

David Sondak

CONTACT INFORMATION

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RESEARCH INTERESTS

Physics-based machine learning and uncertainty quantification; data-driven modeling
Mathematics of machine learning and data science; applications to science and engineering
High performance computing, scientific computing, scientific software
Multiscale phenomena, Fluid mechanics, magnetohydrodynamics (MHD), thermal convection, turbulence
Numerical simulation of turbulence in fluids; turbulence modeling

EDUCATION

Rensselaer Polytechnic Institute, Troy, New York USA
Department of Mechanical, Aerospace, and Nuclear Engineering

Ph.D., Aerospace Engineering, August 2013

- “Novel Residual-Based Large Eddy Simulation Turbulence Models for Incompressible Magnetohydrodynamics.”
- Advisor: Assad A. Oberai

Rensselaer Polytechnic Institute, Troy, New York USA
Department of Mathematical Sciences

M.S., Applied Mathematics, May 2011

Lehigh University, Bethlehem, Pennsylvania USA
Department of Mechanical Engineering and Mechanics

B.S., Mechanical Engineering, May 2008

RESEARCH EXPERIENCE

Harvard University, Boston, MA USA
Lecturer on Computational Science
Supervisor: Pavlos Protopapas

July 2017 - Present

- Supervised graduate students on research projects in fluid mechanics, data science, and machine learning
- Developed autoencoder machine learning models to learn chaotic dynamics
- Analyzed physics-based machine learning algorithms for turbulence models
- Assessed performance of neural networks for solving differential equations
- Graduated two master’s thesis students

University of Texas at Austin, Austin, TX USA

Postdoctoral Research Fellow in the PECOS Center

Supervisor: Robert Moser

January 2016 - June 2017

- Developed stochastic model inadequacy formulations for uncertainty quantification in chemical kinetics
- Assessed turbulence model inadequacy for turbulent combustion applications

University of Wisconsin-Madison, Madison, WI USA

Van Vleck Visiting Assistant Professor

NSF Research Training Grant Post-Doctoral Research Associate

August 2013 - January 2016

August 2013 - January 2016

- Demonstrated working fluid effect on optimal heat transport in Rayleigh-Bénard convection
- Developed algorithms to determine steady-state flows that optimize heat transport
- Developed a code that determines fixed points of the Boussinesq equations
- Assessed performance of data decomposition methods in reproducing governing dynamics
- Developed variational multiscale turbulence model for thermal convection

Rensselaer Polytechnic Institute, Troy, NY USA

DOE SCGF Fellow and Graduate Research Assistant

August 2008 - August 2013

- Developed residual-based large eddy simulation turbulence models for incompressible MHD
- Tested models in decaying homogeneous, isotropic turbulence with a Fourier spectral numerical method
- Generalized models to the finite element method and implemented in the Drekar code at Sandia
- Outperformed current state-of-the-art turbulence models when comparing energy spectra

Sandia National Laboratories, Albuquerque, NM USA

DOE SCGF Internship

Research collaboration visits

Supervisor: John Shadid

August 2012-November 2012

June 2012, July 2013, August 2018, July 2019

- Implemented new turbulence models into the computational MHD code Drekar.
- Performed studies with interesting problems to test the feasibility of the models
- Simulated turbulent channel flow (both MHD and pure hydrodynamics)
- Added capabilities to existing turbulence statistics tools
- Tested spatial and temporal numerical convergence rates of Drekar with new models

Lehigh University, Bethlehem, PA USA

Undergraduate Research Assistant

Supervisor: Eugenio Schuster

June 2007-June 2008

- Studied the effects of time delays on the controllability of tokamak plasmas
- Simulated time-delays in axisymmetric control loop of KSTAR tokamak
- Assessed PID controller in controlling radial plasma position and plasma current
- Proposed modified Smith predictor as a way to enhance controllability of control loop

General Atomics National Fusion Facility, San Diego, CA USA

Research Intern

Supervisors: Michael Walker, Eugenio Schuster, David Humphreys

June 2007-August 2007

- Collaborated with a research scientist on undergraduate research project that studied time delays in the KSTAR tokamak
- Duties involved writing MATLAB and SIMULINK code that performed the tests of the effects of the time delays
- Also responsible for analyzing the data and determining future directions (along with the research scientist and undergraduate research advisor)

