PURDUE UNIVERSITY

2008-2009 ANNUAL REPORT

FALL 2009

RAY W. HERRICK LABORATORIES

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HERRICK LABORATORIES
PURDUE UNIVERSITY™

THE RAY W. HERRICK LABORATORIES

The Ray W. Herrick Laboratories were founded in the mid-1950's as a research laboratory for studying the effects of climate control and for the design of improved climate control equipment. The Labs have grown and evolved into a center where graduate education and engineering research are combined in close partnership with industry in order to develop people and results of great importance. The Herrick Labs goal is to sustain a culture of excellence in an environment of partnership and shared resources.

The research programs of the Herrick Labs can be described in four general areas; electro-mechanical systems, noise and vibration control, perception based engineering, and thermal systems. The community at the Herrick Labs, which includes the faculty, staff, students, and sponsors, is focused on results that are both fundamental research discoveries and of practical importance to sponsors.

The educational experience at the Herrick Labs combines the traditional training of aspiring researchers with exposure to industrial needs and culture. Students study in a strong peer education environment with active mentoring from faculty and sponsors. Almost 700 Masters and PhD candidates have graduated from the Herrick Labs.

The engagement/service programs are highlighted by the well established conference and short course activity sponsored by the Herrick Labs. In addition, technology transfer to sponsors is an integral part of a majority of the research programs. The researchers at the Herrick Labs are also widely published across the spectrum of publications from academic journals to the popular press.

MISSION

An institution dedicated to graduate education and engineering research with emphasis on technology transfer to industry.

VISION

To overcome the barriers between knowledge creation, transfer, and utilization and to become leaders of how graduate education and engineering research are done in partnership with industry.

GOALS

1. To build upon the research excellence of the *Noise and Vibration Control Research Area*, the *Heating, Ventilation, Air-Conditioning, and Refrigeration Research Area* and the *Electro-Mechanical Systems* to enhance their national and international visibility and grow the reputation of these areas as the top research programs in the world.
2. To identify emerging research areas that are synergistic with laboratory focus.
3. To develop a proactive evolutionary strategy for the Laboratories to ensure its long-term stability and growth.
4. To improve the educational environment at the Labs so that its graduate students are multi-functional engineers who rate as the top engineering graduates in the country.
5. To continually monitor the technology transfer process by which research results are transferred to sponsors and the engineering community such that the labs will be recognized as *the* premier source of practical cutting edge research in our areas of expertise.
6. To continually grow the research environment at the Labs for the benefit of the students and faculty at the Labs.

2008-2009 HIGHLIGHTS

Research	*Last Year*	*This year*
Research expenditures (*academic year)	$5,032,708	$5,356,327
Number of sponsors as of September 2009	33	28
Research assistants as of September 2009	56	71
Archival papers published (*calendar year)	56	54
Contracts in force for next academic year (July 2009-June 2010)	$1,605,942	$2,201,532
Proposals pending in September (HL share)	$3,236,411	$5,727,713
Large multi-person proposals	$11,867,756	$4,834,877 (R) +$11,750,000 (B)
Education		
Graduate students as of September	66	86
MS	23	37
Ph.D.	43	49
Students graduated (*calendar year)	20	11
MS	10	6
Ph.D.	10	5
Undergraduate/graduate "research experience" students	9	16
Visiting scholars, Post Doctoral Students, Visiting Research Assistants	16	18
Fellowships	9	7
Grant-in-Aid	2	2
Student Paper/Poster/Thesis Awards	3	3
Technology Transfer		
Conferences/Workshops held (*academic year)	1	9
Conferences planned in the next 2 years	4	4
Short Courses held (*academic year)	7	7
Herrick Labs reports to sponsors (*academic year	13	9
Conference and journal papers (*calendar year)	139	122

Associate Editor of the **International Journal of HVAC&R Research -** (Jim Braun)

Advisory Board Member, **International Journal of Refrigeration** and
Advisory Board Member, Karlsruhe House of Young Scientists, **Karlsruhe Institute of Technology** (Germany) - (Eckhard Groll)

