APPLIED MATHEMATICS AT PENN STATE

Graduate studies in our Department of Mathematics include many possibilities for working in applied mathematics - our faculty have diverse interests covering areas from analysis to numerics to modeling, even to laboratory experiments. Faculty are listed below according to their research interests, defined by the mathematical areas or applications about which they publish. This is followed by an alphabetical listing of faculty with a brief research statement.

Research Areas

1. *Classical Mechanics* - A. Belmonte, F. Costanzo, M. Levi, L-C. Li, C. Liu
2. *Complex Fluids/Polymers* - A. Belmonte, L. Berlyand, J. Brasseur, Q. Du, C. Liu, J. Xu, L. Zikatanov
3. *Control Theory* - A. Bressan
4. *Economic Theory* - E. Green, J. Li
5. *Fluid Dynamics* - A. Belmonte, J. Brasseur, Q. Du, D. Henderson, K. Jenssen, M. Levi, C. Liu, L. Long, A. Mazzucato, A. Novikov, W. Shen, J. Xu, Y. Zheng
6. *General Relativity* - V. Nistor, J. Xu
7. *Hyperbolic Differential Equations/Conservation Laws* - A. Bressan, K. Jenssen, W. Shen, Y. Zheng
8. *Integrable Hamiltonian Systems* - L-C. Li
9. *Laboratory Experiments* - A. Belmonte, W. Cao, D. Henderson
10. *Material Science/Continuum Mechanics* - A. Belmonte, L. Berlyand, W. Cao, F. Costanzo, Q. Du, X. Li, C. Liu, A. Novikov, J. Xu
11. *Mathematical Biology* - L. Berlyand, J. Brasseur, F. Costanzo, Q. Du, C. Liu, L. Long, T. Reluga
12. *Multiscale Analysis* - L. Berlyand, J. Brasseur, F. Costanzo, Q. Du, M. Levi, X. Li, C. Liu, A. Novikov, J. Xu
13. *Numerical Analysis* - J. Brasseur, Q. Du, L. Long, V. Nistor, W. Shen, J. Xu, L. Zikatanov
14. *Ordinary Differential Equations* - M. Levi, L-C. Li, T. Reluga
15. *Partial Differential Equations* - L. Berlyand, A. Bressan, Q. Du, K. Jenssen, L-C. Li, C. Liu, A. Mazzucato, V. Nistor, W. Shen, J. Xu, Y. Zheng
16. *Probability/Statistical Physics/Stochastics* - A. Belmonte, L. Berlyand, Q. Du, A. Novikov, T. Reluga
17. *Wavelets/Fractals* - J. Brasseur, A. Mazzucato, J. Xu

Brief Research Statements

1. **Andrew Belmonte, Associate Professor of Mathematics:** My main research is the experimental and mathematical study of fluid dynamics in the Pritchard Lab, including viscoelastic materials (such as wormlike micellar fluids), the acoustic dynamics of large bubbles, and instabilities in the free surface flow of reactive immiscible fluids. In addition I am studying fragmentation processes in brittle solids and soft gels, developing mathematical tools to model the fragment distribution. A common theme in these areas is the coupled dynamics of local deformation and propagating (via hyperbolic PDE) stress fields, often observed using high-speed video techniques.

2. **Leonid Berlyand, Professor of Mathematics:** My research interests are in the areas of PDEs, calculus of variations and random media. I apply homogenization theory and multiscale analysis to modeling of strongly heterogeneous materials (e.g., composites, metamaterials) and biological fluids. I also work on nonlinear PDE and variational Ginzburg-Landau problems arising in superconductivity and superfluidity. Most recent work is in mathematical modeling of cloaking (invisibility) for electromagnetic and elastic waves using asymptotic analysis of the corresponding PDEs.

3. **James Brasseur, Adjunct Professor of Mathematics (Professor of Mechanical Engineering)**: My primary areas of research are (1) theory, direct numerical simulation, and large-eddy simulation of fluid turbulence, and (2) mathematical modeling, lattice-Boltzmann and finite element numerical methods, image analysis, and physiological data analysis of gastrointestinal physiology. In the first area, we explore nonlinear interscale dynamics underlying high Reynolds number turbulence, boundary layer flows, atmospheric dynamics, and polymer-turbulence interactions. In the second area, we study muscle-fluid interactions and neurological control of gastrointestinal function, sphincter mechanics, transport, mixing, drug delivery, and absorption in the gastrointestinal tract.

4. **Alberto Bressan, Eberly Professor of Mathematics:** Current research in nonlinear partial differential equations: Existence, uniqueness, qualitative properties of solutions to nonlinear wave equations and hyperbolic systems of conservation laws in one and several space dimensions. Rigorous analysis of various approximations methods, including vanishing viscosity, front tracking, finite difference schemes. High order convergence methods for piecewise smooth solutions. Current research in control theory: Construction of nearly optimal patchy feedbacks for various control problems. Stabilization of Lagrangian mechanical systems by means of impulsive controls.

