2005-2006 Annual Report

Ray W. Herrick Laboratories

140 S. Intramural Drive
West Lafayette, IN 47907-2031

Phone: 765-494-2132
Fax: 765-494-0787
E-mail: rhlab@ecn.purdue.edu

Herrick Laboratories
Purdue University™

The Ray W. Herrick Laboratories

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* and the *Heating, Ventilation, Air-Conditioning, and Refrigeration Research Area* and grow the reputations of these areas as the top such research programs in the world.
2. Support the emerging research area of *Electro-Mechanical Systems* to enhance its national and international visibility.
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.

2005-2006 HIGHLIGHTS

Research	*Last year*	*This year*
Research expenditures (academic year)	$4,017,831	$5,378,924
Number of sponsors as of September	40	36
Research assistants as of September	57	61
Archival papers published (calendar year)	32	28
Contracts in force for next academic year (July 1st)	$ 630,757	$1,634,698
Proposals pending in September (HL share)	$2,912,064	$1,872,936
Proposed funding for Center-Type Activities	*$11,869,169	
*Herrick Share		
Education		
Graduate students as of September	74	73
MS	20	21
Ph.D.	54	52
Students graduated (calendar year)	17	24
MS	11	11
Ph.D.	6	13
Undergraduate/graduate "research experience" students	21	25
Visiting scholars, Post Doctoral Students,		
Visiting Research Assistants	7	14
Fellowships	10	10
Grant-in-Aid	1	2
Student Paper Awards	1	1
Technology Transfer		
Conferences/Workshops held	3	5
Conferences planned in the next 2 years	2	3
Short Courses	2	3
Herrick Labs reports to sponsors	23	17
Conference and journal papers	61	83

Americas Co-Editors and Americas Editorial Office, **Journal of Sound and Vibration**
(Patricia Davies and J. Stuart Bolton)

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

Advisory Board Member, **International Journal of Refrigeration**
(Eckhard Groll)

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. Donna Miller serves as editorial assistant for the *Journal of Sound and Vibration*. Additional support staff includes Debbie Istwan, account clerk; Linda Tutin, secretary; Gilbert Gordon, electronic shop coordinator; Bob Brown, mechanical shop coordinator and building deputy; and Frankie Lee, mechanical technician.