Advisory Board Member, **Noise Control Engineering Journal -** (Stuart Bolton)

Editor-in-Chief, **Building and Environment (BAE) Journal -** (Yan Chen)

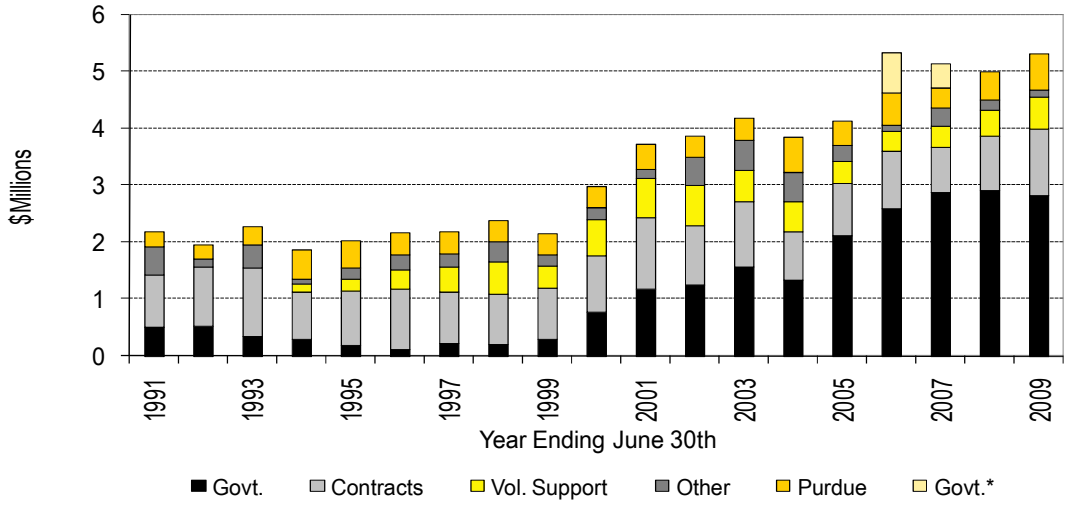
President, **Institute of Noise Control Engineering**, April 1, 2008 – 2010 - (Patricia Davies)

* Academic Year - July 2008 → June 2009 and Calendar Year - January 2008 → December 2008

Administrative and Support Staff

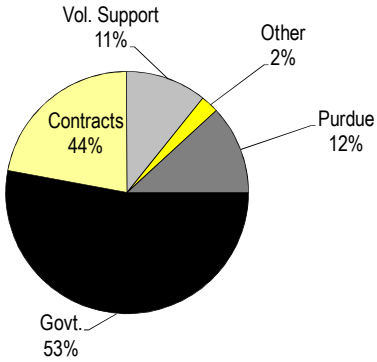
Professor Patricia Davies serves as director of the Ray W. Herrick Laboratories. Judy Hanks is her administrative assistant. The research programs are assisted by the mechanical and electronics shops headed by Fritz Peacock, supervisor of technical services. Ginny Freeman serves as administrative assistant for the Herrick Laboratories' conferences and short courses. Additional support staff includes Donna Cackley, secretary; Gilbert Gordon, electronic shop coordinator; Bob Brown, mechanical shop coordinator and building deputy; and Frankie Lee, mechanical technician.

