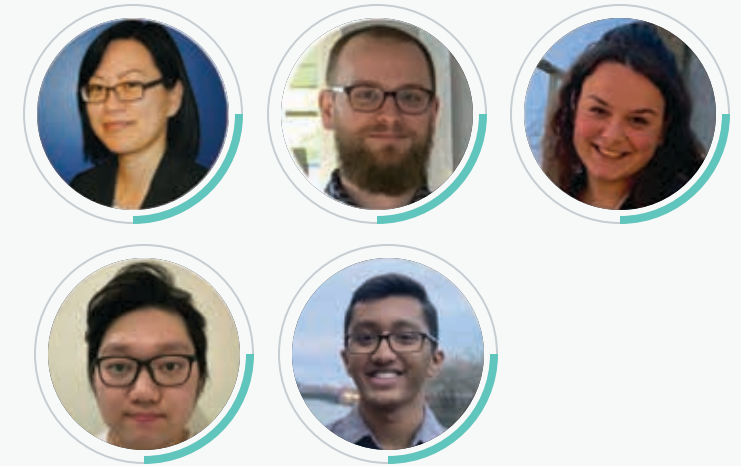
Above: Texas Tech University research team

Development and Standardization of Exoskeleton Test Methods for Mobility on Variable Terrains

UMass Lowell

- Develop standard test methods for mobility, including augmentation: mobility, functional, movement quality, distance, speed, agility, and efficiency.
- Develop structure of the test methodology that allows for flat ground, incline, and decline, uneven terrain (sand, gravel), functional mobility (stairs), and movement around, over, or under obstacles (agility), and the affiliated metrics.
- Expected outcomes are draft test apparatus designs and draft standards documents.

Right: UMass Lowell research team



Development of a New Exoskeleton Safety Standard for Assessing User Fall Risk Due to Stumbling

Vanderbilt University

- A standard protocol is needed to determine if a given exo improves, impedes, or maintains a user's ability to recover from a stumble (i.e., to avoid failing).
- Spent three years designing, fabricating, and validating an open-source stumble/fall evaluation system that can introduce precisely-timed stumble perturbations. This system has been validated on healthy controls and individuals with limb loss, but not yet on exo users.
- Proposed work consists of 1) adapting our current stumble/fall evaluation system for assessing exo users, 2) simplifying the fall-risk outcome metric to match industry and ASTM needs, and 3) updating system and protocol documentation, then drafting a new ballotable ASTM standard on exo fall-risk safety.



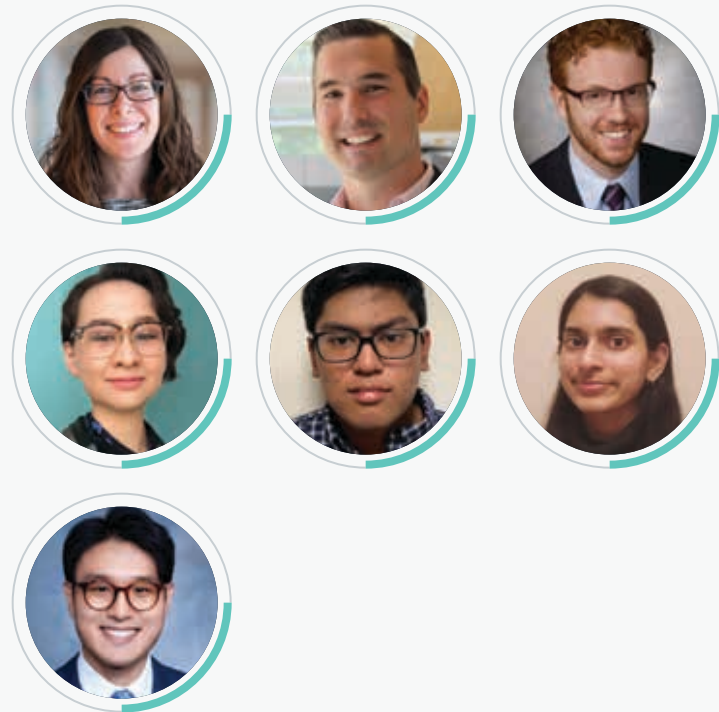
Left: Vanderbilt University research team



Test Method Definition for Lower Extremity Exoskeleton Locomotion Transitions

University of Michigan

- The standard practice defines controlled laboratory assessments to standardize the evaluation of exoskeletons, specifically locomotion-assist exoskeletons, to assess transitions between relevant environments in an acceptable manner.
- The standard practice includes recommended test courses. The goal of the test course is to create realistic transition scenarios based on known environmental requirements (e.g., stairs, ramps, cross-slopes).
- The standard practice also includes recommended performance metrics, which are split into three categories: (1) direct measures, (2) perceived user ratings, and (3) test supervisor observations. The inclusion of metrics across these categories supports system usability as well as characterization of user performance.



