David Sondak

Contact Information

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Research Interests

Physics-based machine learning and uncertainty quantification; data-driven modeling

Fluid mechanics, magnetohydrodynamics (MHD), thermal convection, turbulence

High performance computing, scientific computing

Development of the Sandia MHD code Drekar

Mathematics of machine learning; Algorithm development for fluid dynamics and applications

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

- Dissertation: "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 **July 2017 - Present**
Supervisor: Pavlos Protopapas

- Supervised graduate students on research projects in fluid mechanics, data science, and machine learning
- Developed 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

University of Texas at Austin, Austin, TX USA
Postdoctoral Research Fellow in the PECOS Center **January 2016 - June 2017**
Supervisor: Robert Moser

- 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 **August 2013 - January 2016**
NSF Research Training Grant Post-Doctoral Research Associate **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 **August 2012-November 2012**
Research collaboration visits **June 2012, July 2013, August 2018, July 2019**
Supervisor: John Shadid

- 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 **June 2007-June 2008**
Supervisor: Eugenio Schuster

- 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 **June 2007-August 2007**
Supervisors: Michael Walker, Eugenio Schuster, David Humphreys

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

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**

- ES123 — Introduction to Fluid Mechanics and Transport Processes *Semesters taught: Spring 2020*
  Undergraduate fluid mechanics course
  Supervised and managed 6 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
- CS207 — Systems Development for Computational Science *Semesters taught: Fall 2017, 2018, 2019*
  Graduate computer science course on software development for computational scientists
  Grew enrollment from 45 students (Fall 2017) to 130 students (Fall 2019)
  Supervised and managed up to 8 teaching fellows
- CS205 — Computing Foundations for Computational Science *Semesters taught: Spring 2018, Spring 2020*
  Graduate course on parallel computing
  45-60 students
  Co-taught with Ignacio Llorente
  Supervised and managed 3-4 teaching fellows

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
- Current student

Outreach

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 verison 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, 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.

Graduate Research Forum Coordinator **December 2010 - August 2012**
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. Physical Symmetries Embedded in Neural Networks, M. Mattheakis, P. Protopapas, D. Sondak, M. Di Giovanni, E. Kaxiras, arXiv:1904.08991, 2019
2. High Rayleigh number variational multiscale large eddy simulations of Rayleigh-BÃľnard Convection, D. Sondak, T.M.Smith, S.Conde, R.Pawlowski, J.N.Shadid, to be submitted to Mechanics Research Communications
3. Optimal Heat-Transport Solutions and Transition to Turbulence in Two-Dimensional Rayleigh-Benard Convection, P. Kooloth, D. Sondak, L.M.Smith

Publications

▲ Referred Journal Publications ● Referred Conference Publications ◆ ArXiv Preprints

▲1. 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

▲2. 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

●3. An inadequacy formulation for an uncertain flamelet model, D.Sondak, T.Oliver, C.Simmons, R.D.Moser, 19th AIAA Non-Deterministic Approaches Converence, 2017

▲4. 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

▲5. 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

▲6. 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

▲7. 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

▲8. LES models for incompressible magnetohydrodynamics derived from the variational multiscale formulation, D. Sondak and A.A. Oberai, Physics of Plasmas, 19(10), 102308, 2012.

▲9. 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.

▲10. 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.

●11. 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. Machine Learning in Chaotic and Turbulent Systems, Universality: Turbulence Across Vast Scales, Flatiron Institute, New York, New York, December 2, 2019
2. An Autoencoder for Learning Reduced Dynamics of the Kuramoto-Sivashinsky Equation, Mathematics Colloquium, University of Texas at San Antonio, October 25, 2019
3. 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
4. Towards Machine Learning for Categorizing Optimal Solutions in Turbulent Convection, Center for Mathematical Sciences and Applications Fluid Dynamics Seminar, Harvard University, May 1, 2019
5. Machine Learning, Fluids, and Turbulence, D.Sondak, Institute of Mathematical Sciences Special Colloquium, Stony Brook University, April 22, 2019
6. 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
7. Optimal Solutions in Turbulent Rayleigh-Bénard Convection, D.Sondak, Mathematics Department Seminar, Clarkson University, February 13, 2019
8. Explorations in Physics-Informed Deep Learning, D.Sondak, MITRE College Lecture Series, MITRE, December 7, 2018
9. Fluid Mechanics with Turbulence, Reduced Models, and Machine Learning, D.Sondak, IACS Seminar Series, Harvard University, September 28, 2018
10. 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
11. Signature of Optimal Solutions in Rayleigh-Bénard Convection, D.Sondak, Parvathi, L.M.Smith, SIAM Annual Meeting, Portland, Oregon, July, 2018
12. 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
13. Physics-based Models for Uncertainty Quantification in Chemical Kinetics, D.Sondak, Center for Mathematical Modeling Seminar, Universidad de Chilé, January 15, 2018
14. 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
15. 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 Univeristy, April 28, 2017
16. 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
17. 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
18. 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
19. 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

20. 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
21. 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
22. 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
23. 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, Universdad de Chilé 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, Universdad de Chilé, 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.

Languages

Fluent in English

Conversational French