2008-2009 EXPENDITURES

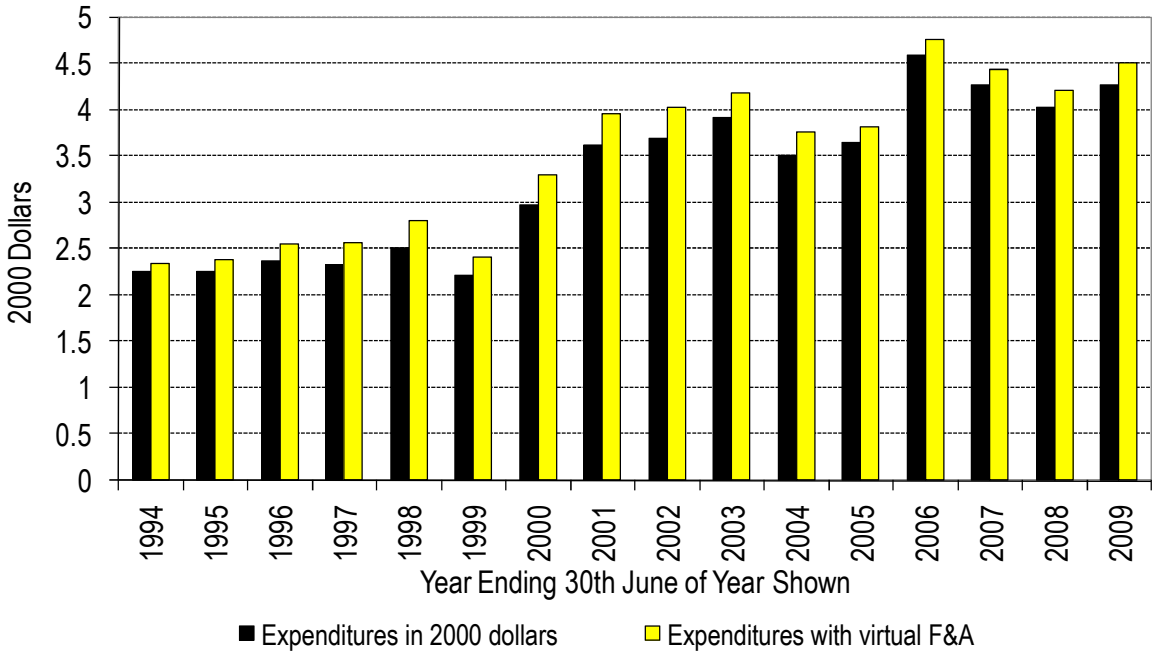


Sources of 2007-2008 Research Expenditures

Expenditures for the 2008-2009 academic year are just below last year. These expenditures reflect a large amount of effort from our faculty, students and staff. Defense industry funding appears in the government section (updated from last year).

