Department of Mechanical Engineering
Northwestern University
www.mech.northwestern.edu

Presentation to Prospective Graduate Students
ME Department Ranking

- The Chronicle of Higher Education, 2007, ranked us as
  No. 1 in Engineering Mechanics
  No. 7 in Mechanical Engineering
- The most recent National Research Council report released on Sept. 28, 2010 put our program as high as No. 2.
- The message: You are considering a very reputable Ph.D. program and we have many things to offer you…
NRC 2010 Report
R-Ranking (Regression-Based) Mechanical Engineering

- The dot represents the best reported rank for an individual program (i.e., the program was ranked this high or higher 5% of the time).
- Each line represents the range of reported ranking results for an individual program.

**Benchmark Programs**

*Non-AAU Institutions

Number of Programs in Field = 127

**NRC 2010 Report**
What can Northwestern offer you?

- Exciting interdisciplinary research programs that put you at the frontier of cutting-edge research and provide you with a solid foundation enabling you to be highly adaptive after graduation
- Excellent reputation of our school and faculty
- Rich experience of a multi-cultural metropolitan area
- Close ties with faculty and fellow graduate students

Apply to Northwestern
Faculty Contact Info:
http://www.mech.northwestern.edu/web/people/index.php
What can Northwestern offer you?

- All Ph.D. graduate students are supported on fellowships, research assistantships, and teaching assistantships.
- Health insurance is covered by NU in the first 6 years of Ph.D. study.
- Sports/fitness facility is free to students
- A matching process will be taken in the first quarter to allow students find the best fit
- Travel fund is available to support students attending conference
- ME students have been winning college-wide and university-wide competitive fellowships.

How to Apply to Northwestern – See the second to the last slide

Faculty Contact Info:
http://www.mech.northwestern.edu/web/people/index.php
Mechanical Engineering at NU

Research Thrust Areas for ME @ NU

- Design
- Mechanics in Bio & Health
- Nano/Micro-science
- Energy
- Multiscale Simulation

Core Groups

- Systems
- Manufacturing
- Mechanics
Collaboration at Northwestern

http://collaboration.mccormick.northwestern.edu/
Research Strengths at NU (Part 1 of 2)

- **Nondestructive evaluation**: Novel methods for testing structures, led by Prof. Jan Achenbach, one of only 11 recipients of both the National Medal of Science and the National Medal of Technology.

- **Computational solid and fluid mechanics**: Numerous awards and honor memberships have been awarded to faculty members in this field, including 3 faculty named as most highly cited researchers by ISI.

- **Mechanics of materials**: Research in composites, polymer and metals, includes one member of National Academy of Engineers (NAE).

- **MEMS/nanotechnology, neuromechanics and biomimetics**: Multiple faculty members with joint appointments in Biomedical Engineering, EECS, and Materials Science bridge interests from materials, fabrication, and devices to systems at the micro and nano scales.
Research Strengths at NU (Part 2 of 2)

- **Tribology**: One of only two NSF centers on Tribology. A multi-disciplinary team led by an NAE member produces one-of-a-kind capability in tribology.

- **Design and manufacturing**: This team stimulates national interest in micro- and nano-manufacturing, desktop factories, hybrid processes, design and optimization under uncertainty.

- **Robotics**: Interdisciplinary research in haptic interfaces, human-robot collaboration, prosthetics and rehabilitation robotics, bio-inspired locomotion, self-organizing systems and robotic manipulation.

- **Fluids**: Research in micro- and nano-scale fluid mechanics, electro-osmotic flows and biological flows.

Diverse research program spanning *traditional* ME topics to highly *interdisciplinary* areas
Research Centers Associated with ME

- **Center for Surface Engineering and Tribology**
  Understanding and control of basic friction, wear, and lubrication processes at sliding/contacting interfaces

- **Center for Intelligent Processing of Composite Materials**
  Development of comprehensive, science based approach for fabrication of affordable, functional and reliable composite structures

- **Center for Quality Engineering and Failure Prevention**
  Optical metrology and ultrasonics as applied to materials characterization and nondestructive evaluation

- **Dynamics of Complex Systems in Science and Engineering**
  Structural stability, long-term behavior, chaos, bifurcations, and the impact of symmetries on the dynamics of complex systems
Advanced Materials

- Nanocomposites
  - Synthesis of nanoparticle-polymer systems
  - Nanoscale characterization of polymers in confinement
  - Multiscale modeling

