NATIONAL ACADEMIES Sciences Engineering Medicine

Opportunities and Challenges for Digital Twins in Engineering - A Workshop

THIS WORKSHOP WILL BE HELD VIRTUALLY—REGISTER HERE

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TUESDAY, FEBRUARY 7, 2023*

10:00–10:15 **Welcome and Introduction**

Conrad Grant (Johns Hopkins Applied Physics Laboratory)

Sponsor Remarks by Michelle Schwalbe (NASEM) on behalf of DOE, DOD, NIH, and NSF

Beth Cady (NASEM)

10:15–10:45 **Opening Plenary**

Definition of Digital Twins (DT) in the context of structural engineering. Moderated by Derek Bingham (Simon Fraser University).

Charles Farrar (Los Alamos National Laboratory)

Over the rest of the workshop day, participants will hear from five use case speakers as they each address three topics in three moderated panels.

- Elizabeth Baron (Unity Technologies, formerly Ford)
  Ms. Baron will present from the perspective of the automobile industry.
- Karthik Duraisamy (University of Michigan)
  Dr. Duraisamy will present based on his work in computational science and fluid dynamics applications.
- Michael Grieves (Digital Twin Institute)
  Dr. Grieves will present from the perspective of manufacturing settings.
- S. Michael Gahn (Rolls-Royce)
  Mr. Gahn will present from the perspectives of aircraft engine design and model-based systems engineering.
- Dinakar Deshmukh (General Electric)
  Mr. Deshmukh will present from the perspective of the aviation industry.

10:45 - 11:45 **Panel 1: Current Methods and Practices**

Moderated by Parviz Moin (Stanford University).

11:45 - 12:00 **Break**

***All times in ET**

12:00 - 13:00 **Panel 2: Key Technical Challenges and Opportunities**

Moderated by Carolina Cruz-Neira (University of Central Florida).

13:00 - 14:00 **Panel 3: Digital Twin R&D Needs and Investment**

Moderated by Conrad Tucker (Carnegie Mellon University).

14:00 - 14:10 **Wrap-up comments and adjourn for day**

Conrad Grant (Johns Hopkins Applied Physics Laboratory)

Opportunities and Challenges for Digital Twins in Engineering

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THURSDAY, FEBRUARY 9, 2023

10:00–10:15 Welcome Back

Conrad Grant (Johns Hopkins Applied Physics Laboratory)
Sponsor Remarks by Michelle Schwalbe (NASEM) on behalf of DOE, DOD, NIH, and NSF

Tho Nguyen (NASEM)

10:15–10:45 Opening Plenary

Definition of Digital Twins (DT) in the context of renewable energy. Moderated by Parviz Moin (Stanford University).

Grace Bochenek (University of Central Florida)

Over the rest of the workshop day, participants will hear from four use case speakers as they each address three topics in three moderated panels.

- José R. Celaya (Schlumberger)
  Dr. Celeya will present from the perspective of computer engineering in the oil and gas industry.
- Pamela Kobryn (Department of Defense)
  Dr. Kobryn will present from the perspective of aircraft sustainment.
- Devin Francom (Los Alamos National Laboratory)
  Dr. Francom will present from the perspective of stockpile assessment.
- Devin Harris (University of Virginia)
  Dr. Harris will present from the perspective of large scale infrastructure systems.

10:45 - 11:45 Panel 1: Current Methods and Practices

Moderated by Carolina Cruz-Neira (University of Central Florida).

11:45 - 12:00 Break

12:00 - 13:00 Panel 2: Key Technical Challenges and Opportunities

Moderated by Conrad Tucker (Carnegie Mellon University).

13:00 - 14:00 Panel 3: Digital Twin R&D Needs and Investment

Moderated by Derek Bingham (Simon Fraser University).

