# 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, 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**, Cambridge, MA USA
*Lecturer on Computational Science* **July 2017 - Present**
*Supervisor: Pavlos Protopapas*

- Supervised graduate students on research in fluid mechanics, data science, and machine learning
- Developed autoencoder machine learning models to learn chaotic dynamics
- Graduated two master's thesis students

**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 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

**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
- 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)

**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

**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

## Publications

### *In Preparation and Under Consideration*

7. Learning a Reduced Basis of Dynamical Systems using an Autoencoder, **D. Sondak** , P. Protopapas, arXiv:2011.07346, 2020, Submitted to PRE
6. Unsupervised Learning of Solutions to Differential Equations with Generative Adversarial Networks, D. Randle, P. Protopapas, D. Sondak arXiv:2007.11133, 2020
5. 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
3. Physical Symmetries Embedded in Neural Networks, M. Mattheakis, P. Protopapas, D. Sondak, M. Di Giovanni, E. Kaxiras, arXiv:1904.08991, 2019
2. Uncertainty Quantification of Neural Network-based RANS Models, X. Zhou, **D.Sondak**, C. Garraffo, P.Protopapas, In preparation
1. Convergence properties of neural networks for solving differential equations, M. Di Giovanni, **D.Sondak**, P.Protopapas, M. Mattheakis, In preparation

### *Publications*

14. Coherent Solutions and Transition to Turbulence in Two-Dimensional Rayleigh-Bé nard Convection, P. Kooloth, **D. Sondak**, L.M.Smith, Physical Review Fluids: To Appear
13. High Rayleigh number variational multiscale large eddy simulations of Rayleigh-Bénard Convection, D. Sondak, T.M.Smith, S.Conde, R.Pawlowski, J.N.Shadid, Mechanics Research Communications, 103614, 2020, doi: https://doi.org/10.1016/j.mechrescom.2020.103614

12. Finding multiple solutions of ODEs with neural networks, M. Di Giovanni, **D. Sondak**, P.Protopapas, M.Brambilla, AAAI Spring Symposium: Machine Learning in the Physical Sciences, 2020
11. 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
10. 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
9. An inadequacy formulation for an uncertain flamelet model, D.Sondak, T.Oliver, C.Simmons, R.D.Moser, 19th AIAA Non-Deterministic Approaches Converence, 2017
8. 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
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
5. 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
4. LES models for incompressible magnetohydrodynamics derived from the variational multiscale formulation, D. Sondak and A.A. Oberai, Physics of Plasmas, 19(10), 102308, 2012.
3. 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.
2. 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.
1. 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

24. 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
23. Machine Learning in Chaotic and Turbulent Systems, Universality: Turbulence Across Vast Scales, Flatiron Institute, New York, New York, December 2, 2019
22. An Autoencoder for Learning Reduced Dynamics of the Kuramoto-Sivashinsky Equation, Mathematics Colloquium, University of Texas at San Antonio, October 25, 2019
21. 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
20. Towards Machine Learning for Categorizing Optimal Solutions in Turbulent Convection, Center for Mathematical Sciences and Applications Fluid Dynamics Seminar, Harvard University, May 1, 2019
19. Machine Learning, Fluids, and Turbulence, D.Sondak, Institute of Mathematical Sciences Special Colloquium, Stony Brook University, April 22, 2019
18. 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
17. Optimal Solutions in Turbulent Rayleigh-Bénard Convection, D.Sondak, Mathematics Department Seminar, Clarkson University, February 13, 2019
16. Explorations in Physics-Informed Deep Learning, D.Sondak, MITRE College Lecture Series, MITRE, December 7, 2018
15. Fluid Mechanics with Turbulence, Reduced Models, and Machine Learning, D.Sondak, IACS Seminar Series, Harvard University, September 28, 2018
14. 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
13. 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

11. Physics-based Models for Uncertainty Quantification in Chemical Kinetics, D.Sondak, Center for Mathematical Modeling Seminar, Universidad de Chilé, January 15, 2018
10. 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
9. 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
8. 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
7. 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
6. 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
5. 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
4. 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
3. 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
2. 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
1. Residual-based LES Models for Magnetohydrodynamics, D.Sondak, A.Oberai, Center for Plasma Theory and Computation Seminar, University of Wisconsin, Madison, February 4, 2013

## Honors and Awards

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| American Physical Society Division of Fluid Dynamics Travel Grant | **Nov 2015** |
| Featured professor in Wisconsin Engineer Magazine | **Spring 2015** |
| Honored Instructors Program Honored Instructor | **Spring 2015** |
| USNCCM 2013 Student Poster Competition Award | **Jul 2013** |
| DOE Office of Science Graduate Research Fellowship | **Aug 2010 - Aug 2013** |
| National Science Foundation Graduate Research Fellowship Honorable Mention | **May 2010** |
| Lehigh University: graduated Magna Cum Laude | **2008** |

## Scientific and Professional Societies

Society of Industrial and Applied Mathematics
American Physical Society
American Institute of Aeronautics and Astronautics
Pi Tau Sigma (Mechanical Engineering Honor Society)

## Teaching Experience

**Harvard University**, Cambridge, MA USA
*Lecturer on Computational Science* **July 2017 - Present**

- CS207 / CS107 / AC207 — Systems Development for Computational Science *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 *Spring 2020*

  Undergraduate fluid mechanics course
  Supervised and managed 6 teaching fellows

- CS205 — Computing Foundations for Computational Science *Spring 2018, 2020, 2021*

  Graduate course on parallel and high performance computing
  $\approx$ 100 students
  Co-taught with Ignacio Llorente (Spring 2018)
  Supervised and managed 3-4 teaching fellows

- AC297r — Computational Science and Engineering Capstone Project *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 *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 *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 *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 *Spring 2014*

  Second semester calculus
  224 students
  Supervised and managed 5 teaching assistants

## Thesis Supervised

*Rui Fang (Master's)* **May 2019**

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

*Feiyu Chen (Master's)* **May 2020**

- 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 workshop for educators of underrepresented/underserved 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.

*$\pi$-Day Talk at Harvard* **March 14, 2018**

- Gave a talk to Harvard staff on $\pi$, 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, International Journal of Thermal Sciences, 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.

## Special Programs

ComputeFest 2020, Institute for Applied Computational Science, Harvard University, January 21-24, 2020
2019 Data Science School, Universdad de Chilé and University of Concepción, August 12 - 23, 2019
Online Project-Based Program in Data Science: Session 1, 2018, 2019
Online Project-Based Program in Data Science: Session 2, 2018, 2019
2018 Data Science School, Universdad de Chilé, January 6 - 19, 2018
2016 Princeton-Combustion Institute Summer School on Combustion, Princeton, NJ, June 19 - 24, 2016
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

3. 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
1. 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.