- Biomaterials, bioinspired materials
  - Mechanics of bone
  - Local characterization of soft tissue
  - Porous shape memory alloys for bone implants

Materials Genome
- Materials informatics
- Data mining and optimization constructs for advanced material design

LC Brinson
ME Chair
Jerome B Cohen
Professor

Composite Materials

Research Areas
- Processing
- Micromechanics
- Characterization
- Stress and Failure Analysis
- Composite Structures
- Nondestructive Evaluation
- Damage Mechanics
- Nanocomposites and Multifunctional Composites

Isaac M. Daniel
Walter P. Murphy Professor
Civil and Environmental Engineering and
Mechanical Engineering
Director, Center for Intelligent Processing of Composites

Widely used textbook by Isaac M. Daniel and Ori Ishai

Department of Mechanical Engineering www.mech.northwestern.edu
Atomistic modeling and simulation, nanobiomechanics

Structural dynamics, mechanics, thermal stability, degradation and failure mechanisms of organic and bioinspired materials for energy, infrastructure and biotechnology applications.

Sinan Keten

Biological material synthesis approaches catalyzed by mechanical forces (i.e. spinning of spider silk, self-assembling peptides).

Reactive modeling of organic polymers under chemical cues and mechanical forces (oxidative/reductive conditions, mechanical stress).
Computational Mechanics & Multiscale Methods

Computational Fracture
Extended Finite Element Methods (XFEM)
Computational Nanomechanics

Ted Belytschko
NAE, NAS, AAAS
6th most-cited engineering researcher worldwide

Computational Dislocations & Fracture Dynamics

Molecular Mechanics
Continuum Mechanics
Quantum Mechanics
Wing Kam Liu, Ph.D., P.E.
Highly cited and influential researcher in engineering

Walter P. Murphy Professor
Founding Director of NSF Summer Institute of Nanomechanics, Nanomaterials and Micro/Nanomanufacturing
Founding Chair of ASME NanoEngineering Council
Founding Co-Director: Predictive Science & Engineering Design

Computational Mechanics

- Use of nano/micro particles and molecules for the design of materials & devices in bio-medical/nano/energy applications
- Finite element, meshfree, and multiscale methods
- Computational biology and nanomedicine
- Simulation based engineering & science

Nanodiamond Platforms for Imaging and Therapeutic Applications
Applications of Nano-Particles to Materials & Devices Design

Nanocomposites
DNA Capturing and Gene Manipulated Cell Adhesion
Intelligent Structural Health Management

Intelligent Structural Health Management systems incorporate continuous diagnostic sensor data for closed-loop prognosis of remaining structural integrity, thereby facilitating timely remedial actions to prevent catastrophic structural failure. ISHM requires integration of several fields of engineering including:

- sensor technology & smart structures
- multifunctional materials
- multiscale analysis
- materials science
- nondestructive characterization
- failure and damage mechanics
- probabilistic lifetime prognosis

Northwestern University is leading an NSF-funded global partnership of universities, laboratories, and companies to engage in cutting-edge research and education in the area of ISHM of safety-critical aerospace, civil & mechanical structures. Information about this program is available at: http://ishm.northwestern.edu.

J. Achenbach, NAE
Scanning Probe Measurement Techniques
• Photoacoustics and Photothermal Microscopy
• Near field Optical Microscopy
• Ultrasound Modulated Atomic Force Microscopy

Materials Characterization and Nondestructive Evaluation
• Mechanical, Thermal, Structural, and Interfacial Properties
• Microstructure – Mechanical Property Relationship

Modeling
• Elastic Wave Propagation
• Laser Generation of Acoustic Waves

Thin Film Thickness Metrology using Laser Generated Surface Acoustic Waves (SAW)
Modeling the Mechanical Properties of Intermetallic/Solder Interfaces

Technical Problems:
Fatigue failure under coupled thermal-mechanical-electric loading
Crack nucleation and propagation near the interface of solder and Intermetallic compound
Thermomigration, Joule heating caused by Higher current density

Research:
Finite Element Analysis of Solder/Intermetallics
Solder constitutive relationship; Interfacial Behavior;
Mechanical & Thermo-Electric Analysis
Phase Transformation Theory Applied to Fatigue Analysis
Electromigration Effect

SEM image of interconnect fatigue crack
Nanotechnology

- Mechanics/Electro-mechanics of Nanostructures
- Biomimetic Nanocomposites
- Cellular Studies and Biomechanics
- Nano-electronics
- Dynamics failure of Materials