14:00 - 14:10 Wrap-up comments and adjourn

Conrad Grant (Johns Hopkins Applied Physics Laboratory)

MEETING ADJOURNED

COMMITTEE BIOS

Karen E. Willcox (Chair) is Director of the Oden Institute for Computational Engineering and Sciences, Associate Vice President for Research, and Professor of Aerospace Engineering and Engineering Mechanics at the University of Texas at Austin. She is also External Professor at the Santa Fe Institute. At UT, she holds the W. A. "Tex" Moncrief, Jr. Chair in Simulation-Based Engineering and Sciences and the Peter O'Donnell, Jr. Centennial Chair in Computing Systems. Before joining the Oden Institute in 2018, she spent 17 years as a professor at the Massachusetts Institute of Technology, where she served as the founding Co-Director of the MIT Center for Computational Engineering and the Associate Head of the MIT Department of Aeronautics and Astronautics. Prior to joining the MIT faculty, she worked at Boeing Phantom Works with the Blended-Wing-Body aircraft design group. She is a Fellow of the Society for Industrial and Applied Mathematics (SIAM), a Fellow of the American Institute of Aeronautics and Astronautics (AIAA), and in 2017 was appointed Member of the New Zealand Order of Merit (MNZM) for services to aerospace engineering and education. In 2022 she was elected to the National Academy of Engineering (NAE). Willcox is at the forefront of the development and application of computational methods for design, optimization and control of next-generation engineered systems. A number of her active research projects and collaborations with industry are developing core mathematical and computational capabilities to achieve predictive digital twins at scale.

Derek Bingham is a Professor and Chair of the Department Statistics and Actuarial Science at Simon Fraser University. He received his PhD from the Department of Mathematics and Statistics at Simon Fraser University in 1999. After graduation he joined the Department of Statistics at the University of Michigan. He moved back to Simon Fraser in 2003 as the Canada Research Chair in Industrial Statistics. He has recently completed a three-year term as Chair for the Natural Sciences and Engineering Research Council of Canada's Evaluation Group for Mathematical and Statistical Sciences. The focus of his current research is developing statistical methods for combining physical observations with large-scale computer simulators. This includes new methodology for Bayesian computer model calibration, emulation, uncertainty quantification and experimental design. Dr. Bingham's work is motivated by real-world applications. Recent collaborations have been with scientists at U.S. national laboratories (e.g., Los Alamos National Lab), U.S. Department of Energy sponsored projects (Center for Exascale Radiation Transport), and Canadian Nuclear Labs.

Caroline Chung is vice president and Chief Data Officer and is an associate professor in Radiation Oncology and Diagnostic Imaging. Her clinical practice is focused on CNS malignancies and her computational imaging lab has a research focus on quantitative imaging and computational modeling to detect and characterize tumors and toxicities of treatment to enable personalized cancer treatment. Internationally, Dr. Chung is actively involved in multidisciplinary efforts to improve the generation and utilization of high quality, standardized imaging to facilitate quantitative imaging integration for clinical impact across multiple institutions, including Vice Chair of the Radiological Society of North America (RSNA) Quantitative Imaging Biomarker Alliance (QIBA) and Co-Chair of the Quantitative Imaging for Assessment of Response in Oncology Committee of the International Commission on Radiation Units and Measurements (ICRU). Beyond her clinical, research and administrative roles, Dr. Chung enjoys serving as an active educator and mentor with a passion to support the growth of diversity, equity and inclusion in STEM, including her role as Chair of Women in Cancer (http://www.womenincancer.com), a non-for-profit organization that is committed to advancing cancer care by encouraging the growth, leadership and connectivity of current and future oncologists, trainees and medical researchers. Her recent publications include work on building digital twins for clinical oncology.

Julianne Chung is an Associate Professor in the Department of Mathematics at Emory University. Prior to joining Emory in 2022, she was an Associate Professor in the Department of Mathematics and part of the Computational Modeling and Data Analytics Program at Virginia Tech. From 2011-2012, she was an Assistant Professor at the University of Texas at Arlington and from 2009-2011 an NSF Mathematical Sciences Postdoctoral Research Fellow at the University of Maryland at College Park. She received her PhD in 2009 in the Department of Math and

Computer Science at Emory University, during which she was supported by a Department of Energy Computational Science Graduate Fellowship. She has received many prestigious awards including the Frederick Howes Scholar in Computational Science award, an NSF CAREER award, and an Alexander von Humboldt Research Fellowship. Her research interests include numerical methods and software for computing solutions to large-scale inverse problems, such as those that arise in imaging applications.