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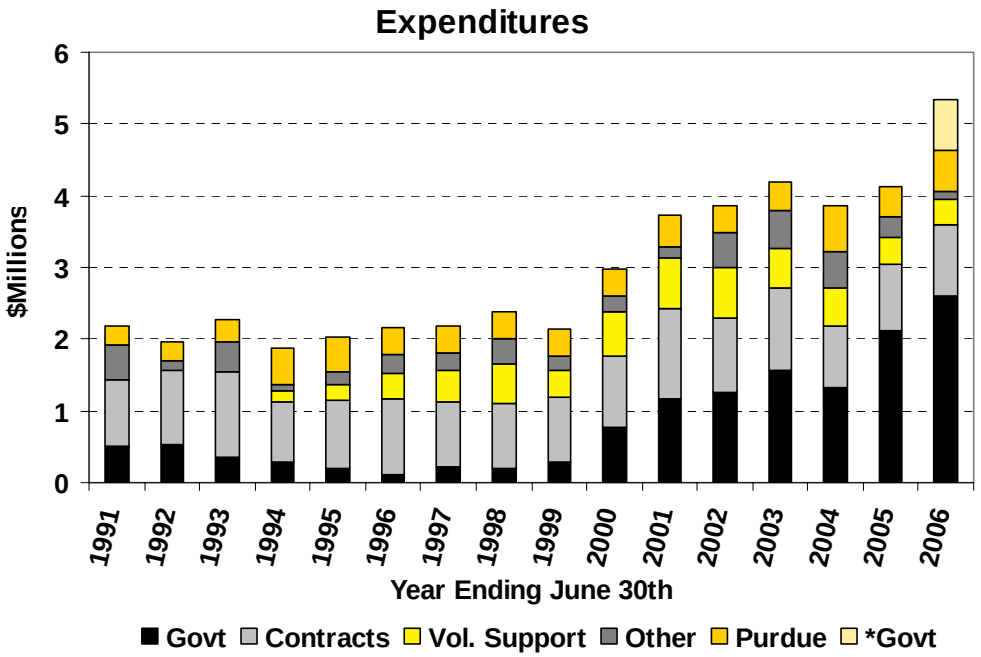
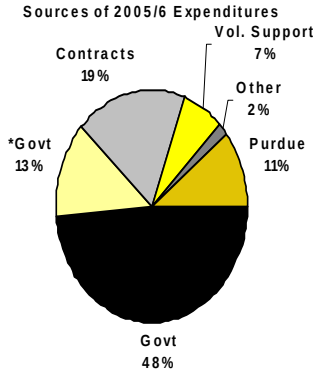
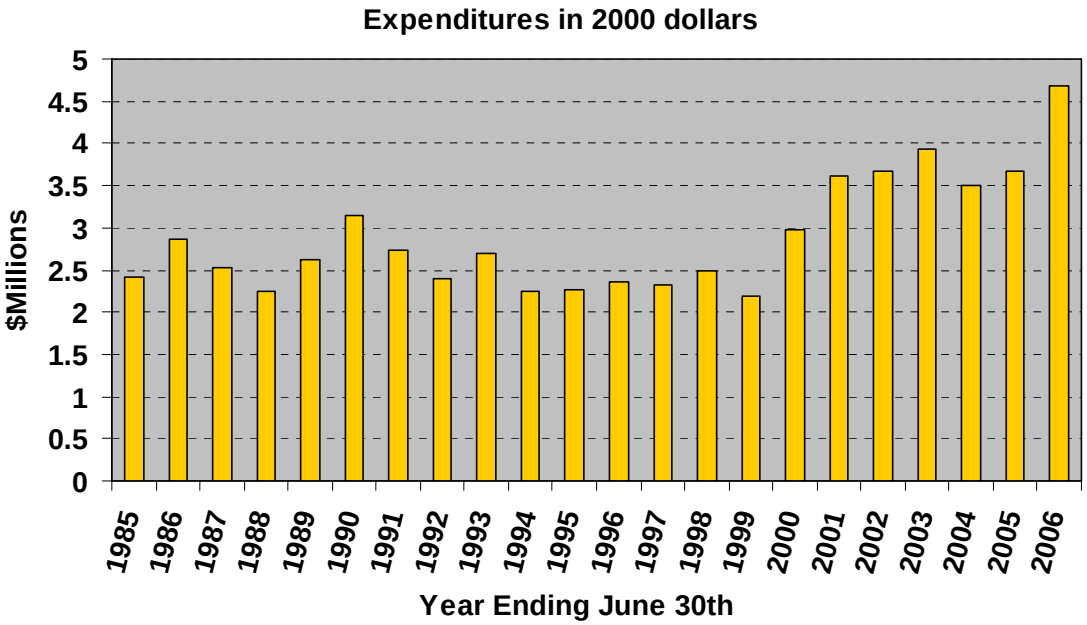
2005-2006 EXPENDITURES



Expenditures for the 2005-2006 academic year are up. There was a one-off special project that we did that is included in these amounts ($709,125) but even taking that out, expenditures are still up. These expenditures reflect a large amount of effort from our faculty, students and staff. Contracts in force appear to be increasing.