HONORS AND AWARDS

American Physical Society Division of Fluid Dynamics Travel Grant

November 2015

Featured professor in Wisconsin Engineer Magazine

Spring 2015

Honored Instructors Program Honored Instructor

Spring 2015

USNCCM 2013 Student Poster Competition Award

July 2013

DOE Office of Science Graduate Research Fellowship

August 2010 - August 2013

National Science Foundation Graduate Research Fellowship Honorable Mention

May 2010

Lehigh University: graduated Magna Cum Laude

2008

PROGRAMMING EXPERIENCE

- **Scientific Programming:** MPI, C + +, Julia, Modern Fortran, Numerical Python, MATLAB
- **Data Science:** Keras, Pytorch, Python
- **General Programming:** Python, Bash, HTML, CSS
- **Version control:** Git, Mercurial, Subversion
- **Applications:** Latex

SCIENTIFIC AND PROFESSIONAL SOCIETIES

Society of Industrial and Applied Mathematics

American Physical Society

American Institute of Aeronautics and Astronautics

American Society of Mechanical Engineers

Pi Tau Sigma (Mechanical Engineering Honor Society)

TEACHING EXPERIENCE

Harvard University, Boston, MA USA

Lecturer on Computational Science

July 2017 - Present

- CS207 / CS107 / AC207 — Systems Development for Computational Science *Semesters taught: Fall 2017-2020*
Computer science course on software development for computational scientists
Grew enrollment from 45 students (Fall 2017) to 130 students (Fall 2019 and beyond)
Supervised and managed up to 10 teaching fellows and course assistants
- ES123 — Introduction to Fluid Mechanics and Transport Processes *Semesters taught: Spring 2020*
Undergraduate fluid mechanics course
Supervised and managed 6 teaching fellows
- CS205 — Computing Foundations for Computational Science *Semesters taught: Spring 2018, Spring 2020*
Graduate course on parallel and high performance computing
 ≈ 100 students
Co-taught with Ignacio Llorente (Spring 2018)
Supervised and managed 3-4 teaching fellows
- AC297r — Computational Science and Engineering Capstone Project *Semesters taught: Spring 2019*
Recruited four project partners to propose real-world problems for students to solve
Students work in teams of 3-4 members to address challenges posed by industry and academic partners
Students present results at end-of-semester poster session open to partners
- AC290r — Extreme Computing *Semesters taught: Spring 2019*
Project-based course to explore the techniques, infrastructure, and algorithms used for extreme computing
Students use tools developed at national labs and in academia to perform large-scale simulations

University of Wisconsin-Madison, Madison, WI USA

Visiting Assistant Professor

August 2013 - January 2016

- MATH 322 — Applied Mathematical Analysis 2 *Semesters taught: Fall 2014, Fall 2015*
Undergraduate course in partial differential equations
19 students (Fall 2014), 24 students (Fall 2015)
- MATH 320 — Linear Algebra and Differential equations *Semesters taught: Fall 2013, Spring 2015*
Undergraduate course covering differential equations and linear algebra
185 students (Fall 2013), 250 students (Spring 2015)
Supervised and managed 3 teaching assistants
- MATH 222 — Calculus and Analytic Geometry 2 *Semesters taught: Spring 2014*
Second semester calculus
224 students
Supervised and managed 5 teaching assistants

THESES SUPERVISED

Rui Fang

May 2019

- Master's thesis
- Machine Learning Approaches for Modeling Turbulent Channel Flow
- Next position: PhD student at the Oden Institute

Feiyu Chen

May 2020

- Master's thesis
- Development of software library for solving differential equations with neural networks
- Next position: Amazon

OUTREACH

Data Science Pedagogy Winter Workshop

Winter 2020-2021

Co-organized a workshop for educators of underrepresented, underserved college students in data science.

Harvard Summer Academic Program organized by AdHarvard LLC.

July 28, 2019

Gave a 3-part lecture on coding and machine learning for physics.

The Basics and Essentials of Version Control

February 1, 2019

Gave a tutorial for the *Sustainable Horizons Institute* on why to use version control and how to use git effectively.

π -Day Talk at Harvard

March 14, 2018

Gave a talk to Harvard staff on the significance of π , why we should care, and how to have fun with it.

An Introduction to Coding Best Practices

November 17, 2017

Gave an active learning tutorial for economics Ph.D. students on how to code efficiently and write accessible software.