Carolina Cruz-Neira is a pioneer in the areas of virtual reality and interactive visualization, having created and deployed a variety of technologies that have become standard tools in industry, government and academia. She is known world-wide for being the creator of the CAVE virtual reality system. She has dedicated a part of her career to transfer research results into daily use by spearheading several Open Source initiatives to disseminate and grow VR technologies and by leading entrepreneurial initiatives to commercialize research results. She has over 100 publications as scientific articles, book chapters, magazine editorials and others. She has been awarded over $75 million in grants, contracts, and donations. She is also recognized for having founded and led very successful virtual reality research centers, like the Virtual Reality Applications Center at Iowa State University, the Louisiana Immersive Technologies Enterprise and now the Emerging Analytics Center. She has been named one of the top innovators in virtual reality and one of the top three greatest women visionaries in this field. BusinessWeek magazine identified her as a “rising research star” in the next generation of computer science pioneers; she has been inducted as a member of the National Academy of Engineering, an ACM Computer Pioneer, received the IEEE Virtual Reality Technical Achievement Award and the Distinguished Career Award from the International Digital Media & Arts Society among other national and international recognitions. She had given numerous keynote addresses and has been the guest of several governments to advise on how virtual reality technology can help to give industries a competitive edge leading to regional economic growth. She has appeared in numerous national and international TV shows and podcasts as an expert on her discipline and several documentaries have been produced about her life and career. She has several ongoing collaborations in advisory and consulting capacities on the foundational role of virtual reality technologies with respect to digital twins.

Conrad J. Grant is the Chief Engineer for the Johns Hopkins University Applied Physics Laboratory, the nation’s largest University Affiliated Research Center, performing research and development on behalf of the Department of Defense, the intelligence community, the National Aeronautics and Space Administration, and other federal agencies. He previously served for over a decade as the Head of the APL Air and Missile Defense Sector where he led 1200 staff developing advanced air and missile defense systems for the U.S. Navy and the Missile Defense Agency. Mr. Grant has extensive experience in the application of systems engineering to the design, development, test and evaluation, and fielding of complex systems involving multi-sensor integration, command and control, human-machine interfaces, and guidance and control systems. Mr. Grant’s engineering leadership in APL prototype systems for the Navy is now evidenced by capabilities on board over 100 cruisers, destroyers, and aircraft carriers of the U.S. Navy and its Allies. He has served on national committees including as a technical advisor on studies for the Naval Studies Board (NSB) of the National Academies as well as membership on the U.S. Strategic Command Senior Advisory Group (SAG). He is a member of the program committees for the Department of Electrical and Computer Engineering (ECE) and the Engineering for Professionals Systems Engineering Program of the Johns Hopkins University Whiting School of Engineering. Mr. Grant earned a Bachelor of Science in Physics from the University of Maryland, College Park, a Master of Science in Applied Physics and a Master of Science in Computer Science from the Johns Hopkins University, Whiting School of Engineering.

James L. Kinter is Director of the Center for Ocean-Land-Atmosphere Studies (COLA) at George Mason University (GMU), where he oversees basic and applied climate research conducted by the Center. Dr. Kinter’s research includes studies of atmospheric dynamics and predictability on intra-seasonal and longer time scales, particularly the prediction of Earth’s climate using numerical models of the coupled ocean-atmosphere-land system. Dr. Kinter is a tenured Professor of Climate Dynamics in the Atmospheric, Oceanic and Earth Sciences (AOES) department of the College of Science at GMU, where he has responsibilities for teaching climate predictability and climate change. After earning his doctorate in geophysical fluid dynamics at Princeton University in 1984, Dr. Kinter served as a

National Research Council Associate at NASA Goddard Space Flight Center, and as a faculty member of the University of Maryland prior to helping to create COLA. Dr. Kinter, a Fellow of the American Meteorological Society, has served on many national and international review panels for both scientific research programs and supercomputing programs for computational climate modeling. Dr. Kinter has served on three previous National Academies committees.