In-situ SEM/TEM electro-mechanical characterization

Nanofountain probes

Nanocomposites & Bio-inspired materials

Carbon nanotube NEMS

H. D. Espinosa
James and Nancy Farley Professor
Director, Theoretical and Applied Mechanics Program
Research Areas

- Mechanics of heterogeneous materials
- Interface mechanics
- Reliability of microelectronic packaging
- Wave propagation
- Ultrasonic nondestructive evaluation
- Nano-scale thermal transfer
- Modeling and simulation of multi-field interactions
- Atomistic level modeling and simulations

Jianmin Qu
Water P. Murphy Professor
Department of Mechanical Engineering
Department of Civil and Environmental Engineering
Biologically-Inspired Sensing, MEMS, Nano Fab

- Biologically-inspired sensors and sensing
  - Artificial haircell sensors
  - Artificial lateral line sensors
  - Tactile sensors
  - Signal processing and control
- MEMS and Nanofab
  - Polymer MEMS
  - Nanocomposite elastomers
  - Intelligent sensing skin
  - Nanofluidics
- Systems application of sensors
  - Autonomous underwater vehicles
  - Sensor networks
  - Energy harvesting

Example: Artificial lateral line research - studying biology, developing micro/nano sensors, and building systems
Nanoscale Science and Engineering at ME

Developing innovative nano-scale fabrication techniques and integrated nano-systems for bio-sensing and high-efficiency energy conversion.

Nano-manufacturing

Nano-imaging

Bio-sensing

Future Integrated Nano-Device/System

C. Sun
Mechanics and Control of Manufacturing Processes

- **Micro-forming**: roll-forming of micro-channels on metallic parts for heat exchangers, micro-fluidics molds, ultra-thin connectors; machine design; material constitutive modeling and experimental characterization.
- **Multi-scale Dieless Incremental Forming**: a new means for rapid prototyping or small volume production: process design, deformation and failure mechanics, machine design and control.
- **Laser Texturing** for increasing energy efficiency in a mechanical system and altering surface behavior: process mechanics and process optimization.
- **Composite Sheet Forming**: material characterization of woven composites and process control.

J. Cao
Director, Graduate Studies

5-axis laser texturing system
MICROMANUFACTURING
- Micro-machining: actuator, dynamics, machine design
- Flexible manufacturing to enable distributed manufacturing
- Embedded sensors
Tribology, Surfaces and Contact Interfaces

TOPICS
Contact Mechanics of Engineering Materials
Design of Surfaces for Energy Efficiency and Durability
Design of Advanced Functional Lubricants
Exploration of Novel Surface Engineering Techniques

Q. Jane Wang
http://othello.mech.northwestern.edu/qwang/
Manufacturing Tribology

-Metal Forming Tribology: Design of unique test apparatus suitable for metal forming applications. Application of hard coating to dies.

-Surface Engineering: Applications of micro textures on tools, analyzing surface behavior, engineering surface fabrications of functional surface.


Kuniaki Dohda

Dimple-Forming on the Inner Surface of Pipes

Ironing Type Tribometer

Inside-Ironing of Pipe
Engineering Design

- Design under uncertainty
- Topology optimization
- Stochastic multiscale analysis and design
- Model validation & uncertainty quantification
- Enterprise-driven Decision Based Design

Design of Materials System

Distribution of mean particle size

Nano inclusion correlation function

\[ C_2^{(i)}(x_1, x_2) \equiv <I^{(i)}(x_1)I^{(i)}(x_2)> \]
Elizabeth Gerber
Creative Action Lab
Department of Mechanical Engineering
Segal Design Institute
Northwestern University
2133 Sheridan Road
Evanston, IL 60208
Email: egerber@northwestern.edu
http://www.creativeactionlab.com

Core Expertise
Creativity and Innovation; Human Centered Design; Human Computer Interaction; Crowdsourcing

Education
PhD in Management Science and Engineering, Stanford University
MS in Product Design, Stanford University

About
Dr. Gerber is an expert in creativity, design, technology, and work. As a professor in the Segal Design Institute at Northwestern University, she holds an appointment in Mechanical Engineering and Communication Studies and by courtesy in Management Science and Industrial Engineering, the Kellogg School of Management, and the School of Education and Social Policy.

Dr. Gerber is the principal investigator for the Creative Action Lab, which investigates the role of technology (digital tools and work practices) in supporting individual, group, and crowd creativity and innovation. In her Lab, she applies the behavioral sciences to the design of tools and practices to improve usability and creative performance. Currently, she is researching and developing tools for collective design. Dr. Gerber’s Lab publishes work relevant to the design, management, and human computer interaction communities.