Research Experience for Undergraduates

Summer 2015

Worked with a group of three undergraduates to study the swimming motion of 2D Janus particles.

Madison Math Circle

October 6, 2014, September 14, 2015

Presented mathematics of fluids and sound waves to middle and high school students using experiments and computation.

Sponsor-A-Scholar Mentor

September 2011 - June 2013

Worked with disadvantaged high school students who displayed academic potential.

Engineers Ambassadors Mentor

September 2011 - September 2012

Facilitated educational outreach work of undergraduate engineering students.

PROFESSIONAL SERVICE

Journal Reviewer

2013-Present

Reviewed papers for the Journal of Turbulence, Physical Review Fluids, AIAA Journal, Journal of Computational and Applied Mathematics, and PLOS ONE.

Session Chair at APS-DFD Meeting

2014, 2015

Chaired sessions on Rayleigh-Bénard convection and Convection and Buoyancy-Driven Flows.

Python Tutorials

June 2015, September 2015

Designed and delivered Python tutorials with an emphasis on scientific computing.

Organized the Mechanical, Aerospace, and Nuclear Engineering department's graduate research forum.

Mathematical Problems in Industry Workshop

June 14-18 2010

Worked on a study which sought to provide a better understanding of a viscous sheet of molten glass.

Graduate Student Mathematical Modeling Camp

June 7-11 2010

Worked with a team of graduate and undergraduate students to determine the optimal design of a steel laying pipe.

PUBLICATIONS IN PREPARATION

1. Unsupervised Learning of Solutions to Differential Equations with Generative Adversarial Networks, D. Randle, P. Protopapas, D. Sondak [arXiv:2007.11133](#), 2020
2. Coherent Solutions and Transition to Turbulence in Two-Dimensional Rayleigh-Bénard Convection, P. Kooloth, D. Sondak, L.M.Smith [arXiv:2006.14132](#), 2020
3. Solving Differential Equations Using Neural Network Solution Bundles, C. Flamant, P. Protopapas, D. Sondak [arXiv:2006.14372](#), 2020
4. Hamiltonian Neural Networks for solving differential equations, M. Mattheakis, D. Sondak, A.S. Dogra, P. Protopapas, [arXiv:2001.11107](#), 2020
5. Physical Symmetries Embedded in Neural Networks, M. Mattheakis, P. Protopapas, D. Sondak, M. Di Giovanni, E. Kaxiras, [arXiv:1904.08991](#), 2019

PUBLICATIONS

▲ Referred Journal Publications

● Referred Conference Publications

◆ ArXiv Preprints

- ▲ 1. High Rayleigh number variational multiscale large eddy simulations of Rayleigh-Bénard Convection, D. Sondak, T.M.Smith, S.Conde, R.Pawlowski, J.N.Shadid, to appear in Mechanics Research Communications
- 2. Finding multiple solutions of ODEs with neural networks, M. Di Giovanni, D.Sondak, P.Protopapas, M.Brambilla
- ▲ 3. NeuroDiffEq: A Python package for solving differential equations with neural networks, F.Chen, D.Sondak, P.Protopapas, M.Mattheakis, S.Liu, D.Agarwal, M.DiGiovanni, Journal of Open Source Software, 5(46), 1931, 2020
- ▲ 4. Neural Network Models for the Anisotropic Reynolds Stress Tensor in Turbulent Channel Flow, R.Fang, D.Sondak, P.Protopapas, S.Succi, Journal of Turbulence, 1-19, 2019
- 5. An inadequacy formulation for an uncertain flamelet model, D.Sondak, T.Oliver, C.Simmons, R.D.Moser, 19th AIAA Non-Deterministic Approaches Conference, 2017
- ▲ 6. Can phoretic particles swim in two dimensions?, D.Sondak, C.Hawley, S.Heng, R.Vinsonhaler, E.Lauga, J.-L. Thiffeault, Physical Review E, 94, 062606, 2016
- ▲ 7. The effect of Prandtl number on optimal scaling laws in Rayleigh-Bénard convection, D.Sondak, F.Waleffe, L.M.Smith, Journal of Fluid Mechanics, 784, 565-595, 2015
- ▲ 8. A new class of finite element variational multiscale turbulence models for incompressible magnetohydrodynamics, D.Sondak, J.N.Shadid, A.A.Oberai, R.P.Pawlowski, E.C.Cyr, T.M.Smith, Journal of Computational Physics, 295, 596-616, 2015
- ▲ 9. A residual-based eddy viscosity model for the large eddy simulation of turbulent flows, A.A. Oberai, J. Liu, D. Sondak, T.J.R. Hughes, Computer Methods in Applied Mechanics and Engineering, 282, 54-70, 2014
- ▲ 10. LES models for incompressible magnetohydrodynamics derived from the variational multiscale formulation, D. Sondak and A.A. Oberai, Physics of Plasmas, 19(10), 102308, 2012.