5. **Wenwu Cao, Professor of Mathematics (Professor of Materials Science)**: My research interests are in ferroelectric materials and their applications. On the theoretical side, I have been studying structural phase transitions and domain microstructure formation using Landau-Ginzburg models, and studying domain dynamics using computer simulations. On the applications side, my interest focuses on medical ultrasonic

transducers and other electromechanical devices. My ultrasonic lab located in the Materials Research Laboratory is equipped to perform full matrix characterization of the physical properties of crystalline, polymer and ceramic materials, as well as evaluating transducer performance. Recently, I have characterized thin films that are only a fraction of wavelength thick by detailed signal processing of ultrasonic waves.

6. **Francesco Costanzo, Adjunct Professor of Mathematics (Associate Professor of Engineering Science & Mechanics)**: My research interests are in the application of continuum mechanics to the solution of dynamic fracture problems and damage propagation problem, both analytically and numerically. In addition, I have a specific interest in the formulation of constitutive models of materials behavior using several approaches including phenomenological, homogenization based, and multiscale via molecular dynamics. Recently, I have begun to consider the application of theory of elasticity to the study of the soft tissues found in the gastrointestinal tract.

7. **Qiang Du, Willaman Professor of Mathematics** (and Professor of Material Science and Engineering): My research interests are mainly in areas like numerical algorithms and scientific computation (numerical analysis, numerical PDEs, parallel algorithms) and mathematical modeling (applied and stochastic analysis, PDEs). I am also working on selected applications in physical, biological and materials sciences (phase transitions, microstructures, superfluids, complex fluids, bio-membranes) and applications in information sciences (model reduction, meshing and tessellations, data mining and image analysis).

8. **Edward Green, Adjunct Professor of Mathematics (Professor of Economics)**: My research concerns noncooperative, extensive-form games (that is, games involving finitely or infinitely many successive moves) in which players possess private information (for example, knowing their own respective preferences). Mathematical questions arise, principally concerning measure and probability. Typical economic applications include models of industry cartels and of efficient contracts between financial intermediaries and their clients.

9. **Diane Henderson, Professor of Mathematics:** The physical problem I am presently studying is the evolution of nonlinear water waves with one– and two–dimensional surface patterns using experiments and collaboration with analysts, modelers and computationalists. In our experiments, we generate wavefields using exact solutions of integrable partial differential equations, such as the nonlinear Schrödinger equation or the Korteweg de Vries equation - model equations that arise in several physical systems. We use the experiments to test predictions of these classical equations and to identify physical effects that should be included in them so that they provide accurate qualitative and quantitative descriptions of the observations. We are interested in the mathematical stability or instability of exact solutions of the original and modified equations, and the observed stability or instability of the corresponding wave patterns.

10. **Kristian Jenssen, Associate Professor of Mathematics:** My research is in the area of applied nonlinear partial differential equations. Specifically I am interested in systems of conservation laws, both viscous and inviscid, and my research focuses on large amplitude phenomena, shocks and detonations, vacuum formation, and stability of waves. Two important examples are the Euler and Navier-Stokes equations describing compressible fluid flow.

11. **Mark Levi, Professor of Mathematics:** I use analysis, geometry and topology to study problems in mechanics, electricity and other physical settings. I work in various areas of nonlinear dynamics - these include KAM (Kolmogorov-Arnold-Moser) theory with applications to stability of particular Hamiltonian systems; adiabatic invariants and chaotic behavior; waves in lattices of coupled oscillators; high-frequency vibrations and stabilization; long-term behavior of charged particles in magnetic fields.

12. **Jenny Li, Associate Professor of Mathematics** (and Associate Professor of Economics): My research interests center around mathematical modeling, analysis and computational simulations for problems arising in economics and finance, including modeling in monetary economics and economic theory, pricing high dimensional and exotic securities, and risk analysis.

13. **Luen-Chau Li, Associate Professor of Mathematics:** I work in the theory of integrable systems and its applications. Integrable Hamiltonian systems are nonlinear differential equations which have a lot of conserved quantities and can be solved in some sense. These equations are universal in the sense that the same equations can arise in different physical situations and mathematical contexts. A good part of my work is to find new integrable systems (which is not clear from the equations itself a priori) and to unravel their marvelous mathematical structures, with the goal of finding effective methods to integrate the equations and to apply them in various problems.

14. **Xiantao Li, Assistant Professor of Mathematics:** My recent research has been focused on multiscale modeling of crystalline solids. The main objectives are to extract material properties from atomistic models, understand the energetics and dynamics of material defects, design novel methods to model material behavior across different scales, and develop effective continuum models.

15. **Chun Liu, Professor of Mathematics:** My main interests are the study of elastic complex fluids, including mixtures and free interfacial motions of complex materials, liquid crystals, polymeric materials, magnetohydrodynamics and electro-kinetics, and viscoelastic materials. I work on the modeling, analysis and numerical simulations, as well as applications of these materials. In addition, we are working on physiological mechanics and transport, especially the deformation and transport of cells in cardiovascular systems.