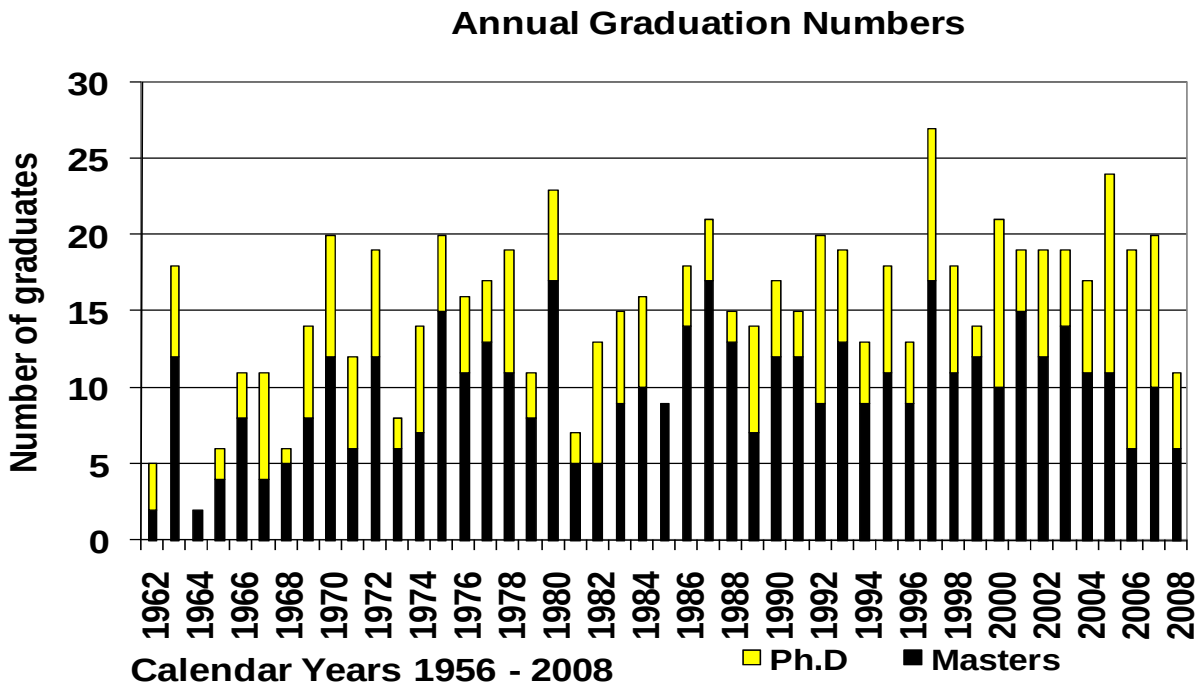


Research Expenditures in 2000 Dollars



HERRICK LABS EDUCATION PROGRAMS

The primary educational program at the Herrick Labs is thesis based graduate education. We believe that the experiential learning, the open-ended and integrative nature of thesis based research is outstanding preparation for both academic and industrial careers. To complement the student/advisor relationship, the Labs offer a learning community to the student. This community includes an outstanding cohort of graduate students as well as a staff prepared to support and teach. In many cases, the student's research is sponsored. Sponsor representatives also participate in educational activities with the student. We also have programs where graduate students do internships in industry or government laboratories. In total we believe this is an outstanding educational opportunity for our graduate students.



Fellowships

Tyler Dare received the 3M E-A-R Acoustics Scholarship at the NOISE-CON 2008 Conference

Carrie Hall received the Laura Winkleman Davidson Fellowship for Doctoral Studies

Derek Hengeveld was named an Air Force Research Laboratory (AFRL) Space Scholar

Feng Liu received The Society of Image Science and Technology Raymond Davis Scholarship

Sarah McGuire received the Amelia Earhart Fellowship

Rajani Modiyani received the Cummins Fellowship

Ryan Schultz received the Helen & John Lozar Endowment Assistantship

Matias Zanarto received the "SHPE AHETEMS Scholarship" (Advancing Hispanic Excellence in Technology, Engineering, Math and Science) from the Society of Hispanic Professional Engineers

Wangda Zuo received the IBPSA-USA Scholarship at the SimBuild Conference and 3rd place in the poster competition

Wangda Zuo received the Graduate School Incentive Grant from Purdue University

Grants-in-Aid

Ian Bell received an ASHRAE Grant-in-Aid

Derek Hengeveld received an ASHRAE Grant-in-Aid

Awards

Craig Bradshaw received an award for best poster presentation at the CTRC Bi-Annual Meeting

Derek Hengeveld received the AIAA Foundation Open Topic Graduate Award

Amit Mohanty received The Magoon Award for Teaching Excellence, School of Mechanical Engineering

Taewook Yoo awarded the Best Student Paper Award at the NOISE-CON 2008 Conference

HERRICK LABS FACULTY RESEARCH INTERESTS

Douglas E. Adams, professor of mechanical engineering. PhD 2000, University of Cincinnati. Experimental nonlinear dynamics and system identification, diagnostics and prognostics, health monitoring, system-level modeling (compressors, suspensions, exhausts, mounts).

Anil K. Bajaj, professor of mechanical engineering. PhD 1981, University of Minnesota. Nonlinear oscillations in structures, chaotic dynamics, stability analysis, flow-induced vibrations, perturbation techniques, mistuned structures, and localization of modes, drum and disk brake squeal-friction induced vibrations, modeling of carseat-occupant dynamics, and modeling/identification of polyurethane foam properties.

Robert J. Bernhard, currently vice president for research at Notre Dame University, but continues his road-tire research at Herrick Laboratories. PhD 1982, Iowa State University. Tire/Pavement noise, acoustics, noise and vibration control, and validation of numerical methods.