Right: University of Michigan research team

System and Method to Perform Job Classification for Return-to-Work Exoskeleton deployment

SwiftMotion

Our specific objectives are:

- Measure physical demands of workers returning to work after injury. We will collect and analyze posture as well as loads handled by workers on job sites.
- Classify jobs based on appropriate thresholds from the sensor data into high- and low-risk categories

for specific body parts (shoulder, low back, etc.). This will lead to the development of recommendations for the type of exoskeleton to be deployed based on the physical demands of the job.

- Use measurements from sensors in addition to exoskeletons to monitor progress of injured workers as well as to guarantee that they stay under limits prescribed by physicians.

Investigating Critical Challenges and Potential Solutions Towards Developing Standards to Guide the Proper Use of Exoskeleton for Injured Workers' Return to Work

University of Michigan – Dearborn (awarded)

Expected outcomes from this project:

- Develop a method for the identification of the limitations and benefits of the use of exoskeleton by injured workers.
- Generate a reference chart for a quick fetch of the approximate exoskeleton supports in the sample conditions.
- Identify initial exoskeleton design gaps and needs to accommodate injured workers.
- Design a sample application as an information system, training, and risk management reference for medical providers in the selection and timing for the proper use of exoskeleton.
- Design a sample application as auxiliary training materials for return to work exoskeleton users.

Development of Measurement Protocols for Efficient and Reliable Exoskeleton Testing and Evaluation

Virginia Tech (awarded)

- Reliable and efficient assessments of the effects of exoskeleton (EXO) use are critical to support the development of EXO testing and evaluation standards and use recommendations; using measures that are unreliable (inconsistent) or insensitive (not responsive to EXO use) can mask the true effects of EXO use.
- We will conduct a systematic, lab-based study to support future decisions regarding study protocols (i.e., number of trials and sessions) for a given EXO type and task of interest.
- Several task types (basic activities, static tasks, and dynamic tasks) will be examined, and during which a broad set of objective and subjective measures will be obtained, including muscle activation levels, joint kinematics, perceived exertion, and aspects of usability.
- Completing the proposed work will provide important practical information to enable efficient and reliable assessments of EXO use under different task conditions.





Rapid Development of Exoskeleton Test Method Standards

Smart HLPR

The following list of standards topics, from ASTM committee on Task Performance and Environmental Considerations (F48.03) Roadmap of Standards to Develop, will be used to guide completed drafts to go to ASTM ready for evaluation and testing. Any change(s) must be requested in writing by both ASTM and Smart HLPR for one or more test methods to be developed where a replacement for any of the following may occur while fulfilling the average two standards developed per three months over nine months. Sufficient draft development time for any changes shall be granted.

- Test method for exoskeleton use: gait (i.e., walking, running)
- Test method for exoskeleton use: stairs
- Test method for exoskeleton use: climbing
- Test method for exoskeleton use: inclined plane (i.e., up and down hill walk)
- Test method for exoskeleton use: pitch/roll terrains
- Test method for exoskeleton use: hurdles (i.e., stepping over objects)
- Test method for exoskeleton use: gaps (i.e., stepping over gaps)
- Test method for exoskeleton use: obstacle avoidance (i.e., maneuvering around objects)
- Test method for exoskeleton use: crawling

Exoskeleton Producer Survey and Report

ET CoE Founding Partners

The purpose of this survey was to collect input and feedback from exoskeleton producers in order to help the ASTM committee on Exoskeletons and Exosuits (F48) develop standards to support and enhance the growth and success of the exoskeleton industry. Additionally, the input and feedback from exoskeleton producers helps the ASTM Exo Technology Center of Excellence prioritize and plan how to allocate time, effort, and resources for supporting the F48 committee and the exoskeleton industry. All data reported was made anonymous and reported in aggregate to protect the privacy of each responder and their responses.