Ruby Leung is a Battelle Fellow at Pacific Northwest National Laboratory. Her research broadly cuts across multiple areas in modeling and analysis of climate and water cycle including orographic precipitation, monsoon climate, extreme events, land surface processes, landatmosphere interactions, and aerosol-cloud interactions. Dr. Leung is the Chief Scientist of the U.S. Department of Energy's Energy Exascale Earth System Model (E3SM), a major effort involving over 100 earth and computational scientists and applied mathematicians to develop state-of-the-art capabilities for modeling human-Earth system processes on DOE's next generation high performance computers. She has organized several workshops sponsored by Department of Energy, National Science Foundation, National Oceanic and Atmospheric Administration, and National Aeronautics and Space Administration to define gaps and priorities for climate research. She is a member of the Board on Atmospheric Sciences and Climate (BASC), National Academies of Sciences, Engineering, and Medicine and an editor of the AMS Journal of Hydrometeorology. She has published over 450 papers in peer-reviewed journals. Dr. Leung is an elected member of the National Academy of Engineering and Washington State Academy of Sciences. She is also a fellow of the American Meteorological Society (AMS), American Association for the Advancement of Science (AAAS), and American Geophysical Union (AGU). She is the recipient of the AGU Global Environmental Change Bert Bolin Award and Lecture in 2019, the AGU Atmospheric Science Jacob Bjerknes Lecture in 2020, and the AMS Hydrologic Sciences Medal in 2022. She was awarded the DOE Distinguished Scientist Fellow in 2021. She received a BS in Physics and Statistics from Chinese University of Hong Kong and an MS and PhD in Atmospheric Sciences from Texas A&M University.

Parviz Moin (NAS/NAE) is the Franklin P. and Caroline M. Johnson Professor of Mechanical Engineering and the director of the Center for Turbulence Research (CTR) at Stanford University. He was the founding director of the Institute for Computational and Mathematical Engineering and he directed the Department of Energy's ASCI and PSAAP centers. Dr. Moin pioneered the use of direct numerical simulation and large eddy simulation techniques for the study of the physics, and reduced order modeling of multi-physics turbulent flows. His current research interests include predictive simulation of aerospace systems, hypersonic flows, multi-phase flows, propulsion, numerical analysis for multi-scale problems, and flow control. Dr. Moin is the co- editor of the Annual Review of Fluid Mechanics and associate editor of the Journal of Computational Physics. Amongst his awards are the American Physical Society (APS) Fluid Dynamics Prize and AIAA Fluid Dynamics Award. Dr. Moin is a member of the National Academy of Sciences, National Academy of Engineering, and the Royal Spanish Academy of Engineering. He is a fellow of APS and AIAA, and the American Academy of Arts and Sciences. Dr. Moin received a Ph.D. in mechanical engineering from Stanford University.

Lucila Ohno-Machado, MD, PhD, MBA, has been appointed deputy dean for biomedical informatics and will lead the newly created free-standing Section for Biomedical Informatics and Data Science at Yale School of Medicine starting 1/1/23. She is currently health sciences associate dean for informatics and technology, founding chief of the Division of Biomedical Informatics in the Department of Medicine, and distinguished professor of medicine at the University of California San Diego (UCSD). She also is founding chair of the UCSD Health Department of Biomedical Informatics and founding faculty of the UCSD Halicioğlu Data Science Institute in La Jolla, California. She received her medical degree from the University of São Paulo, Brazil; her MBA from the Escola de Administração de São Paulo, Fundação Getúlio Vargas, Brazil; and her PhD in medical information sciences and computer science at Stanford University. She has led informatics centers that were funded by various NIH initiatives and by agencies such as AHRQ, PCORI, and NSF. Dr. Ohno-Machado organized the first large-scale initiative to share clinical data across five UC medical systems and later extended it to various institutions in California and around the country. Prior to joining UCSD, she was distinguished chair in biomedical informatics at Brigham and

Women's Hospital, and faculty at Harvard Medical School and at MIT's Health Sciences and Technology Division. She is an elected member of the National Academy of Medicine, the American Society for Clinical Investigation, the American Institute for Medical and Biological Engineering, the American College of Medical Informatics, and the International Academy of Health Sciences Informatics. She is a recipient of the American Medical Informatics Association leadership award, as well as the William W. Stead Award for Thought Leadership in Informatics. She serves on several advisory boards for national and international agencies.