J. Stuart Bolton, professor of mechanical engineering. PhD 1984, University of Southampton. Acoustics, models of porous noise control materials, optimal design of noise control materials and treatments, physical properties of noise control materials, analysis of tire vibration and sound radiation, nearfield acoustical holography, visualization of motor vehicle passby sound radiation, and machinery noise source identification.

James E. Braun, professor of mechanical engineering. PhD 1988, University of Wisconsin. Thermal systems measurements, modeling, analysis, design optimization, and control optimization with applications to air conditioning and refrigeration equipment and systems.

Qingyan (Yan) Chen, professor of mechanical engineering. PhD 1988, Delft University of Technology. Indoor and outdoor airflow modeling by computational fluid dynamics and measurements, protection of buildings from chemical/biological warfare attacks, building ventilation systems, indoor air quality, airline cabin environment.

George T.-C. Chiu, professor of mechanical engineering. PhD 1994, University of California at Berkeley. Mechatronics, modeling/control of digital imaging and printing systems, signature embedding for image/document security, material delivery systems for micro-fabrication, assistive devices for patient handling and movement, motion control, embedded systems/control, and perception-based engineering.

Patricia Davies, professor of mechanical engineering, Director of the Ray W. Herrick Laboratories. PhD 1985, University of Southampton. Signal processing and data analysis applied to mechanical systems, condition monitoring, vibration measurement, sound quality and perception-based engineering, nonlinear system identification, modeling of car seat-occupant dynamics and modeling and identification of foam properties.

Eckhard A. Groll, professor of mechanical engineering. PhD 1994, University of Hannover, Germany. Thermal sciences as applied to advanced HVAC&R systems, components, and working fluids: alternative refrigeration technologies, vapor compression systems, natural refrigerants, compressor research, heat exchangers analysis, miniatur refrigeration systems for electronics cooling.

W. Travis Horton, assistant professor of civil engineering. PhD 2002, Purdue University. Thermal sciences and energy conversion systems, including heating, air conditioning, refrigeration, and electrical systems; combined heat and power systems, and building energy modeling techniques.

Monika Ivantysynova, MAHA Professor of Fluid Power Systems. PhD 1983, Slovak Technical University of Bratislava. Fluid power systems and components measurements, modeling, analysis, design optimization, and control optimization with applications to off-road vehicles, airplanes, cars, robots and other drive systems.

Kristofer Jennings, assistant professor of statistics. PhD 2003, Stanford University. Bootstrap resampling, applied statistics, engine dynamics and fault detection.

Charles M. Krousgrill, professor of mechanical engineering. PhD 1980, California Institute of Technology. Nonlinear oscillation, elastic stability, dynamics, vibrations, rotor dynamics, chaos, automotive brake squeal/vibration, and vibration in gearing systems.

Kai Ming Li, professor of mechanical engineering. PhD 1987, University of Cambridge, UK. Environmental acoustics, sound propagation outdoors, noise control in built environments, monitoring of natural and human produced sounds in the environment, computational acoustics, physical acoustics and wave propagation in a complex medium.

Peter H. Meckl, professor of mechanical engineering. PhD 1988, Massachusetts Institute of Technology. Motion and vibration control of high-performance machines, adaptive control, virtual sensing, and diagnostics. Applications to manufacturing devices, robotics, and automotive engines.

Jeff Rhoads, assistant professor of mechanical engineering. PhD 2007, Michigan State University. Nonlinear dynamics and vibration of macro-, micro-, and nanomechanical systems, micro- and nanoelectromechanical sensor design, mechanical and electromechanical amplifiers, parametrically-excited systems, mechanical and electromechanical radio-frequency (RF) components, system dynamics.

Gregory Shaver, assistant professor of mechanical engineering. PhD 2005, Stanford University. Modeling, design and control of advanced powertrains for the purpose of developing clean, efficient and practical approaches to utilizing conventional and alternative fuels. Coordination of combustion process with aftertreatment systems and hybrid powertrains. Novel combustion methodologies: Homogeneous Charge Compression Ignition (HCCI), clean diesel.

