CENTER FOR COMPACT & EFFICIENT

FLUID POWER

Second Annual Report

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VOLUME
2

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CENTER FOR COMPACT AND EFFICIENT FLUID POWER PROJECTS

RESEARCH PROJECTS

Thrust 1 - Efficiency

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1A2 - Integrated Algorithms for Optimal Energy Use in Mobile Fluid Power Systems, Purdue	Monika Ivantysynova, Ag. and Bio. Eng, Purdue
1B - Study of EHD Effects for Adaptive Surface Design for Pumps and Motors,	Monika Ivantysynova, Ag. and Bio. Eng., Purdue
1D - Drag Reduction via Biomimetic Nano-Surface Features	Eric Loth, Aerospace Eng., University of Illinois at Urbana-Champaign
1E - On/Off Valve Concepts for Throttle-Less Energy Transformation and Control	Perry Li, Mech. Eng, University of Minnesota Thomas Chase, Mech. Eng., University of Minnesota
1E1 – High Pressure Supplement	John Lumkes, Ag. and Bio. Eng., Purdue
1G1 - Optimized Engineered Fluid	Paul Michael, Fluid Power Institute, Milwaukee School of Engineering Matey Kalchev, Physics and Chemistry, Milwaukee School of Engineering
1G2 - Carbon Nano-Tube Additives to Reduce Volumetric and Pressure Losses	Eric Loth, Aerospace Eng., University of Illinois at Urbana-Champaign
Efficiency of Pumps and Motors	Monika Ivantysynova, Parker Hannifen
Improvements of Pumps and Motors	Monika Ivantysynova, Sauer Danfoss
Software Enabled Variable Displacement Hydraulic Pumps	Perry Li, NSF

Thrust 2 – Compactness

Project Name	PI / Department / Institution / Sponsor
2A - Chemofluidic Hydraulic Actuators	Michael Goldfarb, Mech. Eng., Vanderbilt
2B –Free-Piston Engine Compressor	Eric Barth, Mech. Eng, Vanderbilt
2C - Compact Energy Storage	Perry Li, Mech. Eng., University of Minnesota Kim Stelson, Mech. Eng., University of Minnesota
2D - High Pressure, Light Weight Components Using Engineered Materials	Vito Gervasi, Applied Technology Ctr, Milwaukee School of Engineering Doug Cook, Applied Technology Ctr., Milwaukee School of Engineering
2E - Component Integration for Compact Fluid Power Systems	Chris Paredis, Mech. Eng, Georgia Institute of Technology Andrew Alleyne, Mech. Eng., University of Illinois at Urbana-Champaign
2F - Dynamically Scalable Fluid Power Systems	Andrew Alleyne, Mech. Eng., University of Illinois at Urbana-Champaign Chris Paredis, Mech. Eng., Georgia Institute of Technology
Architectural Models for Fluid Power Systems	Chris Paredis, John Deere, Inc.

Thrust 3 – Effectiveness

Project Name	PI / Department / Institution / Sponsor
3A1 : Multimodal Human Machine Interfaces	Daniel Mountjoy, Industrial. and Systems Eng., North Carolina Agricultural and Technical State University Eui Park, Industrial. and Systems Eng., North Carolina Agricultural and Technical State University Perry Li, Mech. Eng., University of Minnesota Silvanus Udoka, Industrial. and Systems Eng., North Carolina Agricultural and Technical State University Wayne Book, Mech. Eng., Georgia Institute of Technology Xiaochun Jiang, Industrial. and Systems Eng., North Carolina Agricultural and Technical State

Project Name	PI / Department / Institution / Sponsor
	University
3A2 - Human/Machine Interfaces – Passified Chemofluidic Control	Perry Li, Mech. Eng., University of Minnesota
3A3 - Human Performance Modeling and User Centered Design	Daniel Mountjoy, Industrial. and Systems Eng., North Carolina Agricultural and Technical State University Eui Park, Industrial. and Systems Eng., North Carolina Agricultural and Technical State University Silvanus Udoka, Industrial. and Systems Eng., North Carolina Agricultural and Technical State University Wayne Book, Mech. Eng., Georgia Institute of Technology Xiaochun Jiang, Industrial. and Systems Eng., North Carolina Agricultural and Technical State University
3B1 - Noise and Vibration Reduction in Fluid Power Systems	Ken Cunefare, Mech. Eng, Georgia Institute of Technology
3B2 - Active Control of Hydraulic Pump Noise	Luc Mongeau, Mech. Eng., McGill University Monika Ivantysynova, Ag. and Bio. Eng., Purdue
3C – CFD Simulations of Cavitation Flows	Monika Ivantysynova, Ag. And Bio. Eng., Purdue Steven Frankel, Mech. Eng., Purdue Steven Werely, Mech. Eng., Purdue
3D - Leakage Reduction in Fluid Power Systems	Richard Salant, Mech.Eng., Georgia Institute of Technology
3D1 – Sealing and Liquid Property Investigations Applied to Hydraulics at High Pressure	Richard Salant, Mech. Eng., Georgia Institute of Technology Scott Bair, Mech. Eng., Georgia Institute of Technology
Control Models for the INCOVA System	Wayne Book, HUSCO International
Hardware in the Loop Simulation for Hydraulic System Development	Wayne Book, HUSCO International
Hydraulic Motor Wear Particle Analysis	Paul Michael, Fluid Power Institute, Milwaukee School of Engineering
Integrated Position Sensors for Fluid	Wayne Book, Sentrinsic, LLP

Project Name	PI / Department / Institution / Sponsor
Actuators	
The Haptic Backhoe	Wayne Book, John Deere, Inc.

Test Beds

Project Name	PI / Department / Institution / Sponsor
Test Bed 1: Excavator	Monika Ivantysnova, Ag. and Bio. Eng., Purdue
Test Bed 3: Small Urban Vehicle	Kim Stelson, Mech. Eng., University of Minnesota Perry Li, Mech. Eng., University of Minnesota
Test Bed 4: Rescue Robot	Michael Goldfarb, Mech. Eng., Vanderbilt University Wayne Book, Mech. Eng., Georgia Institute of Technology
Test Bed 5: Hand Tools	William Durfee, Mech. Eng., University of Minnesota
Test Bed 6: Orthosis	Andrew Alleyne, Mech. Eng., University of Illinois at Urbana-Champaign Elizabeth Hsaio-Wecksler, Mech. Science and Eng., University of Illinois at Urbana-Champaign Eric Loth, Aerospace Eng., University of Illinois at Urbana-Champaign

EDUCATION AND OUTREACH PROJECTS

Project Name	Project Leaders / Institution
A1 – Interactive Exhibits	J. Nwelin, Science Museum of Minnesota Forrest Price, Science Museum of Minnesota Richard Gagnon, Science Museum of Minnesota
A2 – Fluid Power Youth Science Team	Rachel Gates, Science Museum of Minnesota
A3 – Public Television Video	Kim Stelson, Mech. Eng., University of Minnesota

Project Name	Project Leaders / Institution
	Stephanie Bettermann, University of Minnesota
A4 – Web Site Information Repository	Alyssa Burger, University of Minnesota
B1 – Project Lead the Way	Linda Western, University of Minnesota Will Durfee, University of Minnesota Alyssa Burger, University of Minnesota Michael Gust, University of Minnesota
B2- FIRST Robotics Teams	Will Durfee, University of Minnesota Chris Paredis, Georgia Institute of Technology
B3 – Fluid Power Demonstration Curriculum	John Lumkes, Purdue
B4 – Research Experiences for Teachers (RET)	Will Durfee, University of Minnesota
C1 – Research Experiences for Undergraduates (REU)	Will Durfee, University of Minnesota
C2 – Inserting Fluid Power Curriculum into Existing Undergraduate Engineering Courses	Will Durfee, University of Minnesota
C5 – Advanced Graduate Courses	Will Durfee, University of Minnesota
D1 – Intern Program	Linda Western, University of Minnesota Alyssa Burger, University of Minnesota
D2 – Resume Bank	Alyssa Burger, University of Minnesota
D3- Specialized Short Courses	Michael Gust, University of Minnesota
D4- Transportable Universal Fluid Power Laboratory	Medhat Khalil, Milwaukee School of Engineering
D5- The Fluid Power Coloring Book	Roz Dolid, MTS Systems Will Durfee, University of Minnesota
D6 – CCEFP Webcasts	Alyssa Burger, University of Minnesota
E1 – G-Camp	Alyssa Burger, University of Minnesota

Project Name	Project Leaders / Institution
	Holly Pellerin, Fond du Lac Community College Diana Dallboten, University of Minnesota
E2 – LEGO Camp and FIRST Robotics Team	Alyssa Burger, University of Minnesota
E2.1 – Native FIRST Robotics Team	Alyssa Burger, University of Minnesota Holly Pellerin, Fond du Lac Community College Michael Gust, University of Minnesota
E5 – AISES Activity Support	Alyssa Burger, University of Minnesota Holly Pellerin, Fond du Lac Community College Diana Dalbotten, University of Minnesota Richard Pollard, APEXES
E6 – Minority Recruiting	Alyssa Burger, University of Minnesota
F1 – Evaluation of the Education and Outreach Program	Linda Western, University of Minnesota Will Durfee, University of Minnesota
F2 – CCEFP Alumni Society	Alyssa Burger, University of Minnesota

TECHNOLOGY TRANSFER
No projects to report at this time

RESEARCH PROJECT SUMMARIES

Project 1.A1: Integrated Algorithms for Optimal Energy Use in Mobile Fluid Power Systems

1. Statement of Project Goals

The goal of this project is to develop tools and methodologies for optimizing the power generation and power distribution in mobile Fluid power systems. Primary metrics of success will be overall reduction in system power consumption while maintaining prescribed levels of performance.

2. Project's Role in Support of the Strategic Plan

This project will support the efficiency thrust at a very fundamental level. We intend to take a system-theoretic approach to provide general algorithmic solution tools. We propose to examine classes of dynamic systems that are common among fluid power end users. We will then provide algorithms to take maximal advantage of the system structure, independent of the particular physical system. The results of this approach should provide benefits for several of the test beds being proposed, including the excavator and hydraulic hybrid vehicle test bed.

3. Fundamental Research Barriers and Methodologies for Addressing Them

Fundamental barriers to achieving optimal energy usage are (a) the understanding of when to use available power sources and (b) mitigating the smooth transition between the different modes of operation. Fig 1 shows the transitions that need to be made and the Energy Management System (EMS) that does the transition. The methods for achieving these include System Dynamics, Optimization, and Feedback Control. The system dynamics aspects involve the creation of sufficiently detailed dynamic models that will serve the other two methodologies. The optimization uses dynamic programming to create appropriate switching rules. The feedback control maintains the stable transition between modes.

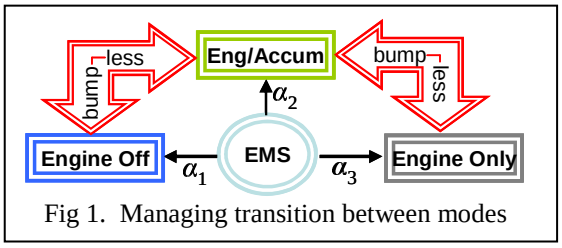


Fig 1. Managing transition between modes

4. Achievements to Date

To date, we have developed a modeling/simulation platform compatible with the Matlab/Simulink environment. We have chosen to focus our attention on a particular test bed, the Small Urban Vehicle. The reason for focusing is that we felt we would be able to maximize our tangible progress if we constrained ourselves to a physical platform and did not approach the problem from too general a standpoint. For the SuV, we implemented a Dynamic Programming optimization algorithm to determine appropriate energy usage strategies, be it engine powering the vehicle, engine charging the storage accumulator, or the accumulator driving the vehicle. This optimization approach was able to perform tradeoffs on the accumulator fill levels that triggered activation of storage. The optimization was performed on standard federal drive cycles for realism. Good initial strategies for energy storage/use were developed. Based on this

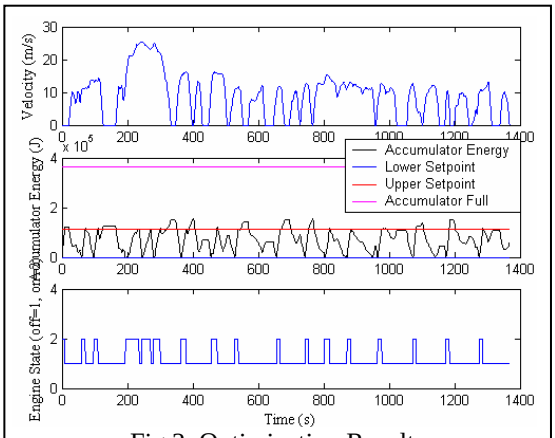


Fig 2. Optimization Results

approach we have evaluated different options for when to utilize prime mover sources of energy versus regeneration versus stored energy sources. An example of such an analysis is shown in Figure 2. We have also developed Bumpless Transfer algorithms for the smooth transition between different modes of operation. This is critical to ensure stability of the overall system when switching back and for the between different modes with different dynamics. Finally, we have begun development of a real-time hardware-in-the-loop simulator with an undergraduate student. This will help to transition the algorithms into the actual testbed.

5. Other Relevant Work

We have spend a fair bit of time developing general purpose gain scheduling control tools that will allow us to handle significant system nonlinearities in our feedback designs.

6. Plans for Next Year

- Task 1: Formulation of dynamic models of SuV test beds [6 months]
- Task 2: Numerical investigation of minimum energy trajectories [6 months]
- Task 3: Development of trajectory generation controller for test bed with operator interface [9 months]
- Task 4: Testing of trajectory generation controller on test bed. [12 months]
- Task 5: Development of Local Multiple Load Control Strategy w/out Regen [3 months]
- Task 6: Develop Real-Time Simulation System to complement HIL testing [6 months]
- Task 7: Real Time Simulation of Control Strategy w/out Regen [6 months]
- Task 8: HIL testing of Control Strategy w/out Regen [8 months]
- Task 9: Development of Local Multiple Load Control Strategy w/ Regen [6 months]
- Task 10: Real Time Simulation of Control Strategy w Regen [12 months]
- Task 11: HIL testing of Control Strategy w Regen [12 months]

7. Expected Milestones and Deliverables

- Real Time Simulation Model for Representative System [month 6]
- Local Control Algorithm [month 3]
- Initial HIL and Real-Time Experiments done by [month 8-9]
- Advanced HIL and Real-Time Experiments done by [month 12]

8. Member Company Benefits

Better understanding of advanced algorithms for optimization and control.

9. Research Team

Project Leader:	Kim Stelson UMN; Andrew Alleyne UIUC
Other Faculty:	Perry Li, UM; Monika Ivantysynova, Purdue
Post Doc(s):	Brandon Hencey
Graduate Students:	Jonathan Meyer
Undergraduate Students:	Timothy Deppen
Industrial Partner(s):	John Deere, Parker, Caterpillar, Eaton

Project 1A2: Machine Power Management by Displacement-Controlled Actuators

1. Statement of Project Goals

The goal of this project is to develop system architectures and control methods for optimal power management in multi-actuator mobile hydraulic machines using displacement-controlled linear and rotary actuators. These concepts will reduce overall machine fuel consumption through use of displacement controlled actuators by avoiding throttling losses and allowing energy recovery. Additional fuel savings are expected due to end-effector control based on path optimization and effective machine power management.

2. Project's Role in Support of the Strategic Plan

The project primarily addresses the efficiency barrier by developing new system concepts and control strategies for multi-actuator mobile machines. The project also addresses the compactness barrier since displacement-controlled systems allow higher operating pressures and a reduction of interfaces and components.

3. Fundamental Research Barriers and Methodologies for Addressing Them

Actuators for hydraulic manipulators are traditionally powered by a single hydraulic pump and controlled by directional control valves arranged in parallel. This configuration incurs energy losses due to metering flow through the valves and does not allow energy to be recovered from overrunning loads. Alternative system designs that reduce losses and allow energy recovery promise significant fuel savings.

Another opportunity for improvement is power management. This refers to actively controlling the engine, pumps, and actuators to produce and distribute the required power while each component operates as close as possible to its region of highest efficiency. Power management, while driving for vehicles with continuously variable transmissions is well known, but power management with a manipulator arm has seen little development.

Project 1A2 focuses on improving the overall efficiency of mobile machines with multiple linear and rotary actuators. Advances in system efficiency will be obtained by:

1. Displacement-controlled actuator systems that eliminate throttling losses
2. Real-time control of power generation and transmission in order to operate each component of the powertrain as close to optimal efficiency as possible
3. Energy recovery without additional storage devices by sharing power between actuators
4. Optimizing machine motion in order to maximize energy recovery and minimize fuel consumption
5. combine the developed concepts under point 1-4 with effective engine management

4. Achievements to Date

Analysis of current state of the art load sensing system of example machine (excavator testbed)
- Development of a coupled hydraulic and multi-body dynamics simulation model in Matlab/Simulink to simulate typical working cycles and predict energy consumption
- Instrumentation of excavator testbed (with load sensing hydraulic system)
- Measurement of excavator performance to validate simulation model

- Measurement of engine performance to generate engine map
- Actuator design for one selected function

5. Other Relevant Work

Significant research has been done on power management for vehicle drive trains based on hydrostatic transmissions and power-split drives. For example, Ossyra (2004) presented a control method for hydrostatic transmissions involving two real-time optimization loops: one feedback loop for the engine based on steady-state efficiency characteristics and the other for the hydrostatic transmission based on detailed steady-state loss models of the hydraulic pump/motor units. However, there has been little work on engine power management for mobile hydraulic machinery in which the primary energy consumers are working functions rather than the propulsion drive. A Japanese industrial R&D group controlled pump flow rates and engine speed on an excavator to improve overall efficiency by about 10% (Kakuzen et al., 1988). Another Asian research group showed 26% fuel savings using similar methods (Chun and Seo, 1993). A Canadian research group constructed a displacement-controlled forestry machine, but did not report fuel measurements (Lawrence et al., 1995). Recently, Alleyne et al. have developed control methods for optimizing the power trains of earthmoving vehicles with respect to energy consumption (Montgomery and Alleyne, 2006). No previous research exists on power management for excavators or similar machines using pump-controlled actuators.

One advantage of displacement control for power management is that each actuator is powered by an independently controllable pump. This arrangement offers more degrees of freedom than valve-controlled systems in which the actuators are arranged in parallel and powered by a single pump, thus allowing more opportunity for optimizing operation.

6. Plans for Next Year

- System design for a complete displacement controlled machine to allow optimal use of regenerative brake energy
- Dynamic model of the displacement controlled actuator including Polymod loss model
- Development of a coupled hydraulic and multi-body dynamics simulation model in MatLab for the combined actuator system (LS and displacement controlled actuators), run simulation to predict energy consumption for typical machine working cycle
- Prototype development for one function based on available hardware
- Development of actuator control

7. Expected Milestones and Deliverables

Year 2: System design for a complete displacement controlled machine to allow optimal use of regenerative brake energy
Dynamic model of the displacement controlled actuator including Polymod loss model
Coupled hydraulic and multi-body dynamics simulation model in MatLab for the combined actuator system (LS and displacement controlled actuators)
Prototype Design and control concept for one function based on available hardware

Year 3: Prototype actuator installed and tested in excavator test bed including CAN bus controller, performance demonstration, fuel consumption for test bed measured

Year 4: Demonstration of machine power management strategy and machine control

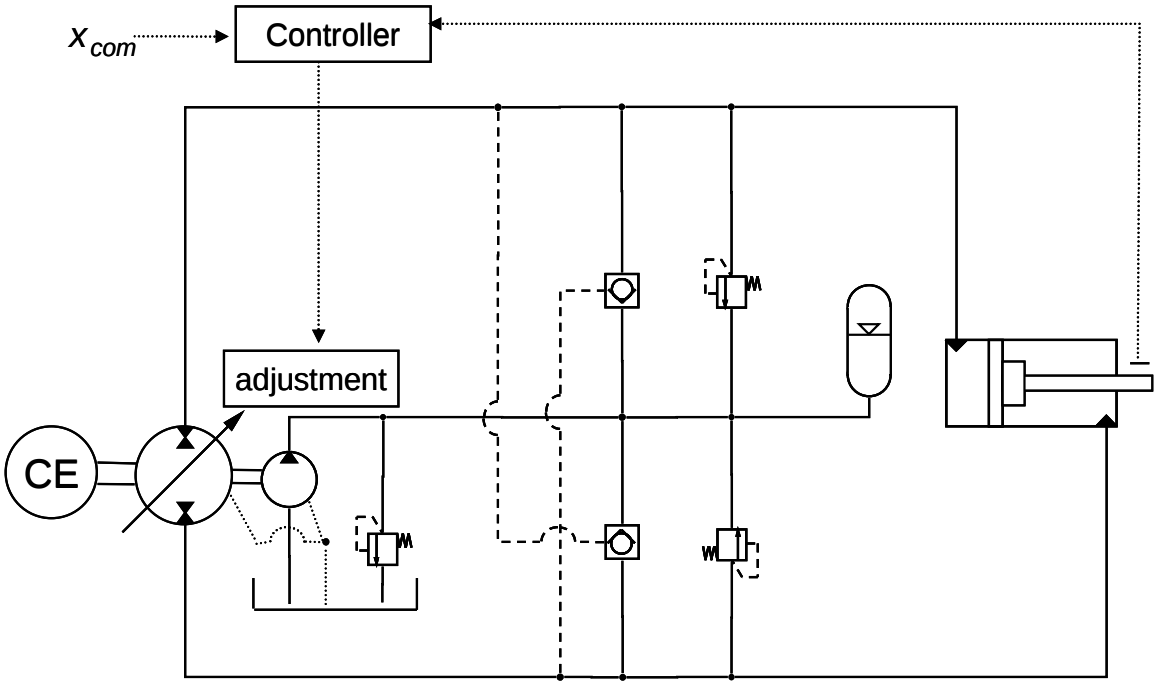
Year 5: Second prototype actuator installed and tested, performance demonstration

8. Member Company Benefits

Design methodology and model based control concept for efficient machine power management based on displacement controlled multiple linear and rotary actuator structure.

9. Research Team

Project Leader:	Monika Ivantysynova, Agricultural and Biological Engineering, Mechanical Engineering, Purdue University
Other Faculty:	Kim Stelson Andrew Alleyne Perry Li
Post Doc(s):	
Graduate Students:	Christopher Williamson, PhD student (Purdue) Joshua Zimmermann, MS student (Purdue)
Undergraduate Students:	
Industrial Partner(s):	Bobcat, Parker Hannifin Corp.



Project 1B: Advanced Surface Design Based on a Fully Coupled Fluid – Structure – Thermal and Multi-Body Dynamics Simulation for a New Generation of Pumps and Motors

1. Statement of Project Goals

The goal of the project is to develop a fully coupled fluid –structure-thermal and multi-body dynamics simulation code for advanced surface design of piston machines. The code will be used to investigate novel surface design methods for all tribological systems of axial piston machines to minimize energy dissipation and to increase the load carrying ability of lubricating gaps. Long term goal is to develop a new generation of variable piston pumps and motors that are more efficient, more compact and quieter.

2. Project's Role in Support of the Strategic Plan

The project addresses primarily the efficiency barrier by providing a computer model based approach for designing and optimizing a new generation of piston pumps and motors that will have higher efficiency in the entire range of operating parameters. Piston pumps will form the heart of the new energy saving fluid power actuators and transmissions to be developed in the ERC. In these systems they represent the main source of losses after replacing throttling valves. The reduction of power loss of pumps and motors will also help to increase system pressure and to improve compactness of fluid power systems. The low efficiency, missing compactness and high noise are barriers for a breakthrough of hydraulic hybrids into automotive transmissions.

3. Fundamental Research Barriers and Methodologies for Addressing Them

Current positive displacement pumps and motors are designed to achieve highest efficiency for a given operating point. Very often the losses increase with reduced displacement volume of a variable pump. This causes a very low efficiency when operating at smaller displacement volumes, i.e. in case of an axial piston pump when running at smaller swash plate angels. The lubricating gaps represent the main source of these power losses. With an appropriate gap design energy loss can be minimized. In previous research the influence of surface shape and surface deformation on energy dissipation has been demonstrated by simulation and experiment. However fluid structure interaction and surface deformation effects have not been considered in previous research. The impact of surface deformation on the pressure field and gap flow properties in lubricating gaps of positive displacement machines has been demonstrated experimentally. The challenge is to develop sophisticated models and algorithms allowing a fully coupled simulation of fluid-structure- thermal and multi-body-dynamics models. This would allow direct calculation of surface deformation by expanding the current fluid grid to the machine parts and adding another iteration loop to the existing in house developed code. This method will also contribute to a more realistic calculation of surface temperature by considering a heat transfer model of the rotating group of a piston machine.

The project focuses on improving the overall efficiency of positive displacement pumps and motors by introducing computer aided design of the rotating group. The main focus is the reduction of energy dissipation in the lubricating gaps by:

1. Development of fully coupled fluid-structure, thermal and multi-body dynamics simulation model including the numerical algorithms for piston-cylinder, cylinder block - valve plate and slipper - swash plate gap.

2. Model validation using available experimental results obtained from measurements on state of the art piston pumps carried out on EHD and tribo test rig
3. Use the new model to investigate energy dissipation in state of the art pumps and motors
4. Develop and investigate designs which adapt the gap height to achieve minimum energy dissipation by modification of surface shape
5. Develop and investigate designs which adapt the gap height to achieve minimum energy dissipation by modification of local surface stiffness
6. Combine the developed concepts and apply them for all three gaps

4. Achievements to Date

- Development of a coupled fluid-structure interaction and multi-body dynamics model for cylinder block- valve plate and piston – cylinder interface of swash plate axial piston machine based on in house developed code.
- Proof of model by comparison of simulation results with friction force measurements on piston-cylinder interface using tribo test rig
- Further model improvements by comparison of simulation results with measured pressure and temperature fields obtained on EHD test rig.
- Comparison simulation results for two standard pumps with measured effective pump flow rates and case flows for large range of operating parameters

5. Other Relevant Work

Due to the complex nature of physical effects taking place in displacement machines the majority of models recently developed focus on special design issues like the prediction of the instantaneous pressure in the displacement chamber, the flow ripple, the gap flow or steady state characteristics. Similar investigations and models were made for different types of pumps and motors. Usually very simplified models assuming parallel surfaces and neglecting hydrodynamic effects have been used. The influence of micro motion of parts forming the gap due to oscillating forces on gap height is usually neglected. Patir and Cheng (1978) developed a flow model based on a modified Reynolds equation, which considers the influence of surface roughness on partial hydrodynamic lubrication with special coefficients. Yamaguchi and Matsuoka (1992) have also considered mixed lubrication in their gap flow model. A similar approach has been used by Fang and Shirakashi (1995), who for the first time computed the position of the piston within the cylinder of a swash plate machine considering the equilibrium of forces (external and fluid forces) applied on the piston for each time step of shaft revolution. Deeken and Murrenhoff (2001) presented a pump and motor simulation model based on a coupling of two commercial software packages, the DSH *plus* and the multi body simulation tool ADAMS. The impact of energy dissipation in the gap on surface temperature, fluid viscosity and therefore change of gap flow conditions has not been considered in these previous works. A first elasto-hydrodynamic model considering surface deformation on the gap flow condition has been presented by Huang and Ivantysynova (2003).

6. Plans for the next year

- Surface optimization study for cylinder block valve plate and piston – cylinder interface to minimize energy dissipation
- Model extension for non-isothermal flow to predict surface temperature and energy dissipation by introducing a fully coupled fluid-structure-thermal and multi-body dynamics simulation for minimum one of the gaps
- Proof of extended model by temperature field measurements

7. Expected Milestones and Deliverables

Year 2: - Surface temperature prediction and comparison with measurements on standard pump
- Demonstration of fully coupled fluid-structure-thermal and multi-body dynamics simulation code & test runs for selected gap

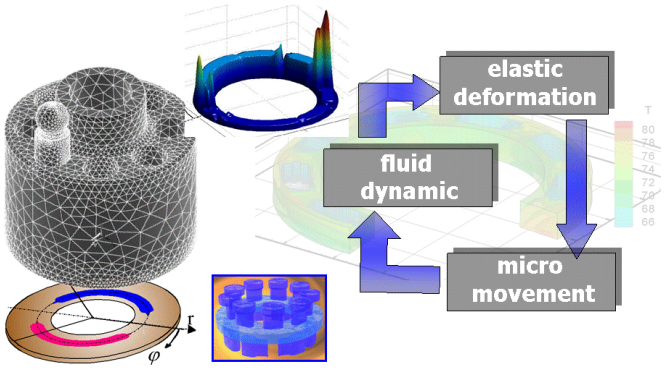
Year 3: - Methodology for piston and slipper design to reduce energy dissipation based on surface shape optimization (consideration of pumping mode only)
- Design of prototype parts and manufacturing of prototype parts

Year 4: - Methodology for cylinder block – valve plate design to reduce energy dissipation in pumping mode
- Demonstration of impact of surface design on energy dissipation for motoring mode

Year 5: - proof of concept by steady state measurements on test pump using prototype parts for rotating group to determine efficiency improvements
- Framework for computer based design optimization for tribological systems for different sizes of axial piston machines

8. Member Company Benefits

Design methodology and simulation code for development of more efficient, compact and more reliable swash plate axial piston pumps and motors. Some of the results can be applied for the design of other types of piston machines.



9. Research Team

Project Leader: Monika Ivantysynova, Agricultural and Biological Engineering, Mechanical Engineering, Purdue University

Other Faculty:

Post Doc(s):

Graduate Students: Andrew Fredrickson, MS student, Jonathan Baker MS student, Najoua Jouini, visiting scholar, Matteo Pelosi, visiting scholar

Undergraduate Students:

Industrial Partner(s): Sauer-Danfoss, Parker Hannifin Corp., Caterpillar, Eaton

Project 1.D: Nano-Texturing for Fluid Power Efficiency

1. Statement of Project Goals

This project will investigate the concept, suitability and performance of nano-textured surfaces in fluid power system components for two different objectives (to be used in two different regions). The first is textured surfaces which allow nano-encapsulated air pockets to reduce the viscous pressure drop along lines. The second is nano-dimpling to reduce leakage and increase the load carrying ability of sealing and bearing surfaces in order to increase efficiency of pumps and motors. Based on previous exploratory studies in other fluid applications, nano-texturing may be capable of reducing viscous and volumetric losses by as much as 50% in actual fluid power systems.

2. Project's Role in Support of the Strategic Plan

The project will attack the efficiency barrier by improving the performance capability of hydraulic hoses and sealing and bearing surfaces from selective application of nano-texturing. By minimizing frictional energy loss in hydraulic lines and increasing volumetric efficiency in pumps and motors, the results of this project will provide benefits for several of the proposed test-beds, particularly the excavator and the small urban vehicle.

3. Fundamental Research Barriers and Methodologies for Addressing Them

4. Achievements to Date

Micro- and nano- texturing techniques were employed in order to produce ultra-hydrophobic and oleophobic surfaces for fluid droplet repellency investigations. An objective of this work was to understand the phobicity performance (both contact angle and sliding angle) of various fabricated surfaces with different types of liquids including distilled water and oil. In particular, a variety of surface geometries were generated by using multiple fabrication schemes including random nano-particle (titanium dioxide and zinc oxide) spray coatings and regular polydimethylsiloxane (PDMS) molded micropost surfaces. A range of surface chemistries were also applied such as thin film coatings of Zonyl 8740, Cytop, and a Trichloro (1H,1H,2H,2H-perfluorooctyl) silane monolayer. An important metric considered in fabrication method selection was to utilize methods that are easily scalable and of reasonable cost for large surface area applications. Surface performance was gauged using a goniometer to measure droplet contact angle and a digital inclinometer to measure droplet sliding angle. Fabricated surfaces were also characterized using scanning electron microscopy (SEM), profilometry, and optical microscopy to obtain detailed images of the surface geometry.

The results yielded water contact angles greater than 160^{o} and oil contact angles of 124^{o} as well as sliding angles on the order of 1^{o} for water. However, it was found that surfaces with a high droplet contact angle did not necessarily achieve a low sliding angle confirming the known independent relationship of droplet contact angle and sliding angle. It was also observed that surface geometries with a mixture of micro-scale texturing and nano-scale texturing achieved the best performance. Micro-scale and nano-scale asperity shape was determined to be independent of repellency performance from comparisons of multiple micro-post cross-sectional shapes as

well as nano-particle shapes. Fluid-structure contact area fraction appeared to be the main geometric performance factor while random versus regular surface geometry was unimportant.

5. Other Relevant Work

Project 1.G .2 at UIUC and Testbed at Purdue

6. Plans for Next Year

Next year, we will begin testing different hydraulic fluids as well as various surfaces for overall drag reduction. In addition, an experimental facility will be designed to investigate nano-texture on piston-cylinder resistance/leakage.

7. Expected Milestones and Deliverables

1) Submit conference/journal paper to discussing oleo-phobicity by March 2008
2) Testing different hydraulic fluids and surface for drag reduction October 2008
3) Design and construct experimental facility for nano-texturing of cylinder/piston combinations by April 2008.
4) Make measurements to investigate nano-texturing of cylinder/piston combination by December 2008.

8. Member Company Benefits

The primary benefit for 2008 will be a knowledge base on oleophobicity (in terms of contact angle and sliding angle) for various surface treatments and fluids. Experimental results for drag reduction in solid and flexible lines as well as piston/cylinder combinations are also expected.

9. Research Team

Project Leader:	Prof. Eric Loth
Other Faculty:	Prof. Andrew Alleyne, Prof. Monika Ivantsynova
Post Doc(s):	Dr. Ilker Bayer (For 2008)
Graduate Students:	Mr. Adam Steele
Undergraduate Students:	Mr. Stephen Moran
Industrial Partner(s):	Parker-Hannifin, Eaton, Bosch Rexroth, Shell, Sauer-Danfoss, Trelleborg, John Deere, Festo, Gates, Caterpillar, DeGussa

Project 1E: On/Off Valve Based Control

1. Statement of Project Goals The goal is to develop methodologies for high performance, efficient control of hydraulic power using on/off valves in a throttle-less manner. This will be demonstrated in on/off valve based virtually variable displacement pumps and motors and example hydraulic circuits. Critical components (high speed on/off valve), system configurations, and control devices will be investigated. The targeted figures of merit are that system control bandwidth and precision is similar to proportional valve based control and energy efficiency comparable to existing variable displacement machines.

2. Project Role in Support of Strategic Plan This project addresses the efficiency barrier by providing a throttle-less control approach that replaces the use of energy inefficient throttling valves. Pulse width modulation (PWM) of on/off valves that are either fully open or fully closed is a potentially loss-less control concept, analogous to switched mode converters in power electronics. On/off valves can also be used to achieve variable displacement machines that are potentially more compact and cost-effective. Figure 1 shows the realization of variable displacement pump function using a fixed displacement pump and a pulse width modulated on/off valve. The configuration is a hydro-mechanical analog of a DC-DC electronic switched mode converter.