Colin James Parris has achieved great academic and professional success while attending and leading some of the most prestigious academic and business institutions in America and the world. His career has been centered on the development and enhancement of digital transformation across multiple industries (telecommunications, banking, retail, aviation, energy) in billion-dollar companies, as well as advocating/evangelizing STEM advancement across minority communities. As GE Digital's Chief Technology Officer, Dr. Parris leads teams that work to leverage technologies and capabilities across GE to accelerate business impact and create scale advantage for digital transformation. He also champions strategic innovations and identifies and evaluates new, breakthrough technologies and capabilities to accelerate innovative solutions to solve emerging customer problems. Dr. Parris created and leads the Digital Twin Initiative across GE. He previously held the position of Vice President, Software and Analytics Research at GE Research in Niskayuna, NY. Prior to joining GE, Dr. Parris worked at IBM where he was an executive for 16 years in roles that spanned research, software development, technology management, and P&L management. He was the Vice President, System Research at the IBM Thomas J. Watson Research Division, the Vice President Software Development for IBM's largest system software development lab (6,000+ developers worldwide), Vice President of Corporate Technology, and the Vice President and General Manager of IBM Power Systems responsible for the company's $5B+ Unix System and Software business. Dr. Parris holds a PhD, Electrical Engineering from the University of California, Berkeley; an MS from Stanford University; an MS, Electrical Engineering and Computer Science from the University of California, Berkeley and a BS, Electrical Engineering from Howard University.

Irene Qualters serves as the Associate Laboratory Director for Simulation and Computation at Los Alamos National Laboratory, a U.S. Department of Energy national laboratory. She previously served as a Senior Science Advisor in the Computing and Information Science and Engineering (CISE) Directorate of the National Science Foundation (NSF), where she had responsibility for developing NSF's vision and portfolio of investments in high performance computing, and has played a leadership role in interagency, industry, and academic engagements to advance computing. Prior to her NSF career, Irene had a distinguished 30-year career in industry, with a number of executive leadership positions in research and development in the technology sector. During her 20 years at Cray Research, she was a pioneer in the development of high-performance parallel processing technologies to accelerate scientific discovery. Subsequently as Vice President, she led Information Systems for Merck Research Labs, focusing on software, data and computing capabilities to advance all phases of pharmaceutical R&D.

Ines Thiele is the principal investigator of the Molecular Systems Physiology group at the University of Galway, Ireland. Her research aims to improve the understanding of how diet influences human health. Therefore, she uses a computational modelling approach, termed constraint-based modelling, which has gained increasing importance in systems biology. Her group builds comprehensive models of human cells and human-associated microbes; then employs them together with experimental data to investigate how nutrition and genetic predisposition can affect one's health. In particular, she is interested in applying her computational modelling approach for better understanding of inherited and neurodegenerative diseases. Dr. Thiele has been pioneering models and methods allowing large-scale computational modelling of the human gut microbiome and its metabolic effect on human metabolism. She earned her PhD in bioinformatics from the University of California, San Diego, in 2009. She was an Assistant and Associate Professor at the University of Iceland (2009 - 2013), and Associate Professor at the University of Luxembourg (2013-2019). In 2013, Dr. Thiele received the ATTRACT fellowship from the Fonds National de la Recherche (Luxembourg). In 2015, she was elected as EMBO Young Investigator. In 2017, she was awarded the prestigious ERC starting grant. In 2020, she was named a highly cited researcher by Clarivate, and

received the NUI Galway President's award in research excellence. She is an author of over 100 international scientific papers and reviewer for multiple journals and funding agencies.