- ▲ 11. Remediation of time-delay effects in tokamak axisymmetric control loops by optimal tuning and robust predictor augmentation, D. Sondak, R. Arastoo, E. Schuster, M.L. Walker, *Fusion Engineering and Design*, 86(6), 1112–1115, 2011.
- ▲ 12. Application of the variational Germano identity to the variational multiscale formulation, A.A. Oberai and D. Sondak, *International Journal for Numerical Methods in Biomedical Engineering*, 27(2), 335-344, 2011.
- 13. Optimal Tuning of Tokamak Plasma Equilibrium Controllers in the Presence of Time Delays, E. Schuster, D. Sondak, R. Arastoo, M. L. Walker and D. A. Humphreys, *Proceedings of the 3rd IEEE Multi-conference on Systems and Control*, Saint Petersburg, Russia, July 8-10, 2009.

INVITED TALKS

1. An Autoencoder for Learning Reduced Dynamics of the Kuramoto-Sivashinsky Equation, *SIAM Mathematics of Data Science*, Special session on “Bridging Data Assimilation with Data-Driven Analysis”, Virtual Meeting, June 29, 2020
2. Machine Learning in Chaotic and Turbulent Systems, *Universality: Turbulence Across Vast Scales*, Flatiron Institute, New York, New York, December 2, 2019
3. An Autoencoder for Learning Reduced Dynamics of the Kuramoto-Sivashinsky Equation, *Mathematics Colloquium*, University of Texas at San Antonio, October 25, 2019
4. Learning the Reduced Dynamics of the Kuramoto-Sivashinsky Equation with Autoencoders, *American Mathematical Society Fall Eastern Sectional Meeting, Special Session on Analysis and Applications of Deterministic and Stochastic Evolution Equations*, Binghamton University, October 12-13, 2019
5. Towards Machine Learning for Categorizing Optimal Solutions in Turbulent Convection, *Center for Mathematical Sciences and Applications Fluid Dynamics Seminar*, Harvard University, May 1, 2019
6. Machine Learning, Fluids, and Turbulence, D.Sondak, *Institute of Mathematical Sciences Special Colloquium*, Stony Brook University, April 22, 2019
7. Machine Learning for Fluid Mechanics and Turbulence Modeling, D.Sondak, *1st International Workshop on Artificial Intelligence in Complex Systems*, University of Rome—Tor Vergata, March 20, 2019
8. Optimal Solutions in Turbulent Rayleigh-Bénard Convection, D.Sondak, *Mathematics Department Seminar*, Clarkson University, February 13, 2019
9. Explorations in Physics-Informed Deep Learning, D.Sondak, *MITRE College Lecture Series*, MITRE, December 7, 2018
10. Fluid Mechanics with Turbulence, Reduced Models, and Machine Learning, D.Sondak, *IACS Seminar Series*, Harvard University, September 28, 2018
11. A class of large eddy simulation turbulence models for incompressible magnetohydrodynamics and some of its properties, D.Sondak, *CSRI Seminar*, Sandia National Laboratories, August 8, 2018
12. Signature of Optimal Solutions in Rayleigh-Bénard Convection, D.Sondak, Parvathi, L.M.Smith, *SIAM Annual Meeting*, Portland, Oregon, July, 2018
13. Physics-Based Stochastic Inadequacy Models for Chemical Kinetics, D.Sondak, T.Oliver, C.Simmons, R.D.Moser, *SIAM UQ Conference, Minisymposium on uncertainty quantification and model inadequacy*, Anahiem, CA, April, 2018
14. Physics-based Models for Uncertainty Quantification in Chemical Kinetics, D.Sondak, *Center for Mathematical Modeling Seminar*, Universidad de Chile, January 15, 2018
15. Residual Based Large Eddy Simulation Turbulence Models for Incompressible Magnetohydrodynamics: Part II, D.Sondak, *Institute for Fusion Studies*, University of Texas at Austin, May 11, 2017
16. A Story on Model Inadequacy Formulations for Chemical Kinetics, D.Sondak, T.A. Oliver, C.Simmons, R.D.Moser, *Seminar in the Department of Mechanical Engineering*, Oregon State University, April 28, 2017