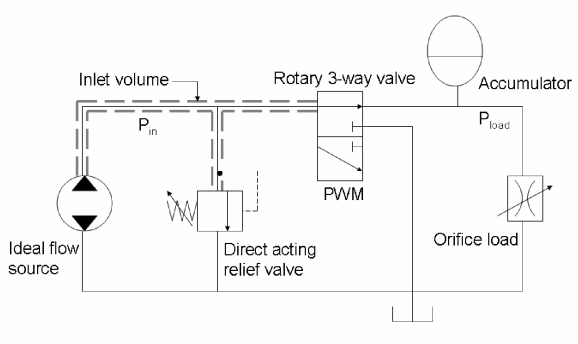


Figure 1 On/off valve realization of a virtually variable displacement pump.

3. Fundamental Research Barriers and Methodologies for Addressing Them
The lack of high speed on/off valves, which are the counterparts to electronic transistors, is a major challenge. These on/off valves must have large orifices (to allow large flow to pass through at low pressure drops), have fast transitions (to reduce the time when the valve is partially open), and can operate at high PWM frequencies (to reduce ripples and to achieve high control bandwidth). A typical control valve consists of a linear translating element such as a spool or poppet. Actuation requires large actuators and power input proportional to the 3rd power of the PWM frequency since the element needs to be accelerated and decelerated rapidly. Our approach is to develop a novel self-spinning rotary PWM on/off valve that uses the continuous rotary motion to generate on/off switching (Fig. 2). This rotary valve does not need to start and to stop, thus, the only power required (proportional to frequency squared) is that to overcome friction. Moreover, the rotary actuation power is obtained by scavenging from the energy in the fluid stream without using an external actuator.

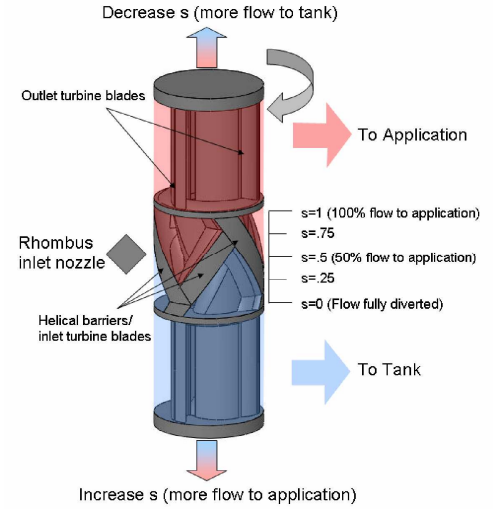


Figure 2: Rotary 3-way on/off valve

4. Achievements to Date

A detailed dynamic model of an on/off valve based virtually variable displacement pump system has been developed for predicting performance and for system design. A self-spinning 3-way rotary on/off valve has been designed, prototyped, and integrated with a 40 lpm fixed displacement vane pump to achieve a virtually variable displacement pump (Fig. 3). The system incorporates an optical non-contact rotary and axial spool position sensing method, an event based Kalman filtering technique for improving sensor resolution, and a compact hydrostatic actuation method for modulating the PWM duty ratio. PWM frequency of 75-95Hz (designed to be 261Hz), closed loop modulation of the virtual displacement with full-on and full-off time of less than 0.1 second have been demonstrated. In addition, a configuration and control method for using low speed, commercially available on/off valve for controlling a linear actuator has been developed. The key contribution lies in the method for canceling the ripples that result from low speed on/off valve to achieve precise control. Experimental testing is in progress.

5. Other Relevant Work

The associated project, 1E.2, is considering using optimized magnetic and hydraulics to achieve a high speed on/off valve.

6. Plans for Next Year

The current generation of rotary is being experimentally characterized. Design of the self-spinning rotary function is currently based on simple momentum analysis without detailed analysis of flow pattern in the turbines. In the next year, CFD analysis in the rotary valve will be developed to improve turbine designs. A next generation of rotary on/off valve with reduced clearance will be developed to improve leakage property. Rotary on/off valve for use with hydraulic motor, hydraulic pump/motor (i.e. can be used in regeneration mode), and bidirectional pump/motors will be developed, prototyped and tested.

7. Expected Milestones and Deliverables

End of yr 2: Rotary on/off valve based pump demonstrated and characterized.

End of yr 3: Rotary on/off valve based 4-quadrant pump/motor demonstrated and characterized.

End of yr 5: Rotary on-off valve based displacement control with regeneration demonstrated on TB1 (excavator) and TB3 (small Urban Vehicle).

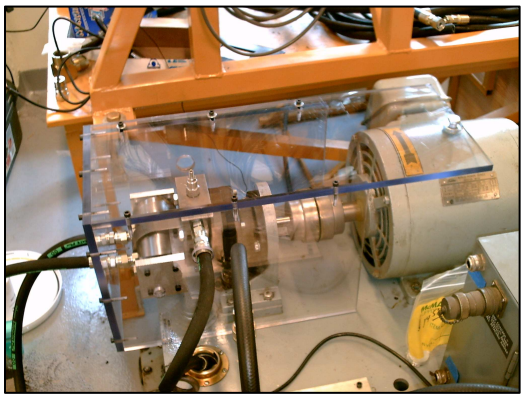


Figure 3: Rotary 3-way on/off valve integrated with a fixed displacement vane pump.

8. Member Company Benefits

Member company will benefits from new on/off valve designs, design insights, control algorithms, and knowledge of applications.

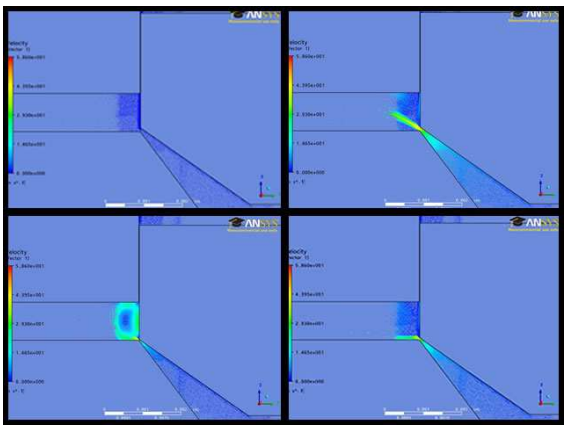
9. Research Team

Project Leader:	Prof. Perry Y Li, Mechanical Engineering
Co-leader	Professor Thomas R. Chase, Mechanical Engineering
Graduate Students:	Michael Rannow, Haink Tu, and Rachel Wang
Industrial Partners:	Eaton Corporation + 17 other ERC member companies

Project 1E.1: High Pressure Supplement (On-Off Valve Based Control)

1. Statement of Project Goals

The goal of the project is to develop advanced models and theoretical understanding of high speed digital hydraulic valves operating at higher pressures. System interactions between the fluid, electromagnetic, thermal, structural, and dynamic parameters will be characterized.



2. Project's Role in Support of the Strategic Plan

An understanding of the interaction between the electrical, mechanical, and hydraulic systems will enable accurate models to be developed and later combined with larger system models for the optimization of system efficiency, operating pressure, reliability, dynamic response, and noise reduction. Successful completion of this project will have a significant impact on the ability to develop and implement the control algorithms proposed in project 1.A, the ability to implement to the concepts described in project 1.E, and the feasibility of project 2.B. The work done in project 3.C will enhance the results of this project by enabling more accurate CFD simulation of the valves. This project will support the efficiency thrust and the compactness thrust of the strategic plan. The efficiency thrust is supported through the reduction of metering losses in typical fluid power systems while the compactness thrust is supported through the development of high speed positive sealing digital valves capable of operating at higher than standard pressures.

3. Fundamental Research Barriers and Methodologies for Addressing Them

There are four basic areas where fundamental science must be applied in this project. Current research indicates that state-of-the-art CFD code utilizing dynamic meshing is not very accurate above switching dynamics of 1000Hz. The proposed on/off valves will cycle faster than this rate. The transient flow forces and resulting cavitation or surface erosion are not well understood in these ranges. Electromagnetic transients constitute a similar problem. High frequency electromagnetic effects such as eddy currents affect the transient force of the actuator. Although eddy currents are relatively well understood in AC transformers there is still much work to do for electromagnets. Effects of eddy currents can be reduced with driving circuitry such as peak & hold or possibly momentary reversed currents and through the minimization of magnetic diffusion time constants. The third area includes the mechanical dynamics, impact forces, and contact sealing models. The combination of high pressures coupled with high switching speeds has the potential to negatively affect the reliability and lifespan of high speed valves. Finally, the behavior of the fluid is also important at the higher pressures and high switching speeds. This aspect of the project will be supported by the work at partner institutions and is necessary to complete the system model of switching valves.

To adequately address, study, and find solutions to these issues a simulation model and the underlying theoretical models must be developed. The "novel" features, i.e. improvements, additions, and changes to the existing current simulation model might include:

- The addition of the piezoviscous properties of the fluid flow through the valve at high pressures and switching speeds
- The addition of transient flow forces during the transition time and how they affect the high pressure performance of the valve, especially at high switching speeds.
- The collection of experimental data to support the development of new simulation algorithms under project 3.C.

In addition to fluid changes resulting from high pressures, the mechanical loads on the digital valve increase as well and research must be done to study how leakage, noise, weight, compactness, and reliability are changed due to micro and macro scales of mechanical deformation. It is necessary that high pressure components be inherently pressure balanced and achieve reliable sealing and movement at all pressures.

4. Achievements to Date

A high speed computer has been acquired to complete the analysis portion of the project. Appropriate software packages have been integrated into the computer. Basic models for studying fluid dynamics within poppet valves have been completed. These models are dynamic and study velocity fields and pressure differentials at discrete openings of the valve. Flow charts have also been developed that document the structure of each coupling interface between the different finite element analyses of the valve.

5. Other Relevant Work

There is relevant work underway within the Center through the efforts of Perry Li, University of Minnesota, within industry as efficiency and bandwidth improvements are desired, and at many international universities, such as University of Edinburgh—Scotland, Institute of Fluid Power Drives and Controls at Aachen University—Germany, Gifu University—Japan, Tampere University of Technology—Finland, and Johannes Kepler University of Linz. The number of publications in the field of digital hydraulics has been increasing in recent years.

6. Plans for Next Year

In the beginning stages of next year, geometry will be finalized for the fully coupled analysis. CFD analysis will then be completed for the valve geometry at a range of operating frequencies and working pressures. Finally, the coupling structure for the fluid, mechanical, and electromagnetic domains will be fully developed.

7. Expected Milestones and Deliverables

January 2008: Axis Symmetric Steady State Solution (flows and forces)
June 2008: Axis Symmetric Dynamic Mesh Transient Solution (flows and forces)
October 2008: Fully Developed Structure and Method for Couple Analysis
December 2008: Axis Symmetric Fully Coupled Analysis Solution
December 2009: Experimental validation of coupled model.

8. Member Company Benefits

This project will directly benefit member companies involved in fluid power component design by providing a methodology and improved tools to optimize and virtually prototype new components, including accounting for the interaction between various physical phenomena and targeting high speed and high pressure applications. All reports and publications will be available to Center members.

9. Research Team

Project Leader:	Prof. John H. Lumkes Jr.
Graduate Students:	John Mahrenholz
Undergraduate:	John Andruch
Industrial Partners:	TBD

Project 1G.1: Optimized Engineered Fluids

1. Statement of Project Goals

The goal of this project is to develop energy-efficient hydraulic fluids that enhance the starting torque and low-speed performance of hydraulic motors.

2. Project Role in Support of Strategic Plan

This project will enhance fluid power efficiency and compactness by providing fluids that improve the starting torque and low-speed performance of motors. The outcome of this research will be used to optimize fluids for the sUV and excavator test beds.

3. Research Barriers and Methodology

This project entails a systematic investigation the effects of novel hydraulic fluid additives (including carbon nanotubes) upon the low-speed and starting efficiency of hydraulic motors. Well characterized mineral oil and biodegradable synthetic ester base stocks containing advanced polymer additive chemistries will be studied. Leakage flow and torque efficiency will be evaluated under constant low-speed and constant-pressure conditions. Starting torque will be evaluated using the locked-shaft method. Geroler, axial-piston and radial-piston motors are included in the test matrix in order to determine if efficiency gains can be extended throughout a range of motor designs. Correlations with laboratory high-shear viscosity and boundary lubrication tests will be investigated.

4. Achievements to Date

A dynamometer has been constructed for low-speed high-torque (LSHT) testing of hydraulic motors. Shown in figure 1, this dynamometer incorporates a pressure-compensated axial piston pump, a digital torque transducer, two 200 HP Powerflex 700S variable frequency drives and an 18-channel data acquisition system that is capable of a 100 kHz sampling rate on each channel. The twin VFD controllers share a DC bus that enables electrical regeneration of the power absorbed by the load motor. This reduces electrical energy and cooling water consumption. Precise pressure, speed, torque and temperature control must be maintained in order to assess motor efficiency accurately. Through the use of a 1000:1 constant-torque AC motor and a high resolution Heidenhain rotary encoder, this dynamometer was able to evaluate the LSHT efficiency of a geroler motor. At 1 RPM the mechanical efficiency was in the range of 50 to 60 %, depending upon fluid viscosity and system pressure. Improvement seems within reach.

Figure 4: 200 HP low-speed high-torque dynamometer with electrical regeneration capability

5. Other Relevant Work

S. Oshima at Namazu College of Technology modeled the low-speed characteristics of a geroler motor and R. Renvert at IFAS Aachen compared the low-speed and starting torque of various designs. None of these studies examined fluid additive effects. S. Herzog at Rohmax evaluated pump efficiency with a variety of fluids but motors were not considered. The effect of polymers and boundary lubricant additive chemistry upon hydraulic motor efficiency is unknown.

6. Plans for the Next Year

During the next year we will benchmark the performance of geroler, axial-piston and radial-piston motors with a standard antiwear hydraulic fluid. Thereafter fluids that incorporate a variety of polymer additives will be tested. Synthetic fluid testing will be carried out to the extent funding allows. Fluid characterizations at Georgia Tech and University of Illinois will be performed concurrently.

7. Expected Milestones and Deliverables

Milestones: See Gantt chart

Deliverables:

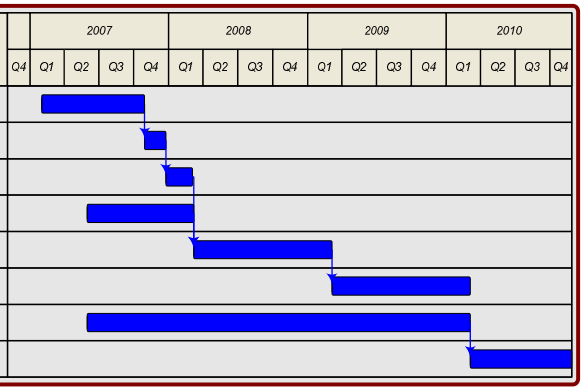
End of Year 2: An interim report containing hydraulic motor efficiency benchmarks and a preliminary assessment of polymethacrylate additives.

End of Year 3: A report containing a detailed assessment of polymer additive effects on efficiency will be provided, including fluid characteristics.

End of Year 4: A report containing an assessment of friction modifier effects.

End of Year 5: Final report

ID	Task Name	Start	Finish	Duration
1	Construct test stand	2/1/2007	10/29/2007	38.6w
2	Breakin hydraulic motors	10/30/2007	12/24/2007	8w
3	Establish LS-HT benchmarks with formulation #1	12/25/2007	3/3/2008	10w
4	Formulate fluids and carbon nanotube blends	6/1/2007	3/6/2008	40w
5	Test prototype polymer-containing formulations	3/7/2008	3/5/2009	52w
6	Test prototype friction modifier containing formulations	3/6/2009	3/4/2010	52w
7	Characterize tribologicat properties of fluids	6/1/2007	3/4/2010	144w
8	Investigate models for leakage flow and frictional torque	3/5/2010	3/3/2011	52w



8. Member Company Benefits

Technical: The torque required to launch a vehicle determines hydraulic motor displacement and system design pressure. Improving the starting torque and low-speed efficiency of hydraulic motors will lead to new compact system designs and significant fuel savings. All reports and publications will be made available to Center members.

Educational: Students in the research team are gaining a great deal of practical experience in fluid power system design and testing.

9. Research Team

Industrial Partners:	Eaton Hydraulics, Gates, Parker, Poclain Hydraulics, RohMax USA, Sauer-Danfoss, Shell, Sun Hydraulics
Project Leader:	Paul Michael, Research Chemist, Fluid Power Institute, MSOE
Other Faculty:	Tom Wanke, Director, Fluid Power Institute, MSOE
Graduate Students:	Aaron Kimball, MS Engineering, MSOE Solid works modeling, nanofluid formulation, atomic force microscopy analysis and filterability testing Andrew Bergesen, MS Engineering, MSOE Test bed engineering, valve manifold design, component selection, procurement, logistics, assembly, commissioning and test stand operation Sarah Johnson, MS Engineering, MSOE Electrical Project Engineer, designed and selected instrumentation. Programming and integration of PLC controls and safety systems. Brian Vanroy, MS Engineering, MSOE Laboratory Manager, test cell renovation, layout, fixture and reservoir design, welding, machining, plumbing, assembly and commissioning
Undergraduate Students:	Brian Blazel, Sophomore ME, MSOE; Fluid formulation, filterability testing and ferrographic wear particle analysis Dan Haeg, Junior ME, MSOE; Test stand assembly and data acquisition Chelsey Jelinski, Junior ME, MSOE; Fluid particle count analysis Dan Moldenhauer, Junior EE, MSOE; Electrical, instrumentation and PLC controls wiring and installation Ricardo Rivera-Lopez, Senior ME, REU, Universidad del Turabo, PR; Nanofluid formulation and filterability testing

Project 1.G.2:
Carbon Nano-Tube Additives to Reduce Volumetric and Pressure Losses

1. Statement of Project Goals

This project will investigate the concept, suitability and performance of carbon nano-tunes in fluid power system components to reduce the viscous pressure drop along lines at turbulent flow conditions, and to reduce leakage and increase the load carrying ability of sealing in order to increase efficiency of pumps and motors.

2. Project's Role in Support of the Strategic Plan

The project will attack the efficiency barrier by improving the performance capability of hydraulic hoses and sealing and bearing surfaces. By minimizing frictional energy loss in hydraulic lines and increasing volumetric efficiency in pumps and motors, the results of this project will provide benefits for several of the proposed test-beds, particularly the excavator and the small urban vehicle.

3. Fundamental Research Barriers and Methodologies for Addressing Them

A critical barrier is addressing dispersion of the nano-tubes. We have been working with MSOE and two companies (Shell and Ashland) on this problem. Another barrier is measuring the effect on fluids which are typical of hydraulic power systems. This is being addressed by designing a new system which can handle higher viscosity liquids at transitional and turbulent Reynolds numbers.

4. Achievements to Date

Interfaced with MOSE and above companies and recently received sample hydraulic oils with and without nano-tube additives. Researched transitional Reynolds number drag reduction for water and found that about 10 ppm is an effective concentration, which ensures that the methodology can be low-cost (important for industrial use). We are currently designing a high viscosity high velocity flow facility.

5. Other Relevant Work

Project 1.G at MSOE and Project 1.D at UIUC and Testbed at Purdue

6. Plans for Next Year

Next year, we will fabricate high viscosity high velocity flow facility and begin testing different hydraulic fluids (various viscosities and various detergent additive for nano-tube dispersion) as well as various carbon nano-tube concentrations and shapes. This knowledge base will then be used to develop overall understanding of nano-tube drag reduction mechanisms. In addition, an experimental facility will be designed to investigate sealing issues of hydraulic fluids with carbon nano-tubes.

7. Expected Milestones and Deliverables

1) Fabricate high viscosity high velocity flow facility by April 2008

2) Testing different hydraulic fluids (various viscosities and various detergent additive for nano-tube dispersion) as well as various carbon nano-tube concentrations and shapes by September 2008

3) Submit conference/journal paper to discussing nano-tube drag reduction mechanisms by December 2008

4) Design experimental facility to investigate sealing issues of hydraulic fluids with carbon nano-tubes by December 2008.

8. Member Company Benefits

The primary benefit for 2008 will be a knowledge base on drag reduction performance of hydraulic fluids with carbon nano-tube concentrations.

9. Research Team

Project Leader:	Prof. Eric Loth
Other Faculty:	Prof. Paul Micheal
Post Doc(s):	Dr. Ilker Bayer (For 2008)
Graduate Students:	Mr. Adam Steele
Undergraduate Students:	Mr. Ghoku Krishna
Industrial Partner(s):	Shell, Sauer-Danfoss, Trelleborg, John Deere, Festo, Gates, Caterpillar, DeGussa

Project 2A: Chemofluidic Hot Gas Vane Motor/Pump

1. Statement of Project Goals

The goal of this project is to develop, demonstrate, and characterize the performance of a monopropellant-powered vane motor for use in high bandwidth actuation of a hydraulic pump. The first five years will primarily involve development of the motor, which is expected to deliver a continuous power in excess of 1000 W/kg (approximately a factor of five better than rare-Earth magnet brushless electric motors). The second five years will integrate the motor into a closed-loop-controlled throttle-less hydraulic actuator to provide compact hydraulic power for small-scale fluid-powered systems, such as compact robots.

2. Project's Role in Support of the Strategic Plan

One of the stated objectives of the Center is to develop compact (i.e., human-scale) fluid powered systems. Project 2A provides a means of efficiently powering and controlling human-scale fluid-powered systems. The approach is not subject to the quenching or scavenging problems in a small-scale IC engine, unlike an IC engine can provide bidirectional, high-bandwidth motion, and unlike an IC engine provides torque without speed. As such, the motor can be used for throttle-less actuation, therefore bypassing the fluid heating and inefficiency problems that plague the systems mentioned above. Further, the liquid propellant that powers the proposed approach is not flammable, the motor can be easily started and stopped, has zero fuel consumption on idle, does not require air (i.e., can be used underwater or in space), and has completely safe reaction products (i.e., can be used indoors). As such, the objective of project 2A is to develop, demonstrate, and energetically characterize a complete, closed-loop controlled, throttle-less actuation system in a human-scale robot (specifically in the CRC testbed). If successful, project 2A will enable the use of high power density fluid-power actuators in human-scale robots, and thus will contribute directly to the fulfillment of the Center's vision.

3. Fundamental Research Barriers and Methodologies for Addressing Them

Challenges in the development of the motor include friction, thermal expansion, and sealing issues. These issues are being addressed by model-based design, experimental assessment, and design iteration. The extent to which these can issues can be mitigated will determine the promise of this technology. With regard to throttle-less control, challenges include achieving a competitive closed-loop bandwidth and achieving sufficient closed-loop positional accuracy in the presence of Coulomb friction and a non-collocated control structure. These issues can be improved via nonlinear and model-based control techniques, but at some point provide a fundamental limitation on control performance.

4. Achievements to Date

Two prototypes have been designed, fabricated, and tested in the first 1½ years of the ERC. The first prototype, V1, ran on 70% peroxide and was experimentally shown to provide 180 W/kg of power output. Note that a good, brushless motor will provide approximately 160 W/kg. The second prototype, V2, was designed to be lighter, have a greater expansion ratio, have a greater torque output, and to have adjustable geometry. The V2 prototype was recently experimentally

shown to provide 650 W/kg, and is expected to provide more power with subsequent tuning. The goal for the second year is to demonstrate 1000 W/kg (more than 5x better than brushless motors).

5. Other Relevant Work

Project 2B is similarly being developed as a power source for human scale actuated systems. No similar approaches are being developed outside the Center. A British company named Oxford Catalysts has developed a monopropellant fuel which appears more energetic and arguably safer than the peroxide we are currently using. Many are exploring their fuel as a potential replacement fuel.

6. Plans for Next Year

The goal for next year is to develop a motor with 1000 W/kg and demonstrate on 90% peroxide. Once that is achieved, we will simultaneously investigate a bidirectional design and begin development of a compact hydraulic pump for valveless control.

7. Expected Milestones and Deliverables

12 month milestones:

- Device model predicting efficiency, torque, power, and motor dynamics.
- Demonstration of unidirectional motor with 70% peroxide monopropellant.

24 month milestones:

- Demonstration of unidirectional prototype with 90% propellant.
- Model validation with unidirectional prototype.
- Performance characterization of unidirectional prototype, include torque, speed, and efficiency characteristics.

36 month milestone:

- Design and demonstration of bidirectional prototype.

48 month milestones:

- Demonstration and performance characterization of bidirectional prototype.

60 months milestones:

- Demonstration and characterization of bidirectional motor driving reversible hydraulic pump.

8. Member Company Benefits

If successful, this project will provide a compact power source for hydraulic machines. As such, if successful, this work will provide whole new potential markets for the member companies.

9. Research Team

Project Leader:	Michael Goldfarb, Ph.D. Mechanical Engineering, Vanderbilt University.
Graduate Students:	Tyler Li, Ph.D. candidate, Vanderbilt University Jason Mitchell, Ph.D. candidate, Vanderbilt University
Undergraduate Students:	Noah Walcutt, Vanderbilt University
Industrial Partner(s):	Enfield Technologies

Project 2.B: Free-Piston Engine Compressor

1. Statement of Project Goals

The goal is to develop a compact high energy density pneumatic power supply applicable to untethered fluid-power applications. This will be achieved by designing, building and testing a free-piston engine utilizing spark-ignited fuel that is specifically load matched to the task of compressing air. Fundamental research will result regarding optimizing the efficiency and power density of the energetic conversion and transduction processes between chemical stored energy, kinetic energy of the free-piston, compression and pumping work, and stored pneumatic potential energy.

2. Project's Role in Support of the Strategic Plan

This project contributes mainly to the compactness thrust. The compactness is achieved both due to the high gravimetric energy density of the driving fuel, and the configuration of the engine which favors dynamic "linkages" over kinematic ones. This project will contribute to the Center's goal of breaking the barrier of low energy density power sources for untethered devices. Additionally, given that an adequate level of overall efficiency is required to break the energy barrier and provide an order of magnitude increase in energy density over conventional technology, this project also has some crossover with the efficiency thrust of the Center.

3. Fundamental Research Barriers and Methodologies for Addressing Them

Free-piston engines have long held the attraction of being compact, mechanically simpler, and having fewer moving parts than crank-shaft based IC engines. Although it is widely recognized that the inertial load presented by a free-piston can be used advantageously to influence the thermal efficiency, previous research fails to explicitly exploit this feature through design. The fundamental research barrier preventing this is a lack of tools regarding the design of "dynamic engines".

Dynamic engines (a non-standard term) replace the kinematic dependencies of traditional engines with dynamic elements and controlled valves. Such a configuration has the potential of increased efficiency and compactness over current small scale kinematic IC engines. Efficiency is enhanced by utilizing a combination of dynamic elements, such as inertial and spring/elastic elements among other possible candidates, to tranduce fuel energy into other energy domains with fewer losses. Compactness is enhanced given that dynamic elements are typically more compact and physically "simpler" than kinematic arrangements.

To address the lack of tools present for the design of dynamic engines, a system dynamics and controls perspective will be applied. Methodologies associated with system dynamics and controls are not typically applied to engine design, and this research provides an opportunity to formulate: 1) the dynamic analysis of such engines in light of exploiting the intermediate kinetic energy storage of the free piston, and 2) a synthesis method for the design of free-piston engine devices that have a load tailored for certain applications, such as pumping hydraulic fluid, compressing air, and other outputs, while also being "shaped" to benefit the combustion cycle for efficiency, power density and/or other metrics.

4. Achievements to Date

The main focus of this work is to exploit the fact that a free piston can present a purely inertial load resulting in a "kinetic energy" phase of the stroke. This kinetic energy phase can be used to stretch, compress, scale, or phase the transduction of energy from and between chemically stored energy, heat energy, pneumatic potential energy, and kinetic energy, to support combustion, expansion, intake, exhaust, work, breathe-in, and other functions in non-traditional ways (i.e. non-kinematic dependencies). The design aspect of the work is to realize a configuration that exploits the kinetic energy of the free piston in order to obtain desirable operational characteristics such as high efficiency, low noise, and low temperature operation in a compact configuration.

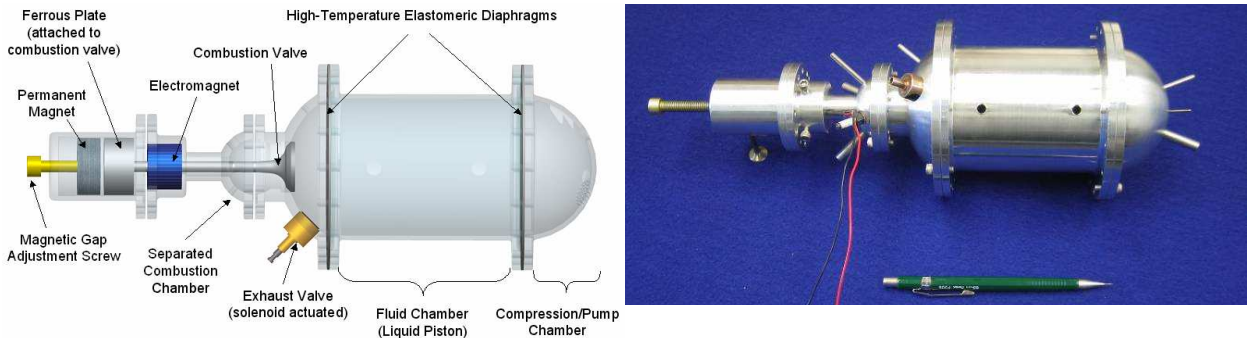


Fig 1: Illustration of the design and hardware realization of the free piston engine compressor.

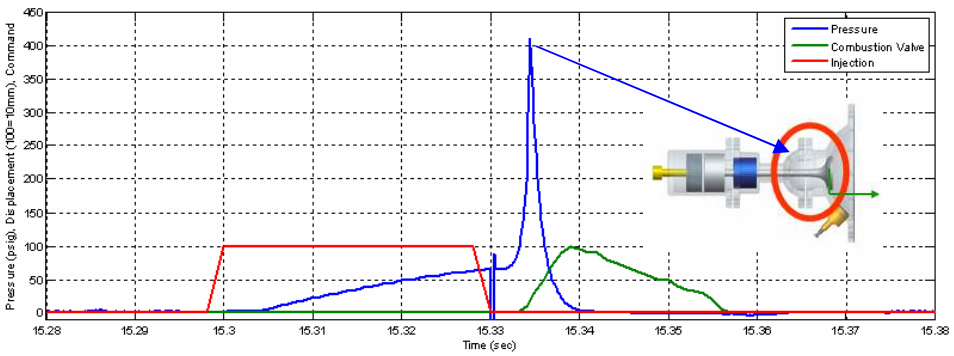


Fig 2: Experimental data showing the air/fuel injection command (red), the pressure in the combustion chamber (blue), and the position of the combustion valve (green).

Achievements within the June 1, 2006 through November 30, 2007 timeframe include: 1) Design and fabrication of an aluminum free-piston engine compressor prototype with separated combustion chamber and liquid free piston (see fig. 1), 2) energy-based dynamic simulation of the a) air/fuel injection dynamics, b) combustion process releasing heat resulting in pressure dynamics, c) combustion valve inertial dynamics, d) compressible mass flow rate dynamics between the combustion chamber and the expansion chamber, e) inertial dynamics of the sprung liquid-piston, f) pressure dynamics of compression and pumping in the pumping chamber, g) mass flow rate dynamics of the output gas, exhaust gas, and breathe-in gas, 3) experimental air/fuel pressure control and injection mechanism, 4) successful 10Hz combustion testing (see fig. 2), 4) design and fabrication of an integrated compressor head and reservoir chamber (not shown), 5) initial development of an event-triggered controller to achieve efficient operation

(utilizing the simulation model), 6) initial tests of the engine under load with indications of good diaphragm integrity and expansion characteristics.

5. Other relevant work in the Center

Within the Center, the work most similar in motivation is chemofluidic actuation. Although different in their approaches to transduction from an energy dense source to controlled mechanical motion, the free-piston compressor project has two important *operational* differences:

1) It aims to provide a centralized source of *cold* pressurized gas, whereas the chemo-fluidic approach results in hot gas and the need for specialized valves and actuators.
2) It utilizes a conventional hydrocarbon fuel as opposed to a less readily available monopropellant.

6. Plans for Next Year

See below.

7. Expected Milestones and Deliverables

Year two:

1) Utilize simulation model to finalize the first prototype design configuration including engine control.

2) Combine tested design elements into finalized engine configuration for a bench-top demonstration. Milestones include:

- experimentally characterize efficiency (including separate transduction steps)
- evaluate the energy flow (relative percentages of useful work and energetic losses as flowing down from available heat energy)
- experimentally determine maximum power output and maximum cycle rate
- implement a simple control strategy to regulate a set pressure in the reservoir

Year Five:

- Completed generation two design integrated into CRC for a fully autonomously powered endurance demonstration
- Extensive fundamental modeling and simulation library of new components and configurations

Year Ten:

- A family of next generation high energy density free-piston engines for fluid powered devices. This family of engines will all share a compactness philosophy of replacing kinematic linkages seen in traditional engines with dynamic elements designed to match the specific load (output) being considered. These engines will be fully demonstrated on the CRC, Hand Tools and sUV testbeds.

8. Member Company Benefits

Not yet identified.

9. Research Team

Project Leader:	Prof. Eric J. Barth, Vanderbilt University, Mechanical Engineering
Graduate Students:	José A. Riofrío (Ph.D.), Chao Yong (Ph.D.), Andy Willhite (Ph.D.)
Undergraduate Students:	Matt Casavant, Robert (Kit) Buckley, Steven Blackmon, Jonathan Webb, Colin Roper, Robert Carter, David Harju

2C: Compact Energy Storage - Open Accumulator Approach

1. Statement of Project Goals The goal of this project is to develop an alternate accumulator configuration to existing hydraulic accumulators that maximizes the usage of energy in the compressed gas. The proposed "open accumulator" configuration will be investigated which, at current pressure level of 35MPa, is potentially an order of magnitude more energy dense than existing configurations. The approach will be considered successful if a system with power and energy requirements suitable for a small passenger car is 5 times more compact than using existing approach.

2. Project Role in Support of Strategic Plan Energy storage density in hydraulic systems are severely limited relative to competing technologies. For example, volumetric energy storage densities of electric batteries are of the order of 1MJ/Liters, whereas those of hydraulic accumulator configurations are less than 10KJ/liters (at 35MPa). Hydraulic systems however have an order of magnitude advantage in power densities relative to electric systems. Dramatic improvement in energy storage densities for hydraulic systems can enable regeneration in many applications where space, weight, and power are critical. One example is the hybrid passenger vehicles where space for energy storage is a premium (compared to larger vehicles such as buses and trucks). For such applications, 5-10 times improvement in energy density is required.