Conrad Tucker is an Arthur Hamerschlag Career Development Professor of Mechanical Engineering at Carnegie Mellon University and holds courtesy appointments in Machine Learning, Robotics, Biomedical Engineering, and CyLab Security and Privacy. His research focuses on employing Machine Learning (ML)/Artificial Intelligence (AI) techniques to enhance the novelty and efficiency of engineered systems. His research also explores the challenges of bias and exploitability of AI systems and the potential impacts on people and society. Dr. Tucker has served as PI/Co-PI on federally/non-federally funded grants from the National Science Foundation, the Air Force Office of Scientific Research, the Defense Advanced Research Projects Agency, the Army Research Laboratory, the Bill and Melinda Gates Foundation, among others. In February 2016, he was invited by National Academy of Engineering (NAE) President Dr. Dan Mote, to serve as a member of the Advisory Committee for the NAE Frontiers of Engineering Education Symposium. He is currently serving as a Commissioner on the U.S. Chamber of Commerce Artificial Intelligence Commission on Competitiveness, Inclusion, and Innovation. Dr. Tucker received his Ph.D., M.S. (Industrial Engineering), and MBA degrees from the University of Illinois at Urbana-Champaign, and his B.S. in Mechanical Engineering from Rose-Hulman Institute of Technology.

Rebecca Willett is a Professor of Statistics and Computer Science at the University of Chicago. Her research is focused on machine learning, signal processing, and large-scale data science. Willett received the National Science Foundation CAREER Award in 2007, was a member of the DARPA Computer Science Study Group, received an Air Force Office of Scientific Research Young Investigator Program award in 2010, was named a Fellow of the Society of Industrial and Applied Mathematics in 2021, and was named a Fellow of the IEEE in 2022. She is a co-principal investigator and member of the Executive Committee for the Institute for the Foundations of Data Science, helps direct the Air Force Research Lab University Center of Excellence on Machine Learning, and currently leads the University of Chicago's AI+Science Initiative. She serves on advisory committees for the National Science Foundation's Institute for Mathematical and Statistical Innovation, the AI for Science Committee for the US Department of Energy's Advanced Scientific Computing Research program, the Sandia National Laboratories Computing and Information Sciences Program, and the University of Tokyo Institute for AI and Beyond. She completed her PhD in Electrical and Computer Engineering at Rice University in 2005 and was an Assistant then tenured Associate Professor of Electrical and Computer Engineering at Duke University from 2005 to 2013. She was an Associate Professor of Electrical and Computer Engineering, Harvey D. Spangler Faculty Scholar, and Fellow of the Wisconsin Institutes for Discovery at the University of Wisconsin-Madison from 2013 to 2018.

Xinyue Ye is Fellow of American Association of Geographers (AAG) and Fellow of Royal Geographical Society (with IBG), holding Harold L. Adams Endowed Professorship in Department of Landscape Architecture and Urban Planning & Department of Geography at Texas A&M University-College Station (TAMU), USA. He directs the focus of transportation in the PhD program of Urban and Regional Science at TAMU, and is the Interim Director of Center for Housing and Urban Development. His research focuses on geospatial artificial intelligence, geographic information system, and smart cities. Prof. Ye won the national first-place research award from University Economic Development Association. He was the recipient of annual research awards from both computational science (New Jersey Institute of Technology) and Geography (Kent State University) as well as AAG Regional Development and Planning Distinguished Scholar Award. He was one of the top 10 young scientists named by The World Geospatial Developers Conference in 2021. His work has been funded by National Science Foundation, National Institute of Justice, Department of Commerce, Department of Energy, and Department of Transportation. Prof. Ye is Editor-in-Chief of Computational Urban Science, an open access journal published by Springer. He also serves as the co-editor of Journal of Planning Education and Research, the flagship journal of Association of Collegiate Schools of Planning.

PANELIST BIOS

Elizabeth Baron leads Enterprise Solution Architecture at Unity Technologies. She manages the development of immersive Digital Twin Enterprise Solutions for Manufacturing, Automotive and Transportation. She connects knowledge with experience for cross-functional teams in enterprise through development of a Digital Twin ecosystem that focuses on presenting timely information in context. Formerly, Elizabeth was Ford Motor's Technical Specialist in Immersive Realities. She is the inventor of the Ford immersive Vehicle Environment process and technology which delivers contextual data with high visual fidelity for global immersive evaluations. Elizabeth was awarded Ford's highest award honoring her career in immersive visualization and her technical leadership. She is Past-Chair and a current Director of ACM SIGGRAPH. She has received the SIGGRAPH Practitioner Award, for contributions to industrial design in multiple industries, and was inducted into SIGGRAPH Academy.