16. **Lyle Long, Adjunct Professor of Mathematics (Professor of Aerospace Engineering)**: My research covers a wide range of computational physics applications, including compressible fluid dynamics, acoustics, detonations, rarefied gases, and turbulence. But I am also very active in the area of computational intelligence, including the use of cognitive architectures on mobile robots, and in developing neural networks for image and pattern recognition. I also run the graduate minor program in computational science, and teach courses in advanced computer programming and software engineering.

17. **Anna Mazzucato, Assistant Professor of Mathematics:** My research focuses on mathematical aspects of fluid mechanics. I study properties of weak and mild solutions to the Navier-Stokes and Euler equations, the partial differential equations describing incompressible viscous and inviscid fluid flow. I employ a variety of techniques, including microlocal and harmonic analysis, weak convergence methods. I also apply microlocal analysis to the study of inverse problems in anisotropic elastodynamics, in particular the problem of unique determination of elastic moduli from surface traction-displacement measurements.

18. **Victor Nistor, Professor of Mathematics:** My research interests are in numerical methods for Partial Differential Equations, and their applications to Structural Mechanics, Fluid Dynamics, Medical Imaging, Schrödinger Equations, and Mathematical Finance. For instance, I am interested in the treatment of singularities arising in PDEs due to singularities in the domain (the vertices and edges of polyhedral domains), singularities of the coefficients (transmission problems), or data ('concentrated loads and couples', which model the effect of forces acting on a small region of the boundary). Such singularities lead to a significant loss in the convergence rate for standard numerical methods. Overcoming this loss of regularity is a significant problem with many practical applications. "In my work I occasionally use in my research results from Geometric Analysis and Operator Theory, two ares in which I have worked in the past.

19. **Alexei Novikov, Assistant Professor of Mathematics:** My main research interests are in theoretical and numerical aspects of partial differential equations. The main topics of my research are transport in turbulent flows, and properties of particulate composites and suspensions. I develop rigorous multiscale methods to determine the effect of small-scale inhomogeneities on effective properties of fluids and composites. I also apply probabilistic methods to the study of martensitic transformations in polycrystals.

20. **Timothy Reluga, Assistant Professor of Mathematics (Adjunct Professor of Biology):** My research interests are in the analysis of biological systems using mechanistic models. Most of my recent research has been studies of transmissible disease dynamics both at the immunological and epidemiological scales and the consequences of these dynamics. I am generally interested in problems in ecology, evolution, and biochemistry. Specific topics that I've worked on include population game theory and vaccination, antibiotic resistance, hepatitis C virus, HIV, evolution of herd behavior, evolution and pathogen emergence, energetics, biological invasions.

21. **Wen Shen, Assistant Professor of Mathematics:** My main research interests lie in partial differential equations, especially in hyperbolic conservation laws. I like to work on theoretical problems as well as numerical simulations and applications. I work on relaxation problems, on the stability of the solution and the convergence to the equilibrium solution. I am also interested in applying hyperbolic theories in differential games, seeking different strategies and behavior of solutions. I like to work on numerical methods for PDEs, in particular finding fast, stable and convergent numerical methods for hyperbolic problems which have shocks (discontinuities) in their solutions. I am also interested in numerical simulation for multi-phase flow in porous media.

22. **Jinchao Xu, Distinguished Professor of Mathematics:** My research area is mainly the design, analysis, and applications of numerical methods for partial differential equations. I am interested in the study of basic discretization schemes (such as finite element), grid adaptation and advanced iterative methods (such as multigrid and domain decomposition). I am also interested in applying these techniques to numerical simulations for practical problems arising for example from complex fluids, electromagnetics, material sciences, and fuel cells.

23. **Yuxi Zheng, Professor of Mathematics:** My research interest is in the theoretical aspects of partial differential equations. Examples of the equations include the Euler systems for compressible and incompressible fluids, Vlasov-Poisson systems for plasmas, and nonlinear wave equations for elastic materials. Theoretical issues include singularity formation, pattern formation, or long time stability of solutions. In recent years I have become particularly interested in shock wave reflections upon an obstacle.

24. **Ludmil Zikatanov, Associate Professor of Mathematics:** My main research interests are in the design, analysis, and implementation of numerical techniques and methods used to obtain quantitative results from mathematical models. A major part of my work is related to algebraic multigrid methods, generalized finite element methods, and mesh-free discretizations of partial differential equations. My research focuses on the convergence properties of these methods, the effect of singularities on approximations, and the relationships between these numerical techniques and other discrete and continuous multiscale methods. Some of the physical models I have recently studied include: supercooling in transient thermoelectrics, Dirac-Wilson system in lattice quantum chromodynamics, electro-kinetic fluids, and free interface motion in fluids.