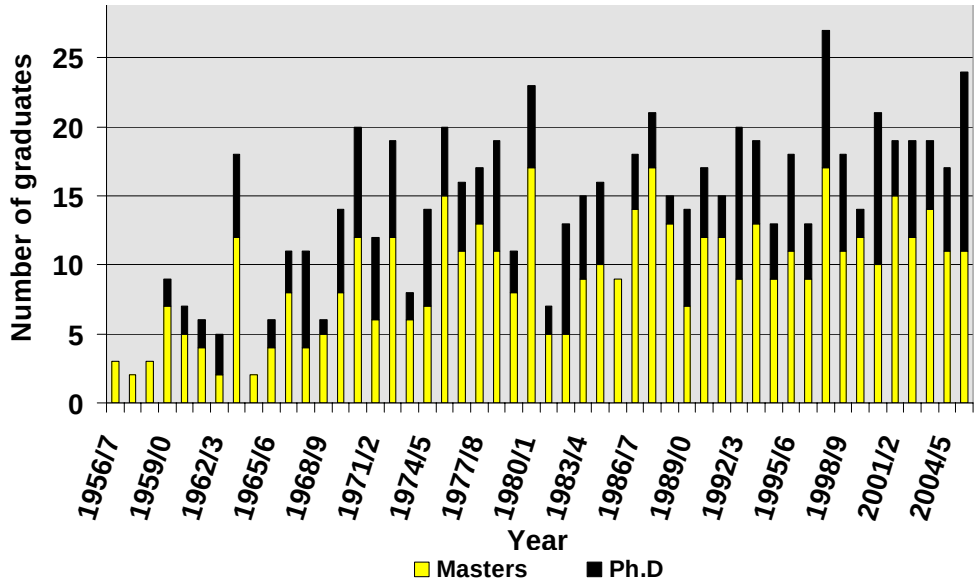




Research Expenditures: Actual Dollars $5,378,924; Year 2000 Dollars $4,679,664.

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

Varun Agrawal received the Andrews Fellowship
Ian Bell received a Purdue University Doctoral Fellowship
Hoyt Yu Chang received a Lozar Fellowship
Derek Hengeveld received an ASHRAE Carrier Fellowship
Rick Meyer received a Purdue University Doctoral Fellowship
James Mynderse received the Laura Winkelman Fellowhip
Emily Prewett received a NSF Fellowship and a Lozar Fellowship
Jonathan White received the Ingersoll/Rand Fellowship and the Adelberg Fellowship
Nathanael Yoder received a NSF Fellowship and a Purdue University Doctoral Fellowship

Grants-in-Aid

Stefan Bertsch received an ASHRAE Grant-in-Aid
Margaret Mathison received an ASHRAE Grant-in-Aid

Awards

Daniel Robinson received one of the 2006 Joseph A. Hartman Student Paper Awards from the Partnership for AiR Transportation Noise and Emissions Reductions (PARTNER), an FAA/NASA/Transport Canada-Sponsored Center of Excellence.

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HERRICK LABS FACULTY RESEARCH INTERESTS

Douglas E. Adams, associate 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, professor of mechanical engineering and Director of The Institute for Safe, Quiet, and Durable Highways. 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, associate 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.

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.

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

Kai Ming Li, associate 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, associate 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.

Katherine Peterson, assistant professor of mechanical engineering. PhD 2005, University of Michigan. Experimental implementation of nonlinear control theory, control of mechatronic systems, control of biological systems, modeling and control of automotive systems, and robotic balancing.

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, associate 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

The Ray W. Herrick Laboratories

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 6 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
- Thermal comfort
- 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

The Ray W. Herrick Laboratories

CURRENT HERRICK LABS STUDENTS

Student	Major Professor	Thesis Subject
Spencer Ackers	Adams	Damage detection in wheel end spindles
Gayatri Adi	Shaver	Modeling, design and control of advanced powertrain
Varun Agrawal	Yao	Adaptive robust control of flexible cable driven surgical robotic devices
Gazi Naser Ali	Allebach/Chiu	Banding characterization and reduction for laser printers
Vijay Ananthanarayanan	Meckl	Engine control
Adam Andruska	Peterson	Robotic endoscope
Ian Bell	Groll/Braun/King	Ericsson cycle cooler
Stefan Bertsch	Groll	Refrigerant flow boiling in microchannel evaporators for electronics cooling
Nasir Bilal	Adams	Prediction uncertainty in compressor modeling and simulation
Arthur Blanc	Bernhard	Numerical model validation
Hoyt Yu Chang	Li	Acoustics
Li-Jen Chen	Mongeau	Fluid structure interactions within the human larynx
Xi Chen	Chen	Airliner cabin environment decontamination research
Douglas Cook	Mongeau/Nauman	Fluid structure interactions
Patrick Cunningham	Meckl	Diagnostics of diesel particulate filters
Paul Deignan	Meckl/King	Virtual sensor development for automotive engines
Shreekant Gayaka	Yao/Meckl	Diagnosis and emission control of engines
Kamran Ahmed Gul	Adams	Engine cold-test driveline modeling and simulation
Jun Han	Li	Environmental acoustics
Muhammad Haroon	Adams	Durability and prognosis of ground vehicle systems
Derek Hengeveld	Braun/Groll	Development of a system design methodology for robust thermal control systems to support operationally responsive space
Kwan Woo Hong	Bolton	Numerical methods in acoustics
Scott James	Meckl/King	Engine diagnostics
Janette Jaques	Adams	Modeling and simulation of rattle vibrations in car seats
Hao Jiang	Adams	Acoustic transmission methods for damage detection
Tim Johnson	Adams	Diagnostics and prognostics for rolling tires
Alok Joshi	Meckl	Diagnostics of engines
Raymond Joshua	Adams	Nonlinear methods and testing of morphing aircraft
Miguel Jované	Braun/Groll	Modeling of a novel rotary compressor
Anup Kulkarni	Shaver	Modeling, design and control of advanced powertrain
Yan Fu Kuo	Chiu	Tone curve stabilization for color electrophotography
Ki Sup Lee	Chen	Air distribution effectiveness with stratified flows in rooms
Kyoung Ho Lee	Braun	Control of building thermal storage
Kyoung Hoon Lee	Davies	Perception of tones in large machinery noise
Phoi Tack Lew	Mongeau/Lyrintzis	Computational aeroacoustics
Feng Liu	Chiu	Xerographic process control
Rachel Logan	Li	Environmental acoustics