Dr. Grace M. Bochenek is a pioneer and leader in research and technology development, fascinated by the next generation of technology capability, future workforce, and the opportunity to drive innovation. As the director of School of Modeling, Simulation and Training (SMST) at the University of Central Florida (UCF), she is capitalizing on UCF's 40-year history as early pioneers in human-centered modeling and simulation research to expand M&S at UCF as an innovative, integrative, and inspirational force across campus both in research and academics. Prior to joining UCF, Dr. Bochenek held positions in both the Department of Energy and Department of Defense serving as the Director of the National Energy Technology Laboratory, NETL, and, in the Department of Army, the Chief Technology Officer of the U.S. Army Materiel Command and the Director of the Tank Automotive Research, Development and Engineering Center. By presidential appointment, she served as the Acting Secretary of Energy during the 2017 administration transition. She is well-versed in science, technology investment strategies, commercialization and performance, technology maturation and integration, and performance analyses with an emphasis on strategic alliances, partnerships, and global/international programs.

José R. Celaya is a Principal Scientist and Leads the Intelligent Systems Lab at the Software Technology and Innovation Center at SLB. Previously, he was Lead Scientist and team Co-lead at the Diagnostics and Prognostics Group and a founding member of the Prognostics Center of Excellence, both at the Intelligent Systems Division of NASA Ames Research Center. He received a Ph.D. degree in Decision Sciences and Engineering Systems in 2008, a M. E. degree in Operations Research and Statistics in 2008, a M. S. degree in Electrical Engineering in 2003, all from Rensselaer Polytechnic Institute, Troy New York; and a B. S. in Cybernetics Engineering in 2001 from CETYS University, México.

Dinakar Deshmukh is a Global Engineering/Technology Leader with 22+ years of progressive experience leveraging data analytics and aviation domain expertise to drive differentiated outcomes for both GE Aviation and customers. He has a unique blend of experience in jet engines along with deep machine learning/AI expertise and building/leading global teams. He also has a proven track record of working with research teams in identifying and scaling solutions.

Opportunities and Challenges for Digital Twins in Engineering

Karthik Duraisamy is a Professor of Aerospace Engineering and the director of the Michigan Institute for Computational Discovery & Engineering (MICDE) @ the University of Michigan, Ann Arbor. He holds a PhD in Aerospace Engineering and a Masters in Applied Mathematics from the University of Maryland. He is known for pioneering machine-learning augmented physical modeling and has led or is currently leading several large collaborative research programs, including a four-year, NASA-funded, leading edge research program in aeronautics on data-driven modeling; and a six-year, Air force-funded Center of Excellence that that is focused on the development of reduced order models for complex physics. He is an associate editor of Physical Review fluids, serves on FAA's Advanced Aviation Advisory Committee and in AIAA's Vision 2030 Integration Committee. He is also a founder and chief scientist of the silicon valley-based startup Geminus.AI, which is focused on developing digital twins for industrial processes.

Charles R. (Chuck) Farrar, Ph. D., PE is currently the leader of Los Alamos National Laboratory's (LANL) Engineering Institute, His research interests focus on developing integrated hardware and software solutions to structural health monitoring (SHM) and damage prognosis problems. The results of this research have been documented in many journal publications, conference proceedings and a book entitled Structural Health Monitoring A Machine Learning Perspective. Additional professional activities include the development of a structural health monitoring short course that has been offered more than 45 times to industry and government agencies in Asia, Australia, Europe and the U.S. He is the founder of the Los Alamos Dynamics Summer School and he is a co-developer of the Los Alamos Judicial Science School. He is a Los Alamos National Laboratory Fellow and an ASME, ASCE and Society of Experimental Mechanics Fellow.

Devin Francom is a scientist in Los Alamos National Laboratory's Statistical Sciences group. He is responsible for developing and applying methods for uncertainty quantification for various complex natural and engineered systems, such as hurricane flooding, oil well stability, and nuclear stockpile safety. The primary focus of his research is advanced Bayesian regression methods for surrogate modeling; combining measurements, simulations, and expert judgements via Bayesian model inversion or calibration methods; and sensitivity analysis for complex systems of models. His research is motivated by application to quantifying uncertainty in computer models. He obtained a PhD in statistics and applied mathematics from University of California Santa Cruz.