Longitudinal Health Effects of Shoulder Exoskeletons in the Manufacturing Sector

NIOSH

A longitudinal design will be adopted to assess the health effects of existing passive shoulder exoskeleton users for repetitive overhead assembly work in a manufacturing setting. Aggregated injury and associated workers' compensation cost information on 600 users and 600 non-users will be collected over a two-year period. A subset (total N = 88; 44 for each study group) of study participants randomly selected from the study cohort will undergo shoulder and back functional assessments at their work sites. The aggregated injury/workers' compensation information and shoulder functional information will be collected by participating companies at three time points: baseline, one-year follow-up, and two-year follow-up.

NIOSH investigators are responsible for recruiting the selected subjects for the shoulder and back functional tests. A NIOSH-funded contractor will conduct the back functional assessment at study sites using the clinical lumbar motion monitor at two time points (baseline and one-year follow-up). Injury and workers' compensation data will be submitted to NIOSH through a website created and managed by ASTM. NIOSH investigators will receive de-identified data that will not be linkable to a specific company or participant. The aggregated injury/workers' compensation information will be analyzed and interpreted by pooling data across multiple sites of multiple participating companies. In addition, quantitative statistical analyses of the aggregated outcome measures will be performed for determining statistical differences between the study groups. The study will assess three types of outcomes:

- Number of musculoskeletal injury cases, lost work time, and workers' compensation costs (medical and indemnity) for the cases;
- Identifiable changes in shoulder function; and
- Risk of impaired back function of study participants.

The study data will be made anonymous, and no personal data of the users will be shared. ASTM will collect, house, and manage data submitted from external resources related to safety concerns and injury incidents tied to exoskeleton usage. Some industries participating in this study include aerospace, military, automotive, and manufacturing.





Medical Exoskeleton Practitioner Survey and Report

ET CoE Founding Partners

The survey, among others will focus on understanding of the use of medical exoskeletons by healthcare providers, as well as their experiences, and recommendations. This data will help us further understand the trends, lessons learned, and gaps that can support identifying needed education, outreach, research, data, and standards gaps that will help guide the outputs of the ASTM Exo community.

Key Outcomes:

- Understand healthcare provider experiences with exoskeleton technologies;
- Identify the types of products selected;
- Understand the overall experience with patients, their general perceptions, and trends;
- Understand approaches to using exoskeleton products with patients;
- Identify and understand research and information gaps ;
- Communicate findings and design a framework for ASTM committee on Exoskeletons and Exosuits (F48) and the insurance community at large ;
- Understand and communicate current barriers for use;
- Understand and communicate barriers for communication;
- Identify lessons learned to benchmark trends, and
- Compare market segment perceptions with those of producers, where such producer data may exist.

Training, Education, and Workforce Development

Roundtable — Nov 19, 2020

Exoskeletons: Considerations When Deciding to Use Them as Personal Protective Equipment (PPE)

Panel Discussion on Exoskeletons: Considerations when deciding to use them as PPE.

Speakers

- Donald R. Peterson, Ph.D., Northern Illinois University
- Christopher R. Reid, Ph.D., Boeing
- Marisol Barrero, Toyota Motor North America
- Gary B. Orr, OSHA
- Delia E. Treaster, Ph.D., Ohio Bureau of Workers' Compensation
- Sascha Wischniewski, Ph.D., German Federal Institute for Occupational Safety and Health (BAuA)

Webinar — May 27, 2021

R2S for Mobility, Cognitive Fit, and Transitions

Vanderbilt University, the University of Michigan, Texas Tech University, and the University of Massachusetts Lowell are accelerating exoskeleton standards through innovative research projects.

The teams discussed their approach and the latest project updates.

Speakers

- Leia Stirling, Ph.D., University of Michigan
- PeiChun Kao, Ph.D., and Adam Norton, UMass-Lowell
- HeeSun Choi, Ph.D., Texas Tech University
- Karl Zelik, Ph.D., Vanderbilt

Roundtable — Aug 11, 2021

Exoskeleton and PPE Interface Challenges

Experts discussed challenges and opportunities with interfacing and testing exoskeletons with PPE in various settings including chemical/biological remediation, medical, first responder, and industrial.