3. Fundamental Research Barriers and Methodologies for Addressing Them In current practice, an accumulator is used to store hydraulic energy. Typically, it consists of a chamber containing a fixed mass of inert gas whose pressure increases and whose volume decreases as hydraulic fluid is pumped into the accumulator. Energy is stored by pumping pressurized hydraulic oil into the accumulator and is regenerated as the compressed gas pushes the stored oil back into the hydraulic circuit. Since the gas is always contained within the accumulator, we refer to it as *closed accumulator*. The energy density of a closed accumulator is optimized when an expansion ratio of approximately 2-3 is employed. Since the closed accumulator needs to accommodate the expanded gas volume, expansion ratio beyond the optimal leads to increase in volume and an overall decrease in energy density.

In the proposed *open accumulator* approach, the compressed gas is exhausted to the atmosphere during expansion, and intake is also taken from the atmosphere during compression. This results in a much higher expansion ratio (350) and the available energy from the compressed gas with the same volume is increased by 6.5 times. Furthermore, since the expanded air is exhausted to the atmosphere, the system does not have to account for its volume, nor the volume of the displaced oil hydraulic. This decreases the total volume by 3.3 times. A potential 20 fold increase in volumetric energy storage density for the same compressed gas pressure can be achieved at conventional hydraulic pressure (35MPa) (Fig. 1). The main challenges in realizing the open accumulator concepts are: 1) safety in compressing and expanding atmospheric air; 2) maintain power density; 3) efficient input and extraction of energy; 4) heat transfer / temperature variation associated with the large expansion ratio. These challenges are being addressed by utilizing safe choice of material, proposing a system architecture that maintains constant pressure, specialized compressor/motor design, and optimizing heat transfer and the use of thermal storage materials.

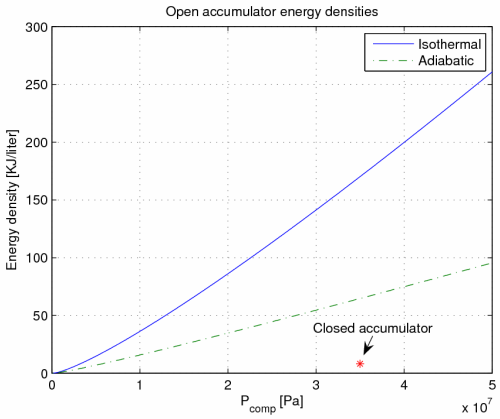
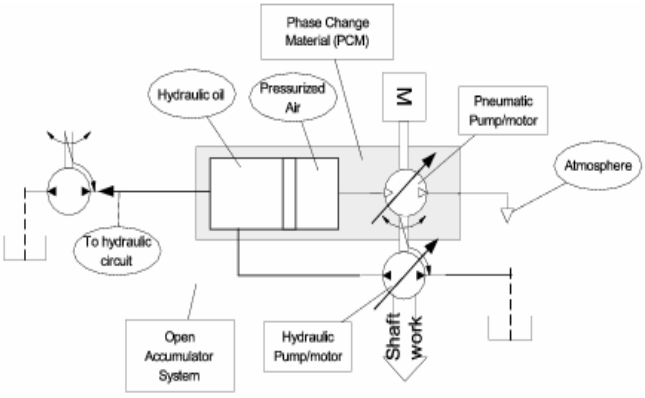


Figure 5: Theoretical energy densities of proposed open accumulator and conventional closed accumulator

4. Achievements to Date

Figure 6 Nominally constant pressure open accumulator architecture



An architecture capable of maintaining constant pressure during normal operation and sustaining large transient power load has been developed (Fig. 2). By maintaining constant pressure, this architecture ensures that energy can be effectively extracted even as energy is depleted from the accumulator. A novel multi-stage air compressor/motor design that minimizes air leakage using liquid pistons has been designed. A system level thermodynamic model for the proposed system has been developed. The model shows that system efficiency under constant pressure operation decreases as heat transfer rate decreases. Since heat transfer rate requirement is directly related to power, a tradeoff exists between efficiency and power. With the importance of heat transfer recognized, two faculty members with heat transfer expertise were recruited into the project. Theoretical trade-off analysis between power density (as determined by compressor/motor capability) and energy storage density has also been conducted. The architecture in Fig. 2 operating in transient power overload mode results in gradual decrease in energy density as power requirement increases. A 2-stage, 0.5MPa prototype has been designed and fabricated and currently being assembled to verify the open accumulator energy storage concept. Analytical heat transfer models of the compression/expansion process in the compressor/motor based on simplified geometry has also been conducted.

5. Other Relevant Work Other approaches of increasing energy density can be investigated.

6. Plans for Next Year As the 2-stage prototype is fully assembled, it will be experimentally tested and characterized for energy density, power density and efficiency. FLUENT based numerical heat transfer model will be developed and validated. This will be used to optimize the heat transfer strategy and the design of the compression/expansion chambers. Pressure control system, not included in the first prototype will be implemented. System optimization will also be conducted to determine optimized tradeoff between power, energy and efficiency.

7. Expected Milestones and Deliverables

End of year 2: Experimental validation of open-accumulator concept
End of year 3: Heat transfer strategy developed
End of year 5: Optimized compressor/motor design. Experimental validation at 35MPa.

8. Member Company Benefits

Order of magnitude increase in energy storage density will be game changing for fluid power. Industry members can exploit knowledge for rapid deployment into products.

9. Research Team

Project Leader:	Prof. Perry Y Li, Mechanical Engineering
Other faculty	Profs Jane Davidson, Terry Simon, Kim Stelson, Mechanical Eng.
Graduate Students:	David Hafvestein, Caleb Sancken
Industrial Partners:	Industry champions: Bosch-Rexroth, Caterpillar, Eaton, Gates, MTS

Project 2D: High-Pressure, Light-Weight Components Using Engineered Materials

1. Statement of Project Goals

The primary goal of project 2D is to overcome several design and fabrication barriers to advance Design Optimization and Hybrid Fabrication (DOHF) to a level that can be leveraged by ERC members for the design and fabrication of future FP components.

Long-term efforts are targeting the use of lattice structures designed specifically to reduce mass and increase functionality in FP components. Examples of these lattice functions within a component are sound damping, fluid storage, and encoding; while providing the required functional structure. A key long-term goal is to automate several steps of generating these complex lattice structures, including the generation of a stress-field-compliant mesh. A second long-term goal is to advance the hybrid fabrication procedure to a higher yield and increased working window.

Short-term goals have been to continue offering off-the-shelf solutions to CCEFP participants interested in applying well-established optimization tools, such as Altair's Hyperworks, and to connect CCEFP fabrication needs to additive-based fabrication solutions.

2. Project's Role in Support of the Strategic Plan

DOHF has widespread direct and indirect impact on almost all thrust barriers and sub-barriers. Examples follow:

Efficiency Barriers

- At the systems level DOHF is anticipated to provide efficient(?) alternatives for high-pressure compact energy storage with a windfall of additional structural functionality, and allows for the integration of several components, thereby improving fluid flow and reducing line losses.
- Component efficiency stands to gain from DOHF through reduced cavitation, friction losses, and increased payload (via mass reduction). Smoothly transitioning flow-paths with structural function and low-friction metal-matrix-composite (MMC) contact surfaces all improve component efficiency.
- Improvements in fluid efficiency and fluid life are likely with high surface-to-volume fluid storage. By keeping fluid temperatures well below temperature limits, viscosity will be maintained and fluid oxidation will be prevented.
- Fabrication of custom components is very feasible via hybrid fabrication methods; and, parametric designs have the potential to be scalable (within reason) to accommodate various unique applications, potentially improving efficiency by providing a size-optimized system. Components used for flow throttling stand to gain from a reduction in line volume and increased stiffness of the system.

Compactness barriers

- Power-supply size, and overall mass, may be reduced through DOHF by removing "dead weight" from the system. Combining system components will result in multi-functional components occupying a smaller volume and/or having reduced mass.
- High Pressure is a significant challenge. Altair's Topology Optimization software, and perhaps DOHF, will provide designs for structural junction-nodes and component interfaces.

Effectiveness Barriers

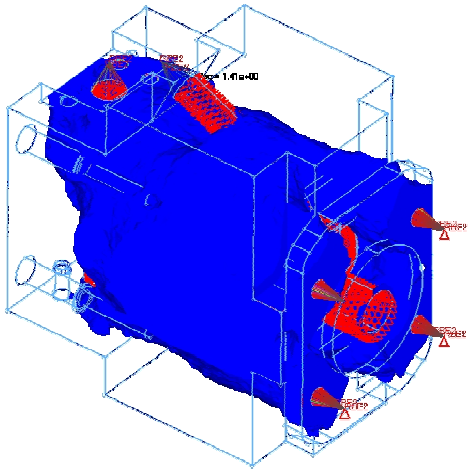
- There is significant potential to create personalized human-machine interfaces by using scanned-in data and additive fabrication processes.
- Noise and vibration may be reduced by smart placement of materials.
- Leakage has been a problem since the earliest fluid power system came online. DOHF provides some opportunities to reduce leakage through component integration.

3. Fundamental Research Barriers and Methodologies for Addressing Them

Design Optimization Challenges: A major challenge is the generation of a stress-field-compliant mesh, i.e. a lattice whose members experience minimal shear stress, particularly under multiple loading conditions. The primary barrier encountered is the lack of software tools available to describe this mesh in a practical manner, i.e. non-automated and non-optimized. In addition to researching a plethora of mesh-generation techniques, we are addressing this barrier by developing software that will generate this lattice structure using a more fundamental approach to analysis and optimization of structural components. This will allow for direct generation of optimized structures, without user interpretation, and for the integration of multiple materials, e.g. a metal-matrix composite.

Hybrid Fabrication Challenges: Fabrication of complex lattice structures in metal with adequate mechanical characteristics is challenging using cast and additive metal processes. Simultaneous high resolution, excellent mechanical properties, and object complexity currently do not coexist in additive direct metal processes. Furthermore, advanced casting processes are challenged to produce high resolution objects due to solidification shrinkage of melts heated well above superheat temperatures. To address these challenges polymer-based additive processes will be used to produce high quality, high resolution, expendable patterns combined with an advanced casting process being developed at MSOE. Castings will be produced at metal injection pressures exceeding typical investment casting methods while maintaining compression in "high-risk" mold regions. Additionally, melt temperature will be reduced to near or below liquidus temperatures during casting to obtain complex intricate lattice structures. The casting process to be employed is called Compressed Mold Pressure Casting (CMP-Hybrid).

4. Achievements to Date



- Casting of ferrous materials and super nickel alloy (Super Invar)
- Deeper understanding of casting factors influencing casting success
- Integration of secondary hot zone into CMP-Hybrid Furnace leading to better casting control and improved yields
- Improved ceramic formula for casting high temperature alloys
- Integration of induction melting into CMP-Hybrid furnace
- Improved temperature monitoring and noise reduction on CMP-Hybrid furnace
- Applying Altair Hyperworks software suite's structural optimization tools to a commercially-available Parker axial-piston pump, resulting in a 33% reduction in mass
- Elimination of Altair's Hypermesh as a stress-field-compliant meshing tool
- Deepened understanding of meshing challenge and proposal of a potentially-patentable stress-field-compliant "meshing" algorithm currently under development
- Hosted an REU student during the summer of 2007

5. Other Relevant Work

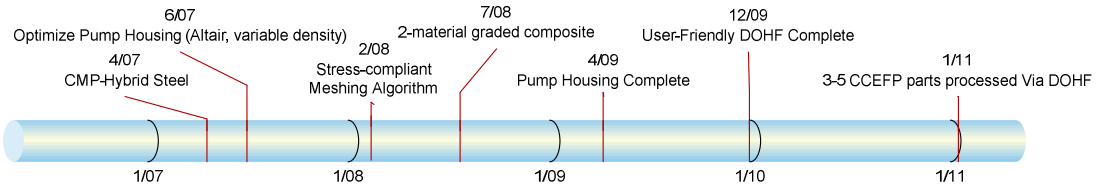
All commercial structural-optimization software solutions remain to be constrained by traditional fabrication constraints. The hybrid fabrication process in development is less constrained, and thus, so must the model-generating software be.

6. Plans for Next Year

- Combined study of structural properties of variable-density lattice structures, both virtual and physical
- Stress-field-compliant lattice structure algorithm and programming
- Sound-damping lattice structure demonstrator
- Stand-alone informational presentation describing topology optimization and its relationship to fluid power components

7. Expected Milestones and Deliverables

- Increased collaboration with CCEFP project teams and member companies, involving the use of existing structural-optimization techniques and hybrid-fabrication capabilities to fabricate "high-performance" components
- Advancement of the CMP-Hybrid process and improved basic understanding of structural properties as a function of cast feature size
- Basic stress field compliant lattice generation technique developed for validation, testing, and partial use



8. Member Company Benefits

The member companies will have the opportunity to be the first to leverage DOHF for existing and new markets.

9. Research Team

Project Leader:	Vito R. Gervasi, Rapid Prototyping Research
Other Faculty:	Douglas Cook – Rapid-Prototyping Research
Post Doc(s):	
Graduate Students:	Gunnar Vikberg
	Aaron Kimball
	Richard Remmers
Undergraduate Students:	Zack Fosse
	Matthew Woodruff
	Brian Erickson
	Andrew Timm
	Brad Knier
	Andrew Steevens (REU 2007)
Industrial Partner(s):	Parker

Project 2E: Component Integration for Compact Fluid Power Systems

1. Statement of Project Goals

The goal of the project is to reduce significantly the time and effort required to formulate and solve systems engineering problems for compact and efficient fluid-power systems. To achieve this, analysis knowledge about fluid-power components from multiple disciplinary perspectives and multiple levels of abstraction will be captured and organized in a modular, object-oriented knowledge repository using a standardized language (SysML), and synthesis knowledge about fluid-power systems will be captured in the form of graph transformations. A systems engineering method and software framework will be developed in which the synthesis and analysis knowledge from the repository is used to explore efficiently and comprehensively large spaces of system architectures with the goal to improve the compactness and efficiency of fluid-power systems while balancing other system objectives such as effectiveness, cost, and reliability. The framework is based on a solid foundation of Multi-Attribute Utility Theory.

2. Project's Role in Support of the Strategic Plan

The project will provide a method and software framework to support the comprehensive and efficient exploration of integrated system architectures. This will enable the integration of the fluid-power subsystem with structural subsystems (compact integration and distribution barrier) and enable the comparison between different system architectures for achieving desired system-level tradeoffs (system integration inefficiency barrier). The framework could also enable the evaluation of the impact of introducing new component technologies (Component efficiency barrier) or higher pressures (high pressure operation barrier) on system-level performance.

3. Fundamental Research Barriers and Methodologies for Addressing Them

With the advent of electronic control, fluid-power systems have become increasingly integrated and multi-disciplinary in nature and the number of potential system architectures has exploded. With new demands on compactness, efficiency, and effectiveness, system engineers need to explore new system architectures that provide adequate tradeoffs across these conflicting objectives. The barrier that needs to be overcome is one of complexity: a very large amount and variety of knowledge is necessary to synthesize and analyze promising system architectures. Unless this knowledge is managed well, the cost of acquiring, validating and applying this knowledge will limit significantly our ability to increase the functionality and performance of future fluid-power systems. The research question is: How should one represent, store, retrieve and use knowledge efficiently and effectively in support of the design of fluid power systems?

The goal of this project is to develop a knowledge repository and corresponding systems engineering methodology and software framework that reduces significantly the time and effort required to formulate and solve design problems for compact and efficient fluid-power systems.

The proposed approach for realizing a system's engineering framework that addresses the issues listed above is based on the formal capture and reuse of knowledge. By capturing the knowledge once and then reusing it often, the cost can be amortized over many re-uses making such a knowledge repository economically attractive. The knowledge in the repository will include both synthesis and analysis knowledge. More specifically, the approach is to use the OMG SysML™ language to represent analysis models formally, including the model context and uncertainty. Within the corresponding systems engineering framework, these models can then be used and re-used to

predict the performance, cost or reliability of fluid power system architectures. The approach for capturing synthesis knowledge is based on graph transformations. The graph transformations will capture the knowledge for how fluid-power components can be configured or composed into promising fluid power system architectures. Graph transformations will also be used to capture the knowledge for model composition, a process through which system-level models can be generated from a limited number of modular, re-usable component models.

4. Achievements to Date

To capture and store analysis models for fluid-power components, we have developed a knowledge structure for Multi-Aspect Component Models (MACM). These MACMs extend the SysML ontology and formally define the context of the models and how they relate to each other. In general, these relationships allow us to maintain consistency between the models that represent different aspects of the instances within a parametrically defined family of components. So far, this has been demonstrated for two different levels of abstraction: high-level predictive tradeoff models and dynamic behavior models; a study for detailed CFD analysis models is currently under way. The MACM knowledge structure has been implemented in SysML and demonstrated in the context of a case study for an excavator.

A second important achievement so far is the development of algorithms for model composition in terms of graph transformations. Both the system structure and the corresponding simulation models can be represented as graphs in which nodes represent components and arcs represent interactions between components. For example, in a schematic of a fluid-power circuit, components are port-based nodes (symbols in the circuit schematic) and the arcs correspond to the fluid lines connecting the components. By taking advantage of the relationships that have been defined in the MACMs, a graph representation of a composition of components can be transformed into a corresponding graph representation of the system-level behavioral models. We have demonstrated this in the context of a case study for an excavator. For the implementation of the algorithms, we combine SysML models for representing the system structure and the corresponding behavior models with the VIATRA graph transformation engine.

5. Other Relevant Work

The need for a systems engineering framework for fluid-power systems has been recognized before with initial work by Krus *et al.* at Linköping University and Tilley *et al.* at the University of Bath, with more recent work by Pedersen at Aalborg University and Schlemmer *et al.* at the Technical University of Aachen. In this past work, the focus has been almost exclusively on the modeling of the fluid power aspects of the system with only a few efforts allowing for seamless integration with other disciplines (e.g., structural mechanical, thermal, electrical, controls). Even then, the models only address the physical behavior of the system at one particular level of abstraction (e.g., lumped parameter, energy-based physical behavior), without considering other important system aspects such as cost or reliability. The work performed and proposed in this project has a broader scope in that it aims to combine models across different aspects and at different levels of abstraction to increase the efficiency of the solution method.

In addition, the proposed work aims to combine synergistically the use of analysis (MACMs) and synthesis knowledge (graph grammars) so that a thorough exploration of the space of system architectures can be achieved efficiently. In contrast, the past work was either based on optimization of the sizing parameters of a specific architecture, or used expert systems to guide the selection of an appropriate architecture.

6. Plans for Next Year

- Task 1: Develop algorithms to support idealization and composition at multiple levels of abstraction. The algorithms will be encoded as graph transformations in the VIATRA graph transformation engine.
- Task 2: Capture synthesis knowledge about fluid power systems as graph transformations — develop a design grammar for fluid power systems. The focus will be on generating meaningful circuits for which an analysis-based search can then efficiently determine the most promising alternatives.
- Task 3: Develop abstract models for families of components. These abstract models capture tradeoffs that exist between high-level attributes of components, such as efficiency, cost, reliability, etc. We will develop models for families of hydraulic pumps, proportional valves, and cylinders, and demonstrate how these models can be used for efficient selection of promising system architectures in the excavator case study.
- Task 4: Validate the exploration of different system architectures through case-study of an excavator (TB-1) and a hydraulic-hybrid vehicle (TB-3).

7. Expected Milestones and Deliverables

- Initial demonstration of the use of automated model composition – December 2007.
- Completion of a case study in the context of the design of an excavator; the case study will include design optimization under uncertainty considering models of a variety of aspects — February 2008.
- Demonstration of the use of models for TB-1 at different levels of abstraction, including abstract tradeoff models – August 2008.
- Demonstrate the framework for the synthesis knowledge capture – December 2008.

8. Member Company Benefits

The proposed systems engineering framework will improve the ability of member companies to explore different system architectures when integrating fluid-power sub-systems into large systems engineering efforts. By formally and unambiguously capturing the system semantics in SysML, the approach provides all the benefits of a model-based system-engineering approach including requirements management, traceability, functional decomposition, behavioral modeling at multiple levels of abstraction, and management of testing and validation. In addition, the model representation and multi-aspect component model library could serve as a "smart," active catalog from which designers could select the most appropriate fluid-power component for a particular application. These models will be made available on the internet for all member companies to use; the models could serve as a formal tool for member companies to communicate knowledge about fluid power components among each other.

9. Research Team

Project Leader:	Prof. Chris Paredis, *School of Mechanical Engineering, Georgia Tech*
Other Faculty:	Prof. Andrew Alleyne, *Mechanical Engineering, UIUC*
Post Doc(s):	None.
Graduate Students:	Jonathan Jobe, Thomas Johnson, Richard Malak
Undergraduate Students:	Alex O'Sullivan, Aleksander Kerzhner, Lina Tucker
Industrial Partner(s):	Deere & Co., Sauer-Danfoss, Pioneer Solutions

Project 2F: Dynamically Scalable Fluid Power Systems

1. Statement of Project Goals

The primary goal of this project is to use the underlying parametric clustering and interdependence found in dimensionless system representations to form scale-invariant dynamic design constraints that can be used to form very small search spaces for CAE design optimization algorithms.

2. Project's Role in Support of the Strategic Plan

This project will attack the integration barriers in both the compactness and efficiency thrusts by developing scalable relationships among the various components. These scalable relationships will become design constraints that an optimization strategy will seek to accommodate. This will improve compactness and efficiency by avoiding a bulky system comprised of individually compact components.

3. Fundamental Research Barriers and Methodologies for Addressing Them

The fundamental research barrier being addressed is that it is difficult to establish good design criteria for new components and systems. Computer Aided Engineering (CAE) can perform optimizations on system models to try and minimize some cost function but it is not clear what the initializations of those optimization routines are. Rather than perform an exhaustive search for optimal designs, the current methodology being proposed seeks to identify "good" designs by uncovering fundamental underlying design parameter relationships inherent in highly successful existing designs and then extrapolating this to new systems. This approach is based on the fundamental premise that all engineered systems have to perform particular functions under a wide range of relatively unforgiving external constraints. For engineered systems, market pressures cause suboptimal products to be eliminated. Examples of common market pressures can be see in Figure 1. These market forces cause engineered systems performing similar functions to make similar design tradeoffs regardless of size. Many of these tradeoffs are implicit in the system functionality and have to be 're-discovered' for each iteration of the particular system design. We seek to eliminate this 're-discovery'.

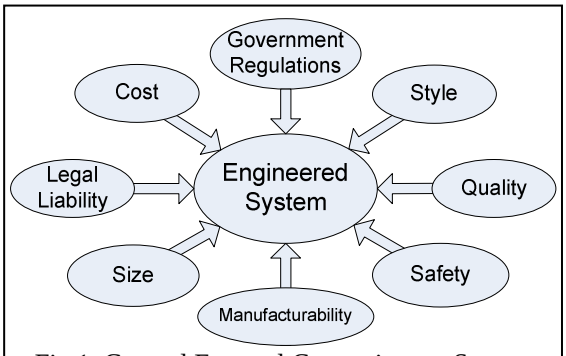


Fig 1. General External Constraints on System Design

Once the system's dynamical description was reformulated in a dimensionless framework, a distinct advantage emerges. The external market pressures of Figure 1 force the dimensionless system's parameters to lie in a very narrowly defined range of values. The main idea here is that the parameters one would need to consider in the dimensioned system representation would span the entire range of available parameters. In the dimensionless setting, the parameters cluster around much smaller subspaces. Functional relationships such as

$$\pi_j = f\left(\pi_1 \ldots \pi_m\right) \quad \forall j \in [m+1, n], \;\; m < n$$

ensure that only an m-dimensional subspace of an original n-dimensional parameter space need be considered. This provides the engineer with constraints or very good initial conditions from which to start their search for a suitable design of their particular system.

4. Achievements to Date

Over the past year, we have begun to model individual dynamic components and determine parameters sets of the dimensional systems. We have started with pumps, valves and motors. We have gathered limited sets of data for valves and pumps and are in the process of gathering more data. We have done preliminary analysis of the data and determined sets of dimensionless parameters that seem to indicate good scalable designs. A key insight resulted from understanding how legacy manufacturing costs constrained innovation in the design process. Once this constraint was accounted for, the parameters for the valve and pump components converged to nominal values that can be used in design decisions. In addition to creating component models, we have begun to investigate how to interconnect component models in a dimensionless sense so as to create dimensionless system models.

5. Other Relevant Work

Previous work by the PI determined significant design insight for the dynamics of planar vehicles.

6. Plans for Next Year

- Task 1: Gather data on representative systems from industry partners and literature.
- Task 2: Populate dimensionless system models.
- Task 3: Search for parametric inter-relationships to use as dynamic design criteria
- Task 4: Create and analyze dimensionless representations of dynamic uncertainty and examine their relationship to system control in a dimensionless framework.

7. Expected Milestones and Deliverables

- Dimensionless system model [month 3]
- Dimensionless system model populated with data [month 6]
- Dynamic design criteria integrated into software tool[month 12]
- Preliminary understanding of dynamic uncertainty in a dimensionless system [month 12]

8. Member Company Benefits

Member companies will get ‘first cut’ design rules that can be used to guide their component designs. Additionally, system design insight will be provided.

9. Research Team

Project Leader: Andrew Alleyne
Graduate Students: Scott Manwaring
Industrial Partner(s): Eaton, Rexroth, Caterpillar

3A1: Multimodal Human Machine Interfaces

1. Statement of Project Goals

This project will develop user interfaces for existing and newly emerging fluid actuated devices that take advantage of multiple sensing and display modalities and technologies incorporating, Augmented Reality (AR) to enhance device operational effectiveness. Augmented reality includes the visual, haptic and auditory senses. In conjunction with the development process, relevant models of operator-machine interaction will be developed, verified and used. Prediction of task needs and performance for new devices will thereby be enabled.

2. Project Role in Support of Strategic Plan

Fluid power devices will be used more effectively, thereby reducing working time and hence the energy consumption (efficiency barrier). New and existing devices will be able to safely perform their intended functions under human direction without undue workload on the operator (safety and human machine interface barrier).

3 .Fundamental Research Barriers and Methodologies for Addressing Them

Fluid power devices often involve many degrees of freedom under direct control of a human operator. Complex and variable human dynamics therefore interact with complex machine dynamics to compromise system performance and stability. The use of haptics (tactile or force feedback) is at the forefront of this challenge, because it is most intuitively by the sense of touch that we comprehend the effect of manual control actions. An interaction loop wherein control stick displacement commands device motion (either position or velocity) which generates reaction forces on the operator's seat and hence perturbs operator commands is one loop we have observed in our experiments. Because of the high forces hydraulic devices must exert, this is a problem not experienced with other haptic interfaces such as surgery or virtual reality. Other channels of our senses will be considered as well, with augmented visual displays considered in this and other projects. The Compact Rescue Crawler, with 18 degrees of freedom, is an excellent opportunity to study the most effective displays and controls for high dof devices.

Prior work with force feedback teleoperation has used high performance servo valves operating from a near constant pressure supply. This is an extremely inefficient approach and we will work with other projects to achieve efficiency and operator effectiveness. For example, Project 1A seeks to provide flow to each of the device degrees of freedom through individual pumps driven by the same prime mover, for example a diesel engine. Dynamics again form a barrier to effective operator interfacing. All pumps rotate at a speed proportional to the engine and the torque on the engine is the sum of the torques on the pumps. Flow from each pump is also proportional to a controlled swash plate angle. The demands of multiple degrees of freedom are now combined in a different way than the traditional valve controlled system, and new dynamics and coupling will be exhibited. Some of these interactions are predictable and if the power demand can be exactly matched by the prime mover in a predictive manner, degrees of freedom should not interfere with each other. However, the response of the prime mover will be slower than the swash plate control. Consequently an increased demand of power by one dof will slow the engine, leading to a reduced flow in all degrees of freedom. The management of this perturbation on the system will require a control system considering not only the complex machine dynamics but the reaction of the human operator and its stochastic nature.

Barriers also result from the feedback loop between sensitive hand controllers and the motion of their base when they are mounted on the equipment. This feedback loop doesn't exist when the operator is removed from the equipment or if the reaction forces generated by the equipment are modest. It is readily observed in our experiments with backhoes and traditional throttling control. Similar barriers will occur when throttleless control is used.

The approach used begins with simulation of the machine's dynamics and the operator's environment and testing the performance at some traditional tasks. Hardware in the Loop Simulation insures a realistic treatment of the most complex dynamics while computer simulation creates the more predictable or less critical aspects of the environment. HIL enables us to get a greater variety of controlled experiments completed quickly. This work is currently directed at Test Bed 1, the excavator with throttleless control. We will design passifying controls that have proven useful in other applications where human operators interact with complex dynamics, but the dynamics will first be studied before specification of the controller details. Collaboration with NCA&T will facilitate operator modeling and avoid extreme operator workloads. More extensive interface improvements such as augmented reality are also being considered by NCA&T which can be incorporated into our simulated operation.

Test bed 4, the Compact Rescue Crawler, also incorporates haptics and is the initial focus of augmented reality, since it is essential that the operator use a visual display instead of direct viewing. Two legs have been constructed at Georgia Tech to facilitate the testing of the operator interface in advance of the six legged device which will be built at Vanderbilt.

4. Achievements to Date

The functioning degrees of freedom of a Bobcat Mini Excavator have been visually modeled in Open GL. It is controllable via a Phantom ® haptic manipulator. The initial version of a trench and other surrounding features has been completed. Simple dynamics have been programmed for the behaviors not provided by the actual hardware in the loop. A Hardware in the Loop (HIL) facility incorporating two 60 hp Siemens electric servo motors under computer control has been constructed. These motors drive variable displacement pumps. One pump will be placed under the command of the operator and one will simulate the load encountered by the excavator. The donated pumps initially used have proven to respond too slowly and they will be replaced in the coming year. Control of the motors and the pumps as commanded by a real time simulation implemented in Simulink and xPC Target ® have been achieved, although we continue to improve this control. Display hardware for the HIL has been specified. In related work, the haptic backhoe experiments have been successfully conducted and form a good basis for extending into the application of advanced interfaces for the excavator test bed. Accomplishments by NCA&T are covered in a separate section.

The Compact Rescue Crawler-Operator Interface (CRC-OI) incorporates haptic control of the front legs and the initial augmented reality displays have been implemented but the cameras are not yet on the crawler. The computers to be placed on the crawler are on order and we will soon have the operator viewing from a riding position. An undergraduate has been studying the "inch worm" locomotion approach proposed for the jack that a crawler might carry to lift heavy obstacles. A simulation of its motion and a working prototype has been constructed.

5. Other Relevant Work

An extensive survey of related work was provided in a previous strategic plan and space limits its duplication here. We are not aware of user interface studies of variable displacement controls and hardware in the loop simulators discussed in the open literature does not have the ability to simulate overrunning loads.

6. Plans for Next Year

In the next year the HIL will be operational for evaluating throttleless control with human in the loop. Experiments with the actual excavator will provide verification of simulation fidelity in one degree of freedom, although that test bed will not be functional with all degrees of freedom until later. The verified dynamics will be used to provide a model for passifying control design which can be deployed on the HIL simulator. Contingency plans are being made to incorporate a structural feedback loop which shakes the operator in the process of moving the simulated excavator, replicating what would be felt by an operator on the excavator. As augmented reality displays are conceived by NCA&T they will be implemented on the HIL for evaluation.

7. Expected Milestones and Deliverables

- Dynamic model of throttleless system available [January 15, 2008]
- Hardware in the Loop interfaced to visual display [February 1, 2008]
- Multiscreen display of operator workstation [March 1, 2008]
- Alternative pumps with high bandwidth swashplate control installed [March 15, 2008]
- Passifying control designed and simulated [March 15, 2008]
- Passifying control implemented on the HIL [April 15, 2008]
- Human operator studies commence on HIL [May 1, 2008]

- CRC-Operator Interface (CRC-OI) available for remote operation [February 1, 2008]
- CRC-OI ready for operator studies [March 1, 2008]
- CRC initial recommendations for 6 legged testbed complete [May 1, 2008]

8. Member Company Benefits

One of the major selling points for mobile equipment is the operator effectiveness. The studies will enhance effectiveness and comfort for new and existing designs of fluid powered equipment.

9. Research Team

Project Leader:	Wayne Book, Georgia Tech
Other Faculty:	Steven Jiang, NCAT, Mountjoy, D., ISE Department, NCA&T, Perry Li, UM, Eui Park , ISE Department, NCA&T, S. Udoka, ISE Department, NCA&T
Post Doc(s):	Haihong Zhu
Graduate Students:	Mark Elton, Brian Guerriero, Longke Wang, R. Delpish, B. Osofo-Yeboah
Undergraduate Students:	R. Vinson, D. Reeves, E. Maddox (NCAT) Lynn Sarcione, David Fernandes, Trevor Stittleburg (GT)
Industrial Partners:	Caterpillar, John Deere, HUSCO International, Enfield Tech., Festo

3A.2: Human/Machine Interfaces – Passified Pneumatic and Chemofluidic Control

1. Statement of Project Goals Passivity is important for safety especially when the systems are to interact with physical environment. Conventional pneumatic and chemofluidic (i.e. hot gas pneumatic) actuations are actuation methods for several of the test beds (TB4 – rescue crawler, TB5 – FP assisted tools, TB6 – FP assisted orthoses). Yet, unlike electro-mechanical and hydraulic systems, passivity concepts for these systems are not well understood. The goal of this project is to model pneumatic and chemo-fluidic actuations from a passivity framework and, using this framework, to develop human force amplification and teleoperation control schemes that are robustly stable and intuitive to interact with.

2. Project Role in Support of Strategic Plan This project addresses one aspect of safety when fluid power system interacts physically with humans and unstructured physical environment. The primary test-beds to be addressed are TB5 (FP assisted hand tools), and TB 3 (rescue crawler), and possibly TB 6 (orthosis). These embody a goal of CCEFP to spawn new industries that take advantage of new portable, powerful, efficient and intuitive to use fluid power. Pneumatics and chemofluidics are likely actuation method for these test beds. These test beds are either in physical contact (TB5, TB6) or haptically teleoperated by humans (TB3). They also interact with uncertain physical environment. It is critical that the systems remain stable when interacting with either physical environment or human. By controlling the system so that it interacts with the physical environment passively, interaction stability can be maintained for a wide range of environments, enhancing safety. Interacting with a passive (or passified) system can also be more intuitive for the human operator, thus enhancing operational efficiency as well. Algorithms that are developed will feed directly into TB3 and TB5.

