Testimony for the *Subcommittee on Energy* of the
House Committee on Science, Space, and Technology (117th Congress)

hearing on

Accelerating Discovery: the Future of Scientific Computing at the Department of Energy
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By

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Chairperson Bowman and Ranking Member Weber: I appreciate this opportunity to submit testimony for this hearing on the future of scientific computing at the Department of Energy (DOE).

My name is Karen Willcox and I serve as the Director of the Oden Institute for Computational Engineering and Sciences at The University of Texas at Austin, where I am also Associate Vice President for Research and a Professor of Aerospace Engineering and Engineering Mechanics.

I offer my remarks today based on my expertise in scientific computing as well as my extensive interactions with the DOE in multiple capacities, which include serving as the current Co-director of the AEOLUS Mathematical Multifaceted Integrated Capabilities Center (MMICC) funded by the DOE Advanced Scientific Computing Research (ASCR) program, serving as a current member of the External Review Board for the Computing and Information Science Research Foundation at Sandia National Laboratories, and serving as a current member of the Advisory Board for the Advanced Simulation and Computing program at Los Alamos.

I wish to convey to you three main points:

1. **The future of scientific computing must be interdisciplinary**. Its very core must involve computer science, computational science, the mathematical sciences, the domain sciences, and engineering.
2. **The DOE ecosystem that supports mission-driven basic research in scientific computing across the National Laboratories and the Nation's universities is a national scientific treasure** that must be nurtured and bolstered to ensure a secure, sustainable, and competitive future for the Nation.
3. **The future of scientific computing hinges critically on the availability of a highly skilled workforce passionate about addressing the Nation's challenges in science, security, and sustainability.**

The interdisciplinary future of scientific computing

Scientific computing has an unquestionably central role to play in future scientific discovery and technological innovation to address societal grand challenges. The pace at which scientific computing can accelerate discovery and innovation will be limited by the rate at which we address foundational challenges that currently limit the complexity, scale, and trustworthiness of computational analysis, prediction, and decision tools. To address these challenges requires scientific computing research and development that draws on many fields, including computer science, computational science, and the mathematical sciences, and also includes close collaborations with domain scientists and engineers.

Particularly important is the critical role of the field of computational science (sometimes called computational science and engineering). Computational science is an interdisciplinary field that uses mathematical modeling and advanced computing to understand and solve complex problems. Computational science differs from computer science because at its core, computational science involves developing mathematical models and simulations rooted in physical and mechanistic principles, in order to understand, analyze, predict, design, and control natural and engineered systems. Quoting Rüde et al.[1]

> *"Advances in computational science have led to more efficient aircraft, safer cars, higher-density transistors, more compact electronic devices, more powerful chemical and biological process systems, cleaner power plants, higher-resolution medical imaging devices, and more accurate geophysical exploration technologies—to name just a few."*

We can draw insight as to the nature and impact of computational science through the historical example of the finite element method—the workhorse of modern computer-aided engineering analysis and design, and the foundation for the multi-billion-dollar computer-aided engineering (CAE) software industry, which has transformed the practice of engineering. What has it taken to make the finite element method a powerful broadly applicable analysis and design tool that is literally in the hands of every engineer? What has it taken to grow the impact of the finite element method from its origins in engineering structural analysis to its modern-day use in diverse applications from nuclear power plants to subsurface contaminants to polar ice sheets to materials processing to combustion processes and everything in between? A key part of the answer is the decades of investment in foundational mathematical and computational basic research, inspired by and connected to driving applications across engineering and the sciences. This research developed the foundational mathematical theory, such as the error analysis that established the finite element method's reliability,[2] the mathematical formulations that tackled the challenges of numerical stability,[3] and the theory and methods that extended the reach of the finite element method to nonlinear problems.[4]

As we look to the future of scientific computing, the boundaries between computational science and computer science are becoming increasingly blurred. The field of computational science is evolving in the face of increased data in its application domains, while computer science is beginning to impact domains in science, engineering and medicine. The future of scientific computing will involve promising new approaches that span the two fields, such as artificial intelligence (AI) and machine learning, enabled by the increasing amount of scientific data and by advances in scalable algorithms. Indeed, the DOE has been at the forefront of defining the notions of *AI for science*[5] and *scientific machine learning*,[6] with the goal of accelerating research and development breakthroughs in energy, basic science, engineering, medicine, and national security. However, as stated in my recent *Nature Computational Science* perspective piece,[7] when it comes to the development and adoption of AI approaches in scientific and engineering fields we must not lose sight of the need for a balanced investment that goes beyond computer science:

> *"For the last six decades these [scientific and engineering] fields have been advanced through the synergistic and principled use of theory, experiments, and physics-based simulations. Our increased ability to sense and acquire data is clearly a game-changer in these endeavors. Yet in our excitement to define a new generation of data-centric approaches, we must be careful not to chart our course based entirely on the successes of data science and machine learning in the vastly different domains of social media, online entertainment, online retail, image recognition, machine translation, and natural language processing—domains for which data are plentiful and physics-based models do not exist."*

We must recognize that energy, environmental, and nuclear challenges by their very nature require *predictions* that go well beyond the available data. There is a critical need to *quantify uncertainty* and our associated confidence in predictions; there is a critical need to make *informed decisions that account for risk*. The future of scientific computing will only address these needs through balanced investment in the foundational mathematical sciences and in computational science, along with data science and computer science. We must also not underestimate the criticality of continuing to invest in *experimental research and development*; advancing discovery through scientific computing requires validated computational models. Again, we can look to examples from our scientific past and appreciate that advances in time/space resolved experimental diagnostics have contributed significantly to establishing trust and credibility in physics-based computational models, because of the ability to do meaningful comparisons and validations at small scales.

The value of the DOE's mission-driven basic research ecosystem

The DOE research and development ecosystem is uniquely positioned to play a leading role in addressing these challenges and in crafting a strong interdisciplinary future for scientific computing.

The National Laboratories exemplify a culture of careful, measured, validated, and verified research that addresses vital scientific and technical application domains. Their leadership in scientific computing is complemented by their world-leading experimental and scientific user facilities. The growing efforts to support research that cuts across computational and experimental domains are essential to the future of scientific computing, and here DOE plays a unique role.

DOE support for basic research at National Laboratories and at the Nation's universities has fostered interdisciplinary computing research in a way that community-driven basic research has struggled to achieve.

As one example, I highlight the Mathematical Multifaceted Integrated Capabilities Center (MMICC) program of DOE ASCR. The Applied Mathematics Program invests $9M per year to fund three MMICC centers. The focus of these centers is on basic research in applied mathematics, but strongly driven by application needs. For example, our current AEOLUS MMICC, led by The University of Texas at Austin, is addressing basic mathematical research needs to enable predictive modeling, optimal process control, and optimal experimental design for applications in advanced materials and additive manufacturing. Over the past eight years, the MMICC program has been transformational in how it has shaped my basic research portfolio. What are the crucial elements? (1) The size of the center is large enough to bring together a diverse team that includes mathematicians, computer scientists, computational scientists, engineers, and domain experts, spanning universities and National Laboratories. This in turn enables a much-needed holistic research approach for increasingly complex systems. (2) The long funding horizon (4 or 5 years) provides the stability to invest in challenging high-payoff basic research ideas. It also provides the opportunity for PhD students to truly integrate with the team and the project. (3) The mission-driven nature of the center goals challenges my mathematical research to target problems that practitioners actually care about, yet the focus on basic research permits the research to lay long-lasting foundations that may ultimately impact a broad range of problems.

This notion of mission-driven cross-cutting mathematical research has been a mainstay of the DOE Applied Mathematics Program. It has provided, and will continue to provide, the rigorous mathematical and computational underpinnings that are essential to advancing scientific computing.

The criticality of the workforce

Achieving this future vision for scientific computing hinges critically on the availability of a highly skilled workforce passionate about addressing the Nation's challenges in science, security, and sustainability. The challenges in front of us include (1) training the workforce with the interdisciplinary skills that cut across the mathematical sciences, computing, and domain sciences, and (2) ensuring a strong, diverse pipeline of highly trained professionals who remain committed to scientific and engineering domains, rather than being lured away by more lucrative positions in commercial and business sectors.