Dr. Gerber is also the faculty founder of Design for America, an award winning educational initiative building creative confidence in students through design for local and social impact (www.designforamerica.com).

Sample Publications
“Crowdfunding: Why People are Motivated to Post and Fund Projects” Conference on Computer Supported Cooperative Work 2012
“Momentum: Getting and Staying on Topic During a Brainstorm” Proceedings of CHI, ACM Press, 2010
Robotics: Laboratory for Intelligent Mechanical Systems

- J. E. Colgate
- K. Lynch
- T. Murphey
- M. Peshkin

- Robotic manipulation
- Haptic interfaces
- Swarming, self-organization
- Human-robot systems
- Puppetry
- Motion planning, bio-inspired sensing

Department of Mechanical Engineering  www.mech.northwestern.edu
Prosthesis Design & Control Lab

Mechatronic Prosthesis Design
- Hands, wrists, elbows
- Ankles, knees
- Motor & transmission design
- Linkage design

Developing-world Prosthesis Design
- Hand, socket, & harness design
- Collaborations with BMVSS, India & Mahidol University, Thailand

Haptics / Human Machine Interfaces
- Miniature wearable Haptic Interfaces

Jon Sensinger
Patient-centered research @ RIC
Neural Engineering Program in ME

- How do animals acquire sensory information?
- How is that information processed by neural circuits to allow the animal to “perceive” an object and guide the animal’s next movement?
- Rat whiskers are a model system for tactile sensing and perception.

M.J. Hartmann

Mechanical Models

Robotic models

Behavioral Studies

Models of neural circuits

Neural Recordings

Department of Mechanical Engineering  www.mech.northwestern.edu
Neural Engineering Program in ME

Hydrodynamics of the ribbon fin in the black ghost knifefish
Ribbon fin allows omnidirectional movement in water → robotic ribbon fin → AUV (autonomous underwater vehicle)

Apteronotus albifrons

Ribbon Finicus roboticus

M. Maclver
Prelude to Neural Engineering in ME

**PROTEIN DYNAMICS**

Proteins are manufactured in the ribosome…

…and then fold into precise 3-D shapes

- Solid mechanics about the slender structures
- Fluid mechanics
- Thermodynamics
- Control theory

S. Lichter
Granular Flow/Complex Systems

Pattern Formation
Mixing and Demixing
Dynamical Systems and Chaos

Julio M. Ottino
Dean, McCormick

Richard M. Lueptow
Senior Assoc. Dean, McCormick
r-lueptow@northwestern.edu
Computational Fluid Dynamics

CFD: Immersed Bodies
- Swim, flight, sediment
- Basic algorithms
- Brownian motion
- Cellular processes
- Lotus effect
- EHD flows/Micromixing
- Instabilities AC/DC

Overview of research in Patankar group

Mesoscale Brownian simulation of protein diffusion and binding

Aquatic Locomotion & Animation
- Blackghost knife fish
- Eel
- Jellyfish

Molecular scale liquid slip

Sediment transport

Eel

Animated images

N. A. Patankar
Mathematical Theory of Micro & Nano-scale Fluid Mechanics

- Electrokinetic flows in microchannels
- Transport problems in microfluidics
- Electrodiffusion & Electrohydrodynamics
- Single molecule transport through nanopores

Sandip Ghosal
Associate Professor

**Figure:** Transport equations for Electromigration Dispersion in a CE channel may be reduced to the Burgers Equation that describe wave breaking in a variety of contexts.
Biotransport and Ocular Biomechanics

Mark Johnson

Research Areas
Lipid & Macromolecular Transport
Biofluid Mechanics
Cellular Mechanics
Diffusion in Chaotic Processes

Morphometry, Stereology &
Advanced Electron Microscopy

Atomic Force Microscopy

\[
\phi' = 1 - (1 - \phi) \exp \left( \frac{-aD_f}{4(1 - \phi)} \right)
\]

\[
\alpha' = \frac{a\pi}{4} \exp \left( \frac{-aD_f}{4(1 - \phi)} \right) \left( 1 + \frac{2aD_f}{3\pi\phi} \frac{aD_f}{4(1 - \phi)} \right)
\]
Quick facts of faculty and school
Mechanical Engineering at NU – Quick Facts