3. Fundamental Research Barriers and Methodologies for Addressing Them
A characteristic of devices such as TB3, TB5 and TB6 is that they are in physical contact with the environment or are directly controlled by humans. For such systems, passivity is a useful property as it relates to both safety and ease of control. Roughly speaking, a passive system is one that does not generate energy but only stores, dissipates, and releases it. The amount of energy that a passive system can impart to the environment is limited by the external input and so some safety is ensured compared to non-passive systems. This results in the useful property that coupling between a (strictly) passive system and another passive system remains stable. Notice that this is not the case if the systems are merely (input/output) stable individually. Since most physical objects are passive, a passive system can safely interact with a broad class of environments without fear of being destabilized. Moreover, Because the concept of "power" can be used to plan and execute manipulation tasks, passive systems are potentially more intuitive to use.

Passivity concept has been relatively well developed for hydraulic systems in the past few years by the project leader. Passive control design methods have been developed both for teleoperation and human power amplification. The challenges of developing this framework for pneumatics and chemofluidic actuation are: 1) all pneumatic systems are significantly more compressible than hydraulics; 2) in pneumatics and chemofluidic systems, significant heating and cooling occur during compression and expansion; so that effect of temperature variation and heat

transfer will affect the overall dynamics, and hence passivity; 3) chemofludic systems that involve complex reaction dynamics which not been subjected to passivity analysis.

The research approach is to consider the problem in three stages: a) isothermal/adiabatic pneumatic systems, b) pneumatic systems with finite heat transfer, c) chemofluidic actuation. Bond graph and pseudo bond graph modeling, as well as exploitation of similarities with previously known domains (hydraulics and electromechanical) will be essential techniques that are being applied in the research.

4. Achievements to Date

During the 1st year, pneumatic systems under isothermal or adiabatic process has been modeled and investigated. Structural similarity between these systems and previously studied hydraulic system has been identified, so that human power amplification control approach previously developed for hydraulic systems can be adapted for these types of pneumatic systems. An experimental setup has been developed and preliminary results show that the human power amplifier control algorithm is effective.

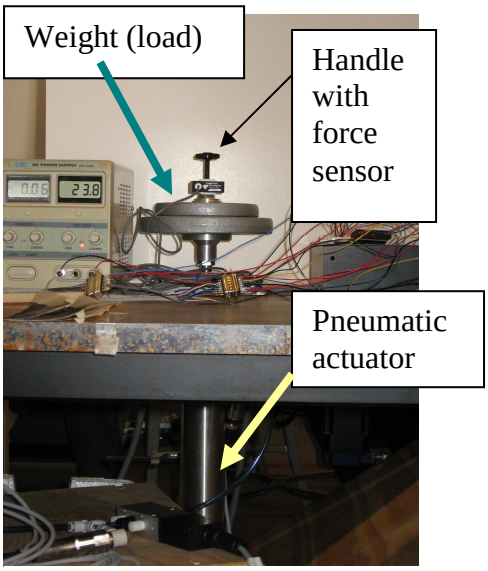


Figure 7 1-DOF pneumatic human power amplifier experimental setup

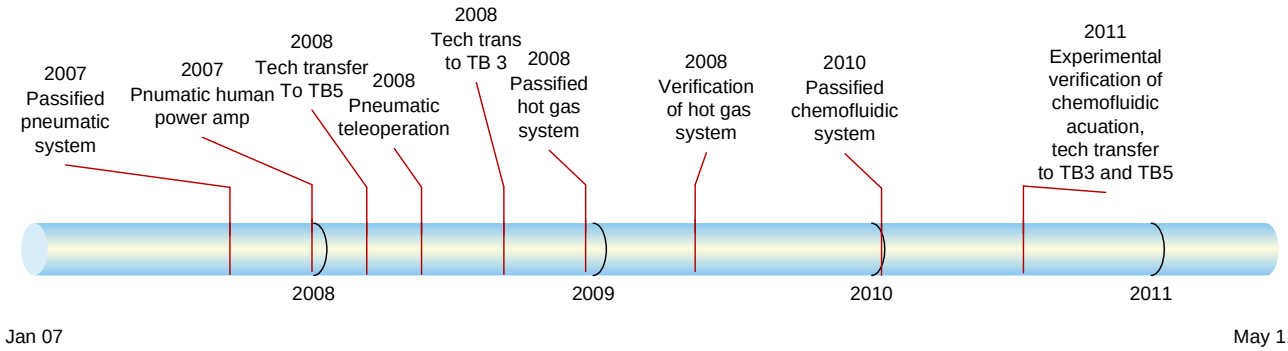
5. Other Relevant Work

The initial version of TB3 that uses off board pneumatic power is currently being developed. It can make use of the pneumatic teleoperation algorithms to realize the haptic teleoperation mode. Similarly, various versions of TB5 are being developed that the human amplification algorithms will feed into.

6. Plans for Next Year

In the coming year, knowledge of isothermal/adiabatic pneumatic human power amplifier control will be transferred to TB5 (FP assisted hand tools). Isothermal/adiabatic pneumatic teleoperation controller will be developed and results transferred to TB3 (rescue crawler). We will also begin investigation of pneumatic systems with heat transfer.

7. Expected Milestones and Deliverables



8. Member Company Benefits

Knowledge of control designs for pneumatic and chemofluidic systems that can safely and intuitively interact with humans.

9. Research Team

Project Leader:	Prof. Perry Y Li, Mechanical Engineering
Co-leader	Profs. Eric Barth, Wayne Book, Will Durfee, Mechanical Engineering
Graduate Students:	Venkat Durbha
Industrial Partners:	Industry champions / donations:: Enfield Technologies and Festo

Project 3A.3: Human Performance Modeling and User Centered Design

1. Statement of Project Goals

The goal of the project is to study human performance in fluid power (FP) systems, develop a framework to guide the development of models of human performance for use in new FP systems, and to use user centered design approach to develop human machine interface for selected fluid power systems (test beds) that are user-centered, safe, easy and comfortable to use.

2. Project's Role in Support of the Strategic Plan

This project will attack the effectiveness barrier by gaining a better understanding of human capabilities, both physical and cognitive, when operators use fluid power systems. A human performance model, as it applies to FP systems, will enable us to take human performance into consideration when designing/innovating FP systems. By integrating human performance and machine performance, the overall system performance can be improved. This project will also attack the effectiveness barrier by using a user centered approach to design or redesign (if existing already) the interface for various test beds. By soliciting users' needs and observing real users operating the machine, the new or revised interface will meet user requirements, and will be easy, comfortable, and safe to use, and consequently, will be more effective.

3. Fundamental Research Barriers and Methodologies for Addressing Them

Many existing fluid power applications – such as an excavator, require direct human operation (Frankel et al., 2004). Operators often need to operate on those systems for a long period of time. Most of the time, it takes a lot of skills, concentration, and effort to complete a task. For example, an excavator operator needs to coordinate four or more axes to dig, lift, level, and fill on a construction site. However, many such systems have poorly designed human machine interfaces. Consequently, the operator performance is affected and their safety is potentially in jeopardy (Lyons, et al., 2005). Moreover, it takes a large amount of training and experience before an operator can effectively use the machine. For a novice user, it is a very challenging job. An intuitive and easy to use interface is, therefore, very important. Unfortunately, even today, many design processes still tend to put far more attention on the technical performance of the equipment than the human component (Lyons, et al., 2005). In 2005, Underground Construction interviewed the representatives of four tractor mounted loader-backhoe (TLB) manufacturers about their views on ergonomics in their companies and concluded that improvement in ergonomics can not only bring comfort, reducing fatigue and stress to operators, but also increase productivity (Griffin, 2005).

This project aims to use human performance modeling as a tool to better understand human performance in a fluid power system, and to develop a framework that integrates both physical and cognitive human performance models in such systems. This framework will be used to guide design and development of fluid power systems in order to achieve overall system performance.

Human performance modeling can be used in both physical and cognitive aspects, ranging from digital human model to task network analysis. Although efforts have been made to develop adequate human performance models for various systems, there is still a long way to go. It is important to point out that there is no "one size fits all". Given the state of human performance

modeling research and current computer technology, it is not possible to create a single integrative model that can be applied to all applications. Furthermore, developing such models will require both quantitative (such as anthropometric data as applied in digital human, predictive model for human errors, etc.) and qualitative approaches (such as task analysis, guidelines, etc.), as well as simulation tools (e.g., using Micro Saint).

In developing the framework, the following needs to be emphasized: (1) collect and disseminate human performance data, (2) develop procedures for using models of human performance, (3) develop models in focused area, and (4) support theory development and basic research in relevant areas. These themes cover from short term goals of identifying and collecting relevant human performance data to long term goals of basic research in human behavior.

Given the fact it is not possible to develop one model that can apply to all, efforts will be focused on selected applications. For instance, rescue robot (one of the test beds) will be chosen for model development. Specific research efforts including Task analysis that will detail the tasks, procedures, and structures that provide the foundation for modeling human performance for those applications. Quantitative and qualitative approach as well as simulation tools will be used to build the models. In this study, the parameters of human behavior embedded within the model framework will be based on empirical research in both basic and applied human performance. Scenarios with high probability of human error will be identified as well as its precursors. The modeled operator will be set to interact with computer-generated representations of the operating environment over a series of repeated runs in much the same manner as testing human subjects over repeated experimental sessions. Elements of the human performance model (for example, performance time for a particular task) can be made a stochastic variable and their values can fluctuate across these multiple runs. Technological and procedural solutions will be assessed through development of computational models of scenarios and candidate solutions will be proposed and evaluated. Since validation with full generality is not possible, it will focus and match closely to the intended uses for each model. Simulation based experiments will be conducted to collect data for validation purpose. To support long term effort of theory development and basic research, areas such as decision making, situation awareness, trust, and learning will be chosen to study future generations of models. One common problem in many system designs is that they focus on utility of the system and pay little attention to its usability. As a result, many users have to operate machines in an uncomfortable posture/position, and in the long run, can suffer cumulative trauma disorder (CTD). The user-centered design (UCD) is a method for designing ease of use into the total user experience with products. It focuses on the requirements of a potential user from the product's inception, and checks at each step of the design phase with these users to ensure satisfaction with the final interface design. The user-centered approach puts user needs at the center of the design, involves users throughout the design process, and has been proven to be very effective to ensure usability, safety, as well as effectiveness of the interface. A typical iterative process involves a usability evaluation of the current interface (if it is a new product, use similar ones), identifying customer/user needs by interviewing them, conducting task analysis, setting up usability goals, developing prototypes, and conducting usability testing. Although almost all test beds will have some interface design issues, it is necessary to identify a few and focus on them. In this project, UCD approach will be applied to the interface development of TB 4 (rescue robot) as well as the Haptic interface for TB1 (Excavator).

In summary, the development of new fluid power technology will provide opportunities and changes in both operator and machine performance. In order to improve the effectiveness of the system performance, it is necessary to study operator behavior and to model human performance. Meanwhile, new features of machines will become feasible. Based on these new inputs, a user centered design approach needs to be used to develop the human machine interface.

4. Achievements to Date

- Developed surveys for collecting user information
- Applied for Institutional Review Board (IRB) approval
- Conducted task analysis for rescue robot and excavator
- Developed prototype GUI interface for rescue robot
- Developed a preliminary Micro Saint based model for excavators
- Developing preliminary Jack models for excavators

5. Other Relevant Work

None

6. Plans for Next Year

- Complete task network model for excavators
- Complete a digital human model for excavators
- Complete task network model for the rescue robot
- Develop a framework that integrates both cognitive and physical model in a fluid power system.
- Conduct usability testing on the prototype interface
- Develop trust model that can be used to investigate the operator trust in human robotic interaction.

7. Expected Milestones and Deliverables

- Human performance models for excavator -- End of year 2
- Human performance models for rescue robot -- End of year 2
- Framework to integrate cognitive and physical models -- End of year 2
- Trust model for human robotic interaction --- End of year 2

8. Member Company Benefits

Results of this project will be available to Center members.

9. Research Team

Project Leader:	Jiang, X., ISE Department, NCA&T
Other Faculty:	Park, E., Udoka, S., ISE Department, NCA&T
Post Doc(s):	none
Graduate Students:	Delpish, R., Boone, F., Lee, A., Benson, K., Hughes, K., Jenkins, Q.
Undergraduate Students:	Jumper, F., Johns, S., Maddox, E.
Industrial Partner(s):	John Deere Caterpillar

3B-1: Passive Noise Control Opportunities in Fluid Power

1. Statement of Project Goals
Develop compact, lightweight fluid power component designs with reduced noise and vibration signatures as compared to existing technology.

2. Project's Role in Support of the Strategic Plan
The project will attack the effectiveness barrier, by seeking means to reduce the vibration and noise levels of fluid power systems. Noise (and associated vibration) is an identified barrier within three of the four visions for the Center. The project will seek novel means for passive noise control, exploiting, for example, optimized spatially variable material properties. Further, lightweight, compact components such as envisioned in other project areas present additional challenges to traditional vibration and noise control approaches by limiting the available material and volume; such constraints therefore call out for novel approaches to noise mitigation.

3. Fundamental Research Barriers and Methodologies for Addressing Them
The fundamental research barrier involves how to achieve significant noise reduction from compact, high power density systems. Successful technologies already exist for fluid power noise control for the current generation of systems. But, to achieve the ERC's goal of broadening the application of fluid power will require performance beyond the capabilities of these existing technologies. Within the specifics of this project, the most significant challenge involves the modeling of complex fluid-structure interactions where the structure may have intentional non-linearities as well as spatially varying material properties. In this project, particular focus will be paid to functionally graded materials, composites, and microvoided polymers. The methodologies for addressing the barriers include an incremental approach of increasing model complexity in order to develop the lowest order model that achieves an acceptable level of prediction fidelity when compared to parallel experimental efforts. For example, an in-line dissipative silencer model is currently under development in which the dissipative material also exhibits nonlinear acoustic propagation. Nonlinear modeling techniques are currently being studied to address the issues both of modeling the material, and of creating a proper coupling interface between linear and nonlinear portions of the modeling domain.

4. Achievements to Date
A transmission loss model was developed for a silencer with a linear dissipative material. By assuming a high wavenumber and locally reacting materials, the model allows the analytical prediction of the acoustic impedance in the silencer section of flow and the corresponding axial wavenumber of the plane wave propagation mode, which are then used to predict acoustic losses due to reflections and material dissipation. Extension of the model to incorporate non-linear materials (dispersive, amplitude-dependent loss factor, etc.) is a major focus of current efforts.

A hydraulic test rig was designed and constructed for the measurement of acoustic transmission loss for two-port devices. It was designed and built according to the recommendations presented in ISO 15086, "Hydraulic fluid power – Determination of fluid-borne noise characteristics of components and systems" as well as recommendations in various archival literature pertaining to the method. Figure 1 presents a picture of the rig with a commercially available silencer

installed. Implementation of the rig and its associated data acquisition and processing system supported the activities of an REU undergraduate student who is continuing with the project for additional semesters (and for course credit).

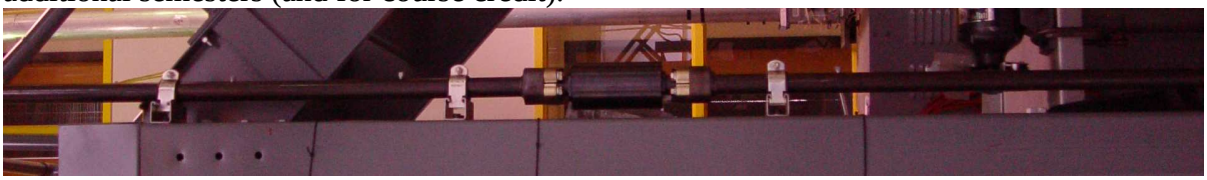


Figure 1: Hydraulic transmission loss test rig (rotated)

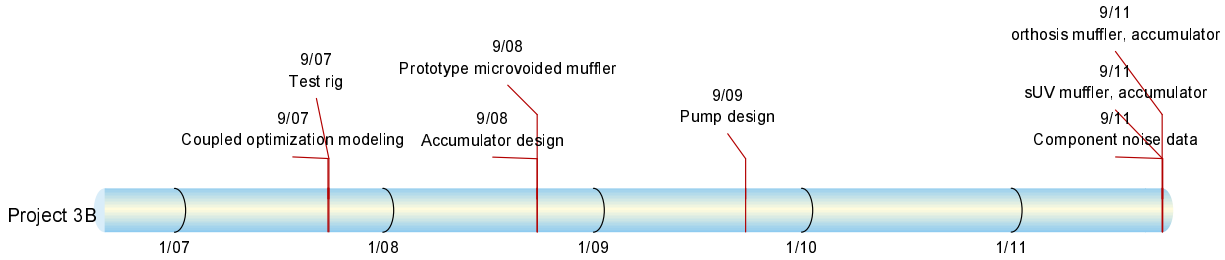
5. Other Relevant Work

There is a great deal of prior art within this field, and on-going efforts. The most extensive program is at the University of Bath's Centre for Power Transmission and Motion Control, directed by Prof. Edge. Recent work there has considered active control methods for noise suppression; the active control approach is not considered to be directly within the scope of 3B-1.

6. Plans for Next Year

The coming year should see the completion of Transmission Loss performance testing of both a commercial off-the-shelf silencer and a prototype voided-polymer silencer. In addition, the design and modeling capability developed for the voided polymer silencer will be integrated into a generic optimization tool for purposes of design refinement.

7. Expected Milestones and Deliverables



Year 2:
Implementation of accumulator and muffler models within optimizer
Analysis, design, fabrication and testing of microvoided polymer muffler
Deliverable: Optimal designs for accumulator, microvoided polymer muffler design and prototype

Project Completion: Year 5:
Deliverables:
Optimized designs and design guidelines for pump, accumulator, and muffler/tube segment
Prototype of low noise pump, accumulator, and muffler/tube segment
Performance data on pump, accumulator, and muffler/tube segment

8. Member Company Benefits

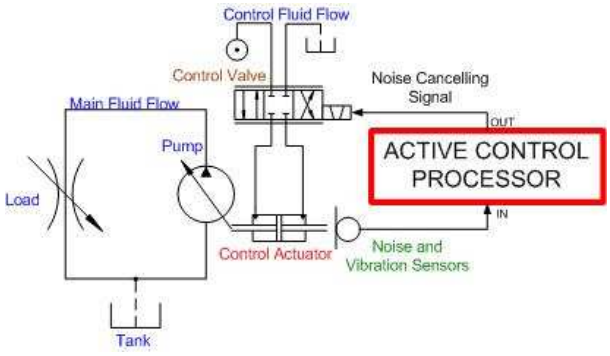
The benefit of this project to the member companies include the potential for alternative noise control approaches for existing applications, as well as demonstrated means to achieve noise control in the new applications developed by the ERC. ***The metric for success is the reduction in the radiated sound power for an optimized component as compared to the industry norm for such a component of the same rating (or, for a comparable prototype fabricated of homogenous materials).***

9. Research Team

Project Leader:	Kenneth A. Cunefare, Mechanical Engineering, Georgia Tech
Graduate Students:	Ken Marek, Nicholas Earnhart
Undergraduate Students:	John Giglio
Industrial Champion:	Mike Tonyan, Bosch-Rexroth

Project 3.B.2: Active Control of Hydraulic Pump Noise

1. Statement of Project Goals



The project goal is to reduce acoustic noise emissions in variable displacement, axial piston hydraulic pumps through the use of active noise and vibration control methods. Control of swash plate vibrations using dynamic actuation will first be considered. The swash plate control actuator will be used for steady-state pump conditions to actively cancel low order harmonics of the pump's total noise emissions. Piezoelectric actuators will be used for the control of high frequency harmonics. The active control of pressure pulsations in the fluid lines will then be investigated. The contribution of the swash plate vibrations to the total noise emissions of a piston pump will be understood and quantified through both simulations and measurements.

2. Project Role in Support of Strategic Plan

The project will address the issue of hydraulic, axial piston pump noise emissions. The pump is the primary noise source in most hydraulic systems. One significant component of the radiated noise is the vibration of the pump casing driven by the fluctuating forces produced by the rotating piston group on the swash plate. Reduction of vibration transmission to the pump casing will result in a quieter pump and enable implementation of the pump into a wider array of applications. Reduction of the pressure pulsations in hydraulic lines is also important since sound radiation from hoses can be a significant contributor in some applications.

3. Discussion of fundamental research barriers and methodologies used to address them.

The largest barrier for the success of this project is the ability for the active noise reduction method to achieve control over a sufficiently broad range of frequencies. Active control methods usually work best for frequencies below 1000 Hz; however, the human ear is most sensitive at around 3 kHz. Active noise control methods need to be improved, and possibly supplemented with passive methods in order to achieve significant noise reduction. Electro-hydraulic actuation systems are not typically designed to operate at the high frequencies at which pumps vibrate. Fast actuation is possible at low servo valve flow rates to achieve small displacement amplitudes of the control piston. The bandwidth of some actuators available today is around 300 Hz. Upon verification of the concepts in a few pump test beds, the integration of piezoelectric actuators will be considered to provide a larger bandwidth for greater noise reduction at higher frequency. Many sensors and actuators (i.e. dozens) will be needed to control the higher order modes of the pump structure at high frequencies. A method to provide the active control feedback signals to the actuators indirectly is needed. Systematic measurements of the transfer functions between each element in the signal chain and the actuation signals are needed, from which a robust active control scheme can be designed. A model of the pump

control system including the vibration effects of the swash plate moment is needed to optimize the number and location of the sensors and actuators needed.

4. Achievements in the Past Year

A model of an electro-hydraulic displacement control system was developed which accounts for the vibration effects on the swash plate due to the moment about the tilt axis and the flow of the hydraulic fluid through the valve orifice needed for actuation. The dynamics of the system were captured for any operating condition. Active control techniques were tested in simulations. A hydraulic pump test bed was built and instrumented to measure the noise and vibration response of a pump over a range of operating conditions. The effect of active swash plate control actuation on pump vibration was quantified, and the authority of the swash plate actuator on the vibration response was assessed. Correlations between command actuator motion and swash plate response were established over a number of operating conditions.

5. Other Relevant Work

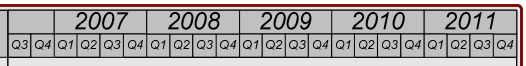
A passive muffler system to attenuate the propagation of sound and structural waves in hydraulic hoses is developed. A model for the vibrations of the hoses treated as shells is used for design. Periodic inclusions with varying properties were designed to create stop bands at the excitation frequencies of interest. Experimental verification is pending.

6. Plans for Next Year

Continue to investigate active control methods and design a digital controller which can be implemented into the pump control system. Quantify operational requirements to improve control system operational bandwidth; design and implement a superior system on the test bed.

7. Expected milestones and deliverables

ID	Task Name	Start	Finish
1	State of the Art Review	07/03/ 2006	12/15/ 2006
2	Swash Plate Control Modeling and Simulation	09/15/ 2006	09/14/ 2007
3	Pump Test Rig Setup, Baseline Measurements	02/01/ 2007	11/15/ 2007
4	Design and Simulation of Active Controller	10/01/ 2007	05/30/ 2008
5	Implementation of Active Controller	05/01/ 2008	01/01/ 2009
6	Active controller optimization and repeat measurements	11/17/ 2008	07/31/ 2009
7	Valve and Control Actuator Design, Sensor Improvements	09/10/ 2008	05/25/ 2010
8	Integrate active noise control solution along with passive methods into ERC test bed	07/02/ 2010	01/04/ 2012



8. Member Company Benefits

The goal of this project is to reduce pump noise emissions, a major problem in fluid power. All reports and publications will be made available to Center members.

9. Research Team

Project Leader:	Luc Mongeau, Mechanical Engineering, Purdue University
Other Faculty:	Monika Ivantysynova, Mechanical Engineering, Purdue University
Graduate Student:	Jeffrey Peters
Industrial Participants:	Parker Hannifin Corp., Eaton, MTS, Caterpillar.

Project 3C: Simulation of Cavitation and Noise in Fluid Power

1. Statement of Project Goals

The goal of this project is to develop and apply new computational tools to enable the study and control of cavitation noise in fluid power components. High-fidelity large eddy simulation (LES) is the computational method being employed here and laser-based diagnostics, specifically particle imaging velocimetry (PIV), along with fiber-optic probes and piezo-electric pressure transducers are to be used to make detailed flow, void fraction, and dynamic pressure measurements in venturi-type flow passages.

2. Project's Role in Support of the Strategic Plan

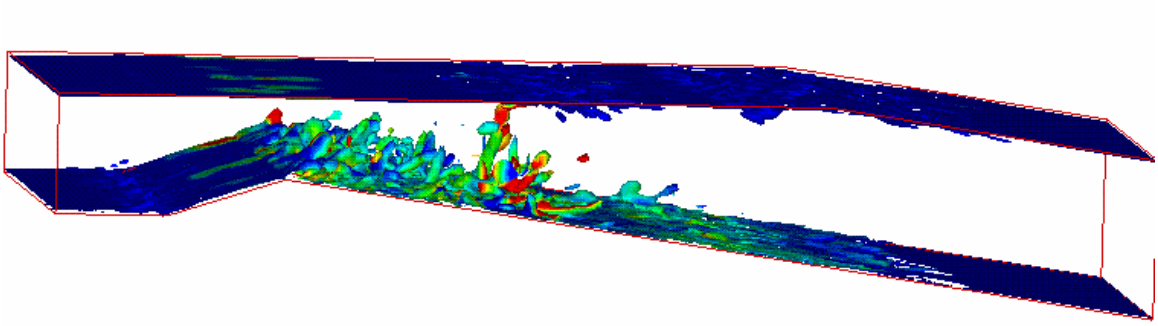
This project fits into the overall strategic plan of the ERC as the design and development of next generation fluid-power components that are both compact and efficient will involve, in the case of valves and pumps for example, higher flow rates and potentially more cavitation and noise related problems. In addition, the use of commercial CFD codes for modeling axial piston pumps creates a direct link with industry and also with other projects and test beds in the ERC.

3. Fundamental Research Barriers and Methodologies for Addressing Them

Cavitation is a two phase phenomenon that occurs on two different levels. The first, sometimes called pseudo-cavitation, is when dissolved air comes out of solution; the second, sometimes referred to as vapor cavitation, is when the pressure drops below the vapor pressure of the fluid and it effectively boils. The two phases have significant density disparity creating an extremely stiff equation of state that necessitates a very small time step. The ability to combine both effects and spatially and temporally differentiate between the two makes for an intricate and complex system. As a first attempt, one of the two processes will be assumed to dominate so the other is neglected. Furthermore modeling the intricate geometry in a piston pump requires a complex and dynamic grid.

4. Achievements to Date

Since January 2007 significant progress has been made on both the computational and experimental fronts. On the computational front, an in-house computational aeroacoustics code based on the LES technique has been converted to a computational hydroacoustics code for cavitation noise studies. A homogeneous equilibrium based cavitation model has been implemented and tested which involves solving an additional transport equation for void fraction with source terms for condensation and vaporization. A two-phase equation of state has been added to specify the pressure-density relationship for cavitating flows. Initial two-dimensional computations showed that the code was able to capture transient cavitation events and in particular the influence of vapor formation on flow and vortical dynamics.



Since April 2007, the focus has been to extend these preliminary simulations to three-dimensions and move closer to making quantitative comparisons to previously published experimental data in the open literature. Preliminary results for the 3D LES of cavitation in a venture were very encouraging in that they highlighted for the first time the inherently complex 3D vortical structure associated with cavitating internal flows. It is the control of these vortical structures that we hope to exploit in our future studies as a means to control cavitation either passively through geometric changes or actively through flow modification. Our most recent simulations are for a Reynolds number of 20,000 (significantly less than the experiment) as we are currently planning to implement a near-wall model to allow us to run at higher Reynolds numbers closer to the experiment. We have also obtained some preliminary on active control of cavitation showing how through wall transpiration (blowing and suction) we can modify the total amount of vapor associated with the cavitation process in this flow.

Another aspect of the computational modeling work involves the use of a commercial CFD code, namely FLUENT, to develop and test a 3D model of flow and cavitation in a 9-piston industrial axial piston pump. Modeling this pump represents a very challenging geometry and grid generation process involving rotating and reciprocating meshes. At the present time, we have successfully developed this model and conducted a complete set of computations for this pump. We have validated the in-cylinder pressure dynamics through quantitative comparisons to previous hydrostatic simulations and experimental data and show excellent agreement. By examining graphical output from this simulation, including animations, we hope to provide a clear description of the main flow processes associated with this complex pump and specifically focus on those flow features which are most likely responsible for cavitation. Future simulations may involve parametric studies related to geometric changes to reduce cavitation and fluid-borne noise.

Finally, we have made considerable progress on the design and fabrication of the experimental facility for our laser-based measurements of venturi cavitation. The flow loop has been designed and, most importantly, the test section has been completely designed to facilitate optical access for PIV measurements and also instrumented for local pressure transducer measurements. The rig was designed with versatility in mind to also allow for void fraction measurements using a fiber-optic probe and interchangeable nozzle geometries for initial investigations into passive and possibly active cavitation control. All custom parts are currently in the fabrication stage.

5. Other Relevant Work

Professor Arndt at the University of Minnesota is developing an LES code and testing it using PIV and water flows around a hydrofoil. PIV alone however is not able to capture dynamic acoustic pressures or void fraction.

6. Plans for Next Year

The oil cavitation test rig will be assembled, operated and inspected to ensure safety that everything is working as expected. PIV and other measuring equipment will be brought in and installed to conduct the planned flow measurements.

7. Expected Milestones and Deliverables

- Testing/Validation of 2D LES code using water with results in open literature
- FLUENT simulation of 9 piston axial piston pump using hydraulic oil
- Operational oil cavitation test rig and local 2D velocity and void fraction measurements
- Preliminary results of 3D wall bounded LES simulations of cavitating water
- Initial investigations into passive cavitation control
-

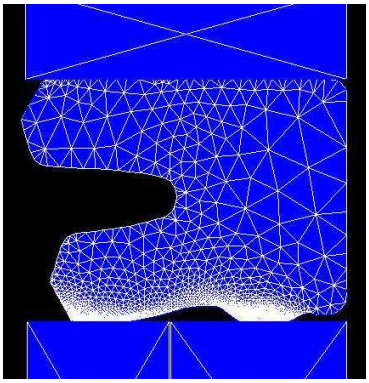
8. Member Company Benefits

The goal of this project is to generate and validate a CFD code to accurately predict cavitation and noise in hydraulic components such as valves and axial piston pumps. Traditionally hydraulic components have been designed through trial and error. This code is aimed at curbing the high costs associated with manufacturing and testing multiple prototypes by providing visual insight to aid in design modification for improvement.

9. Research Team

Project Leader:	Prof. Steven Frankel
Other Faculty:	Prof. Steven Wereley
Graduate Students:	Nagedra Dittakavi, Ph. D.
	Dheeraj Saxena, Ph. D.
	Jeffrey Dougan, M.S.
Industrial Partner(s):	Caterpillar, John Deere, MTS

Project 3D: Leakage Reduction in Fluid Power Systems



1. Statement of Project Goals

The goal of this project is the development of realistic numerical models of the seals used in fluid power systems, which would be capable of predicting the key seal performance characteristics, especially seal leakage and friction, and serve as design tools.

2. Project Role in Support of Strategic Plan

The project will attack the effectiveness barrier by providing tools that will allow the development of seals that will eliminate or substantially reduce leakage from fluid power components such as actuators, valves and pumps.

3. Fundamental Research Barriers and Methodologies for Addressing Them

This project will encompass the development of numerical models (and associated computer programs) of reciprocating seals (applicable to rod, piston and valve seals) and rotary seals (applicable to pump seals), the validation of the models, and use of the models to simulate particular applications of interest. Previous models assumed full film lubrication in the sealing interface, greatly simplifying the problem but giving unrealistic results. In the present work, realistic mixed lubrication is considered. For reciprocating seals, a basic model will first be developed. This will include analyses of the quasi steady state fluid mechanics, contact mechanics and deformation mechanics. The model will be validated by comparison with experimental results in the literature and obtained from industrial collaborators, and will be used to simulate particular applications of interest. Then the basic model will be expanded to create an enhanced model that takes account of transient and thermal effects. This enhanced model will be validated and used in a simulation, as was done with the basic model. For rotary seals, only a single model will be developed. This will include the same types of analyses as in the basic reciprocating seal model plus a thermal analysis.

4. Achievements to Date

Development of the basic model, including a thermal analysis, has been completed. It has been used to analyze several types of U-cup rod seals: double lip and tandem seals have been compared with single lip seals for an injection molding application. Among the results, it has been found that the following features promote zero or reduced seal leakage: small seal surface roughness, small lubricating film thickness, a thicker film during instroke than during outstroke, cavitation during the outstroke, and no cavitation during the instroke. Planning of tests to validate the model has begun.

5. Other Relevant Work

George Nikas at Imperial College has been developing models of hydraulic seals for aircraft brakes. But these are restricted to rectangular cross-section geometries and do not account for mixed lubrication. The present project involves models that can be applied to a wide range of geometries and take account of mixed lubrication.

6. Plans for Next Year

During the next year, the basic model will be validated through testing by an industrial partner. The basic model will be applied to the analysis of additional seal applications, including a step seal. Development of the enhanced model will begin. Work on very high pressure seal technology will be carried out to the extent funding allows.

7. Expected Milestones and Deliverables

Milestones: see task endpoints on time line below.

Deliverables:

Report containing completed basic model of reciprocating seal and associated computer program, validation of basic model and simulation of a particular application using the basic model. – End of Year 2

Report containing completed enhanced model of reciprocating seal and associated computer program, validation of basic model and simulation of a particular application using the basic model. – End of Year 3

Interim report on the rotary seal development. – End of Year 4.

Final Report – End of Year 5

In between the above reports, publications on the work in progress will be made available to Center members.

	year 1	year 2	year 3	year 4	year 5
Recip. seal basic model development	xxxxxxxxxxxxxxxx				
Validation		xxxxxxxxxxxxx			
Simulation of application		xxxxxxxxx			
Recip. seal enhanced model development			xxxxxxxxxxxx		
Validation			xxxxxxxx		
Simulation of application			xxxxxxxx		
Rotary seal model development				xxxxxxxxxxxxxxx	
Validation					xxxxxxx
Simulation of application					xxxxxxx

8. Member Company Benefits

The goal of this project is to substantially reduce, if not completely eliminate, leakage, a major problem in fluid power. All reports and publications will be available to Center members.

9. Research Team

Project Leader:	Prof. Richard F. Salant, Mechanical Engineering
Graduate Student:	Bo Yang
Industrial Partners:	Eaton Hydraulics, Trelleborg Sealing Solutions

Test Bed 1: Excavator

1. Statement of Testbed Goals

Develop new system concepts based on throttle-less actuator technology to demonstrate fuel savings and the improvement in performance and compactness for the large sector of construction, agricultural and forestry machinery. The excavator will also be used to demonstrate effective control strategies for complex multi actuator systems and robot like machine functions. This will include new human/machine interfaces, including those that provide haptics feedback,
.