The Oden Institute at The University of Texas at Austin has a globally recognized interdisciplinary graduate program in Computational Science, Engineering, and Mathematics (CSEM).[8] The CSEM program is unique in that we sit outside the usual departmental and school structure; our students are truly trained at the interfaces. A critical part of that training is the immersive research experience enabled by basic research grants, such as the MMICC program I described earlier, or the Predictive Science Academic Alliance Program (PSAAP).[9] Our graduate students work with collaborators from the National Laboratories and from industry partners. They engage in internships. They are immersed in the notion of basic research that targets societal grand challenges together with a culture of rigorous mathematically grounded approaches and a culture of high performance computing at scale. This prepares them to contribute to some of the Nation's most pressing scientific and technological challenges. For example, under our previous Diamond MMICC center, we trained scores of doctoral students and postdoctoral researchers, many of whom have gone on to careers in academia and the National Laboratories.[10]

Maintaining a strong investment in DOE basic research funding for universities, while also continuing to support the collaborative and academic alliance programs at the National Laboratories, is absolutely critical to addressing the Nation's future workforce needs.

Summary

Scientific computing will play a central role in future scientific discovery and technological innovation to address societal grand challenges. Scientific computing has and will thrive in an ecosystem that fosters interdisciplinary basic research and that provides the culture, environment, and resources needed to train a highly skilled workforce passionate about addressing the Nation's challenges in science, security, and sustainability. The DOE has been uniquely strong in providing this ecosystem in the past decades, and, with the proper support, is well positioned to do so in the future.

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[2] Babuška, I., Strouboulis, T. and Whiteman, J.R., 2001. *The Finite Element Method and its Reliability*. Oxford University Press, Oxford, United Kingdom.
[3] Hughes, T., Franca, L. and Balestra, M., 1986. A new finite element formulation for computational fluid dynamics: V. Circumventing the Babuška-Brezzi condition: A stable Petrov-Galerkin formulation of the Stokes problem accommodating equal-order interpolations. *Computer Methods in Applied Mechanics and Engineering*, 59(1), pp.85-99.
[4] Oden, J.T., 1972. Finite Elements of Nonlinear Continua. McGraw Hill, New York, NY.
[5] Stevens, R., Taylor, V., Nichols, J., Maccabe, A.B., Yelick, K. and Brown, D., 2020. AI for Science (No. ANL-20/17). Argonne National Laboratory (ANL), Argonne, IL.
[6] Baker, N., Alexander, F., Bremer, T., Hagberg, A., Kevrekidis, Y., Najm, H., Parashar, M., Patra, A., Sethian, J., Wild, S. and Willcox, K., 2019. Workshop report on basic research needs for scientific machine learning: Core technologies for artificial intelligence. USDOE Office of Science (SC), Washington, DC.
[7] Willcox, K., Ghattas, O. and Heimbach, P., 2021. The imperative of physics-based modeling and inverse theory in computational science. *Nature Computational Science*, 1(3), pp.166-168.
[8] https://www.oden.utexas.edu/graduate-studies/
[9] https://psaap.llnl.gov/
[10] http://dmd.mit.edu/young-gems

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Karen E. Willcox 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. 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 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. Willcox has co-authored more than 120 papers in peer-reviewed journals and advised more than 60 graduate students. She is the recipient of multiple best paper awards and several awards for leadership and teaching. In 2017 she was appointed Member of the New Zealand Order of Merit (MNZM). She is a Fellow of the Society for Industrial and Applied Mathematics (SIAM) and a Fellow of the American Institute of Aeronautics and Astronautics (AIAA).

Education

1994 University of Auckland, Bachelor of Engineering, First Class Honours (Engineering Science)
1996 Massachusetts Institute of Technology, Master of Science (Aeronautics and Astronautics)
Thesis: *Aeroelastic Computations in the Time Domain using Unstructured Meshes*
2000 Massachusetts Institute of Technology, PhD (Aeronautics and Astronautics)
Thesis: *Reduced-Order Aerodynamic Models for Aeroelastic Control of Turbomachines*

Experience

University of Texas at Austin
- 2020-present Associate Vice President for Research
- 2018-present Director, Oden Institute for Computational Engineering and Sciences
- 2018-present Professor of Aerospace Engineering and Engineering Mechanics