CURRENT HERRICK LABS STUDENTS
(CONTINUED)

Student	Major Professor	Thesis Subject
Vishal Mahulkar	Adams	System of systems modeling and optimization in Navy ships
Adam 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
Paloma Mejia	Mongeau	Flow-induced cavity resonance of road vehicles
Rick Meyer	Yao	Modeling and adaptive robust control of fuel cell power systems
Amit Mohanty	Yao	Coordinated control of electro-hydraulic robot manipulators
Shashi More	Davies	Aircraft noise characteristics and metrics
James Mynderse	Chiu	Motion and vibration control
Jeffrey Peters	Mongeau/Ivantysynova	Aerodynamic noise of compressor mufflers
Emily Prewett	Adams	Structural analysis and health monitoring under combined loads
Daniel Robinson	Bernhard	Low frequency sound insulation and rattle noise
Premjee Sasidharan	Meckl	Fuel injection control for engine noise attenuation
Abhijit Sathe	Groll/Garimella	Miniature-scale compressors for electronics cooling
Chintan Shah	Meckl	Diesel particulate filtering
Yoon Shik Shin	Bolton	Electronic cooling fan noise
David Snyder	Shaver	Modeling, design and control of advanced powertrain
Mychal Spencer	Mongeau/Siegmund	Digital image correlation methods
Nick Stites	Adams	Diagnostics for fault detection in gas turbine engine wire harnesses
Shankar Sundararaman	Adams	Damage identification using wave propagation
Pranati Surve	Meckl	Diesel particulate filters
Will Thornton	Bernhard	Tire/pavement interaction noise
Liangzhu Wang	Chen	Detailed multi-zone air flow simulation
Jonathan White	Adams	Structural diagnostics in thermal protection systems
Adam Wichman	Braun	Analysis of FDD tools for heat pump systems
Anthony Wright	Groll	Non-thesis student
Lesley Wright	Groll	Miniature-scale linear compressor for electronic cooling
Nate Yoder	Adams	Diagnostics and prognostics for rolling tires
Taewook Yoo	Bolton	Sound absorbing materials
Matias Zanartu	Mongeau/Wodicka	Voice synthesis
Tengfei Zhang	Chen	Air quality in aircraft cabins
Zhao Zhang	Chen	Particle dispersion indoor environment
Zhipeng Zhong	Braun	Modeling of heat and mass transfer in building materials
Wangda Zuo	Chen	Rapid simulation of contaminant transport in buildings

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RECENT HERRICK LABS TECHNOLOGY TRANSFER PROGRAMS

2006

April 10-12, 2006, the **FHWA Tire/Pavement Noise Strategic Planning Workshop** sponsored by the U.S. DOT/RITA/Volpe Center and organized by Robert Bernhard and Donald Johnson of Purdue University was held in Indianapolis, Indiana.

March 16-17, 2006, the **Carbon Dioxide Interest Group (c-dig) Seminar** was sponsored by the Carbon Dioxide Interest Group and organized by Andrew Pearson of Star Refrigeration, Glasgow, Scotland in coordination with Eckhard Groll of the Ray W. Herrick Laboratories, Purdue University. The seminar was held in the Burton Morgan Building on Purdue University campus. This twice-yearly seminar is attended by senior design, development and management staff from key refrigeration companies.