17. Residual-Based Large Eddy Simulation Turbulence Models for Incompressible Magnetohydrodynamics, D.Sondak, J.N.Shadid, A.A.Oberai, 19th International Conference on Finite Elements in Flow Problems, Minisymposium on Stabilized, Multiscale, and Isogeometric Methods in CFD, April 7, 2017
18. Calibration of a Stochastic Operator-Based Model Inadequacy Representation for Chemical Kinetics, D.Sondak, T.A.Oliver, C.Simmons, R.D.Moser, SIAM Numerical Combustion 17, Minisymposium on uncertainty quantification and model inadequacy in combustion simulations, April 3, 2017
19. Residual Based Large Eddy Simulation Turbulence Models for Incompressible Magnetohydrodynamics: Part 1, D.Sondak, Institute for Fusion Studies, University of Texas at Austin, March 16, 2017
20. Optimal Heat Transport and Exact Coherent States in Rayleigh-Bénard Convection, D.Sondak, F.Waleffe, L.M.Smith, Center for Plasma Theory and Computation Seminar, University of Wisconsin, Madison, December 14, 2015
21. Scaling Laws in Coherent Rayleigh-Bénard Convection and the Effect of the Prandtl Number, D.Sondak, F.Waleffe, L.M.Smith, RTG Workshop on Turbulent and Coherent Convection, University of Wisconsin-Madison, May 29, 2015
22. A Class of Finite Element Variational Multiscale Turbulence Models for MHD, D.Sondak, J.N.Shadid, A.A.Oberai, R.P.Pawlowski, E.C.Cyr, T.M.Smith, Seminar at the Department of Aerospace Engineering Sciences, University of Colorado-Boulder, January 14, 2015
23. MHD SGS Turbulence Models Derived from VMS Formulations, D.Sondak, A.Oberai, J.Shadid, T.Smith, E.Cyr, R.Pawlowski, Workshop on Large Eddy Simulations of MHD Turbulence, NCAR, Boulder, Colorado, May 20-23, 2013
24. Residual-based LES Models for Magnetohydrodynamics, D.Sondak, A.Oberai, Center for Plasma Theory and Computation Seminar, University of Wisconsin, Madison, February 4, 2013

SPECIAL PROGRAMS

1. 2019 Data Science School, Universidad de Chile and University of Concepción, August 12 - 23, 2019
2. Online Project-Based Program in Data Science: Session 1, 2018, 2019
3. Online Project-Based Program in Data Science: Session 2, 2018, 2019
4. 2018 Data Science School, Universidad de Chile, January 6 - 19, 2018
5. 2016 Princeton-Combustion Institute Summer School on Combustion, Princeton, NJ, June 19 - 24, 2016
6. Turbulent Flow Simulation at the Exascale: Opportunities and Challenges Workshop, Sponsored by the U.S. Department of Energy Office of Advanced Scientific Computing Research, Autograph Mayflower Hotel, Washington, DC, August 4 - 5, 2015

POSTERS

1. Calibration of a Stochastic Model Inadequacy Representation for Chemical Kinetic, D.Sondak, M.K.Lee, T.Oliver, C.Simmons, R.D.Moser, Workshop on Uncertainty Quantification and Data-Driven Modeling, Austin, Texas, March 23-24, 2017
2. Residual-Based Large Eddy Simulation Models for Magnetohydrodynamics, D.Sondak, A.Oberai, J.N.Shadid, 12th US National Congress on Computational Mechanics, Raleigh, North Carolina, July 22-25, 2013
3. Tokamak Plasma Equilibrium Controllability Limitations Due to Delays, D. Sondak, E. Schuster, M.L. Walker, 49th Division of Plasma Physics (DPP) Annual Meeting of the American Physical Society (APS), Orlando, Florida, November 12-16, 2007.