- 35 faculty members and 8 courtesy faculty
- 1 winner of National Medal of Science
- 1 winner of National Medal of Technology
- 6 members of the National Academy of Engineering
- 3 members of the National Academy of Sciences
- 4 members of the American Academy of Arts and Sciences
- 21 faculty members are fellows of at least one professional society
- 8 editors-in-chief of international research journals
- 13 associate editors of at least one research journal
- 16 awardees of young investigator awards (NSF CAREER, ONR, Whitaker Foundation)
- > $8.1 million research expenditures
- Top 5 ME Department in 2010 NRC Rankings
- No.1 in Engineering Mechanics and No.7 in Mechanical Engineering – The Chronicle of Higher Education

Outstanding Central Facilities

- Mechanical Engineering Machine Shop
- Rapid Prototyping Laboratory
- *NUANCE*: NU Atomic and Nanoscale Characterization Experimental User Facility
- Mechanical Properties & Fatigue Facility
- Optical Microscopy and Metallography Facility
- Chemical analysis facilities
- Center for Nanofabrication and Molecular Self-Assembly
- Center for Nanoscale Materials (CNM) @ Argonne
- plus specialized equipment in research group labs…
Strong interactions within Engineering School:

- Applied Mathematics
- Biomedical Engineering
- Chemical and Biological Engineering
- Civil and Environmental Engineering
- Computer Science
- Electrical and Computer Engineering
- Industrial Engineering
- Materials Science and Engineering

And across the university:

- Chemistry Department
- Medical School
- Kellogg Graduate School of Management
- Rehabilitation Institute of Chicago
- .....

Diverse research program spanning traditional ME topics to highly interdisciplinary areas
Northwestern University

- Private university
- Established in 1851
- 17,700 students
  * 7,600 undergraduate
  * 6,100 graduate
  * 4,000 part-time
- One of the top-ranked universities in USA
- Beautiful campus on Lake Michigan
- Fabulous theatre and arts program
- Downtown Chicago easy access by the “EL” (rail mass transit)
- Many summer festivals in Evanston & Chicago
- Abundant convenient housing close to campus
- Great sports center/athletic fields/boating center
- Wonderful and affordable restaurants
- Exciting, friendly, collaborative atmosphere
SPAC/ Henry Crown Sports Pavilion

- Olympic pool
- Jogging track
- Weight rooms
- Tennis, racquetball, squash
- Basketball courts
- Cardiovascular equipment
- Private beach
- Membership free to students
Chicago – Population 7 Million
Chicago Millennium Park

“Millennium Park honors and builds on several proud Chicago traditions at once - beautiful architecture, landscaped and protected parklands, and the ongoing celebration of the arts.”

- Mayor Richard M. Daley
Museums
Professional Sports

- Chicago is a great sports town. It is one of the few cities in the nation with two professional baseball teams (Cubs and White Sox), football (Bears), soccer (Fire), basketball (Bulls) and hockey (Blackhawks and Wolves).

- Visit [http://egov.cityofchicago.org](http://egov.cityofchicago.org) for more information about Chicago.
ME Graduate Student Society (MEGSS)
http://www.mech.northwestern.edu/students/megss/Welcome.html

- Student voice in department
  - Representatives on faculty committees
- Social Interaction
  - Promotes meeting students outside lab/research area
  - Bi-monthly social
  - Semi-annual outings (concerts, new student welcome)
- Mentor Program
  - Pairs incoming students with current MEGSS members
  - Assist in quick acclimation to NU environment
    - housing, advisor selection, courses, Chicago/Evanston activities
Mechanical Engineering at NU – Ph.D. Program

- 15 courses post-BS degree
- MS thesis with defense (optional en route to PhD)
- Candidacy exam: written thesis proposal and oral exam
- Opportunities for internship (industry, govt lab…)
- Ph.D. placement statistics:
  - 40% - academia
  - 4% - government labs
  - 56% - industry
How to Apply?

- On-line application only: https://app.applyyourself.com/?id=nwu-grad
- Deadline: December 31, 2012
- Application fee: $75 paid by credit card only
- GRE: school code – 1565
  - GRE scores must be no older than September 1, 2008.
- TOEFL: school code – 1565
  - Test scores must be no older than September 1, 2011
- Frequently asked questions and answers at http://www.mech.northwestern.edu/web/graduate/FAQ.htm

Contacts:
- Prof. Jian Cao, jcao@northwestern.edu, Director, Graduate Studies
- Ms. Pat Dyess, j-dyess@northwestern.edu, Graduate Program Assistant, 847-491-7190.
The Department of Mechanical Engineering hopes to receive your application!

www.mech.northwestern.edu