Bin Yao, professor of mechanical engineering. PhD 1996, University of California at Berkeley. Coordinated control of intelligent and high performance electro-mechanical/hydraulic systems; mechatronics; robotics; automotive control; optimal adaptive/robust controls; nonlinear observer design and neural networks for virtual sensing, modeling, fault detection, diagnostics, and adaptive fault-tolerant control; data fusion.

MAJOR RESEARCH FACILITIES

Thermal Systems Research Area

- Two 7000 ft^3 psychrometric rooms with –10° to 130°F temperature range
- Two room indoor air quality (IAQ) laboratory
- Psychrometric wind tunnel with dust injection system
- Large HVAC equipment lab with 90 ton centrifugal chiller
- Two computer controlled compressor load stands for small compressors
- Many bench test facilities and special experimental setups

Noise and Vibration Research Area

- 25 by 20 by 18 ft reverberation room
- Anechoic room with useful volume 12 by 12 by 12 ft
- Hemi anechoic room with useful volume 41 by 27 by 18 ft
- 8 by 8 ft audiometric room
- Acoustical materials laboratory
- Two wheel chassis dynamometer with 67 inch rollers
- Anechoic wind tunnel with 18 by 24 inch test section and flow velocity up 120 mph
- Three 1000 lb_f hydraulic shakers with 4 inch stroke
- Two 400 lb_f electromagnetic shakers
- 64 microphone acoustical holography array and 90 channel data acquisition system

Perception Based Engineering

- 8 by 8 ft audiometric room
- Printer image quality facilities
- Binaural measurement system and sound quality estimation software
- Steering wheel vibration perception facility
- Two room indoor air quality (IAQ) laboratory
- Perception Based Engineering Lab *(future*) (combined thermal, acoustic, motion, and visual perceptions)

Electro-mechanical Systems Research Area

- 1500 psi 3-axis electro-hydraulic robot
- Four post experimental electro-hydraulic lift system
- Diesel engine control load stand with eddy current dynamometer, EGR, and exhaust after-treatment with transient emissions analyzers
- Gasoline engine control load stand with eddy current dynamometer and transient emissions analyzer
- Prognostics modeling and simulation facility
- Thermal/acoustic test facility
- Environmetrics material conditioning chamber
- MTS static/dynamic/fatigue test apparatus
- Large inventory of vibration and acoustics sensors and actuators

CURRENT HERRICK LABS STUDENTS

Student	Major Professor	Thesis Subject
Gayatri Adi	Shaver	Modeling, design and control of advanced power train
Varun Agrawal	Yao	Adaptive robust control of flexible cable driven surgical robotic devices
Yousof Azizi	Davies	Modeling of polyurethane foam and seat dynamics
Christian Bach	Groll	Optimizing refrigerant distribution in evaporators
Michelle Bash	Groll	Smart Compressors
Ian Bell	Groll/Braun/King	Ericsson cycle cooler
David Berdy	Rhoads	Wireless sensors for structural health monitoring
Chaitanya Bhat	Meckl	Multi-objective optimization of small electric power units
Udbhau Bhattiprolu	Davies	System identification techniques for foam systems
Nasir Bilal	Adams	Prediction uncertainty in compressor modeling and simulation
Craig Bradshaw	Groll	Analysis of miniature-scale linear compressors for electronics cooling
Carson Budde	Adams	Load identification in composite rotors
Matt Butner	Adams	Characterizing dynamic response of structural systems that interact through an interface
Hoyt Yu Chang	Li	Acoustics
Li-Jen Chen	Mongeau	Fluid structure interactions within the human larynx
Howard Cheung	Braun	Modeling and testing of ductless heat pumps
Josh Cummins	Adams	Tire diagnostic testing
Scott Dana	Adams	Integrated blade sensing
Tyler Dare	Bernhard	Investigation of tire/pavement noise generation mechanisms
Yash Deshmukh	Davies	Nonlinear dynamics of seat-occupant systems
Tiffany Di Petta	Adams	Health monitoring of military vehicles
Frank Eberhardt	Davies/Bolton	Diesel engine noise
Kevin Foertsch	Davies	Aircraft noise
Shreekant Gayaka	Yao/Meckl	Diagnosis and emission control of engines
Jitendra Gupta	Chen	Infectious disease transmissions in airliner cabins
Thanh Huy Ha	Chiu/Allebach	Electromechanical systems
Carrie Hall	Shaver	Fuel flexible combustion control
Derek Hengeveld	Braun/Groll	Development of a system design methodology or robust thermal control systems to support operationally responsive space
Julio Ho	Bolton/Wodicka	Speech acoustics
Kang Hou	Bolton	Acoustics of small enclosures
Matt Houtteman	Adams	Nondestructive testing
Andy Jessop	Bolton	Acoustic radiation from tires
Gauri Joshi	Davies	Nonlinear dynamics of seat-occupant systems
Raymond Joshua	Adams	Nonlinear methods and testing of morphing aircraft
Ravindra Kakade	Meckl	Engine diagnostics
Nicholas Kim	Bolton	Microperforated materials
Woohyun Kim	Braun	Methods for evaluating diagnostic protocols for packaged air conditioning equipment
Lyle Kocher	Shaver	Variable valve actuation engine research
Ed Koeberlein	Shaver	Variable valve actuation engine research
Vijay Kumar	Rhoads	Parametric amplification
Yan Fu Kuo	Chiu	Tone curve stabilization for color electrophotography
Ki Sup Lee	Chen	Air distribution effectiveness with stratified flows in rooms
Sheng Liu	Li	Transmission of low frequency sound above a poro-elastic ground
Yangfan Liu	Davies/Bolton	Acoustics/signal processing