Speakers

- Kalavati Bhashyam, Harmonic Bionics
- Karola Hagner, Bundeswehr
- Tricia Hock, SEI
- Philip Mattson, U.S. Department of Homeland Security
- Brian Shiels, ArcWear

Roundtable — Aug 31, 2021

Applications for Exoskeletons

This roundtable covered applications in healthcare, military, industry, and construction.

Speakers

- Medical: Ozell Sanders, Ph.D., U.S. Food and Drug Administration
- Military: Jennifer Neugebauer, Ph.D., U.S. Army Data and Analysis Center
- Industry: Christopher Reid, Ph.D., Boeing
- Construction: Karl Jefferson, LiUNA, Travis M. Parsons, Laborers' Health & Safety Fund of North America

Exoskeleton Training Modules for U.S. Army

The U.S. Army Development Command, Soldier Center (DEVCOM SC) ensures the dominance of Army capabilities by creating, integrating, and delivering technology-enabled solutions to our soldiers. Soldier Center follows a simple mandate: to ensure that American soldiers are the best fed, the best protected, and the most highly mobile military in the world.

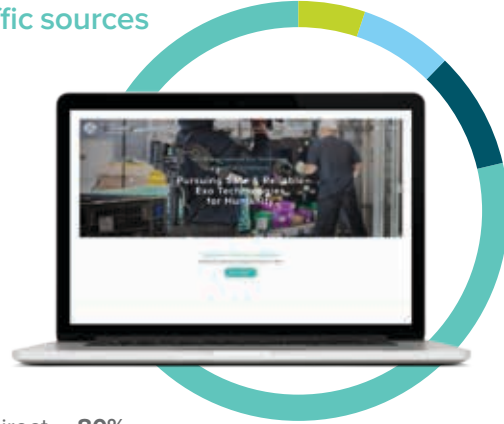
The Army is interested in exoskeleton technology to assist in addressing the soldier load problem and exploring the use of exoskeleton technologies as viable tools, the ET CoE is partnering with Boston Engineering to deliver training on the following topics:

- Exoskeleton Report 101 as a case study - what are the best sources for Exoskeleton information
- What are exoskeletons? Types of Exos and utilities
- Demystifying exoskeletons. Features, how to use, etc.
- The difference between robots and exoskeletons
- Exoskeletons for military applications – powered exoskeletons
- Passive exoskeletons
- Exoskeletons in the marketplace
- Medical exoskeletons - rehabilitation vs. mobility vs return to work
- Who is an optimal wearer? How do I know the exoskeleton is working?

ACCOMPLISHMENTS & METRICS

ET CoE Website (etcoe.org)

Traffic sources



- Direct — **80%**
- Search (Google, Bing) — **9.12%**
- Referral - (exoskeletonreport.com, marketing.astm.org, astm.webex.com) — **5.86%**
- Social (Linkedin, Twitter, Facebook) — **4.89%**

9

Press Releases (6)/
SN Articles (3)

333

Unique Visitors
(one-year average)

392

Visits Per Month
(one-year average)

76

Countries

675

Monthly Page Views
(one-year average)

94 sec.

Time Spent Per Page
(one-year average)



Launched October 2021!

www.linkedin.com/company/exo-technology-center-of-excellence/

Training Sessions

- Average attendance per webinar — **40**
- Number of webinars completed — **2**
- Number of ET CoE webinars planned — **4**
- Number of U.S. Army training webinars — **Up to 10**
- Total number of webinar speakers — **19**

Partnerships

- Private companies who worked with ET CoE — **4**
- Universities who worked with ET CoE — **4**
- Memorandum of Understanding (MOU) — **HFES**
- Contract work — **Boston Engineering & Army CCDC**
- Projects underway — **13**
- Joint events — **ErgoX**
- Informal partners — **LIUNA, NIOSH, Army CCDC, NIST, AExG, SCRA**
- Average meetings per month — **10**

R2S Projects

- Total RFPs issued — **2**
- Average number of proposals per RFP reviewed — **3**
- Projects awarded — **5**
- Average project cost — **\$38k**
- Average project length — **10 months**
- Average meetings per year to review projects — **12**
- Number of presentations by project teams per year — **3**

Supporting Committee on Exoskeletons and Exosuits (F48)

- Subcommittees supporting — **6**
- Work items active participation — **16**
- New members recruited by CoE — **10**
- Average meetings attending per month — **5**

9

Draft standards
submitted by CoE



Research to Standards

EXO TECHNOLOGY