May 2-3, 2006 the **Air Transport Center of Excellence for Cabin Airliner Environment Research (ACER)** held its semi-annual partner meeting at Burton D. Morgan Center for Entrepreneurship Building. The meeting was organized by Yan Chen of Purdue University and William F. Gale of Auburn University

July 15-16, 2006, the **Noise Control Methods for HVAC&R Applications (compressor short course)** and the **Latest Developments with Respect to the Transcritical CO_2 Cycle Technology (refrigeration short course)** was held at Purdue University. These courses started on Saturday afternoon and ended on Sunday around 5 p.m.

July 17-20, 2006, the **18th International Compressor Engineering Conference at Purdue** and **11th International Refrigeration and Air Conditioning Conference at Purdue** were held at Purdue University. Over 500 people attended and plenary talks were given by Sam Ha, LG Electronics; Mike Moran, Ohio State University; Alberto Cavallini, University of Padova, Italy; and our own Werner Soedel, Herrick Laboratories. Werner gave a retrospective of his live in engineering. His talk was titled, “How I Learned to Love Compressors.”

2005 HERRICK LABS GRADUATES

Vincent Badagnani	MSME	*Method for Predicting the Acoustic Spectra of Axial Flow Fans*
Stefan Bertsch	MSME	*Theoretical and Experimental Investigation of a Two Stage Heat Pump Cycle for Nordic Climates*
Hung Ming Cheng	PhD	*Encoding of Sampled-Data Systems: Applications to Finite Wordlength Controller Implementation and Adaptive Sampling of Atomic Force Microscopy*
Rudy Chervil	MSME	*Air Pollutant Emissions and Mitigation by Diet Manipulation at Two High-Rise Layer Barns*

2005 HERRICK LABS GRADUATES (CONTINUED)

Douglas Cook	MSME	*Computational Models of Fluid Flow, Structural Vibration and Fluid-Structure Interactions of Human Phonation*
Donald Gallant	MSME	*An Experimental Study of the Perceptual Attributes of Tonal Sounds and Annoyance with Application to Automotive Component Noise*
Phanindra Garimella	PhD	*An Adaptive Robust Framework for Model-Based Fault Detection*
Mert Geveci	PhD	*Robust Cylinder Health Monitoring for Internal Combustion Engines*
Grant Ingram	PhD	*Lean NOx Trap Modeling for Lean Burn Engine Control and Improved Fuel Economy*
Harold Kess	MSME	*Investigation of Operational and Environmental Variability Effects on Damage Detection Algorithms in Heterogeneous (Woven Composites) Plates*
Jeong-Woo Kim	PhD	*Sound Transmission Through Lined, Composite Panel Structures: Transversely Isotropic Poro-Elastic Model*
Jun-Hyeung Kim	PhD	*Analysis of a Bowtie Compressor with Novel Capacity Modulation*
Theodore Kostek	PhD	*Aging of Zeolite Based Automotive Hydrocarbon Traps with Applications to Diagnostics*
Jaeho (Tony) Kwak	PhD	*Modeling and Control of an Electro-mechanical Brake (Brake-by-Wire) System*
Josephine Lau	MSME	*The Performance of Floor-Supply Displacement Ventilation in Workshop Configurations with Measurements and Simulation Studies*
Song Liu	PhD	*Automated Modeling and Energy Saving Adaptive Robust Control of Electro-Hydraulic Systems with Programmable Valves*
Insu Paek	PhD	*Performance Characterization of Thermoacoustic Cooler Components and Systems*
Kenji Totsuka	MSME	*Tone Curve Stabilization for Color Electrophotography*
Richard Widdle, Jr.	PhD	*Measurement and Modeling of the Mechanical Properties of Polyurethane Foam*
Tao Yu	MSME	*Non-Thesis: Acoustics*
Kiho Yum	PhD	*Control of Structural-Acoustic Radiation from Tires by Structural Modification*
Zhao Zhang	MSME	*A Study on Transport and Distribution of Indoor Particulate Matter*
Xiaotang Zhou	PhD	*Dynamic Modeling of Chilled Water Cooling Coils*

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