2. Testbed's Role in Support of Strategic Plan

This test bed supports the center first goal to achieve a drastic improvement in efficiency of existing fluid power applications and to reduce petroleum consumption and pollution. The test bed will be used demonstrating fuel savings by more efficient fluid power actuator technology and effective power machine management especially for large and high power equipment. The demonstrated new actuator technology will open new applications in both large scale heavy duty machinery and robots and in human scaled applications like surgery robots, or other portable devices, where efficient and compact actuator technology is necessary.

3. Primary and secondary attributes to be demonstrated in testbed

The primary attributes to be demonstrated are efficiency improvements achieved by:

- different concepts of throttle less actuators
- new system architectures and energy recovery concepts
- effective power management strategies
- advanced machine control concepts together with new effective human interfaces
- engineered fluids
- new sealing concepts for linear actuators
- drag reduction due to nano-surface texturing applied to hoses
- new generation of pumps and rotary motors based on advanced design of rotating group

Secondary attributes to be demonstrated include leak-free operation, noise reduction, and binary on/off control approaches.

4. Achievements to Date

Full instrumentation of the test bed
Engine map measurement
Steady state measurements of drive pump
Steady state measurement of load sensing pump
Fuel and performance measurements on existing machine for defined operating cycle

5. Which projects are expected to deliver enabling technologies for integration in the TB?

Primary:

- 1A: Throttle-less Control and Regeneration for Fluid Power System will provide the actuator concepts including control, system architecture and power management strategy
- 1B: Advanced surface design will provide the models and technology for design of new generation of pumps and motors, which will be used for displacement controlled actuators.
- 3A: An efficient multi-modal human interface will be developed and implemented into the testbed in order to effectively interact with automatic control functions
- 1D: Hoses with modified surfaces using new developed nano-texturing techniques for drag reduction will be implemented into testbed and tested
- 1E: Fast on/off valve based actuator concepts will integrated and tested if possible.
- 1G: Engineered Fluids will be tested in selected actuation systems of the testbed
- fast responsiveness of valve controlled systems, and the efficiency of a variable

Secondary:

- 2D: Engineered materials will be integrated into the testbed if possible.
- 2E: An integrated design will be developed for implementation in the second phase
- 3B: Noise reduction techniques will be integrated into the testbed if possible.
- 3D: New sealing concepts will be implemented in selected components of the excavator and tested if possible.

6. Plans for Next Year

- Design modifications of machine structure for installation of displacement controlled actuators,
- Prototype installation of at least one displacement controlled actuator
- Modification of machine control
- Test and demonstration of haptic teleoperation

7. Expected Milestones and Deliverables

Year 2: - Modification of machine control, test and demonstration of haptic teleoperation
- Implementation of displacement controlled actuator for one machine function

Year 3: - Test of machine with minimum one displacement controlled actuator completed.
-Fuel and performance measurement for modified machine

Year 4: - Design modifications to install multiple throttle-less actuator systems completed
- Sensor installation and test for power management and automatic machine control
- Test of machine using engineered fluids and nano-textured hoses

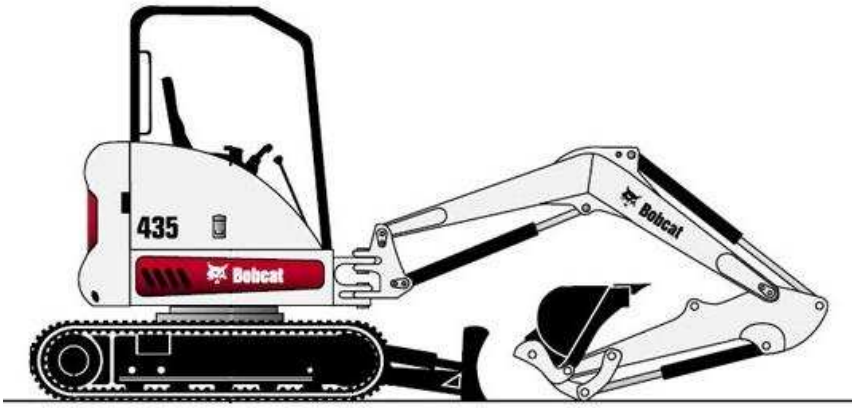
Year 5: - Displacement control of minimum two DOF
- Displacement control using on/off valve control
- Demonstration of advanced multi-modal human interface for teleoperation
- Fuel and performance measurements using defined operating cycle

8. Anticipated Member Company Benefits

Introduce new technologies to heavy duty machines (construction, forestry and agriculture) and establish new applications rescue robots, deep see robots, and surgery robots etc. for fluid power

9. Research Team

Testbed Leader:	Monika Ivantysynova, Agricultural and Biological Engineering, Mechanical Engineering, Purdue University
Other Faculty:	Andrew Alleyne, UIUC Wayne Book, ME, Georgia Tech Perry Li, ME Minnesota Eric Loth, AAE UIUC Paul Michael, MSOI Kim Stelson, ME Minnesota
Test bed manager/staff:	Edat Arslan Kaya
Graduate Students:	Joshua Zimmermann MS student (Purdue)
Undergraduate Students:	Najoua Jouini, Travis Brubaker, Jim Bartle
Industrial Partner(s):	Bobcat, Parker Hannifin Corp



TB3: small Urban Vehicle (sUV)

1. Statement of Test Bed Goals
To develop a platform for demonstrating and integrating efficient hybrid fluid power power-train technologies that are compact and lightweight enough to be suitable for small passenger cars setting, and that will enable major fuel savings.

2. Project Role in Support of Strategic Plan This testbed directly supports the goal of the center to develop and to migrate fluid power technologies to passenger cars segment so as to enable major fuel savings and to reduce negative impact on the environment. The passenger car segment is targeted because of its large size. While hydraulic hybrid technologies have been demonstrated for large vehicles, the stringent weight and size constraint of passenger cars will require breakthrough in compact efficient fluid power concepts. TB3 serves to determine and focus research effort, and to integrate results from individual projects.

3. Fundamental Research Barriers and Methodologies for Addressing Them
Major research challenges and projects that address these:
1) Determination of efficient power-train architecture – TB-3
2) Efficient hydraulic components and their controls (pump/motors and fluid) – 1B, 1E, 1G
3) Compact energy storage – 2C
4) Energy management strategy – 1A.1
5) Effective control strategy – TB 3

4. Achievements to Date

The first generation for the test bed is to utilize the open mechanical structure of a utility vehicle (a donated Polaris Ranger) as a platform to implement a hydraulic hybrid train-train with off-the-shelf components. This is to elucidate operational and component performance requirements. A novel hydro-mechanical hybrid architecture (Fig. 2) with regeneration and independent wheel torque control has been chosen as the architecture for detailed development and study. Mechanical design is complete and a downsized diesel engine has been installed. Manufacturing and hydraulic implementation is near completion. Sensing and control instrumentation is in progress. In addition to implementing the hydro-mechanical architecture, with small modifications, the design also allows other architectures (series and parallel) to be investigated as well. Dynamic model for the vehicle with generic component models has been developed and control strategy identified.

5. Other Relevant Work

Hydraulic hybrid vehicles aimed at larger vehicle segments are being developed companies such as Eaton and the EPA. University of Michigan also has a group working large hydraulic vehicles.

6. Plans for Next Year

As the construction of the vehicle platform completes, issues of precise vehicle control will be tackled. Models of the actual components (engine and pump/motors) will be developed and incorporated into vehicle model for efficiency prediction and optimization of the operational strategy. Experimental testing and modeling will determine which critical components' performance affect overall performance, and where efforts are needed to improve them.

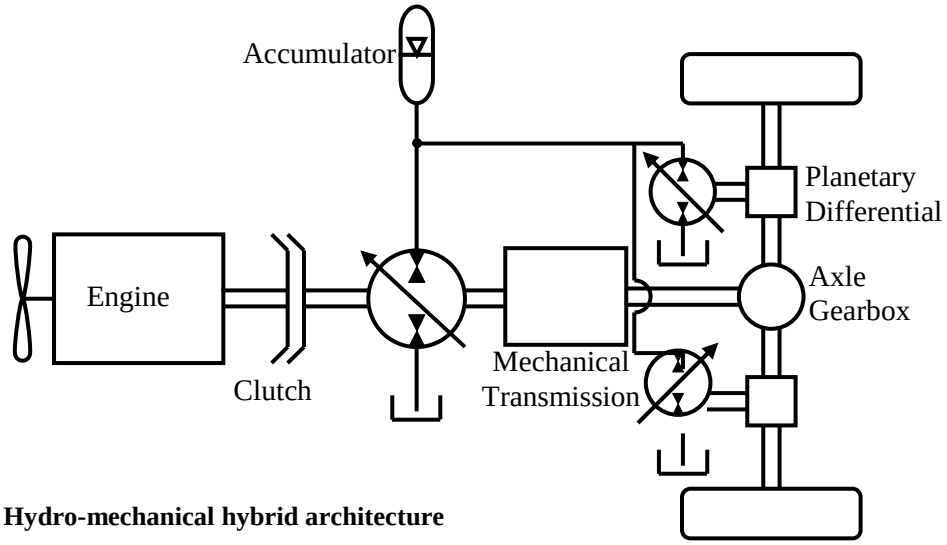


Figure 8: Hydro-mechanical hybrid architecture

7. Expected Milestones and Deliverables

End of Year 2: Generation 1 vehicle drivable with power management
End of Year 3: Generation 1 vehicle modified with more efficient components
End of Year 4: On/off valve based controlled pump/motors demonstrated on Gen 1 vehicle.
Generation 2 vehicle design complete.
End of Year 5: Generation 2 vehicle with CCEFP developed efficient pump/motors
End of Year 6: Compact energy storage concepts implemented.

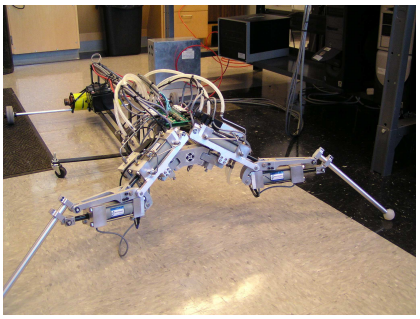
8. Member Company Benefits

Since hydraulic hybrid vehicles are potentially more power dense, cost-effective and reliable than electric hybrid vehicles, they are a competitive alternate as key barriers are overcome. By being involved, companies can benefits from new technologies associated with these breakthroughs.

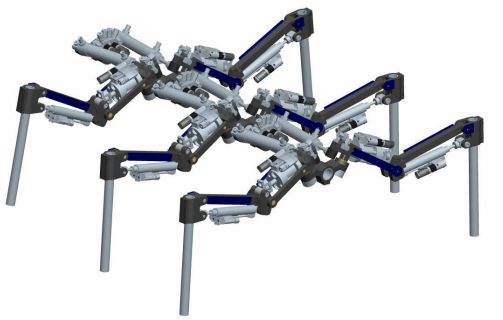
9. Research Team

Project Leader:	Prof. Perry Y Li, Mechanical Engineering
Other faculty	Kim Stelson, Mechanical Engineering
Post-doctoral researcher	Jim Van de Ven, Mechanical Engineering
Graduate Students:	David Grandall, Justin Lapp, Jonathan Meyer, Michael Olson
Industrial Partners:	Eaton, Gates, Sauer-Danfoss, Rohmax, Poclain

Test Bed 4: Compact Rescue Crawler



Operator Interface Prototype (Georgia Tech)



Six Legged Design (Vanderbilt)

1. Statement of Project Goals

Develop and demonstrate a fluid-powered compact robot crawler with significantly improved force, power, and energy capabilities relative to motor/battery-powered versions, and to demonstrate intuitive, effective, and efficient human control of the multi-legged testbed.

2. Project's Role in Support of the Strategic Plan

The Center will both significantly improve existing fluid power applications and will introduce new transformative approaches to fluid power technology. The primary role of this testbed is to concretely demonstrate the latter (the introduction of new transformative approaches to fluid power). The testbed serves several of the Center's "Key Strategic Goals" as stated in the strategic plan, including the development of "new to the world" transformative technologies, the potential jump-starting of new industries, and the goal of embracing the stewardship of society.

3. Fundamental Research Barriers and Methodologies for Addressing Them

Development includes several challenges, such as implementation of on-board power, and control of hot gas, which requires development of custom valves. With 18 degrees of freedom to control in a chaotic disaster environment, effective operator interfaces with partial autonomy is critical.

4. Achievements to Date

Generation one design has been completed, based on current chemofluidic approach. Front legs of generation one prototype have been fabricated and are being tested. Custom valves and associated control electronics are currently being fabricated so that legs can be thoroughly tested, prior to full fabrication. Current plans are to demonstrate front legs with on-board valves and electronics, and complete fabrication of remaining legs. Year two milestones is the demonstration of full generation one prototype with on-board valves. Operator interfaces incorporating head tracking camera and helmet mounted display with audio and voice control, and haptically controlled front legs have been implemented. For operator evaluation a prototype of two front legs manually controlled device with the rear legs replaced by wheels has been fielded. Refinement of the operator controls is underway. The options of the workstation and interface design have been presented to NCAT for review and recommendations.

5. Other Relevant Work

DARPA-funded "Big Dog" at Boston Dynamics. The compact rescue crawler testbed is expected to be considerably smaller and quieter than Big Dog. As for operator interfaces, forestry equipment currently manufactured has perhaps the largest number of degrees of freedom and is operated with high operator workload and after much operator training.

6. Plans for Next Year

- Complete fabrication and implement on-board electronics/control of generation one prototype.
- Illustrate teleoperated and semiautonomous control over the Internet with limited sensing and feedback modalities.
- Demonstrate self-powered operation for NSF review.

7. Expected Milestones and Deliverables

Year 1:

- Generation one prototype design completed, based on current chemofluidic approach.
- Most of generation one prototype fabricated.
- Teleoperation of multijoint function enabled over the Internet.

Year 2:

- Generation one prototype operational.
- Generation one prototype demonstration with rudimentary controller.
- Generation one user interface formulated and multiple functions operational over the Internet.
- Limited sensory modalities and feedback functional with simple shared autonomy.
- Evaluation and critique of initial operator interface fielded on 2 legged plus wheel prototype

Year 5:

- Demonstration of advanced multi-modal human interface on generation one prototype.
- Generation two prototype completed, powered by centralized hot gas vane motor (2A) and/or free piston engine (2B).

Year 10:

- Generation three prototype completed, demonstrating distributed hot gas vane motor powered throttle-less hydraulic actuation and control.
- Demonstration of advanced multi-modal human interface on generation two prototype.

8. Member Company Benefits

This testbed will introduce new technologies and industries to fluid power industry. Improved operator interfaces for existing multi degree of freedom devices will be enabled.

9. Research Team

Project Leaders:	Professor Michael Goldfarb, Vanderbilt University and Professor Wayne Book, Georgia Tech
Other Faculty:	James Huggins, (Research faculty), Georgia Tech
Post Doc(s):	Haihong Zhu, Georgia Tech
Graduate Students:	Keith Wait, Ph.D. candidate, Vanderbilt University Ryan Farris, Ph.D. candidate, Vanderbilt University Brian Guerriero, MS Student, Georgia Tech
Undergraduate Students:	Reed Williams, Vanderbilt University Trevor Stittleburg, Georgia Tech
Industrial Partner(s):	Enfield Technologies, FESTO, Sentrinsic

Test Bed 5: Fluid Power Hand Tools

1. Statement of Project Goals

The goal of this project is to develop a series of novel commercial and industrial hand tools that enhance human capability and integrate at a systems level technology developed by the center to prove technical feasibility. The hand tools demonstrate the advantages of compact, portable fluid power for applications where the fluid power machine works cooperatively with the user. The hand tools are powered, portable and non-tethered. The specific goals are to prove technical feasibility of compact pneumatic power supplies and control of complex pneumatic haptic interfaces.

2. Project's Role in Support of the Strategic Plan

The key attributes of the hand tools are energy generation, energy storage and energy control, all needed to implement a power tool that is small, light and easy to use. These support the CCEFP strategic plan to open new application solutions based on research from the compactness thrust.

3. Fundamental Research Barriers and Methodologies for Addressing Them

Research Barrier 1: compact pneumatic power supplies. Address by developing miniature pneumatic power supplies (Project 2.B.)
Research Barrier 2: compact energy storage. Address by developing compact accumulators (Project 2.C) and by integrating energy storage into the structure of the tool (Project **.)
Research Barrier 3: control of pneumatic haptic systems. Address by developing stable controllers for haptic systems that use pneumatic actuators (Project 3.A2.)
Research Barrier 4: intuitive user interfaces. Address by researching human factors of novel, haptic hand tools (Project 3.A1, 3.A2.)
Research Barrier 5: system integration to prove technical feasibility. Address through system design, test and evaluation.

4. Achievements to Date

Development plans for the first two hand tools finalized. One tool has immediate application, the second is speculative. The first is a fluid power assisted yard tool for trimming tree branches with haptic interface. The tool shears wood with pneumatic assist while the use feels a scaled version of the cutting force through the haptic interface. The energy required to cut through branches of various sizes was measured through a series of experiments to determine power supply and storage requirements for the tool. System design of the tool has begun. The second tool is a multi-agent tool to assist in manipulating awkward, heavy sheet goods such as plate glass and drywall. Each agent is a self-contained powered, pneumatic strut that can be clipped to three corners of the load with the fourth corner handled by the user. The agents are wirelessly and cooperatively controlled so that the user feels a scaled weight and rotary inertia of the actual load. A single degree-of-freedom pneumatic haptic interface, the core for a solo agent, has been designed as part of project 3.A2 for the purpose of developing and evaluating control algorithms. An instrumented test stand for measuring parameters of pneumatic servovalves has been created so that actual hardware and be used to parameterize mathematical simulation models.

5. Other Relevant Work

Development of mathematical models of pneumatic servovalves (see project 3.A2)

6. Plans for Next Year

During the next year a preliminary prototype of the haptic yard tool will be created. In addition, a general approach and prototype design will be delivered for optimizing the structural members of a pneumatic tool where the structure carries the task loads and is also a pressure vessel for storing compressed air. The single agent pneumatic haptic load scaling device will be demonstrated and evaluated. A planar, two-agent load assist system will be designed, built and evaluated. The planar system will be designed to lift and twist. All systems will be powered by shop air as usable results from Project 2.B are not expected until Year 3.

7. Expected Milestones and Deliverables

May 2008: Prototype, shop powered, haptic yard tool demonstration and evaluation report.
May 2008: Technical report on optimized structures that carry loads and pressure.
May 2008: Single degree-of-freedom haptic pneumatic device demonstrated and technical report created (same goal as 3.A2.)
August 2008: Planar, two-agent load assist system demonstrated.
December 2008: Hardware for prototype 3-agent system completed.

8. Member Company Benefits

The potential for new categories of hand tools are demonstrated with member companies gaining first look for prototype demonstrations and technical reports.

9. Research Team

Project Leader:	Will Durfee, University of Minnesota
Other Faculty:	Perry Li, University of Minnesota
Post Doc(s):	N/A
Graduate Students:	Peter Johnson, (2^{nd} to be named)
Undergraduate Students:	Kevin Wubben, Andrew Steevens
Industrial Partner(s):	To be named

Test Bed 6: Fluid Power Assistive Orthosis

1. Statement of Project Goals

This testbed will drive development of enabling and systems technologies from the thrust area projects, and thus provide a *technology pull* with respect to center projects. The initial (five-year) focus of this testbed will be the development of novel Ankle-Foot-Orthoses (AFO's) for gait stabilization. These orthoses assist the wearer by correcting gait deviations caused by weakness or paralysis of muscle groups below the knee. The long term goal is to develop a series of prototype devices that will incorporate different technologies developed within this center. These technologies will follow an evolutionary roadmap addressing the highest priority aspects of the overall testbed first and then integrating developments from other center projects over the lifetime of the center.

2. Project's Role in Support of the Strategic Plan

This testbed will severely stretch the center's capabilities to provide fluid power systems that meet the specifications necessary for a wearable untethered system. The designed systems must be extremely compact, efficient and effective to avoid wearer rejection of the unit. This testbed will have high impact because of the number of people that could be affected by advanced orthoses.

3. Fundamental Research Barriers and Methodologies for Addressing Them

The designed systems must be compact, efficient and effective to avoid wearer rejection of the unit. The design weight for current advanced carbon fiber AFO's is approximately 1 kg with a total volume of approximately 10 cm^3. Primary attributes to be demonstrated in this testbed are extremely compact fluid power assistive systems for integration into footprints of existing orthoses. The weight and space constraints will drive technology innovation to develop systems that can aid in gait stabilization using minimal power and minimal size.

To achieve these attributes, it will be essential to effectively address the following four key (PASS) design elements for each design version: *Power* harvesting, generation, storage, and application; *Actuation* mechanisms; *Sensing* and control; and *Structure* and tightly integrated overall system design

4. Achievements to Date

Design of our first device (V1.0) which uses a passive fluid-controlled system to correct for a swing phase gait impairment, i.e., toe drop, has been completed. This design uses a pneumatic power harvesting design, through a bellow embedded in the heel insole, to actuate a locking mechanism which restricts ankle extension to prevent toe drop during swing. A passive artificial leg (PAL) test fixture and treadmill were also constructed. The PAL has articulating joints to represent the knee, ankle, and toes. This test structure allows for bench-top testing of preliminary component designs. We are currently assembling components to produce a wearable V1.0 prototype.

We have also begun work on V2.0 and V3.0. For V2.0, we envision a device that can both provide support for toe drop (locking), while controlling the descent of the forefoot upon initial stance and preventing foot slap (damping). We are currently investigating design requirements

and the suitability of either pneumatic or hydraulic control. For V3.0, we have accelerated our entry on this design and are developing computer simulations of healthy and pathological gait to understand design requirements for providing active ankle extensor torque to assist with propulsion during late stance.

5. Other Relevant Work

Commercially available AFO's provide toe drop/foot slap assistance through solid or articulating polypropylene, carbon-fiber composite, or traditional double upright metal designs. No commercially available, untethered, AFO effectively mimics ankle extensor torque (competition for V3.0). Currently all AFO's with any actuation or power capabilities are tethered. These devices are typically used in clinical or research rehabilitation settings, i.e., robotic assistive walking devices. Our designs (V1&2) will be superior to the commercial AFO's for toe drop and foot slap as these will allow for greater ankle motion and tunability for control requirements. Our plantarflexor torque assist design (V3.0) will be the only untethered powered device.

6. Plans for Next Year

- **V1.0** Integrate components onto AFO frame to achieve wearable prototype.
- **V2.0** Determine capability of new design. Identify functional design components.
- **V3.0** Examine initial V3.0 hardware design and enhance interaction with TB 5 (hand tools), other center projects and investigators, and industry contacts.
- Identify new and existing center projects to integrate with testbed (areas include miniaturization, materials, seals, compact power sources).
- Bring on post-doc to facilitate center and industrial liaisons, as well as push design development of V3.0.

7. Expected Milestones and Deliverables

- **V1.0** Deliver wearable prototype (5/30/08).
- **V2.0** Determine new design requirements (12/31/07). Deliver test fixture prototype (5/30/08).
- **V3.0** Determine basic power design requirements from experiments and simulations of healthy/pathological gait (5/30/08). Examine and identify possible center technologies for use with this design (5/30/08).

8. Member Company Benefits

Design requirements dictate the need for new technologies that miniaturize current components such as valves, cylinders, and motors. This work will spawn new market opportunities.

9. Research Team

Project Leader:	Prof. Elizabeth Hsiao-Wecksler, MechSE UIUC
Other Faculty:	Prof. Andrew Alleyne, MechSE UIUC; Prof. Eric Loth, AAE UIUC; Prof. Will Durfee, ME Minnesota; Dr. Geza Kogler, Medical School UI-Springfield
Graduate Students:	Robin Chin, Scott Manwaring, Alex Shorter, Serena Tyson, Louis DiBerardino
Undergrad Student:	Lauren Merry
Industrial Participants:	Jason Thomas, Caterpillar; Jerry Zawada, Trelleborg

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EDUCATION / OUTREACH PROJECT SUMMARIES

A1: Interactive Exhibits

1. Statement of Project Goals

The purpose of this project is to create interesting exhibits that convey the basic message of fluid power as well as exhibits that highlight CCEFP research. Prototypes and exhibits developed and field-tested at the Science Museum of Minnesota, an organization affiliated with the CCEFP, will serve as models for dissemination to other science museums around the world.

2. Project's Role in Support of the Strategic Plan

SMM will support CCEFP by developing products for public exhibition that will reach Minnesota museum audiences and that can be replicated and/or adapted by other educators and program leaders for new audiences. These products will introduce public audiences to the concepts behind fluid power and the possibilities for future industrial and social applications of fluid power.

3. Fundamental Challenges and Solutions

Challenge: to interest museum visitors in what might seem to them a prosaic and old technology.
Solution: focus on interesting and accessible new applications; highlight applications that address high-profile physical, social, and economic problems; develop open-ended exhibits that allow visitors to engage for longer and more deeply in investigation and experimenting.

Challenge: to get around the usual hydraulic problems of leaks, friction, need for high pressures, invisible flow. Solution: try to build exhibits that use water-based hydraulic fluids and are leak-tolerant; experiment with pneumatic systems where appropriate.

Challenge: to find off-the-shelf hardware that is the appropriate size for use in museum displays.
Solution: this is a hard one. CCEFP industry partners might help if there is a convenient way to contact them; it may be necessary to fabricate some parts in the museum machine shop (though this is expensive and not always ideal);

4. Achievements to Date

SMM has pursued two approaches to date: working with senior undergraduate mechanical engineering classes to develop exhibit prototypes as capstone design projects; and building display prototypes in SMM's exhibit shop.

Capstone Projects

In the spring semester, 2007, a team of six mechanical engineering students produced two exhibit prototypes. One was an exhibit about a hydraulic scheme for regenerative braking in vehicles. The second was a an exhibit that introduced two basic principles of fluid mechanics – the use of fluids to transmit force and the development of mechanical advantage through coupling cylinders of different diameters.

Spring Semester, 2007

The Hydraulic Hybrid Car is a working model of how a hydraulic hybrid car might work. In this exhibit, visitors turn a crank to pump hydraulic fluid from a reservoir through hoses and valves to a hydraulic motor, which drives a car wheel.

After the wheel is going, visitors can press a button to brake the wheel. The brake button closes a valve, effectively turning the

wheel motor into a pump that pumps hydraulic fluid into a closed pressure tank called an accumulator. Our accumulator is pre-charged with 500 pounds/square inch of nitrogen gas. Incoming hydraulic fluid pressurizes this gas more.

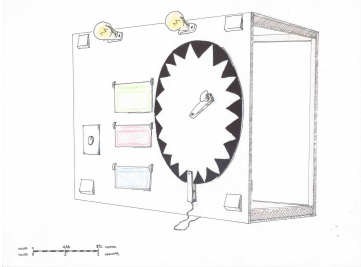
When the visitor wants to start the wheel going again, he or she can press a button to reopen the brake valve and open a valve that allows pressurized oil from the accumulator to flow to the wheel motor. In this way, energy gained from braking the wheel is reused to accelerate the wheel again. The hand crank can also be used to pump hydraulic fluid into the accumulator directly. This could happen when the power of a car engine isn't fully needed for accelerating the car.

The Hydraulic Lab (version 1) is an exhibit that shows two basic ideas behind fluid power. One side shows that force can be transferred from one piston to another by means of a fluid – in one case air and the other water. Both systems are used in industry. Air has less resistance but the transfer of motion is spongy and is harder to control. Water (or oil) provides very precise control because it is incompressible. As soon as one piston is moved, the other moves in response. But water has more inertia, so more starting and stopping energy is required. Also water is harder to push through narrow tubes and valves.

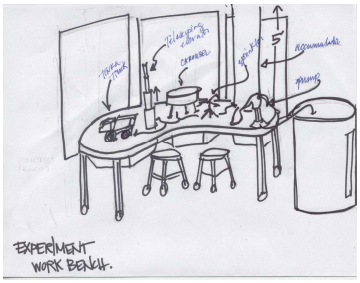
The second side of this exhibit shows the mechanical advantage that results when two pistons of different sizes are coupled together. It consists of three pistons: the first with a diameter of 2", the second with a diameter of 4", and the third with a diameter of 8". A series of one-way valves allow the smaller pistons to be pumped up and down to raise the large piston with the steel weights on top. A valve at the side is provided for visitors to let the big cylinder drain into the reservoir. There's a pressure relief (safety) valve that opens when the big piston gets to the top of its cylinder and can't rise any more.

Fall Semester, 2007

A team of seven students developed rough prototypes of two exhibits. The first is a pair of displays that introduces the use of pulse-width modulation for control of electrical and fluid power loads. The second is an "experiment bench" that allows young visitors – especially girls – to explore ways of controlling fluid-powered motion.



PWM Exhibits



The first of this pair of displays presents two incandescent lamps. The brightness of one is controlled by a rheostat (variable resistor) while the brightness of the other is controlled by a toothed wheel that, when spun, turns the current to the lamp on and off rapidly. Two watt meters show the power consumed by each lamp when dimmed. Visitors can also feel the heat (energy) dissipated by the rheostat when it is set to dim the lamp. [This exhibit needs some work before it will be ready to place on the museum exhibit floor for visitor use.]

The second of these displays compares water flow from two water jets. One is connected to a fast-acting valve controlled by a toothed wheel that sends pulses of water to a vertical water jet. The other is connected to a throttle valve that controls the water flow. (Eventually, flow meters will show how much water each jet is using.) Visitors will see that the PWD control achieves the same fluid flow rate but provides more energy to the water, causing it to shoot higher. [This exhibit needs considerable work before it is ready to try on the museum exhibit floor.]

The Experiment Workbench allows visitors to pump water and air into an accumulator and then use the pressurized water to drive a model carousel, operate a piston, and operate a model hydraulic elevator by

using a three-way valve or a four-way spool valve. Quick-change couplings on the fluid-carrying hoses allow visitors to experiment with fluid circuits. [This exhibit needs considerable work before it is ready to try on the museum exhibit floor.]

SMM Project Work
SMM exhibit prototypers built several small models to show fluid power components. One was a self-sealing piston inside a glass cylinder. Another was an accumulator built out of a plastic coke bottle and a balloon.

They are also working on a fluid transmission exhibit that consists of a variable displacement, hand-cranked, pump connected to a pre-charged accumulator and a variable displacement motor, which is connected to a tire and wheel. In this exhibit, visitors may adjust the pump displacement to send pressurized fluid to the accumulator and to the hydraulic motor. Depending on the setting of the motor displacement, it will stay still, rotate the tire and wheel "backwards", or rotate it forwards. Any fluid not used by the motor collects in the accumulator. Once the tire is spinning, setting the motor displacement to neutral will allow it to coast; or setting it to the opposite direction will brake the wheel, sending fluid into the accumulator. This exhibit also has a transparent cylindrical reservoir' visitors can observe the fluid level fall in the reservoir as fluid is pumped into the accumulator. We have had some difficulty finding a suitable off-the-shelf hydraulic motor due to the small size needed for a hand-cranked system.

5. Other Relevant Work

6. Plans for Next Year
SMM prototypers will complete prototyping work on the fluid transmission exhibit and test it with visitors. Prototypers will develop the two rough (student-developed) PWD exhibits until they are stable enough to be tested with visitors and left on the museum exhibit floor. We will also analyze the fluid power lab workbench and develop a practical water-based wet-lab prototype for testing with visitors. SMM prototypers will develop a new fluid power centerpiece exhibit that will allow visitors to feel the mechanical advantage between two pistons of different sizes. SMM will approach Hennepin County Technical College to see if students might be interested in building a visible, working, variable-displacement pump for display at the museum. SMM will also consult with CCEFP leaders to select a different thrust to explore through a fall semester (2008) capstone design course. And SMM prototypers and graphic designers will support the Fluid Power Youth Team in the development and production of a small CCEFP display.

7. Expected Milestones and Deliverables By the end of 2008, a nucleus of four interactive exhibits plus a panel display about CCEFP will be on the Science Museum of Minnesota Exhibit Floor.

8. Member Company Benefits - NA

9. Research Team

Project Leader:	J. Newlin
Other Personnel:	Forrest Price, Richard Gagnon
Post Doc(s):	
Graduate Students:	
Undergraduate Students:	**Spring '07:** Aaron Gendler, Jeremiah Jones, Cory Miller, John Pogatschnik, Ryan Schmuck, Ben Thompson **Fall '07:** Andy Chesla, Robert Dahlstrom, Shelley Fabry, Nathan Jones, Jack Petty, Anna Pieper, Alex Stoetz
Industrial Partner(s):	Eaton

Project A.2 Fluid Power Youth Science Team

1. Project Goals

The Fluid Power Youth Science Team is a group of 10 high school sophomores and juniors from St. Paul public schools employed through the Youth Science Center at the Science Museum of Minnesota. The Youth Science Center is both a youth employment and youth development program designed to engage underrepresented middle to high school students in STEM (Science Technology Engineering and Math) learning through museum work. The goals of the Fluid Power Youth Science Team are to develop hands-on fluid power activities to test with visitors in the museum galleries and teach K-12 groups at outreach sites including schools as well as after-school centers. In addition, the Fluid Power Team will design and co-fabricate an exhibit display with assistance from Science Museum of Minnesota Exhibits staff highlighting the research projects and applications in the CCEFP. The third goal is to foster relationships between youth, Science Museum of Minnesota staff, volunteers, the University of Minnesota, and CCEFP.

2. Project's Role in Support of the Strategic Plan

The mission of the Education and Outreach Program of the NSF center for CCEFP includes educating the general public, integrating current research findings into education, and actively recruiting and retaining a diversity of students in fluid power research and industry. The Fluid Power Team was recruited in October 2007 and is composed of a diversity of students including girls, economically disadvantaged youth, and youth of color. Many of these youth are exploring the field of mechanical engineering for the first time and already have expressed interest in pursuing careers in this field. The hands-on fluid power activities they are creating will be used on outreaches and in the Science Museum of Minnesota galleries to educate the general public about fluid power and its applications. Once the youth complete the exhibit display in collaboration with Science Museum staff, the exhibit will serve to disseminate the researh and applications of the CCEFP to the general public.

Fluid Power Youth Science Team explores the concept of an accumulator through designing a fluid toy.

3. Fundamental Challenges and Solutions

A potential fundamental challenge for the Fluid Power Team is developing successful partnerships with researchers so youth can gather stories about fluid power research topics. To overcome this challenge, 1-2 key contacts in the network of researchers will be established and with clearly communicated expectations for researcher commitment. Another potential challenges disseminating the fluid power activities and findings of the Fluid Power Team with the CCEFP network. The solution is to update contacts within the CCEFP network regularly and disseminate findings to future Youth Science Center teams to continue the youth team's work after the program ends in the summer of 2009.

4. Achievements to Date

Four hands-on fluid power activities have been created to date. The first activity is an air cannon exploring the concept of air as a fluid and how it is compressible. The second is a fluid theater exploring the concept of the compressibility and motion of water and air using syringes and tubing. The third is taking apart and building fluid toys to explore the concept of an accumulator (Figure 1). The fourth is using Lego pneumatic kits to create elevators and dentist chairs to explore fluid power systems and circuits.