CURRENT HERRICK LABS STUDENTS
(CONTINUED)

Lu Lu	Yao	Integrated direct/indirect adaptive robust control with quantitative parameter estimation
Vishal Mahulkar	Adams	System of systems modeling and optimization in Navy ships
Andrew Marshall	Davies	Human response to supersonic aircraft noise
Margaret Mathison	Braun/Groll	Modeling of a two-stage rotary compressor
Sagnik Mazumdar	Chen	Airliner cabin environment research
Sarah McGuire	Davies	Feasibility of constructing a survey and measurement database for validating environmental noise metrics
Shawn McKay	Adams	System of systems reliability analysis in Navy ships
Alan Meyer	Adams	Mechanics and Vibrations
Janette Jaques Meyer	Adams	Modeling and simulation of rattle vibrations in car seats
Rick Meyer	Yao	Modeling and adaptive robust control of fuel cell power systems
Rajani Modiyani	Shaver	Modeling and control of HCCI
Amit Mohanty	Yao	Coordinated control of electro-hydraulic robot manipulators
Ranjit More	Meckl	Diagnostics of advanced diesel fuel injectors
Shashi More	Davies	Aircraft noise characteristics and metrics
James Mynderse	Chiu	Motion and vibration control
Joe Poland	Groll	Acoustically enhanced heat transfer in microchannels
Tyler Robbins	Adams	Acoustic leak detection in engine blocks
Chris Satkoski	Shaver	Modeling and control of piezo-electric fuel injection
Ryan Schultz	Meckl	Diesel particulate filter diagnostics
Bryce Shaffer	Groll	Conduction cooled EIE modules in liquid cooled cabinets
Hsin-Chien Shih	Yao	Modeling and control of a hydraulic arm
Hyunjun Shin	Bolton	Acoustical materials
Yoon Shik Shin	Bolton	Electronic cooling fan noise
Janene Silvers	Adams	Active vibration control of fuselage structure
David Snyder	Shaver	Modeling, design and control of advanced powertrain
Karla Stricker	Shaver	Advanced combustion control with variable valve actuation
Hales Swift	Davies	Health effects of noise
Hongdan Tao	Li	Sound structural transmission
Bao Tong	Li	Environmental acoustics
Sara Underwood	Adams	Composite damage detection using laser vibrometry
Dan Van Alstine	Shaver	Advanced mode combustion control with variable valve actuation
Miao Wang	Chen	Modeling low velocity large scale fluctuating flows in ventilated spaces at transitional Reynolds numbers
Jonathan White	Adams	Structural diagnostics in thermal protection systems
Brandon Woodland	Braun/Groll/Horton	Organic rankine cycle with solution circuit for waste heat recovery
Guangqing Xue	Chen	Infectious disease transmissions in airliner cabin
Nate Yoder	Adams	Diagnostics and prognostics for rolling tires
David Yuill	Braun	Methodologies for evaluating the performance of HVAC diagnostic systems
Joseph Yutzy	Adams	Monitoring and detection of damage in gear drive, using dynamic torque sensing
Matias Zanartu	Mongeau/Wodicka	Voice synthesis
Wangda Zuo	Chen	Rapid simulation of contaminant transport in buildings
Alain Zoro	Yao	Integrated direct/indirect adaptive robust control with quantative parameter estimation
Brandon Zwink	Adams	Damage detection in a composite rotor blade using forced vibration data