Santa Fe Institute
- 2019-present External Professor

Massachusetts Institute of Technology
- 2001-2018 Assistant/Associate/Full Professor, Aeronautics and Astronautics
- 2011-2013 Associate Department Head, Aeronautics and Astronautics
- 2008-2018 Founding Co-Director, MIT Center for Computational Engineering

Singapore University of Technology and Design
- 2018 Visiting Professor (7-month stay)
- 2015 Visiting Professor (6-month stay)
- 2011 Visiting Associate Professor (6-month stay)

University of Auckland, New Zealand
- 2015 Visiting Professor, Department of Engineering Science (8-month stay)
- 2008-2009 Visiting Associate Professor, Department of Engineering Science (15-month stay)

Sandia National Laboratories
- 2005 Visiting Researcher, Computer Science Research Institute (5-month stay)

Stanford University
- 2005 Visiting Scholar (1-month stay)

Boeing Phantom Works
- 2000-2001 Visiting Researcher, Blended-Wing-Body Aircraft Design Group (1-year stay)

NASA Dryden Flight Research Center
- 1996 Aerospace Intern, Aerodynamics Branch

Professional Interests

Research: Data to decisions in engineering systems. Computational models and methods for design, optimization, control and uncertainty quantification of engineering systems. Predictive data science and scientific machine learning. Reduced-order modeling and multi-fidelity methods. Future aircraft technologies, aircraft system optimization, aircraft environmental impact, multidisciplinary design, unmanned aerial vehicles, Digital Twin, Digital Thread.

Education: EdTech for data visualization, modeling and analytics (mapping.mit.edu). Fly-by-Wire intervention to enable scalable differentiated instruction in community colleges (fbw.mit.edu). Mapping learning outcomes across the undergraduate engineering curriculum (xoces.mit.edu); linking topics across the curriculum (crosslinks.mit.edu).

Teaching: Principles of Automatic Control (undergraduate), Computational Methods in Aerospace Engineering (undergraduate), Signals and Systems (undergraduate), Multidisciplinary System Design Optimization (graduate), Flight Vehicle Aerodynamics (graduate), Numerical Methods for Partial Differential Equations (graduate).

Diversity, Equity and Inclusion: Established new Diversity, Equity, Inclusion and Outreach Committee at the Oden Institute. Grew diversity of undergraduate and graduate aerospace engineering student body as Associate Department Head in MIT. Led Rising Stars events at MIT and UT Austin to foster gender diversity in aerospace engineering and computational sciences. Active in outreach activities to promote girls' interest in science, mathematics and engineering, including volunteer grade school science extension classes, many outreach visits to K-12 schools, and participation in the Advisory Board for Girls' Angle. First-generation student mentor at MIT.

Professional Memberships

Fellow, American Institute of Aeronautics and Astronautics (AIAA)

Fellow, Society for Industrial and Applied Mathematics (SIAM)

Member, American Society for Engineering Education (ASEE)

Member, American Mathematical Society (AMS)

Member, Design Society

External Boards and Committees (current)

Advanced Simulation and Computing (ASC) Advisory Board at the Los Alamos National Laboratory (2021 – present)

MATH+ Scientific Advisory Board, Germany (2021 – present)

SIAM Activity Group on Data Science (Inaugural Program Director, 2021 – 2022)

Co-Chair, SIAM 2022 Conference on Mathematics of Data Science

AIAA 2022 SciTech Forum Executive Steering Committee (2021 – 2022)

AIAA Board of Trustees (2020 – 2023)

Institute for Mathematical and Statistical Innovation (IMSI) Board of Trustees (2020 – 2024)

Advisory Board, Center of Excellence on Sustainable and Energy Efficient Aviation, TU Braunschweig, Germany (2020 – present)

NSF Advisory Committee for Cyberinfrastructure (2019 – present, Co-chair 2020 – 2022)

Science Board, Santa Fe Institute (2019 – present)

SIAM Journals Committee (2019 – present)

External Advisory Board, Michigan Institute for Computational Discovery and Engineering, University of Michigan (Member, 2017 – present)

National Academies Board on Mathematical Sciences and Analytics (BMSA) (2016 – present)