S. Michael Gahn is the Chief of Technology, Product Cyber and is on the leadership team of Rolls-Royce LibertyWorks Research and Technology based in Indianapolis, Indiana. He has nearly 25 years of aerospace experience, predominantly in propulsion and power systems. He's supported all stages of the product lifecycle, from early research and development to production programs and aftermarket support in addition to five years in corporate strategy. Mike is responsible for all the research and technology development activities required to secure current and future products across the company and directs a portfolio of internal projects through TRL6 that utilize a global university research network and other key industry partners. Current research activities include feature/capability development, demonstrators, and digital modelling of cyber-physical systems. Previously, Mike worked for both the U.S. Air Force and U.S. Navy and has a master's degree in Mechanical Engineering from the University of Dayton and an MBA from Butler University.

Opportunities and Challenges for Digital Twins in Engineering

Dr. Michael Grieves is an internationally renowned expert on digital twins, a concept he originated, and Product lifecycle Management (PLM) a discipline he wrote the seminal book for. Dr. Grieves has over five decades of executive, board, and technical experience in both global and entrepreneurial technology and manufacturing companies. He has consulted and done research at some of the top global organizations (NASA, Boeing, GM, Unilever) and has served as a senior executive at both Fortune 1000 companies and entrepreneurial organizations. Academically, he has had appointments and has done research and/or taught at the University of Michigan, Purdue University, and University of Iowa. Dr. Grieves has a BS Computer Engineering from Michigan State, and MBA from Oakland University, and his doctorate from Case Western Reserve University.

Dr. Devin Harris is a Professor of Civil (Structural) Engineering and Chair of the Department of Engineering Systems at the University of Virginia (UVA). He is also the Director of the Center for Transportation Studies, and a member of UVA's cyber-physical systems collaborative research lab, the Link Lab. His research interests focus on large scale civil infrastructure systems with an emphasis on smart cities. Dr. Harris often uses both numerical and experimental techniques for evaluating the performance of the built environment, both in the laboratory and the field with applications centered in the transportation infrastructure domain. His work has included studies on image-based measurement techniques, crowdsourcing, data analytics, condition assessment and structural health monitoring, and the application of innovative materials in civil infrastructure. Most recently the work within his research group, the Infrastructure Simulation, Sensing and Evaluation (I-S2EE) Laboratory, has explored new strategies for assessment large scale infrastructure systems built around the framework of digital twins. This work seeks to leverage artificial intelligence coupled with image-based evaluation and simulation techniques to guide performance-based decision-making of existing infrastructure systems.

Dr. Pam Kobryn is the Chief Engineer of the Digital Capabilities Directorate of the Air Force Research Laboratory (AFRL) at Wright-Patterson Air Base in Ohio. She is responsible for developing the vision and strategy for applying digital engineering principles and techniques – including digital threads and digital twins – inside of AFRL to transform investment decision making and streamline technology transition. Dr. Kobryn has extensive experience in materials, manufacturing, and airframe engineering, including working on AFRL's Airframe Digital Twin Program. She has spent over a decade as an advocate for the development and application of digital engineering technologies to Department of Defense acquisition and engineering.

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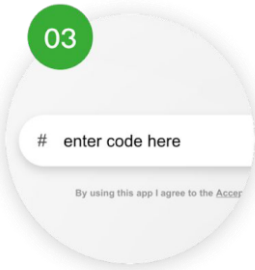

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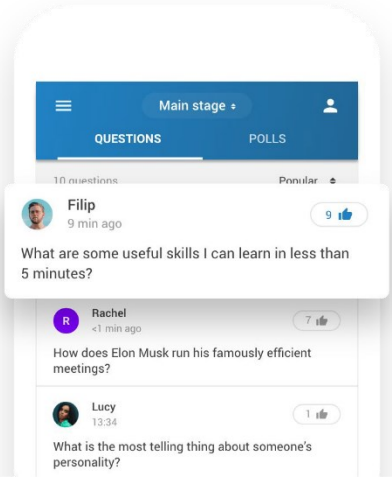

Questions and votes will appear in real-time on an interactive wall