HERRICK LABS TECHNOLOGY TRANSFER PROGRAMS

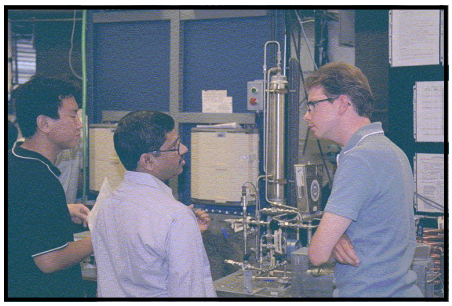
2010

July 10-15, Twentieth International Compressor Engineering Conference
Thirteenth International Refrigeration and Air Conditioning Conference
First International High Performance Buildings Conference
Compressor and Refrigeration Short Courses

2008

July 12-17, Nineteenth International Compressor Engineering Conference
Twelfth International Refrigeration and Air Conditioning Conference
Compressor and Refrigeration Short Courses

2007



October 17-19, Short Course: Nonlinear Vibration: Theory & Practice, Indianapolis Aviation Technology Center

November 1-4, 10th Annual Colloquium on International Engineering Education

2006

July 17-20, Eighteenth International Compressor Engineering Conference
Eleventh International Refrigeration and Air Conditioning Conference

July 15-16, Short Course: Noise Control Methods for HVAC&R Applications

July 15-16, Short Course: Latest Developments with Respect to the Transcritical CO_2 Cycle Technology

July 24-28, Short Course: Nonlinear Vibrations, Los Alamos Dynamics Summer School

September 21, Short Course: Measurements of Acoustic Materials, Brüel & Kjaer, Novi, MI

October 16-18, Short Course: Health Monitoring, Palmdale, CA

2008 HERRICK LABS GRADUATES

Stefan Bertsch	PhD	*Refrigerant Flow Boiling in Microchannel Evaporators*
Hao Jiang	PhD	*Material Damage Modeling and Detection in a Thin Metallic Sheet and Sandwich Panel Using Passive Acoustic Transmission*
Anup Kulkarni	MSME	*Investigation of High Efficiency, Ultra-Low Emission, Advanced Mode Diesel Combustion in a Validated, Flexible and Computationally Efficient Whole Engine Model*
Jeffrey T. Peters	MSME	*Noise Control in Hydraulic Systems*
Emily Prewett	MSME	*Modeling and Identification of Damage in Composite Materials*
Premjee Sasidharan	MSME	*Development of an Electronic Fuel Injection System for a Small Electric Power Unit*
Abhijit Sathe	PhD	*Miniature-Scale Diaphragm Compressor for Electronics Cooling*
Chintan Shah	MSME	*Particulate Matter Load Estimation in Diesel Particulate Filters*
Pranati Surve	MSECE	*Diesel Particulate Filter Diagnostics Using Correlation and Spectral Analysis*
Taewook Yoo	PhD	*The Modeling of Sound Absorption by Flexible Micro-Perforated Panels*
Zhipeng Zhong	PhD	*Combined Heat and Moisture Transport Modeling for Residential Building*