Advisory Board, Girls' Angle (2014 – present)

External Boards and Committees (past)

National Academies Planning Committee on the Workshop on the Frontiers of Mechanistic Data-Driven Modeling for Additive Manufacturing (2019)

AIAA Fellows Selection Committee (2019 – 2021)

SIAM Fellows Selection Committee (2018 – 2020)

Department of Energy Working Group on Basic Research Needs for Scientific Machine Learning (2017 – 2019)

National Academies Committee to Assess the Risks of Unmanned Aircraft Systems (UAS) Integration (2017 – 2018)

SIAM Committee on Science Policy (2016 – 2018)

SIAM Activity Group on Computational Science and Engineering: Vice President (2013 – 2015), Program Director (2011 – 2013)

Co-Chair, SIAM 2013 Conference on Computational Science and Engineering

Co-Chair, Institute-wide Task Force on the Future of MIT Education (2013 – 2014)

MIT OpenCourseWare Faculty Advisory Committee (2011 – 2018; Chair 2015 – 2018)

Advisory Board, Department of Engineering Science, University of Auckland (Member, 2008 – 2018)

National Research Council, Committee to Conduct an Independent Assessment of the Nation's Wake Turbulence Research and Development Program (2007)

National Academies Decadal Survey of Civil Aeronautics, Aerodynamics and Acoustics Panel (2005 – 2006)

AIAA MDO Conference Technical Chair (2011 – 2012)

AIAA Multidisciplinary Design Optimization Technical Committee (2001 – 2021); Chair (2019 – 2021); Vice-Chair (2017 – 2019); Awards Subcommittee Chair (2003 – 2006); Publications Subcommittee Chair (2011 – 2018)

Visiting Committees and Review Boards

ExxonMobil Corporate Strategic Research, Capability Assessment External Review Panel (Physics and Mathematical Science and Scientific Computing) (2021)

Review Committee, Research Assessment of Aerospace Engineering, Delft University of Technology, Netherlands (2020 – 2021)

Committee to Visit Harvard University Information Technology (Member, 2019)

National Academies Panel on Review of the Information Technology Laboratory (ITL) at the National Institute of Standards and Technology (NIST) (2018)

Review Committee, TU Braunschweig Universities of Excellence, German Excellence Initiative (2018)

External Review Board, Computing and Information Sciences Research Foundation, Sandia National Laboratories (Member, 2016 – present)

Visiting Committee, Applied Mathematics & Statistics Department, Colorado School of Mines (Member, 2017)

HarvardX Review Committee, Harvard University (Member, 2016)

Board of Visitors, Institute for Computational Engineering and Sciences, University of Texas at Austin (2012 – 2018; Chair 2015 – 2018)

Assessment Committee, Accreditation of Aerospace Engineering, Delft University of Technology, Netherlands (2013)

Committee of Visitors, Division of Mathematical Sciences, National Science Foundation (Member, 2010)

Editorial Boards

Acta Numerica (Editorial Board Member, 2021 – present)

IEEE Computing in Science and Engineering (CiSE) (Associate Editor, 2021 – present)

AIAA Journal (Editorial Board Member, 2021 – present; Associate Editor, 2015 – 2020 and 2009 – 2011)

Journal on Data Centric Engineering (Advisory Board, 2019 – present)

SIAM Journal on Scientific Computing (Section Editor, 2013 – 2019; Associate Editor, 2008 – 2013)

ASA/SIAM Journal on Uncertainty Quantification (Associate Editor, 2012 – 2013)

SIAM Book Series on Computational Science and Engineering (Editorial Board Member, 2009 – present)

Leadership Activities

Academic: Given hundreds of invited lectures in the US and internationally, including multiple plenary/keynote talks at major international conferences. In 2021 delivered plenary talks at AIAA Scitech Forum (largest aerospace engineering conference) and SIAM Conference on Computational Science and Engineering (largest computational science and engineering conference). Published over 120 papers in refereed archival journals. Supervised theses for 60 graduate students (40 M.S., 20 PhD). Multiple graduate students and postdocs hold academic positions at prestigious universities and leadership positions in industry. Secured funding and managed multi-institutional research projects from many sources including the U.S. Air Force, Boeing, U.S. Department of Energy, Federal Aviation Administration, NASA, National Science Foundation, DARPA, and U.S. Department of Education.