The Fluid Power Team also collaborated with another Youth Science Center team, Learning Places, to do an activity critique (Figure 2). Each team member tested the activities and recorded both positive remarks and constructive criticism and discussed ways of improving each project. The Fluid Power Youth Team is currently reviewing and improving their projects for outreaches.

5. Other Relevant Work

The Fluid Power Team connected with Exhibits staff on a tour of the Exhibit Shop to begin thinking about future fluid power activities and applications as well as the exhibit display. The team also worked with Learning Places to create straw rockets, an activity designed by a previous Youth Science Center team called Make It using air to launch a straw rocket at a target. Since Learning Places students have worked with youth in the community before, they discussed the positive aspects and challenges when working with visitors and kids on outreaches.

6. Plans for Next Year

Outreaches in the Science Museum and community will begin in January. Target Kids day on January 12 is an event at the Science Museum designed to invite 2,000 kids under age 12 with an adult to the museum. The Fluid Power Team in collaboration with other Youth Science Center teams will help museum visitors make straw rockets and explore fluid power through the use of a fan to make objects fly and float. Other outreaches will include fluid power activities like air cannons and fluid toys to teach kids about fluid power at museum magnet schools, community centers, and Seniors and Students in Science Day with Burnsville elementary schools.

The Fluid Power team will also begin fieldtrips to various sites. Potential sites include the University of Minnesota engineering research labs, Bonfe's auto shop, and Ford Dam (Mississippi Lock and Dam No. 1). They will document their trips and interview researchers to start brainstorming content for new fluid power activities and the exhibit display.

Fluid Power Youth Science Team collaborates with Learning Places Team to discuss ways to improve fluid theater activity.

7. Expected Milestones and Deliverables

By January, the Fluid Power Team will have completed four projects to use in outreaches. They will start working with museum visitors and on outreaches in the community bimonthly. Over the next 6 months, the team will modify their current 4 projects and create 4 more activities. By the end of the winter 2008, students will have started researching, planning, and developing a small display on CCEFP by interviewing researchers and professionals in fluid power and working with Exhibits staff. In the

winter of 2009, students will have implemented an update to the CCEFP floor display and started testing Project Lead the Way kit components with museum visitors and kids on outreaches. The team will wrap up in the summer of 2009.

8. Member Company Benefits

The Fluid Power Team provides a youth employment and development experience for youth in the Youth Science Center at the Science Museum of Minnesota. They develop an understanding and appreciation for the field mechanical engineering and connect to researchers in the field. Also, they gain an appreciation for engineering applications and provide opportunities to share fluid power content with community partners and visitors through development and testing of fluid power activities.

Research Team

Project Leader:	Rachel Gates
Other Personnel:	Kristen Murray (education advisor), J. Newlin (Project Leader of Exhibit Team)
Post Doc(s):	
Graduate Students:	
Undergraduate Students:	
Industrial Partner(s):	

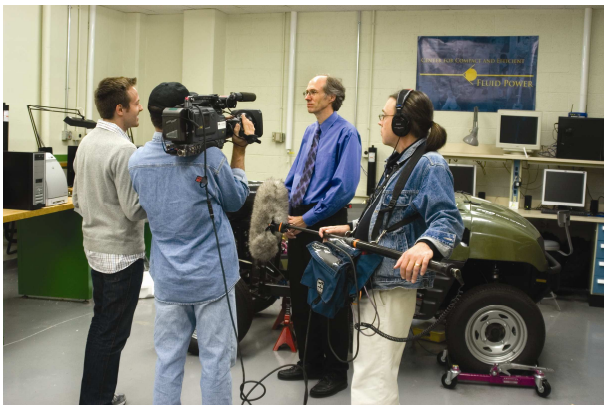
Project A.3 Public Television Video

1. Statement of Project Goals
Two videos will be produced by Twin Cities Public Television (TPT), one introducing fluid power to the general public, and the other showing the advantages of engineering careers in fluid power.

2. Project's Role in Support of the Strategic Plan
The project supports the goals of improving public understanding of fluid power and increasing the size of the fluid power engineering workforce.

3. Fundamental Challenges and Solutions
The main challenge is to create compelling videos with no narrator and a limited budget and time.

4. Achievements to Date
Fundraising began in spring of 2007. Funding was a shared responsibility of CCEFP, NFPA and other national fluid power organizations. Planning was begun in the summer of 2007. Beginning in September 2007, video clips were obtained from CCEFP and NFPA members and international sources. Filming was conducted in October 2007, and a rough cut of both videos was created in December 2007.



5. Other Relevant Work
No current videos on fluid power for the general public or engineering audiences exist, although the History Channel has produced a video on the history of fluid power.

6. Plans for Next Year
The video will be completed and broadcast in the Twin Cities. It will be made available to other public television stations around the country. A campaign to solicit additional broadcasts in other cities will be launched. The videos will be available on DVD. A distribution plan to maximize distribution to appropriate audiences will be created and executed.

7. Expected Milestones and Deliverables
Videos completed (Feb. 2008). Broadcast in the Twin Cities (April 2008). DVD shown at IFPE (March 2008) and CCEFP Annual Meeting (May 2008). Further broadcast in other cities (summer and fall of 2008). DVD distribution plan developed (Spring 2008).

8. Member Company Benefits
The copyright for the videos is owned by the CCEFP, NFPA and other national fluid power organizations. This will allow broad distribution by NFPA and CCEFP member companies to promote fluid power understanding and development of the fluid power workforce.

9. Research Team

Project Leader:	Kim Stelson
Other Personnel:	Stephanie Bettermann, Perry Li, Andrew Alleyne, Wayne Book, Monika Ivantysynova
Post Doc(s):	
Graduate Students:	Serena Tyson, Caleb Sancken and others (bit parts).
Undergraduate Students:	
Industrial Partner(s):	NFPA (Eric Lanke, Tammy Molter), TPT (Tom Trow, Mark Fisher), many companies provided video clips

Project A.4 Information Repository

1. Statement of Project Goals
The goal of this project is for the CCEFP web site to be a leading repository of information on fluid power. Examples of information to be included are: information and archived presentations on CCEFP research, REU reports, RET curriculum, K-12 classroom visit curriculum, links to fluid power tutorials, world list of fluid power degree granting institutions, list of undergraduate and graduate fluid power courses in the U.S., professional training courses, fluid power videos, and more.

2. Project's Role in Support of the Strategic Plan
This project will collect and disseminate information pertinent to the fluid power industry on behalf of industry, academia and the public sector such as K-12 institutions and teachers to public educators such as a science museum.

3. Fundamental Challenges and Solutions
To determine, search, collect and properly distribute information requires time and an on-going attention to new information, old information, continually updating the existing information. A SLC representative is appointed to assist in this effort and information will be collected, revised, updated regularly by way of requests to those in the fluid power industry, the CCEFP faculty and students, and the feedback by the audience.

4. Achievements to Date
A draft of the information repository has been created and is in the review process. This information will be posted on the CCEFP website under the (to be determined) link of the site.

5. Other Relevant Work
N/A

6. Plans for Next Year
To complete the information repository and post electronically.

7. Expected Milestones and Deliverables
Expected post date: June 2008

8. Member Company Benefits
Full access to information supported in the information repository.

9. Research Team

Project Leader:	Alyssa A. Burger, Education Outreach Director
Other Personnel:	
Post Doc(s):	
Graduate Students:	*SLC Representative*
Undergraduate Students:	
Industrial Partner(s):	

Project B.1 Project Lead The Way (PLTW)

1. Project Goals

In partnership with classroom teachers employed in schools districts across the country, PLTW staff develop pre-engineering and engineering technology curriculum for students in middle- and high schools. PLTW is an Affiliated Outreach Institution of the CCEFP. The National Fluid Power Association (NFPA), also a CCEFP Affiliated Outreach Institution, has funded the development of revised and added fluid power content in several PLTW courses. NFPA and PLTW, together with the CCEFP, form a three-way partnership for this project. Content and curriculum developed through this partnership is leading students, teachers and counselors engaged in PLTW to a better understanding of the basics of fluid power technology and its cutting-edge applications, guided by subject matter experts from the fluid power industry and the CCEFP.

2. Project's Role in Support of the Strategic Plan

Facilitation of knowledge transfer is central to the CCEFP's strategy. So is its focus on programs that capitalize on existing, broadly distributed education and outreach networks to maximize program impact. The PLTW program within CCEFP supports these strategies by bringing together three strong partners: the CCEFP; industry as represented by NFPA, the leading trade association for the fluid power industry; and Project Lead The Way* with its established national base of support.

3. Fundamental Challenges and Solutions

- Each organization in this three-way partnership shares in goals to enrich STEM-related experiences among many students. In finding ways to work together to achieve these goals, each partner needed to chart "new waters." These efforts were facilitated by approaching this project on a task-by-task basis, forming small groups to meet and/or communicate via e-mail in order to share content, evaluate progress, and make plans.
- Writing the caliber of curriculum expected by PLTW is in itself a challenge, made more difficult in this case since fluid power technology is not broadly understood outside of its own industry base. A task force of industry and CCEFP representatives has and will continue to help PLTW's curriculum writers to focus on key fluid power basics and review new course material for accuracy and currency.
- As programs of the CCEFP develop, it is important to find ways to apply Center resources in meeting PLTW needs and interests. Effective communication continues to be key here as PLTW sees how other of the Center's Education and Outreach Projects (e.g., A,3, Public Television Video; B.3, Fluid Power Demonstration Curriculum; and B.4, RET Program) can provide value and opportunities to its activities.
- As noted above, understanding of fluid power technology and applications is not widespread. Partners in this program, particularly PLTW and the CCEFP, see the potential for facilitating knowledge transfer—from the Center's subject matter experts to the PTLW teacher base. With the potential clearly evident, PLTW and CCEFP are exploring how the Center faculty can contribute to sessions at PLTW Teacher Training Institutes held on college campuses during the summer and through on-line resources at the PLTW website.

4. Achievements to Date

- A strategy to engage subject matter experts from the Center and industry in reviewing PLTW curricular materials, as they relate to fluid power, has been tested and is in place. In response to these reviews, PLTW has/will act on task force recommendations.
- Immediate impact: One lesson and one project in PLTW's Introduction to Engineering Design and one lesson and one project in its Engineering Design & Development class are in place (the former in 1400 schools, with 2 sections per school, each with 25 students, and the latter in 315 schools, 1 section per school, each with 25 students).
- In development this year: lessons and projects in the Introduction to Engineering Design and Principles of Engineering classes at the high school level, and the Science and Technology unit for middle school.
- Next steps are underway in engaging CCEFP faculty in PLTW Teacher Training Institutes at the Milwaukee School of Engineering, University of Minnesota and University of Illinois-Urbana/Champaign campuses. Sessions on fluid power may be taped for viewing at other PLTW Teacher Training Institutes and at the PLTW website. Tapes would include presentations as well as field trips to the labs where fluid power research is being conducted through the Center.
- PLTW will work with CCEFP in recruiting its teachers for the Center's RET program in summer 2008.
- PLTW will share the "Meet an Engineer" student profiles posted at the CCEFP website among its many audiences. These profiles were created by students in the CCEFP in a project led by the Center's Student Leadership Council. While each is unique, these profiles offer insights into the interests, backgrounds and current studies/research of Center undergraduates and graduates as well as their advice to middle and high school students concerning pursuing engineering as a field of study.

5. Other Relevant Work

PLTW is recommending other avenues (e.g., programs of other organizations) to the CCEFP for maximizing the work and successes of the Center's research, education and outreach.

6. Plans for Next Year

Following the PLTW course review and revision schedule, additional courses are scheduled for new and/or revised fluid power content. Assuming successful participation in PLTW's 2008 Teacher Training Institute, subject matter experts may be able to play a larger role in these institutes in 2009.

7. Expected Milestones and Deliverables:

- New lessons and projects will be completed in the Principles of Engineering and Engineering Design and Development classes in 2007-08 for broad use within PLTW in 2008-09.
- PLTW will measure the impact of the new course content relevant to fluid power that was put into place beginning in the fall of 2007.
- Interaction between the CCEFP, NFPA volunteers and PLTW will be ongoing in reviewing and suggesting content for new classes. This interaction includes the transfer of knowledge gleaned from CCEFP research.

- The CCEFP will participate in 2008 PLTW Teacher Training Institute on campuses which both host the institutes and serve as core Center schools (MSOE, UIUC and UMN).
- A minimum of four PLTW teachers will be engaged in the 2008 RET program.

8. Member Company Benefits

The fluid power industry is united in its concern about the future for its technology and its industry. Collectively and individually, the worry about who will be the engineering leaders and technicians needed to take over the reins. The PLTW program, with its STEM focus and with the current and future inclusion of fluid power content, responds to that concern by offering a widely regarded curriculum to a broad base of participants.

9. Research Team

CCEFP team members serve/will serve as subject matter experts for PLTW.

Project Leader:	Linda Western, Education Co-Director, CCEFP
Other Personnel:	Alyssa Burger, Outreach Director; Will Durfee, Education Co-Director, CCEFP; Mike Gust, Industrial Collaboration and Transfer Director, CCEFP
Post Doctoral Candidates:	None
Graduate Students:	None
Undergraduate Students:	None
*Other participants:	Not all PLTW participants will engage in the units, lessons and projects with fluid power content developed through this project. However, the potential for impact can be estimated through knowledge of overall PLTW program totals, as reported at their website: states with PLTW programs = 50 plus the District of Columbia); total schools with PLTW programs = 2,200; total teachers trained = 7,000; total counselors trained = 5,000; total students enrolled in PLTW classes = 200,000; total number of students who have experienced PLTW by taking at least one class = 250,000
Industrial Partners:	All of industry will benefit from this STEM-focused program and partnership.

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B.2 FIRST Robotics Teams

1. Statement of Project Goals

Create additional curricular material on pneumatics for use by high school FIRST Robotics teams. Two types of material are being developed: (1) web-based self learning material for students, and (2) workshop curriculum for delivery by mentors. The goal is for 100% of FIRST Robotics teams to learn the basics of pneumatics and to at least consider the use of pneumatics in the design of their robot.

2. Project's Role in Support of the Strategic Plan

FIRST Robotics involves over 30,000 high school students every year. Introducing pneumatics technology to FIRST teams leverages CCEFP's ability to bring fluid power education to pre-college students.

3. Fundamental Challenges and Solutions

Challenges: (1) development of audience-appropriate pneumatics training and workshop materials, (2) dissemination to reach every one of the 1,500 FIRST teams. Solutions: (1) pilot testing of materials with FIRST teams local to CCEFP sites, (2) dissemination through member companies and through FIRST web site.

4. Achievements to Date

Workshops for FIRST teams in Fall 2006 at GT and Fall 2007 at GT and UMN reaching about 150 students. A low-cost workshop kit was developed with parts from McMaster-Carr and Grainger. Tutorial presentation introduced pneumatics and CCEFP research. Students learned about pneumatic components and the capability of controlled pneumatics through hands-on activities. Feedback from the students was generally positive and demonstrated new awareness of fluid power possibilities for robotics.

5. Other Relevant Work

The CCEFP is sponsoring an all American Indian FIRST team, the first in the country. CCEFP staff are on the planning committee for the Minnesota FIRST Regional event, to be held at UMN in March 2008.

6. Plans for Next Year

Revise and package the workshop curriculum and kits for workshop delivery by CCEFP faculty and students to local FIRST teams. Deliver workshop at all seven CCEFP sites. Develop self-learning tutorial material for posting on a web site. Develop an assessment plan to determine whether the curriculum and workshops are increasing awareness of fluid power and increasing the use of pneumatics in FIRST robots. Encourage CCEFP member companies to sponsor a local FIRST team.

7. Expected Milestones and Deliverables
Workshop materials ready for dissemination (June 2008). Workshops at seven CCEFP sites (December 2008). Tutorial web site (August 2008). Assessment materials prepared (June 2008).

8. Member Company Benefits
Increased awareness of fluid power by high school students. Sponsoring a FIRST team connects company to students and the local school system.

9. Project Team
Project Leader: W. Durfee (UMN)

Other Personnel: C. Paredis (GT)

Project B.3 Hydraulic and Pneumatic Demonstration Kits

1. Statement of Project Goals

Hydraulic and pneumatic demonstration kits will be developed for K-12 classrooms, with an initial focus on middle and high schools. The kits can connect to PLTW, FIRST Robotics, Science Museum and other CCEFP activities.

2. Project's Role in Support of the Strategic Plan

This project directly supports the CCEFP mission to "develop research inspired, industry practice directed education for pre-college, university and practitioner students; to integrate research findings into education; to educate the general public; and through active recruiting and retention, to increase the diversity of students and practitioners in the fluid power research and industry".

Project B.3 specifically targets the fifth component of the ERC's vision for education, to "increase public and K-12 student awareness of the importance of fluid power, and the excitement and possibilities that new technologies of the Center will bring".

3. Fundamental Challenges and Solutions

The fundamental challenges include 1) incorporating learning focused research techniques to the design of the kits and assessing the results, and 2) to design kits with maximum usefulness while not making them to complex and/or expensive.

The proposed solution is two-fold: one, to determine through background research and literature reviews the best methodology, learning objectives, learning outcomes, and assessment methods, and two, to determine through background research and with help from the K-12 ad-hoc committee, the optimal kit design to meet these objectives.

4. Achievements to Date

Since beginning this project in August, 2007, biweekly conference calls were organized and facilitated, minutes for each meeting were recorded, a summary of existing pneumatic training kits was developed, and two students from Purdue have been recruited for an independent study from January-May, 2008, to help design the demonstration kit and curriculum. The ad-hoc committee members included representatives from academia, FIRST, FPEF, NFPA, PLTW, and the Minnesota Science Museum.

5. Other Relevant Work

There is relevant work underway within the Center through the coordinated efforts the Education Outreach Network of the Center, through similar educational outreach activities at other Engineering Research Centers in the United States, at several industrial partners who have training programs, and at various Universities around the world where Engineering education research is underway.

6. Plans for Next Year

There will be two graduate students from Purdue taking an independent study class and designing a demonstration kit and related curriculum. Although these activities are not part of

this project or the ERC the results are related to the goals of this project and will be shared with interested members of the ERC.

7. Expected Milestones and Deliverables

- November 2007: Assessment of current hydraulic and pneumatic training kits available for purchase.
- June 2008: Design of a pneumatic demonstration kit for high school students.
- August 2008: Development of a curriculum for the pneumatic demonstrator.
- September 2008: Integration of pneumatic kit and a curriculum suitable for PLTW.

8. Member Company Benefits

This project will directly benefit member companies involved in fluid power by providing a methodology and demonstration kits to capture the imagination of future engineers, their future workforce. All reports and publications will be available to Center members.

9. Research Team

Project Leader:	Prof. John H. Lumkes Jr.
Graduate Students:	Jose Garcia and John Mahrenholz
Industrial Partners:	TBD

B.4 Research Experiences for Teachers (RET)

1. Statement of Project Goals
To bring fluid power to pre-college students by immersing teachers in CCEFP research labs to study and to develop research-inspired curriculum modules to bring back to their classroom. Targeted teachers are those instructing PLTW program courses and faculty in community colleges that teach fluid power technology courses.

2. Project's Role in Support of the Strategic Plan
The RET program brings research-inspired curriculum to high school students and will increase awareness about fluid power. PLTW teachers are targeted so that research-inspired ideas can be brought to the fluid power curriculum being created by PLTW (Project B.1). Significant training of fluid power professionals occurs through the community college system. Fluid power teachers at community colleges are targeted to bring research-inspired ideas to traditional fluid power technology training.

3. Fundamental Challenges and Solutions
Challenge: recruiting PLTW and community college teachers. Solution: use PLTW network and community college contacts. Challenge: building a community among RET participants. Solution: multiple teachers at selected CCEFP sites rather than one at each of the seven sites.

4. Achievements to Date
Four teachers participated in the 2007 CCEFP RET program, the first for the Center. An RET supplement was submitted but not funded and the 2007 RET program was paid through Center base funds. One teacher each was in CCEFP research labs at UMN, Purdue, Vanderbilt and Georgia Tech. While each project was valuable, expectations of the participants and coordination among projects to develop a teacher community needed improving. The experiences from 2007 helped to define the RET program plan for 2008.

5. Other Relevant Work
None.

6. Plans for Next Year
A coherent, integrated plan for six RET participants in summer 2008 is in development. Teachers will spend six weeks full time in the research lab with appropriate days at the start for orientation and at the end for developing curriculum. Expectations and responsibilities for participants will be clearly defined. There will be either three teachers at two sites or two teachers at three sites. Regular video conferencing sessions will be scheduled to link the participants. Recruiting for summer 2008 will target PLTW teachers while community college teacher participation will start in summer 2009.

7. Expected Milestones and Deliverables
RET application materials on CCEFP web (January 2008). RET participant handbook (February 2008). Six teachers recruited (April 2008). Evaluation plan (April 2008).

8. Member Company Benefits

High school students learn modern fluid power concepts through the curriculum developed by their teachers. Future employees receiving fluid power technical training at a community college are exposed to cutting edge fluid power research.

9. Research Team

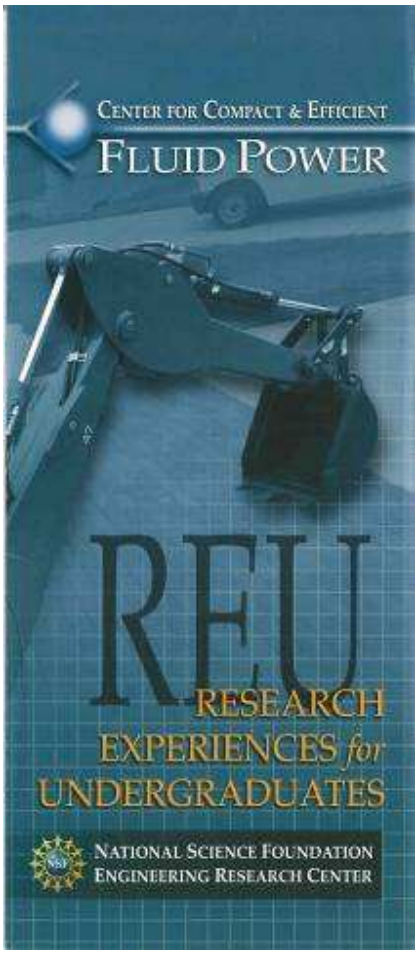
Project Leader:	W. Durfee (UMN)
Other Personnel:	CCEFP faculty hosting RET participants.
	A. Burger (UMN), Program Coordinator

C.1 Research Experiences for Undergraduates (REU)

1. Statement of Project Goals
Provide undergraduate engineering students with a significant summer experience in cutting edge fluid power research. Students undertake a 10 week project under the supervision of a faculty mentor. The program includes professional development activities. Recruiting for REU students targets a diverse audience.

2. Project's Role in Support of the Strategic Plan
Students in engineering REU programs are far more likely to enroll in graduate engineering programs, often at the school that hosted the REU. By hosting an REU program, the CCEFP is more likely to attract high quality prospective Masters and PhD students to CCEFP research projects who in turn go on to responsible positions in industry or to become professors. Targeted REU recruiting aimed at diverse student populations will increase the overall diversity of students and professionals in fluid power.

3. Fundamental Challenges and Solutions
Challenges: (1) recruiting a diverse REU cohort, (2) coordinating REU activities across the seven CCEFP sites. Solutions: (1) recruit through LSAMP network and SLC takes significant role in recruiting, (2) central recruiting of CCEFP REU students, common expectations for REU students, introductory fluid power and CCEFP training at start of REU experience.



4. Achievements to Date
Twenty-three REU students participated in summer 2007, the inaugural year for the CCEFP REU program. The distribution was UMN: 4, UIUC: 3, Purdue: 3, Vanderbilt: 5, MSOE: 2, NCAT: 3, GTech: 3. None of the students were affiliated with the CCEFP prior to their REU experience, although more than we would have liked were students enrolled at the REU host site. One student, hosted by UIUC, won first place in the undergraduate category of the poster competition at the Great Midwest Regional Space Grant Conference. While all students had significant research experiences, we were not satisfied that the students were sufficiently connected to their fellow REU students at other CCEFP sites or to the center as a whole. While the students were talented academically, we were not satisfied with the diversity of the cohort.

5. Other Relevant Work
None.

6. Plans for Next Year

The 2008 REU program will be significantly different than 2007. An REU site application was submitted, but not funded so REU support will come from the core CCEFP budget. Information on the 2008 program is posted on the CCEFP web site and brochures have been printed. A recruiting schedule has been developed (see Project E.6) and recruiting activities have been active. The application deadline is February 15 because early deadlines and early decision dates are one way of getting the best students. The target size of the program is 14 students, two per CCEFP site. The center will fund additional students if requested by the site. An REU handbook for students and another handbook for faculty mentors will be developed so that expectations are clear. An introductory training boot camp is under development. Revised entrance, mid-summer and exit surveys, as well as long-term tracking of REU graduates, are being developed for formative and summative assessment. of the program. Details of the REU program will follow the plan described in the REU site application. A specific goal is to increase the diversity of the REU pool, and particularly to increase the number women REU students as the fluid power profession is currently predominantly men.

7. Expected Milestones and Deliverables

Identify faculty advisors (March 2008). REU student and faculty advisor handbooks (April 2008). Professional development workshops finalized (April 2008). REU acceptance decisions (April 2008). Assessment methods and protocols (May 2008). Boot camp curriculum and schedule (May 2008). Follow-up of 2008 participants (November 2008).

8. Member Company Benefits

Member companies can participate in projects as industry champions. Member companies have defined rights to IP generated by the project. Member companies get a first look at a bright, diverse pool of students trained in fluid power who may become future intern or permanent employees.

9. Research Team

Project Leader:	W. Durfee (UMN)
Other Personnel:	CCEFP faculty adivsing REU participants.
	A. Burger (UMN), Program Coordinator

C.2 Fluid Power Curriculum in Existing Undergraduate Courses

1. Statement of Project Goals

Insertion of fluid power into existing core mechanical engineering curriculum, specifically targeting introductory system dynamics and introductory fluid mechanics courses taken by every mechanical engineering student in the world. Methods include creating text book material and example problems tailored to the material being taught in the core course. The long range goal is for every mechanical engineering student in the country to be exposed to fluid power.

2. Project's Role in Support of the Strategic Plan

Consensus is that new departments and a four-year fluid power degree are unrealistic goals. Insertion of fluid power into standard engineering courses is not only achievable but also the most direct route towards increasing the number of engineering students trained in the basics of fluid power.

3. Fundamental Challenges and Solutions

Challenge: dissemination of curricular material beyond CCEFP universities. Solution: Adoption by CCEFP universities and a vigorous dissemination plan.

4. Achievements to Date

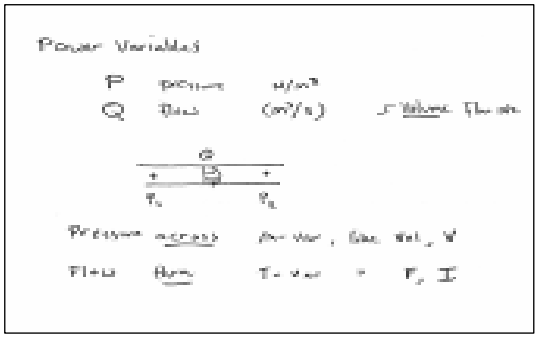
A fluid power section has been inserted into ME 3281 System Dynamics and Control, the introductory system dynamics course at the University of Minnesota. The unit consists of several lectures and a problem set. It has been delivered three times. A chapter on fluid power, for use in system dynamics courses, is under development. The chapter will be co-authored by several CCEFP controls faculty.

5. Other Relevant Work

None.

6. Plans for Next Year

Survey top mechanical engineering programs, 50 in U.S plus 10 international, to determine textbooks used in introductory system dynamics and fluid mechanics courses. Survey textbooks to determine most logical places to insert fluid power material and examples. Develop an information repository system for fluid power example problems, suitable for lecture and homeworks. Collect example problems from CCEFP faculty. Complete draft of fluid power text chapter for systems courses. Create an instructors guide, including solutions to examples. Disseminate chapter to CCEFP sites.



7. Expected Milestones and Deliverables
Survey report (April 2008). Systems course chapter (May 2008). Disseminate chapter to CCEFP sites for use in Fall semester 2008. Fluid power example repository has at least 20 entries (September 2008).

8. Member Company Benefits
Mechanical engineering graduates who understand basic fluid power.

9. Project Team

Project Leader:	W. Durfee (UMN)
Other Personnel:	CCEFP faculty teaching controls courses

C.5 Advanced Graduate Courses

1. Statement of Project Goals
Develop new, semester length graduate courses in fluid power at CCEFP university sites, and to enhance existing graduate courses with the results of CCEFP research.

2. Project's Role in Support of the Strategic Plan
Advanced, graduate level courses in fluid power will result in a pool of highly skilled students who will become future fluid power industry professionals and future engineering faculty.

3. Fundamental Challenges and Solutions
Challenge: new courses require significant development effort by faculty and must be compatible with teaching loads and department new course policy, which are outside the control of the center. Solution: continually encourage CCEFP faculty to develop new courses and modify existing courses based on the results of CCEFP research.

4. Achievements to Date
Course ABE 591D Design of Fluid Power Systems is a new graduate course at Purdue University jointly listed in Mechanical and Agricultural & Biological Engineering. The course was developed and taught by Dr. Ivantysynova.

5. Other Relevant Work
None

6. Plans for Next Year
Continue to encourage CCEFP faculty to create and modify graduate level courses based on CCEFP research.

7. Expected Milestones and Deliverables
One new graduate level course (September 2008).

8. Member Company Benefits
Access to highly trained graduate students.

9. Project Team
Project Leader: W. Durfee (UMN)

Other Personnel: CCEFP faculty teaching new graduate courses

Project D.1 Intern Program

1. Project Goals

The Engineering Research Center for Compact and Efficient Fluid Power (CCEFP) coordinates the placement of undergraduate engineering students from U.S.-based universities in internship positions offered by fluid power companies supporting the CCEFP. By doing so, interns will have opportunities to learn by doing, applying classroom knowledge to their work assignments and learning through industry practice. Companies offering internships will benefit, too, through access to a diverse pool of talented engineers as the CCEFP strives to engage students reflecting the gender, racial and ethnic composition of this country.

2. Project's Role in Support of the Strategic Plan

Facilitation of knowledge transfer is central to the CCEFP's strategy. The intern program supports this strategy, focusing on two key audiences—undergraduate students and industry. Students will learn from practical experience shared through their industry mentors, and industry will learn from the skills and questions that their student interns bring to their new roles. This program also supports the CCEFP's plan to bring diversity to the fluid power industry through recruitment efforts that target underrepresented populations.

3. Fundamental Challenges and Solutions

- Introducing this program to students and to industry is a challenge since there are competitors for the attention and time of both groups. In meeting this challenge, the Center's promotional campaign for this program uses multiple channels including print, websites (the Center's, job boards, the National Fluid Power Association, etc.), e-mail, telephone, conference presentations and tabletops, posters, introductions to the program by faculty in their classrooms, and contacts with organizations with student outreach including HBCU, AISES and SACNAS.
- This program is open to all of the more than 60 companies supporting the Center, but some of these companies have never hosted an intern before. In order to encourage these companies to begin, the CCEFP website features the section: "Getting Started: Introducing and Launching an Internship Program." The CCEFP staff members are also available to provide assistance.
- Once an internship is defined by a company's management and engineering personnel, its human resource department is typically responsible for taking the next steps toward filling the position. However, these staff members may be daunted by looking through the many student applications, particularly if an intern program is new to them. To facilitate placements that well suit both students and host companies, the Center's Industrial Collaboration and Transfer Director reviews all applications and suggests a field of approximately six candidates to each company. The suggestions are based on the company's product and market focus as well as each student's academic background, geographic location and interests. Note that companies are not bound to draw from these lists—the entire field of candidates is open to them—and the final selection is, of course, each company's.

4. Achievements to Date

- 15 companies have or have pledged to post intern positions—more than 20% of the CCEFP's supporting companies. They represent the range of companies within the fluid power industry: large and small, public and private, US and internationally owned, hydraulic and pneumatic, manufacturer and distributor (with engineering services). Additional companies have expressed interest.
- 22 internships are available to students.
- 35 students representing 8 universities have posted applications.
- Promotions—selected key numbers: Distribution of more than 1000 brochures (one written for students and the other for industry), two mass e-mailings to professional and student societies, postings on six national internship websites, three external recruiting efforts, engagement of the CCEFP Education Outreach Network (EON) representing the Center's seven universities.

5. Other Relevant Work

The CCEFP's Industrial Board, comprised of representatives of companies supporting the Center at Principal and Sustaining levels, provides ongoing support and guidance in developing and promoting the intern program.

6. Plans for Next Year

The Intern Program for the summer of 2009 will be developed based on experiences and evaluations of the 2008 program. Tentatively, the program may be expanded beyond a summer timeframe, and may include graduate students and students from international universities.

7. Expected Milestones and Deliverables:

- At least 25 students will be placed in internship positions by March, 2008.
- Recruitment efforts will continue throughout the winter and spring of 2008 in the hope of exceeding the above goal—a target of an additional 10 interns.
- Experiences of students and industry hosts will be measured by pre- and post surveys during the summer of 2008.
- Both audiences will be followed longer term in order to learn if companies continue their internship programs and if students' career and/or academic choices are influenced by their internship experiences.

8. Member Company Benefits

- The intern program provides companies with opportunities to directly participate in educating and training a next generation of engineers who will know about fluid power technology and applications.
- Short term (and practically), this program provides an excellent way to locate motivated, short-term engineering help.
- Long-term, this program is viewed by many in industry as an invaluable tool for identifying talented candidates for future full-time employment.

9. Research Team

Internship candidates include students of the CCEFP research team.

Project Leader:	Linda Western, Education Co-Director, CCEFP
Other Personnel:	Alyssa Burger, Outreach Director; Will Durfee, Education Co-Director, CCEFP; Mike Gust, Industrial Collaboration and Transfer Director, CCEFP
Post Doctoral Candidates:	None
Graduate Students:	None
Undergraduate Students:	Student applicants (to date, 35)
Industrial Partners:	Companies offering internship positions to date: Deltrol Fluid Products; Eaton Corporation; Enfield Technologies; Festo Corporation; Gates Corporation; MTS Systems Corporation; MICO Incorporated; Moog Inc; Parker Hannifin Corporation; Poclain Hydraulics; ROSS Controls; Sauer-Danfoss, Inc.; Schroeder Industries, Sun Hydraulics Corp.; SunSource

Project D.2 Resume Bank

1. Statement of Project Goals

A resume bank of all CCEFP undergraduate, graduate and post-doc students will be developed. The resume bank will be available to CCEFP member companies. This will include an electronic resume database which will be in conjunction with the CCEFP Alumni Society. Students and companies will be invited to post resumes to seek employment opportunities within Industry or Academia during or past their academic career within the CCEFP. The resume bank will be a private addition to the CCEFP website in which only students and industry members within the Center will be able to review. Students post their resumes with the intention of being approached or recruited for employment opportunities.

Industry will be invited to post similar positions on the CCEFP website that is similar in scope to the Industry Internship Program, however, the Center does not play a role in match-making or placing recommendations for the companies. Industry is welcome to post entry-level job postings only. (Year 3)

2. Project's Role in Support of the Strategic Plan

The use of the resume bank by the undergraduate and graduate students as well as the industry members of the CCEFP will support the strategic plan to promote research inspired engineers as well as the diversity of the students entering the academic or industrial workforce.

3. Fundamental Challenges and Solutions

Creating the on-line database requires time and programming requirements of an Information Technologist. Challenges to this effort are building the database.

4. Achievements to Date

Internal database is built.

5. Other Relevant Work

CCEFP Alumni Society

6. Plans for Next Year

Plan and implement entry level job postings by industry for Year 3.

7. Expected Milestones and Deliverables

Electronic database will be built by June 2008 and will be implemented on the private side of the CCEFP website.

8. Member Company Benefits

Industrial members will have access and the invitation to peruse the students who have posted their information in the resume bank.

9. Research Team

Project Leader: Alyssa A. Burger, Education Outreach Director

Other Personnel:

Post Doc(s):

Graduate Students:

Undergraduate Students:

Industrial Partner(s):

Project D.3 Specialized Short Courses

1. Statement of Project Goals

The objective of this project is to develop short (1- 5 day long) advanced professional development courses that highlight the research activities of the Center. The targeted audiences for these courses are degreed industry design and/or manufacturing eng's at fluid power companies.

2. Project's Role in Support of the Strategic Plan

One element of our Center's E & O strategy is to develop and deliver high quality projects that wherever possible capitalize on existing, broadly distributed education and outreach networks to maximize program impact to targeted audiences. This project will do so by drawing upon educator expertise within the center to develop course matter directly related to their research work. By doing so we believe that the effort will be minimal as much of the material already exists and will therefore be easily justified.

3. Fundamental Challenges and Solutions

The key challenge is to determine what the subject matter "need" is within the targeted audience and then subsequently locate a qualified provider within the Center. Our proposed solution is to conduct both internal and industry surveys.

4. Achievements to Date

Informal surveys conducted with both internal Center educators and industry. Both parties are receptive to the proposed approach.

5. Other Relevant Work

Other organizations such as SAE have an already demonstrated successful working model. Internally MSOE has a successful industry training model that we plan to compliment, not compete, with.

6. Plans for Next Year

Finalize and conduct surveys. Work with Center educators to identify the subject matter for the initial courses. Launch marketing campaign in support of course offerings.

7. Expected Milestones and Deliverables

- Clear identification of ~3 - 6 Center affiliated instructors and the corresponding course description by Q2, 2008
- Determine infrastructure requirements such as billing, marketing, etc., by Q4.
- Conduct initial course in 2009.

8. Member Company Benefits

Many of the PIs operating within the Center are recognized experts in their fields of study. Some of these fields are quite unique and therefore it is not uncommon for our industry partners to lack

internal expertise. Thus, having a readily available source of training expertise and subsequent short course materials should be invaluable to them.

9. Research Team

Project Leader:	Michael J. Gust
Other Personnel:	*Thrust leaders and various PI's*
Post Doc(s):	
Graduate Students:	
Undergraduate Students:	
Industrial Partner(s):	IAB members

Project C.4: Transportable Universal Fluid Power
Laboratory for Professional Training Courses

1. Statement of Project Goals

The goal of this project is to develop first class universal fluid power laboratory to maximize the rewarded learning experience of the cutting edge fluid power and motion control technology. The word "Universal" simply means to cover

- Hydraulic and Pneumatic Technology
- Basic and Advanced Topics
- Standard and Tailored Courses
- Industrial and Mobile Applications
- On-campus and off-campus (Portable)

2. Project Role in Support of Strategic Plan

The project satisfies the CCEFP strategic objective of technology transfer to the industry professionals

3. Fundamental Challenges and Solutions

The main challenges in this project was how to generate curriculums, specify a number of exercises and find out the best equipments to perform technology training not manufacturer-biased training.

The problem has been resolved by studying the whole effort previously done by the leading manufacturer of fluid power. In addition to the accumulated experience at MSO, we end up with the best solution to achieve our goal. More than 20 different text book have been used to define 40 exercises distributed over 10 different courses for the industry professionals.

4. Achievements to Date

Development of the prototype model, including the following action items, expected to finish by June, 2008

Phase 1: July 2007- June 2008

- 100% Completed: Strategic objectives.
- 100% Completed: General features and technical specs.
- 80% Completed: Courses curriculums & experimental capabilities
- 100% Completed: BOM, specs and symbols.
- 0% Completed: Cost estimate.
- 0% Completed: Order equipments
- 10% Completed: Software development.
- 0% Completed: Prototype assembling and testing.

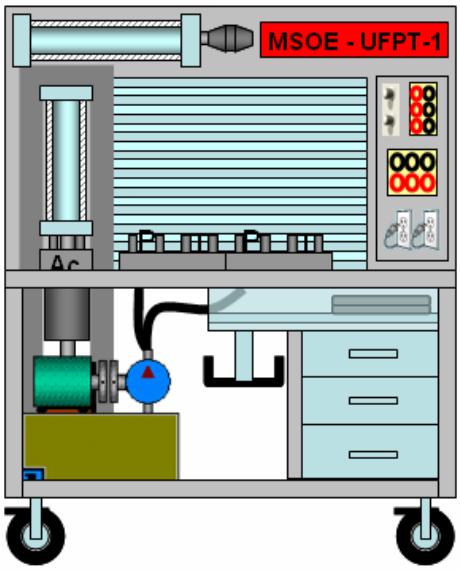
5. Other Relevant Work

New software to interface with and control variable displacement pump will be developed and most probably it will be patented.

6. Plans for Next Year

Phase 2: July 2008 – June 2009

- 50% Completed: Course manuals.
- 50% Completed: Lab manuals.
- 50% Completed: Animated circuits.
- 0% Completed: Duplicate the Trainer
- 0% Completed: Training the trainers from different universities.



7. Expected Milestones and Deliverables

Milestones:

- Capability of delivering new courses to the industry professionals
- Ability to increase the current offerings and mobilizes the current courses

Deliverables:

- Report containing completed prototype definition and course curriculums, June 2008

8. Member Company Benefits

- All the member universities can be benefited from the project
- In phase 2 of the project, MSOE will conduct training session for fluid powr trainers and instructors

9. Research Team

Project Leader: Dr. Medhat Khalil

Industrial Partner(s): Bosch Rexroth - Festo

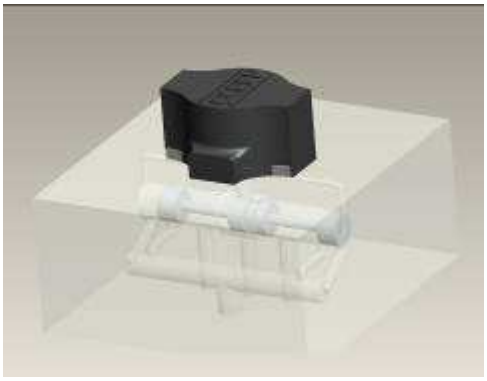
D.5 Fluid Power Coloring Book

1. Statement of Project Goals

The "Anatomy Coloring Book" is used world-wide by medical school students as part of their formal training in anatomy. The pedagogic theory is that the act of actively coloring a drawing anchors knowledge that is detailed and complex and that is tied to a three-dimensional object. The "Fluid Power Coloring Book" takes the same approach to create training materials for learning about complex fluid power components for an audience of industry engineers.

2. Project's Role in Support of the Strategic Plan

Novel training materials for fluid power components will aid students and professionals to become knowledgeable about fluid power.

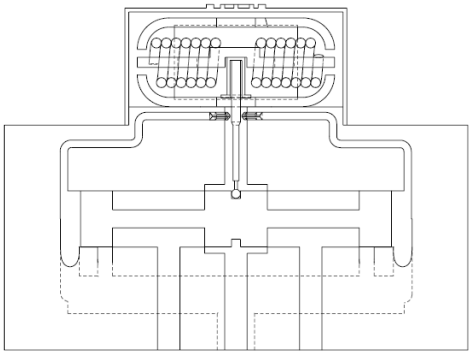


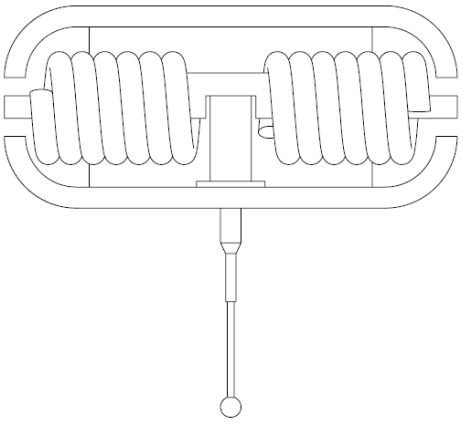
3. Fundamental Challenges and Solutions

Challenge: overcoming perception that coloring books are for children. Solution: disseminate in serious tutorial learning workshops.

4. Achievements to Date

The first coloring book explains how a two-stage hydraulic servo valve works. It is being developed by Roz Dolid, a fluid power professional at MTS in Eden Prairie MN. Ms. Dolid discovered that although MTS is one of the worlds leaders in the design and manufacturing of single and two-stage hydraulic servo valves, many MTS engineers and many MTS sales reps did not understand how this complex component works, despite having read company training materials and on-line tutorials. Servo valves have complex geometries and understanding their operation comes from knowledge of the spatial relations between internal features. This is the same learning paradigm required for understanding how the human body works, therefore an active learning coloring book approach, successful in anatomy education, was a logical approach. Two pilot coloring book workshops were held for MTS engineers, one in 2006 and one in 2007. The first had over 80 attendees. The outline drawings for the valve used in the pilot workshops were incomplete and sometimes caused confusion. A UMN undergraduate developed a Pro/E solid model rendering of a complete valve from which sections can be taken and printed as drawings for the book.





5. Other Relevant Work
None.

6. Plans for Next Year
Continue development of the servo valve coloring book with the goal of creating a bound volume similar in style to one section of the "Anatomy Coloring Book." Tasks include refinement of the Pro/E model, selection of the final drawing set, generation of accompanying text and booklet production. A draft servo valve coloring booklet will be pilot tested by CCEFP graduate students and by engineers from CCEFP member companies. Long range plan is to produce a series of booklets with the next covering the variable swash plate pump.

7. Expected Milestones and Deliverables
Drawing set selected (March 2008). Text completed (April 2008). Draft booklet printed (May 2008). Booklet piloted tested (Summer 2008). Booklet revised and disseminated (October 2008).

8. Member Company Benefits
Receive training materials for complex fluid power topics.

9. Project Team

Project Leader:	Roz Dolid, MTS
Other Personnel:	Will Durfee, UMN
Post Doc(s):	
Graduate Students:	
Undergraduate Students:	Nathan Millner
Industrial Partner(s):	MTS

Project D.6 CCEFP Webcasts

1. Statement of Project Goals

Every two weeks, the CCEFP hosts a webcast with two to three presenters, each describing their research project. The webcasts are open to all CCEFP students and faculty and to all CCEFP member companies. The webcasts are the primary means for internal communication about research advances. The webcasts are presentation based, with audio and visual capabilities. The audience is welcome to pose questions by way of the chat feature during the question and answer time following each presentation. Each webcast is recorded and archived for retrieval and is posted and available on the Center web site.

2. Project's Role in Support of the Strategic Plan

This program aligns well with the mission, vision and strategy of the Center for Compact and Efficient Fluid Power by creating awareness of the research and education that is currently active within the Center. This program fosters growth among the graduate and undergraduate students in the Center as well as provides a means for information dissemination and recruiting opportunities for our industrial members.

3. Fundamental Challenges and Solutions

Serving as a multi-university research center continues to offer its many challenges. The Center evaluated the options for software and costs associated with the web casts and selected Adobe Presentation software in which the University of Minnesota has a site license to use. There was a steep learning curve in using this software and while the initial stages of the webcasts were cumbersome, the curve has now leveled off and the presentations run smoothly. A challenge that still exists is to offer a verbal feedback option, and the Center continues to evaluate those features.

4. Achievements to Date

The Center initiated the CCEFP Web casts in June 2007 with a bi-weekly schedule of presentations given by the graduate students working on their respective project. Each web cast represented students from different campuses and projects. The web cast schedule concluded just before the Thanksgiving holiday and will resume mid-January 2008. The Center distributed a survey which generated many suggestions and helpful comments in planning for the next round of web casts. The Center also used this as an opportunity to have a State of the CCEFP address by the Center Director as well as a Intellectual Property discussion lead by the Industrial Liaison Officer.

5. Other Relevant Work

N/A

6. Plans for Next Year

The Center will continue to host the webcasts which have been a success and popular among the Center and its Industrial Members.

7. Expected Milestones and Deliverables

Webcasts will resume in January 2008 and will continue with intermittent breaks appropriate to the academic year.

8. Member Company Benefits

Industrial members have the opportunity to have monthly updates on research conducted within the Center. All participants are able to become familiar with the staff, faculty, researchers and graduate students within the Center. It is an excellent recruiting tool.

9. Research Team

Project Leader: Alyssa A. Burger, Education Outreach Director

Other Personnel:

Post Doc(s):

Graduate Students: SLC President and Vice President

Undergraduate Students:

Industrial Partner(s):

Project E.1 GIDAA Science Camp

1. Statement of Project Goals

Fond du Lac Tribal and Community College, together with the National Center for Earth-Surface Dynamics, organizes camps known as *gidakiimanaaniwigamig* (Our Earth Lodge, in Anishinaabe), for students in 3rd through 10th grade. Offered during the summer as well as after school and weekends (on a quarterly basis), these camps provide students with a mix of lab science and field science experiences. Program highlights include an introduction to the scientific method and a focus on Native American culture .The CCEFP will co-host a *gidakiimanaaniwigamig* Science Camp in Cloquet, Minnesota four times each year.

2. Project's Role in Support of the Strategic Plan

An essential part of the CCEFP strategic plan is to promote diversity in science, technology, engineering, and math (STEM) fields. We do this within the center by recruiting undergraduate research interns, graduate students, and researchers from diverse backgrounds. We also promote diversity in the sciences in general as part of our overall diversity mission. This program answers that goal by working to interest and prepare Native American youths for STEM careers.

3. Fundamental Challenges and Solutions

At this point the program is well established, with a solid core group of teachers, curriculum aligned to national standards, visits to the camp by research scientists from the University of Minnesota and other institutions. The most critical challenges we faces as we move forward are 1) to establish programs at the undergraduate level at the University of Minnesota and FDLTCC that will meet the needs of our students as they graduate from high-school and transition into their undergraduate program, 2) to maintain and extend the partnership we have with other institutions that enrich our program, 3) to continue working with national and state standards as we develop our curriculum for the next years. We face these challenges by utilizing the *gidakiimanaaniwigamig* Circle of Learning which promotes good communication between all partners and participants in the program by mediating between the at times contradictory goals and visions of our stakeholders to find the shared goals that drive our strategic plan.

4. Achievements to Date

Four camps were held in 2007 in conjunctions with the seasons. CCEFP presented modules at the camps, leading the students in activities on the subject of hydraulic and pneumatics and principles of physics. We have started a Robot Team at FDLTCC with gidaa students making up the team. Students will participate in this year's FIRST Robotics competition. We piloted our first Lego Camp with students in grades 3-6 in the summer of 2007. Although we were forced to disband early due to electrical problems at the gidakiimanaaniwigamig house,

5. Other Relevant Work

Partners in the gidakiimanaaniwigamig program are working in conjunction with the University of Minnesota-led North Star Louis Stokes Alliance for Minority Participation to create a Minnesota state alliance of American Indian Science and Engineering Society student chapters. The Northstar LSAMP is an NSF-funded alliance of Minnesota colleges and universities which promotes diversity in STEM fields by increasing the number of undergraduates graduating with 4-year STEM degrees.

6. Plans for Next Year

We plan to continue the program next year with 4 camps; a regional science fair; the robot team, and a Lego Camp.

7. Expected Milestones and Deliverables

- 90 students per year participate in the camps and related programs.
- Documented improvement in grades and test scores for students in program.
- Majority of participants attend college, with substantial fraction majoring in science, math, engineering or technology.

8. Member Company Benefits

Several students from the gidakiimanaaniwigamig program have begun taking classes at the FDLTCC as part of the Minnesota Post-secondary Education Option, which allows students to take college courses without charge while still in high school. These students will begin transferring to 4-year programs. We also have introduced our center to students who are current undergraduates at FDLTCC. These students will be encouraged to job-shadow at local corporations as part of the Northstar Alliance for Minority Participation. We expect this program will help us match students to our member companies for internships as they begin transferring into 4-year programs.

9. Research Team

Project Leader:	Alyssa A. Burger, Education Outreach Director
Other Personnel:	*Holly Pellerin, Camp Coordinator, Diana Dalbotten, Diversity Director, National Center for Earth-surface Dynamics*
Post Doc(s):	
Graduate Students:	
Undergraduate Students:	
Industrial Partner(s):	

Project E.2 LEGO Camp

1. Statement of Project Goals

Fond du Lac Tribal and Community College, located in Cloquet, MN, offers a Lego Camp program intended to introduce STEM-related initiatives and post-secondary options to middle and high school students. Using Lego Dacta equipment, students are instructed in small machines, mechanical and structural engineering, and robotics. The CCEFP will host a fluid power Lego camp one weekend per month during the academic year and two separate camps during the summer introducing students to basic fluid power technology. Beginning in the academic year of 2008, in conjunction with the Native FIRST team, the Lego Camp will be offered during one Saturday per month for an academic year. Middle school students participating in the Lego Camp will be mentored by high school students of the FIRST Team.

2. Project's Role in Support of the Strategic Plan

An essential part of the CCEFP strategic plan is to promote diversity in science, technology, engineering, and math (STEM) fields. We do this within the Center by recruiting undergraduate research interns, graduate students, and researchers from diverse backgrounds. We also promote diversity in the sciences in general as part of our overall diversity mission. This program answers that goal by working to interest and prepare Native American youths for STEM careers.

3. Fundamental Challenges and Solutions

Facilities have created a challenge for this camp as the Fond du Lac Tribal and Community College campus is currently under renovation. To build and host a camp of approximately 40 students, it is imperative to have a space able to accommodate the students, staff and equipment. In summer 2007 the Lego camp started the third week of July, but had to be postponed due to facilities renovations. Beginning in the academic year of 2008, in conjunction with the Native FIRST team, the Lego Camp will be offered during one Saturday per month for an academic year. Middle school students participating in the Lego Camp will be mentored by high school students of the FIRST Team.

4. Achievements to Date

The equipment for the Fluid Power Lego Camp has been purchased.

5. Other Relevant Work

This project is closely aligned with several of the Center's initiatives with Fond du Lac Tribal and Community College and the local area schools in Cloquet, Minnesota that continue to foster and mentor the K-14 students of the reservation as well as create programs to bridge middle school to high school to college. The high students who belong to the Native FIRST team will serve as mentors to the GIDAA Science Camp and the Fluid Power Lego Camp. This is a very important recipe in making these programs successful is repetition, relationships, trust and a support structure within the community as well as with the Center for Compact and Effieient Fluid Power, the National Center for Earth-surface Dynamics, the Northstar LSAMP, the University of Minnesota and the Fond du Lac Tribal and Community College.

6. Plans for Next Year

To build and host a camp of approximately 40 students, it is imperative to have a space able to accommodate the students, staff and equipment. Beginning in the academic year of 2008, in conjunction with the Native FIRST team, the Lego Camp will be offered during one Saturday per month for an academic year. Middle school students participating in the Lego Camp will be mentored by high school students of the FIRST Team.

7. Expected Milestones and Deliverables

The conclusion of the FIRST Competition will kickoff the Lego Camp, summer 2008 the Center will host two Lego Camps, according to age and number of students who wish to participate. The camp will continue into the next academic year and will be an excellent lead into the 2009 Native FIRST Team as the student mentors from the Lego Camp will be the participants of the FIRST Team.

8. Member Company Benefits

Several students from the gidakiimanaaniwigamig program have begun taking classes at the FDLTCC as part of the Minnesota Post-secondary Education Option, which allows students to take college courses without charge while still in high school. These students will begin transferring to 4-year programs. We also have introduced our center to students who are current undergraduates at FDLTCC. These students will be encouraged to job-shadow at local corporations as part of the Northstar Alliance for Minority Participation. We expect this program will help us match students to our member companies for internships as they begin transferring into 4-year programs.

9. Research Team

Project Leader:	Alyssa A. Burger, Education Outreach Director
Other Personnel:	*Holly Pellerin, Camp Coordinator*
Post Doc(s):	
Graduate Students:	
Undergraduate Students:	
Industrial Partner(s):	

Project E.2.1 Native FIRST Robotics Team

1. Statement of Project Goals

FIRST stands for "For the Inspiration and Recognition of Science and Technology" (www.usfirst.org). The Center for Compact and Efficient Fluid Power and the University of Minnesota with support from the Fond du Lac Tribal and Community College, located in Cloquet, MN, has initiated a rookie FIRST Robotics team of 20 high students from the Fond du Lac Indian Reservation community. This team will serve as the areas first robotics team to enter the FIRST Robotics competition. The Center will continue to mentor students and provide funding opportunities that will assist in the development of the STEM initiatives within the American Indian community. The goal of this team is exposure to the exciting world of robotics. This team has received a $10,000 grant from the University of Minnesota Foundation to join the competition.

2. Project's Role in Support of the Strategic Plan

An essential part of the CCEFP strategic plan is to promote diversity in science, technology, engineering, and math (STEM) fields. We do this within the Center by recruiting undergraduate research interns, graduate students, and researchers from diverse backgrounds. We also promote diversity in the sciences in general as part of our overall diversity mission. This program answers that goal by working to interest and prepare Native American youths for STEM careers.

3. Fundamental Challenges and Solutions

The FIRST Robotics competition is a 6-week challenge. The FIRST mission is to "create a world where science and technology are celebrated … where young people dream of becoming science and technology heroes". This Native's team challenges and solutions are distance and proximity to the Twin Cities area and the mentorablility the Center is able to provide. The team has many commitments from local area mentors including teachers, parents, and the Center will be providing resources to the Team to help them achieve their goals. This team is new to the competition, the learning curve is steep and the challenge is meant to be stimulate minds, creativity and teamwork.

4. Achievements to Date

The TEAM has received a grant from the University of Minnesota foundation to cover the initial costs to join the competition. Local fundraising continues as the Team needs to support for travel to and from the robot building site and competition events. The team has been formed. Mentors and advisors have been identified. The FIRST Robotics Competition kicks off on Saturday, January 5, 2008 where all teams will receive their instructions and the kit. The Native team will be with Center faculty and industry mentors following the kickoff to brainstorm on robot ideas, cultivate relationships and have a lesson on fluid power and the ability to use the pneumatic parts included with the FIRST kit.

5. Other Relevant Work

This project is closely aligned with several of the Center's initiatives with Fond du Lac Tribal and Community College and the local area schools in Cloquet, Minnesota that continue to foster and mentor the K-14 students of the reservation as well as create programs to bridge middle school to high school to college. The high students who belong to the Native FIRST team will

serve as mentors to the GIDAA Science Camp and the Fluid Power Lego Camp. This is a very important recipe in making these programs successful is repetition, relationships, trust and a support structure within the community as well as with the Center for Compact and Effieient Fluid Power, the National Center for Earth-surface Dynamics, the Northstar LSAMP, the University of Minnesota and the Fond du Lac Tribal and Community College.

6. Plans for Next Year

Following the end of the 2008 FIRST competition, the Team will evaluate its strengths and weaknesses. Fundraising efforts will begin. Recruiting efforts to replace graduating students and introduce new students to the Team. The Center will identify industry members who may be interested in mentoring or advising this Team. Plans for a second Native team have been initiated and the process to recruit will be the same as the listed, however the first team will serve as a mentor to the second team.

7. Expected Milestones and Deliverables

In 2007 the team was initiated and created, in 2008 the team will compete in the Regional competition in March of 2008 at the University of Minnesota. The national competition occurs in April 2008 in Atlanta, GA where the Center would be pleased to find a robot from the Native team at the National competition.

8. Member Company Benefits

The Center welcomes participation from Industrial members in the form of sponsoring, hosting or mentoring a FIRST team. In addition to the Center's own team, the Center has bridged connections between industrial members and other local FIRST teams.

9. Research Team

Project Leader: Alyssa A. Burger, Education Outreach Director

Other Personnel: *Holly Pellerin, Camp Coordinator, Mike Gust, ILO*

Post Doc(s):

Graduate Students:

Undergraduate Students:

Industrial Partner(s):

Project E.5 AISES Activity Support

1. Statement of Project Goals

The University of Minnesota and the Fond du Lac Tribal and Community College AISES Chapters; the Center for Compact and Efficient Fluid Power; The National Center for Earth-surface Dynamics, and the Institute of Technology's Academic Programs for Excellence in Science and Engineering (APEXES) would like to submit this proposal to The Northstar LSAMP Small Grants Program for funds to hold the initial meeting of the giiwed'anang (Northstar) AISES Alliance.

This alliance aims to form a partnership between the AISES chapters in Minnesota and to provide tools and resources to assist the students that participate in the state of Minnesota's AISES chapters. The goals of the giiwed'anang (Northstar) Alliance is to form relationships between Minnesota AISES chapters, provide educational opportunities, academic guidance, open research doors, bridge the gap between high school, pre- and post-secondary education and industry in Science, Technology, Engineering and Mathematics (STEM). By networking with Minnesota corporations and educational institutions, this alliance fosters fundraising capabilities and professional support, and by doing so will increase the number of AISES chapters in Minnesota for a larger representation of American Indians in STEM fields and disciplines.

Goals of the giiwed'anang (Northstar) AISES Alliance:

- To bring together AISES Chapters from across Minnesota
- To support and strengthen the MN AISES chapters and increase enrollment
- To support fledgling or new chapters at MN institutions
- To allow students to network with other students interested in the sciences
- To increase student interest in STEM careers
- To increase student interest in pursuing school beyond the two-year degree
- To increase student interest in graduate school
- To increase student ability to succeed in STEM academics by reinforcing mathematics, physics, chemistry, and other core courses.
- Help students learn more about potential STEM careers.
- To increase the number of American Indians who are active participants in the Northstar LSAMP, so that American Indians are reaping the benefits of the Alliance
- To provide opportunities for students to interact with scientists, both corporate and academic, and to find mentors
- To provide support for students as they transfer from a two-year to a four-year institution
- To provide support for students who wish to go to graduate school
- To provide internships for students who want to work in a non-academic STEM careers
- Increase the number of American Indian students in Center internships, Research Experiences for Undergraduates, and graduate programs
- To provide ideas and resources for fundraising for AISES chapters
- To support outreach activities of AISES chapters
- To bridge high school, college and professional AISES chapters.

Activities of the giiwed'anang (Northstar) AISES Alliance:

- Two retreats during the academic year, one summer retreat
- President's Dinners at local, regional and national AISES events

- Lectures by researchers, research highlights
- Talks by industry people
- Support for transfer from admissions, financial aid
- Corporate mentors
- Internships
- Research experiences
- Help in identifying financial aid; fellowships
- Advising, networking or mentoring on campus
- Participation in LSAMP activities in allied schools
- Support to attend national conferences
-

2. Project's Role in Support of the Strategic Plan

An essential part of the CCEFP strategic plan is to promote diversity in science, technology, engineering, and math (STEM) fields. We do this within the center by recruiting undergraduate research interns, graduate students, and researchers from diverse backgrounds. We also promote diversity in the sciences in general as part of our overall diversity mission. This program answers that goal by working to interest and prepare Native American youths for STEM careers.

3. Fundamental Challenges and Solutions

The Center is initiating this effort with formal alliances and collaborations from several other National Science Foundation funded organizations and the University of Minnesota as well as the professional and national AISES Chapters. This program is a large endeavor, however the biggest challenge is locating the students around Minnesota that at Native American students in STEM fields. The Center has identified several four-year colleges and universities that do not have an active AISES chapter due to lack of participation or lack of chapter activity. This program will require dedication and constant attention, but the benefits are so great it is a necessary alliance to form within the geographically opportunistic state of Minnesota. The Center acknowledges the challenges this alliances faces but intends to earn by-in from the students of the AISES chapters and eventually turn it into a revolving, self-supporting program due to the benefits to the students and their desire to see their brothers and sisters to have opportunities within academia, research and industry.

4. Achievements to Date

The Center has formed the committee of the Alliance. The Alliance has submitted a small grants proposal to the Northstar LSAMP seeking funding for the first retreat to be held February 1-3, 2008 at the Cloquet Forestry Center, Cloquet, MN.

5. Other Relevant Work

This project is closely aligned with several of the Center's initiatives with Fond du Lac Tribal and Community College and the local area schools in Cloquet, Minnesota that continue to foster and mentor the K-14 students of the reservation as well as create programs to bridge middle school to high school to college. The high students who belong to the Native FIRST team will serve as mentors to the GIDAA Science Camp and the Fluid Power Lego Camp. This is a very important recipe in making these programs successful is repetition, relationships, trust and a support structure within the community as well as with the Center for Compact and Effieient

Fluid Power, the National Center for Earth-surface Dynamics, the Northstar LSAMP, the University of Minnesota and the Fond du Lac Tribal and Community College.

6. Plans for Next Year

Continue to grow and strength this Alliance. Seek more funding sources such as the AISES Professional Society and the AISES National Society. Continue to foster and mentor the students who participate in this Alliance. This Alliance will hold a maximum of three retreats per year.

7. Expected Milestones and Deliverables

Through this alliance we intend on increasing the number of students in AISES Chapters in Minnesota as well as increase the number of chapters. We expect to see an increase in transfer from 2-year to 4-year institutions and see the number of students participating in LSAMP increase to a represent a great number of Native American students. Milestones this Allaince aims to achieve is to hold two retreats in 2008, to build upon the first retreat in February 2008 and to increase the participation within one year.

8. Member Company Benefits

Several students from the gidakiimanaaniwigamig program have begun taking classes at the FDLTCC as part of the Minnesota Post-secondary Education Option, which allows students to take college courses without charge while still in high school. These students will begin transferring to 4-year programs. We also have introduced our center to students who are current undergraduates at FDLTCC. These students will be encouraged to job-shadow at local corporations as part of the Northstar Alliance for Minority Participation. We expect this program will help us match students to our member companies for internships as they begin transferring into 4-year programs.

9. Research Team

Project Leader:	Alyssa A. Burger, Education Outreach Director
Other Personnel:	*Holly Pellerin, Diana Dalbotten (NCED), Richard Pollard (APEXES)*
Post Doc(s):	
Graduate Students:	
Undergraduate Students:	AISES Participants: April Bebault (FDLTCC) Ben Kenote, Zuri Bender (U of MN)
Industrial Partner(s):	

Project E.6 Minority Recruiting

1. Statement of Project Goals
Recruiting for REU students, RET teachers, FIRST teams, prospective graduate students, faculty, industry interns, industry jobs is a function of the center. To diversify the face of fluid power it is essential that women and underrepresented minorities be actively recruited for positions. A particular emphasis for the center is recruiting Native Americans. This project conducts minority recruiting functions and coordinates minority recruiting throughout the center and works with affiliated LSAMP and AGEP institutions.

2. Project's Role in Support of the Strategic Plan
An essential part of the CCEFP strategic plan is to promote diversity in science, technology, engineering, and math (STEM) fields. We do this within the Center by recruiting undergraduate research interns, graduate students, and researchers from diverse backgrounds. We also promote diversity in the sciences in general as part of our overall diversity mission. This program answers that goal by working to interest and prepare Native American youths for STEM careers.

3. Fundamental Challenges and Solutions
Building a network to recruit a diverse population of students. The CCEFP has been actively building relationships, networks by attending research conference as an exhibitor, introducing the Center's programs to other program similar in nature, participating in committees and task forces that aim to improving the diverse makeup of students in the STEM fields.

4. Achievements to Date
The CCEFP has been represented at the National Science Foundations Educator's Awardee's Conference, The HBCU-UP Research Conference, SACNAS, AISES National Conference, and will be an exhibitor at the Florida LSAMP Research Conference in February 2008.

5. Other Relevant Work
The Northstar AISES Alliance (CCEFP Project E.5)

6. Plans for Next Year
To continue to drive the building of our recruiting network and form relationships with other staff and faculty in similar roles at pre-determined institutions representing women and minorities in the STEM fields.

7. Expected Milestones and Deliverables
We expect to see an increase in women and a diverse representation of underrepresented minorities in our REU programs, RET programs, graduate students, faculty and staff. We recognize that the number of women in the Center is below average for other ERC's but is actually greater than the national average for women in the Mechanical Engineering field but we intend to promote our programs to women to increase the number of women in fluid power, in particular.

8. Member Company Benefits

Recruited students will be encouraged further their education by participating in REU programs or internships within our fluid power member companies as well as an opportunity for the seven schools to use this as a graduate school recruiting opportunity.

9. Research Team

Project Leader: Alyssa A. Burger, Education Outreach Director

Other Personnel:

Post Doc(s):

Graduate Students:

Undergraduate Students:

Industrial Partner(s):

F.1 Evaluation of the Education and Outreach Program

1. Statement of Project Goals
A comprehensive and rigorous assessment of individual education and outreach projects and the education and outreach program as a whole to determine if projects are meeting their goals and if the program is true to its mission and moving towards its vision.

2. Project's Role in Support of the Strategic Plan
The education and outreach program has a mission and vision statement, and a strategic plan to reach the vision. Regular assessment is required to determine if projects are effective, if the project mix is appropriate and if the program is achieving its desired impact.

3. Fundamental Challenges and Solutions
Challenge: creating a formal assessment plan and process that is effective, informative while at the same time is not burdensome. Solution: partner with education evaluation experts to develop formative and summative assessment methods.

4. Achievements to Date
A summary plan for evaluating projects has been created. Refinement and implementation of the plan is behind schedule as the original center assessment team was not able to participate in significant assessment activities. A new assessment team, based in the UMN College of Education and Human Development, is being formed to provide the expertise needed for proper assessment. In November 2007, every education and outreach project was formally evaluated with the same process used for reviewing research projects. Project leaders prepared a four-up slide with project overview, milestones, progress and next steps. In a webcast-conference call, leaders presented their project to a review panel and responded to questions. The review panel consisted of CCEFP leaders and members of the Education and Industry Advisory Boards. Review panel members privately voted each project a red, yellow or green and wrote comments. Review results were submitted to project leaders with a request for response if the project was voted yellow or red. This review will occur three times each year. Projects repeatedly voted red will be considered for elimination by the center Executive Committee.