Major multi-institution research grants as lead include: Co-lead PI and Co-Director, AEOLUS Multifaceted Mathematics Capability Center on Advances in Experimental Design, Optimal Control, and Learning for Uncertain Complex Systems (Department of Energy, $10M total budget over 4 years). Lead PI, Multidisciplinary University Research Initiative (MURI) project on Managing Multiple Information Sources of Multi-physics Systems (Air Force Office of Scientific Research, $7.2M total budget over 5 years). Lead PI, MURI project on Machine Learning for Physics-Based Systems (Air Force Office of Scientific Research, $2M total budget over 3 years). Lead PI, RISE of the Machines: Robust, Interpretable, Scalable, Efficient Decision Support (Department of Energy, $4.4M total budget over 3 years). Co-lead PI and Co-Director, DiaMonD Multifaceted Mathematics Capability Center on Mathematics at the Interfaces of Data, Models, and Decisions (Department of Energy, $16.7M total budget over 5 years). Lead PI, Dynamic Data Driven Methods for Self-aware Aerospace Vehicles (Air Force Office of Scientific Research, $2.5M total budget over 6 years). Lead PI, Towards Scalable Differentiated Instruction using Technology-Enabled Competency-Based Dynamic Scaffolding (Department of Education, $2.9M total budget over 4 years).

Administrative: Director of the Oden Institute for Computational Engineering and Sciences at UT Austin (2018-present). Oversees Oden Institute operations involving >350 people, >$80M in active research contracts/grants, and >$150M endowment funding. Served as the founding co-director of the MIT Center for Computational Engineering (2008-2018) and the Associate Head of the MIT Department of Aeronautics and Astronautics (2011-2013). In Associate Head role, led reforms in the undergraduate degree program and put in place initiatives that successfully increased undergraduate enrollment in aerospace engineering.

Professional: Active professional service and leadership through multiple conference organizing committees, conference chair positions, technical committee leadership, organizational review committees, advisory boards, and editorial positions.

Selected Awards and Honors

Best Paper Award, "Toward predictive digital twins via component-based reduced-order models and interpretable machine learning", AIAA Multidisciplinary Design Optimization Best Paper, 2020

SIAM Student Paper Prize (E. Qian), "Multifidelity Monte Carlo estimation of variance and sensitivity indices," 2020

Southwest Research Institute Best Student Paper Award (M. Kapteyn), "Toward predictive digital twins via component-based reduced-order models and interpretable machine learning," AIAA Non-Deterministic Approaches Conference, Scitech Forum, 2020

Paper "Variance-based sensitivity analysis to support simulation-based design under uncertainty" one of the top 10 most accessed articles in *Journal of Mechanical Design* in 2019.

AIAA Fellow, Class of 2019

SIAM Fellow, Class of 2018

Conference on Neural Information Processing Systems (NeurIPS) paper "Contour location via entropy reduction leveraging multiple information sources" selected for Spotlight Presentation (3% of submissions), 2018.

Best Paper Award, "Towards a Low-Order Model for Transonic Flutter Prediction," AIAA Theoretical Fluid Mechanics Conference, AIAA Aviation Forum, 2017

Member of the New Zealand Order of Merit (MNZM), 2017

Distinguished Alumni Award, University of Auckland, 2016

Member, Harvard Higher Education Leaders Forum, 2016 – 2019

SIAM SIGEST Award for paper "Goal-oriented inference: Approach, linear theory, and application to advection-diffusion," 2013

Sir Peter Blake Trust Emerging Leader Award, 2010

Selected for National Academies Frontiers of Engineering Education Symposium, 2010

AIAA MDO Technical Committee Service Award, 2008 and 2013

J. T. Oden Faculty Research Fellow, University of Texas at Austin, 2006

New Zealand Management Magazine, Young Leader, 2006

MIT Junior Bose Teaching Award, 2005

MIT Department of Aeronautics and Astronautics Teaching Award, 2004

Best Paper Award, "A Framework for Aircraft Conceptual Design and Environmental Performance Studies," AIAA Multidisciplinary Analysis and Optimization Conference, 2004