5. Other Relevant Work
None

6. Plans for Next Year
New assessment team works with center education and outreach leadership to develop specific assessment strategies, tactics and protocols for every education and outreach project. Assessment plans are implemented and data analyzed to determine center impact.

7. Expected Milestones and Deliverables
Assessment team named (January 2008). Assessment protocols for every education and outreach project (April 2008). Education and outreach assessment report (October 2008).

8. Member Company Benefits

Assessment activities ensure that education projects are meeting overall goal of increasing awareness of fluid power and of training the next generation of fluid power leaders.

9. Project Team

Project Leader: TBA (assessment expert)

Other Personnel: W. Durfee (UMN), L. Western

Project F.2 CCEFP Alumni Society

1. Statement of Project Goals
All CCEFP participants, including faculty, graduate students, post-docs, undergraduate research students, REUs, RETs and special program participants automatically become members of the CCEFP Alumni Society and receive periodic newsletters and requests for information on current status. Membership starts a CCEFP information packate given to every participant when they start their formal affiliation with the CCEFP. An exit to measure experiences and to gather follow up contact information is given when the participant completes their formal CCEFP affiliation. The Alumni Society database will be used for long-term follow ups when evaluating program impact.

2. Project's Role in Support of the Strategic Plan
An essential part of the CCEFP strategic plan is to promote diversity in science, technology, engineering, and math (STEM) fields.

3. Fundamental Challenges and Solutions
N/A

4. Achievements to Date
The Center has built its internal database.

5. Other Relevant Work
In conjunction with the private side of the Center web site and the CCEFP Resume Bank (See Project D.2).

6. Plans for Next Year
To create the Center's welcome packet and to introduce the Alumni Society to the Center. To have an interactive database built by June 2008.

7. Expected Milestones and Deliverables
To have an interactive database built and launched by 2008.

8. Member Company Benefits

9. Research Team

Project Leader:	Alyssa A. Burger, Education Outreach Director
Graduate Students:	SLC Representative

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ASSOCIATED PROJECT ABSTRACTS

THRUST 1 –EFFICIENCY

Efficiency of Pumps and Motors –Monika Ivanytysnova, Purdue University
Sponsor: Parker Hannifen

Abstract unavailable due to confidentiality of project

Improvements of Pumps and Motors –Monika Ivanytysnova, Purdue University
Sponsor: Sauer Danfoss

Abstract unavailable due to confidentiality of project

Integrated PTQ Sensing for Fluid Power Systems –Kim Stelson, University of Minnesota
Sponsor: National Fluid Power Association

* NOTE: Funding ended in fiscal year 1.

The purpose of this project is to develop and demonstrate integrated PTQ (pressure, temperature and flow rate) sensing for fluid power systems. The approach will use the latest developments in solid state electronics to create sensors that are simple, accurate, rugged, compact and inexpensive. Because of their low cost, these sensors can be embedded into high-volume commercial products to implement advanced monitoring and control approaches. The sensors proposed here will be tailored and calibrated to the particular flow situation within the component or system. The approach uses the existing product geometry and does not require the introduction of loss inducing elements such as orifices to measure flow rate.

Self Contained Underwater Power Generation and Distribution Unit –Andrew Alleyne, University of Illinois at Urbana-Champaign
Sponsor: Army Research Office

* NOTE: Funding ended in fiscal year 1.

The proposed research investigates the dynamic performance of a power generation and distribution unit. This system will provide support for manned underwater tasks such as augmenting human performance via an exoskeleton attached to a person. The key questions addressed by this research are how best to generate and distribute power, in a mobile human-scaled system, such that operational objectives can be achieved while maximizing the useful operational range. Associated questions focus on the best methods for storing energy and converting it to useful power in an underwater environment. To answer the questions put forward, an analytical investigation is performed in conjunction with simulations to find out the best methods for optimally storing and converting power, then dynamically distributing it to actively varying loads. The decision making algorithms that develop these optimal methods should be able to handle varying system configurations and should provide acceptable performance over a wide operational range.

Software Enabled Variable Displacement Pump – Perry Li, University of Minnesota
Sponsor: NSF

A mechatronics approach is proposed to redesign variable displacement pumps. Current variable displacement pumps are not compact and do not have high control performance. Compact and high performance variable displacement pumps can significantly improve energy efficiency and address new applications. By combining a compact fixed displacement pump and a high speed pulse width modulated (PWM) on/off valve, a highly controllable and versatile, compact variable displacement pump, capable of achieving many new software enabled feature will be possible. For example, the pump can be used to directly control of hydraulic actuators, without using throttling valves, thus significantly improving efficiency and reducing the system complexity. The proposed concept is inspired by the success of switched mode converters in power electronics. The feasibility of this approach relies on the availability of on/off valve capable of very high PWM frequency, and the ability to control PWM systems. To this end, a combined hardware and control approach will be taken. Approach includes the design of an innovative high frequency on/off valve based on continuous rotary valve motion; as well as design of control that takes into account finite PWM frequency.

Transmission Noise and Pump and Motor Design –Monika Ivantysynova, Purdue
Sponsor: Borg Warner
* NOTE: Funding ended in fiscal year 1.

Abstract unavailable due to confidentiality of project

THRUST 2 – COMPACTNESS

Anthropomorphic Transhumeral Prosthesis for Revolutionizing Prosthetics - Michael Goldfarb, Vanderbilt University
Sponsor: Defense Advanced Research Projects Agency

The objective of this work is to develop a highly anthropomorphic upper extremity prosthesis, which is to be hardwired into the human nervous system. In order to achieve human-like power density and output impedance in the limb, the prosthesis will incorporate chemo-fluidic liquid-fueled actuation, as developed by the investigators.

Architectural Models for Fluid Power Systems –Chris Paredis, Georgia Institute of Technology
Sponsor: John Deere, Inc.

The goal of this project is to develop the capability to represent continuous dynamics models in the OMG SysML language, and to demonstrate this capability in a case study of a hydraulically actuated excavator. In the context of model-based systems design, it is important to be able to represent all aspects of a system in a formal, unambiguous and computer-interpretable fashion. SysML provides a foundation for achieving this. However, SysML mainly supports the modeling of the system behavior at a very high level, in terms of a logical architecture. To formulate design tradeoffs involving the physical behavior of the

system, it is important that we extend these high-level logical models towards physics-based, continuous system dynamics models.

Our approach for achieving this goal is to build on the formal semantics in the Modelica modeling language and establish a formal mapping between Modelica constructs and SysML constructs. Through this mapping, Modelica's ability to represent system dynamics in terms of hybrid discrete-event and differential algebraic equation models is combined with SysML's ability to represent the system in terms of information models of the physical, functional, logical and operational architectures. We will define a detailed language mapping, develop translators between Modelica and SysML and illustrate these capabilities through a case study ofa hydraulically actuated excavator.

Self Contained Underwater Power Generation and Distribution Unit – Andrew Alleyne, University of Illinois at Urbana-Champaign
Sponsor: Army Research Office
* NOTE: Funding ended in fiscal year 1.

The proposed research investigates the dynamic performance of a power generation and distribution unit. This system will provide support for manned underwater tasks such as augmenting human performance via an exoskeleton attached to a person. The key questions addressed by this research are how best to generate and distribute power, in a mobile human-scaled system, such that operational objectives can be achieved while maximizing the useful operational range. Associated questions focus on the best methods for storing energy and converting it to useful power in an underwater environment. To answer the questions put forward, an analytical investigation is performed in conjunction with simulations to find out the best methods for optimally storing and converting power, then dynamically distributing it to actively varying loads. The decision making algorithms that develop these optimal methods should be able to handle varying system configurations and should provide acceptable performance over a wide operational range.

THRUST 3 – EFFECTIVENESS

Control for the INCOVA System – Wayne Book, Georgia Institute of Technology
Sponsor: HUSCO International and GT internal (HUSCO/Ramirez endowment for Fluid Power and Motion Control)

Modern control design is commonly accompanied by the challenge of dealing with complex systems or plants that combine nonlinear behavior, state constraints, parametric uncertainty, and time varying characteristics. Because of these features, such systems are often difficult to model using first principles, and as a result, the task of designing a suitable controller becomes difficult. One simple approach to circumvent this problem is to use a calibration map. The purpose of the map is to translate desired outputs or desired states into appropriate inputs for the plant. Usually, the map is obtained from the inversion of the steady state characteristics of the plant, and is stored in a lookup table. The output of the lookup table is then employed for feed forward compensation in open-loop or closed-loop control. However,

when the plant is time varying, the resulting control performance is affected by the fact that the calibration becomes less reliable as time progresses.

In an effort to present a new alternative, this research develops a general theoretical framework for online auto-calibration and control of general nonlinear systems. More specifically, the inverse input-state mapping of the plant is learned while in operation (online). This is done by employing a simple neural network structure that emulates an adaptive lookup table. In this approach, the inverse mapping is learned from the current and past states and it is refined in a composite manner by employing input errors and state errors. The learned mapping is used simultaneously in the feed forward path to control the plant along the desired state trajectory. The performance of the plant subject to this novel controller is verified through simulations and experimental data. It is seen that good state tracking is achieved without requiring exact or detailed knowledge of the plant. The main requirements for the successful operation of the novel control approach are the knowledge of the order of the plant and some generic data to initialize the inverse mapping. This last requirement can be fulfilled from steady-state data.

The control theory developed herein is applied to a novel Electro-Hydraulic Poppet Valve (EHPV), which is currently controlled open-loop via an inverse calibration map. The EHPV.s are used in a Wheatstone bridge arrangement for motion control of hydraulic actuators. Such a configuration is preferred over the conventional use of spool valves due to the energy savings potential. It is shown in this dissertation that this method improves the value of using these types of valves for motion control in hydraulics. This is due to the combination of self-learning (auto-calibration) and better performance, which results in a more efficient operation of hydraulic equipment. Additionally, it is shown that the auto-calibration of the valves can be used for health monitoring of the same, which consequently improves their reliability, expedites maintenance downtime, and reduces maintenance costs.

Hardware in the Loop Simulation for Hydraulic System Development – Wayne Book, Georgia Institute of Technology
Sponsor: Husco International

The difficulty in simulating the complex dynamics of some fluid power components, coupled with the difficulty and cost of full scale testing behooves the use of hardware in the loop simulation. This concept can mean different things as different parts of the system are in hardware form and others are in software. For this project we provide 60 hp electric motors to power pumps for both the hydraulic supply and load. Computer simulation directs the supply motor to imitate the appropriate prime mover, (diesel engine) while the load motor imitates the load with possible over running behavior. The creation of this capability was initiated for testing control strategies for alternative metering strategies for arrangements of electro-hydraulic poppet valves. It provides the basis for also testing pump displacement controls and their interaction with haptic interfaces to human operators. In the latter application, a human operator will be commanding the operation of the system via an interface with enhanced haptic and augmented reality based on a graphic depiction of the machine which is being controlled. This is needed for Project 3A1.

Hydraulic Motor Wear Particle Analysis - Paul Michael, Milwaukee School of Engineering
Sponsor: Milwaukee School of Engineering Fluid Power Institute

Hydraulic motors convert the flow produced by a hydraulic pump into rotary motion. These motors are frequently used to propel skid steers, excavators, loaders, feller bunchers and other heavy equipment. While hydraulic pumps operate under relatively constant high-speed conditions, motors frequently come to a complete stop, particularly when equipment engages its payload. As a result, hydraulic motors operate under boundary lubrication conditions which can promote wear-particle generation. In this study we examine wear particles generated by hydraulic motors under low-speed, high-load conditions using direct-imaging laser particle analysis, ferrography and Atomic Force Microscopy. AFM analysis of wear particle morphology reveals nano-scale features. These results suggest that hydraulic motors reach steady-state wear conditions in a relatively short period of time.

Integrated Position Sensors for Fluid Actuators – Wayne Book, Georgia Institute of Technology
Sponsor: Sentrinsic, LLP

Position sensing is required for many advanced controllers which use position feedback to allow modification of the dynamic behavior. This project extends from a previous NSF project referred to as Digital Clay for which an integrated position sensor was developed. A startup company, Sentrinsic, LLC, was created by students on that project to capitalize on that development. Georgia Tech is working with Sentrinsic to deploy that sensor in high pressure pneumatics and ultimately hydraulics. The sensor is being deployed on the robotic rescue crawler of Test Bed 4. The sensor consists of a resistive film embedded in a layer of the composite cylinder and capacitively coupled to the piston, giving the position of piston relative to the cylinder.

Modeling Fluid Actuators interacting with Flexible Robots –=Wayne Book, Georgia Institute of Technology
Sponsor: Georgia Tech's HUSCO/Ramirez endowment for Fluid Power and Motion Control
* NOTE: Funding ended in fiscal year 1.

Flexible link robots are challenging to model due to the distributed nature of their flexibility. Transfer matrices overcome many of these obstacles. When the robot is hydraulically powered the actuation system must be modeled in transfer matrices as well. This project was completed by Dr. Ryan Kraus who completed his Ph.D. in 2006.

The Haptic Backhoe – Wayne Book, Georgia Institute of Technology
Sponsor: John Deere, Inc.

The traditional backhoe hand controllers are not intuitive and lack haptic feedback. This has been addressed by a Ph.D. thesis funded primarily by gifts from John Deere. Matthew Kontz completed his thesis in 2007. The work has been continued by an incoming student, Heather Humphreys, who is looking at further improvements possible for the backhoe. While the control uses fairly conventional spool valves for actuation, it does provide experience in achieving and verifying improved performance at excavation tasks, similar to that that will be used in Test Bed 1, the excavator. The excavator will be controlled at least partially using displacement control, that is varying the fluid provided by the excavator's pump.

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PUBLICATIONS

THRUST 1 - EFFICIENCY

Hencey, B. and A. Alleyne, “A KYP Lemma for LMI Regions.” IEEE Transactions on Automatic Control, 52 (10): 1926-1930 (2007).

Hencey, B. and A. Alleyne, “A Robust Controller Interpolation Design Technique.” 2007 American Controls Conference, New York, New York, 5347-5353 (2007).

Hencey, B. and A. Alleyne, “"A Static Anti-Windup Compensator Design Technique for Robust Regional Pole Placement." Proceedings of the 2006 ASME IMECE, Chicago, Illinois, IMECE2006-14653 (2006).

Huang, C. and M. Ivantysynova, “An Advanced Gap Flow Model Considering Piston Micro Motion and Elastohydrodynamic Effect.” Proceedings of the 4th FPNI Ph.D. Symposium, Sarasota, Florida (2006).

Ivantysynova, M., C. Huang, and A. Japing, “Determination of Gap Surface Temperature Distribution in Axial Piston Machines.” Proceedings of the ASME International Mechanical Engineering Congress, Chicago, Illinois, IMECE2006-15249, (2006). *Best Paper Award*

Kumar, R., M. Ivantysynova, and K. Williams, “Study of Energetic Characteristics in Power Split Drives for on Highway Trucks and Wheel Loaders.” 2007 SAE International Commercial Vehicle Engineering Congress, Chicago, Illinois, SAE Technical Paper 2007-01-4193 (2007).

Michael, P., “Study Reveals Factors that Affect Particle Counting Accuracy.” Proceedings of Lubrication Excellence, Louisville, KY (2007).

Michael, P. Herzog, S. and Marougy T., "Determining Hydraulic Fluid Viscosity Requirements." Machinery Lubrication, 7(1):40-42 (2007).

Michael, P. Wanke, T. and McCambridge, M., "Additive and Base Oil Effects in Automatic Particle Counters." Journal of ASTM International 4(4):100941 (2007).

Montgomery, A. and A. Alleyne, “Optimizing the Efficiency of Electro-Hydraulic Powertrains.” Proceedings of the 2006 ASME IMECE, Chicago, Illinois, IMECE2006-16008 (2006).

Rannow, M., H. Tu, P. Y. Li, and T. R. Chase, “Software Enabled Variable Displacement Pumps –Experimental Studies,” ASME-IMECE, Chicago, Illinois, IMECE2006-14973 (2006).

Rannow, M. and P.Y. Li, “On/Off Valve Based Control of Linear Actuators with Ripple Cancellation.” Proceedings of the ASME-IMECE, Seattle, Washington, IMECE2007-42590 (2007).

Tu, H., M. Rannow, M. Wang, J. Van de Ven, P.Y. Li and T.R. Chase, "High Speed Rotary Pulse Width Modulated On/Off Valve." ASME-IMECE, Seattle, November, IMECE2007-42559 (2007).

Williamson, C. and M. Ivantysynova, "The Effect of Pump Efficiency on Displacement Controlled Actuator Systems." Proceedings of the 10th Scandinavian International Conference on Fluid Power, (SICFP'07), Tampere, Finland (2007).

Zimmermann, J., M. Pelosi, C. Williamson, and M. Ivantysynova, "Energy Consumption of an LS Excavator Hydraulic System." Proceedings of the ASME International Mechanical Engineering Congress, Seattle, Washington, IMECE2007-42267 (2007).

THRUST 2 - COMPACTNESS

Gulati, N. and E. J. Barth, "Dynamic Modeling of a Monopropellant-Based Chemofluidic Actuation System." ASME Journal of Dynamic Systems, Measurement, and Control, 129 (4): 435-445 (2007).

Johnson, T.A., J.M. Jobe, C.J.J. Paredis, and R. Burkhart, "Modeling Continuous System Dynamics in SysML." Proceedings of the 2007 ASME International Mechanical Engineering Congress and Exposition, Seattle, Washington (2007).

Li, Y., B. Hencey, and A. Alleyne, "Dimensional Analysis for Control for Planar Vehicle Dynamics." International Journal of Robust and Nonlinear Control, early view online version available (2007).

Li, P.Y., J.D. Van de Ven and C. Sancken, "Open Accumulator Approach for Compact Energy Storage." Proceedings of the ASME-IMECE, Seattle, Washington, IMECE2007-42580 (2007).

Malak, R.J. Jr. and C.J.J. Paredis, "Using Parameterized Pareto Sets to Model Design Concepts." Proceedings of the 2007 ASME International Mechanical Engineering Congress and Exposition, Seattle, Washington (2007).

Riofrío, J., and E. J. Barth, "A Free Piston Compressor as a Pneumatic Mobile Robot Power Supply: Design, Characterization and Experimental Operation." International Journal of Fluid Power, 8 (1): 17-28 (2007).

Riofrio, J.A. and E. J. Barth, "Design and Analysis of a Resonating Free Liquid-Piston Engine Compressor." Proceedings of the 2007 ASME International Mechanical Engineering Congress and Exposition (IMECE), Seattle, Washington, IMECE2007-42369 (2007).

Zhu, Y. and, E J. Barth, "Energy-Based Control of a Pneumatic Oscillator with Application to Energy Efficient Hopping Robots." 2006 ASME International Mechanical Engineering Congress and Exposition (IMECE), Chicago, Illinois, IMECE2006-15015 (2006).

THRUST 3 - EFFECTIVENESS

Delpish, R., X. Jiang, **E.** Park, and S. Udoka, "A User-Centered Design for the Rescue Robot with Fluid Power." Proceedings of the Industrial Engineering Research Conference, Nashville, Tennessee (2007).

Klop, R., K. Williams, D. Dyminski, and M. Ivantysynova, "A Simulation Study to Reduce Noise of Compact Power-Split-Drive Transmissions." Bath Workshop on Power Transmission and Motion Control PTMC 2007, Bath, United Kingdom (2007).

Kontz, M., M.C. Herrera, J.D. Huggins and W.J. Book, "Impedance Shaping for Improved Feel in Hydraulic Systems." Proceedings of 2007 ASME International Mechanical Engineering Congress and Exposition, Seattle, Washington, IMECE2007-41712 (2007).

Kontz, M.E., W.J. Book and J.G. Frankel, "Pressure Based Exogenous Force Estimation." Proceedings of the 2006 ASME International Mechanical Engineering Congress and Exposition, Chicago, Illinois, IMECE2006-14441 (2006).

Kontz, M. E. and W.J. Book, "Electronic Control of Pump Pressure for a Small Haptic Backhoe." International Journal of Fluid Power Research 8(2): 5-16 (2007).

Kontz, M. E. and W.J. Book, "Flow Control for Coordinated Motion and Haptic Feedback." International Journal of Fluid Power Research 8(3): (2007).

Krauss, R. and W.J. Book, "A Module for Modeling and Control Design of Flexible Robots." Computing in Science and Engineering (IEEE CS and AIP), 9 (3): 41-45, (2007).

Krauss, R. and W.J. Book, "A Python Software Module for Automated Identification of Systems Modeled with the Transfer Matrix Method," 2007 ASME International Mechanical Engineering Congress and Exposition, IMECE2007-42319, Seattle, Washington (2006).

Krauss, R., W.J. Book and O. Brüls, "Transfer Matrix Modeling of Hydraulically Actuated Flexible Robots." International Journal of Fluid Power Research 8(1):51-58 (2007).

Salant, R.F. and B. Yang, "Elastohydrodynamic Model of Reciprocating Hydraulic Seals," Proceedings of the ROTRIB 2007 International Tribology Conference, Bucharest, Romania (2007).

Salant, R.F. and B. Yang, "Elastohydrodynamic Model of a Reciprocating Hydraulic Rod Seal with a Double Lip." Proceedings of the BHRG 19th Intl. Conference on Fluid Sealing, Poitiers, France (2007).

Salant, R.F. and B. Yang, "Numerical Modeling of Reciprocating Hydraulic Rod Seals," Proceedings of the XIth International Conference on Seals and Sealing Technology, Kudowa Zdroj, Poland (2007).

Shenouda , A., "Anti-Cavitation Analysis in a Four-Valve Independent Metering Configuration Controlling a Hydraulic Cylinder." Proceedings of the Session 7, 4th Fluid Power Net Ph.D. Symposium, Sarasota, Florida (2006).

Yang, B. and R.F. Salant, "Numerical Model of a Reciprocating Rod Seal with a Secondary Lip," Proceedings of the 62nd Annual Meeting, STLE, Philadelphia, Pennsylvania (2007).

Yang, B. and R.F. Salant, "Numerical Model of a Tandem Reciprocating Hydraulic Rod Seal." Proceedings of the STLE/ASME International Joint Tribology Conference, San Diego, California (2007).

Zhu, H. and W.J. Book, "Active Shielding for a Novel Sensor." Proceedings of the 2007 ASME International Mechanical Engineering Congress and Exposition, Seattle, Washington, IMECE2007-42574 (2007).

Zhu, H., B. Paul, and W. J. Book, "Control Issues of Digital Clay – Massive Hydraulic Actuator Array for Man-Machine Communication." Proceedings of the 2006 ASME International Mechanical Engineering Congress and Exposition, Chicago, Illinois, IMECE2006-15340 (2006).

TEST BEDS

Shorter, K.A., J.D. Polk, K.S. Rosengren, and E.T. Hsiao-Wecksler, "Detecting Asymmetries in Braced and Unbraced Limbs." Proceedings of the 31st Annual Meeting of the American Society of Biomechanics, Stanford, California (2007).

Shorter, K.A, J.D. Polk, K.S. Rosengren, and E.T. Hsiao-Wecksler, "A New Method for Assessing Gait Symmetry." Proceedings of the 18th Meeting of the International Society of Posture and Gait Research, Burlington, Vermont (2007).

Andrew Alleyne
Department of Mechanical and Industrial Engineering
Coordinated Science Laboratory
University of Illinois at Urbana-Champaign

Professional Preparation

Princeton University	Mechanical Engineering	B.S.E., 1982
University of California	Mechanical Engineering	M.S., 1992
University of California	Mechanical Engineering	Ph.D., 1994

Appointments

2004-present	Professor, Department of Mechanical and Industrial Engineering, University of Illinois Urbana-Champaign
2004-present	Professor, Coordinated Science Laboratory, University of Illinois Urbana-Champaign
2002-present	Ralph M. and Catherine V. Fisher Professor of Engineering, University of Illinois Urbana-Champaign
2000-present	Academic Advisory Board, Quanser Inc, Toronto, CA
2000-2004	Associate Professor, Department of Mechanical and Industrial Engineering, University of Illinois Urbana-Champaign
1999-present	Consultant, Moog Inc, East Aurora, NY
1999-2000	Professor, Coordinated Science Laboratory, UIUC
1996	Faculty Fellow, Caterpillar Inc., Mossville, IL
1995	Faculty Fellow, Ford Motor Company, Dearborn, MI
1994-2000	Assistant Professor, Department of Mechanical and Industrial Engineering, University of Illinois Urbana-Champaign
1994-1995	Assistant Professor, Coordinated Science Laboratory, UIUC
1989-1994	Research Staff, Jet Propulsion Lab, Pasadena, CA

Publications

1. Alleyne, S. Brennan, B. Rasmussen, R. Zhang and Y. Zhang, "Controls and Experiments: Lessons Learned," *IEEE Control Systems*, **23**(5), pp. 20-35, 2003.

2. S. Brennan and A. Alleyne, "Using a Scale Vehicle Testbed: Controller Design and Evaluation," *IEEE Control Systems*, **21**(3), pp. 15-26, 2001.

3. S. Brennan, and A. Alleyne, "Robust Scalable Vehicle Control Via Non-Dimensional Vehicle Dynamics," *Vehicle System Dynamics*, **36**(4-5), pp. 255-277, 2001.

4. A.G. Alleyne and R. Liu, "Systematic Control of a Class of Nonlinear Systems with Application to Electrohydraulic Cylinder Pressure Control," *IEEE Transactions on Control Systems Technology*, **8**(4), pp. 623-634, 2000.

5. Alleyne and R. Liu, "On the Limitations of Force Tracking Control for Hydraulic Servosystems," ASME *Journal of Dynamic Systems, Measurement, and Control,* **121**(2), pp. 184-190, 1999.

Synergistic Activities

Guest Editor, IEEE Transactions on Mechatronics focused section on "Mechatronics in Automotive Systems", Vol. 4, no. 3, September 1999

Associate Editor, ASME Journal of Dynamic Systems, Measurement, and Control, October 2000 through September 2003.

Guest Editor, Vehicle System Dynamics, Special Issue from AVEC 2000, August 2000 through 2001

Guest Editor, JSAE Review, Special Issue from AVEC 2000, December 2000 through 2001.

Editorial Board, International Journal of Vehicle Autonomous Systems, December 2000-date.

Co-Editor, Vehicle System Dynamics, February 2001-present.

Associate Editor, IEEE Control Systems, Jan 2003-2005.

Collaborators & Other Affiliations

Collaborators and Co-Editors: C. Bullard, C. Dutton, A. Elnashai, P. Ferreira, P. Guebelle, J. Ghaboussi, P. Hrnjak, D. Kuchma, J. Lewis, E. Loth, N. Miller, P. Seiler, B. Spencer, D. Tortorelli, C. Tucker III, S. White, Q. Zhang (UIUC); H. Peng, A. Stefanopoulou (Univ. of Michigan).

Thesis Advisor or Postgraduate-Scholar Sponsor: M.S. Students: S. N. Brennan (Penn State); D. Bristow (Doctoral Candidate, UIUC); D. Carter, N. Ploplys (Raytheon, Inc.); P. Crisman, T. D. Hull, M. A. Pomykalski (Northrup Grumann); M. C. Depoorter, R. J. Thacher (John Deere); B. Edler, P. Gupta, E. A. Prasetiawan, S. Sonneberg (Caterpillar, Inc.); C. Gwynn (Ford Motor Company); H. Havlicsek (Motorola); W. Langson (Honeywell); R. Liu (Excite, CA); D. P. Lynch (General Motors); H. W. Ng (Singapore); M. Polley (MPC Inc.); B. P. Rasmussen (Texas A&M); B. J. Rosenthal (Anteon); R. Shah (Behr, Inc.); K. Smith (U.S. Navy); M. L. Tharayil (Xerox Research).

PhD Students: S. N. Brennan (Pennsylvania State); E. B. Erdem (Porter, Inc.); B. Rasmussen (Texas A&M); M. Tharayil (Xerox); R. Zhang (General Motors); Y. Zhang (Eaton Corp.); D. Zheng (General Electric).

Scott S. Bair
George W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology

Professional Preparation

Georgia Institute of Technology	Mechanical Engineering	B.S.	1972
Georgia Institute of Technology	Mechanical Engineering	M.S.	1974
Georgia Institute of Technology	Mechanical Engineering	Ph.D.	1990

Appointments

Principal Research Engineer	Georgia Institute of Technology	1992
Senior Research Engineer	Georgia Institute of Technology	1985-1992
Research Engineer	Georgia Institute of Technology	1974-1985

Publications

1. Bair, S., "Pressure-Viscosity Behavior of Lubricants to 1.4 GPa and Its Relation to EHD Traction," STLE Tribology Transactions, 43, 1, pp 91-99, 2000.

2. Bair, S. and Qureshi, F., "The Generalized Newtonian Fluid Model and Elastohydrodynamic Film Thickness," ASME, J. Tribology, 125, 1, pp. 70-75, 2003.

3. Bair, S. and Winer, W.O., "A New High-Pressure, High Shear Stress Viscometer and Results for Lubricants, "Tribology Transactions, 36, 4, pp. 721-725, 1993.

4. Bair, S., "Normal Stress Difference in Liquid Lubricants Sheared Under High Pressure," Rheologica Acta, 35, 13, pp 13-23, 1996.

5. Bair, S., "The High Pressure Rheology of Some Simple Model Hydrocarbons," Proc. I. Mech. E., 216, J, 2002, pp. 139-150.

6. Bair, S., Qureshi, F., and Khonsari, M., "Adiabatic Shear Localization in a Liquid Lubricant Under Pressure," Trans. ASME, Journal of Tribology, 116, 4, 1994.

7. Bair, S., Qureshi, F., and Winer, W. O., "Observations of Shear Localization in Liquid Lubricants Under Pressure," Trans. ASME, Journal of Tribology, 115, 3, 1993.

8. Bair, S., Green, I., and Bhushan, B., "Measurements of Asperity Temperatures of a Read/Write Head Slider Bearing in Hard Magnetic Recording Disks," Trans. ASME Journal of Tribology, 113, No. 3, 1991.

9. Bair, S., McCabe, C. and Cummings, P., "Comparison of NEMD with Experimental Measurements in the Non-Linear Shear Thinning Regime," Physical Review Letters, 88, 5, 8302, 2002.

10. Bair, S., McCabe, C. and Cummings, P., "Calculation of Viscous EHL Traction for Squalane using Molecular Simulation and Rheometry," Tribology Letters, 13, 4, pp. 251-254, 2002.

Synergistic Activities

Awards

Co-Recipient of the 1983 Best Paper of the Year for the Tribology Division/ASME
Co-Recipient of the 1991 Best Paper of the Year for the Tribology Division/ASME
Jacob Wallenberg Foundation, 1996
Recipient of the 2000 Alfred Hunt Award from STLE for best paper
Fellow of ASME
Fellow of STLE

US. Patents

4,349,130	Liquid Metering Pump
4,347,643	Power Assist Drive Upright Vacuum Cleaner and Power Assist Drive System
4,391,018	Vacuum Cleaner with Wheel and Nozzle Height Adjusting Mechanism [with Vermillion and Gromek]
4,998,228	Drinking Water Filter [with Eager]
5,562,692	Fluid Jet Surgical Cutting Tool
5,643,299	Hydrojet Apparatus for Retractive Surgery
5,735,815	Method of Using Fluid Jet Surgical Cutting Tool
5,853,384	Fluid jet Surgical Tool and Aspiration Device
5,865,790	Method and Apparatus for Thermal Phaco-emulsification by Fluid Throttling
6,126,668	Microkeratome
6,527,766	Instrument and Method for Phacoemulsification by Direct Thermal Irradiation

Collaborators And Other Affiliations

Collaborators: Philippa Cann (Imperial College), Peter Gordon (ExxonMobil), Ton Lubrecht (INSA Lyon), Peter Kottke (Georgia Tech), C.M. Roland (NRL), Clare McCabe (Vanderbilt Univ.), Farrukh Qureshi (Lubrizol Corp.), Richard Salant (Georgia Tech), Philippe Vergne (INSA de Lyon), M. Khonsari (LSU), Q.J. Wang (Northwestern Univ.).

Graduate Advisors: David Sanborn (Georgia Tech), Ward Winer (Georgia Tech).
Thesis Advisor: Aleks Bakman (Martin Marietta), Theodore Byer (Briggs&Straton), Peter Kottke (Georgia Tech), Steve Obermark.

Eric J. Barth
Department of Mechanical Engineering
Vanderbilt University

Professional Preparation

University of California Berkeley	Engineering Physics	B.S.	1994
Georgia Institute of Technology	Mechanical Engineering	M.S.	1996
Georgia Institute of Technology	Mechanical Engineering	Ph.D.	2000
Vanderbilt University	Mechanical Engineering	Postdoctoral Associate	2000-2002

Appointments

2002 – present	Assistant Professor of Mechanical Engineering, Vanderbilt University, Nashville, TN
2000 – 2002	Research Assistant Professor of Mechanical Engineering, Vanderbilt University, Nashville, TN

Publications

1. N. Gulati, E. J. Barth. "Dynamic Modeling of a Monopropellant-Based Chemofluidic Actuation System". *ASME Journal of Dynamic Systems, Measurement, and Control*, vol. 129, no. 4, pp.435-445, July 2007.

2. J. Riofrio, E. J. Barth. "A Free Piston Compressor as a Pneumatic Mobile Robot Power Supply: Design, Characterization and Experimental Operation". *International Journal of Fluid Power*, vol. 8, no. 1, pp.17-28, 2007.

3. K. B. Fite, J. E. Mitchell, E. J. Barth, M. Goldfarb. "A Unified Force Controller for a Proportional-Injector Direct-Injection Monopropellant-Powered Actuator". *ASME Journal of Dynamic Systems, Measurement, and Control*, vol. 128, no. 1, pp. 159-164, March 2006.

4. K. A. Al-Dakkan, E. J. Barth, M. Goldfarb. "Dynamic Constraint Based Energy Saving Control of Pneumatic Servo Systems". *ASME Journal of Dynamic Systems, Measurement, and Control*, vol. 128, no. 3, pp. 655-662, September 2006.

5. B. L. Shields, E. J. Barth, M. Goldfarb. "Predictive Control for Time-Delayed Switching Control Systems". *ASME Journal of Dynamic Systems, Measurement, and Control*, vol. 128, no. 4, pp. 999-1004, December 2006.

6. Y. Zhu, E J. Barth. "Energy-Based Control of a Pneumatic Oscillator with Application to Energy Efficient Hopping Robots," *2006 ASME International Mechanical Engineering Congress and Exposition (IMECE)*, IMECE2006-15015, November 5-10, 2006, Chicago, IL.

Synergistic Activities

Program Committee Member of the 2007 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM 2007).

Program Committee Member of the 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), October 9-14, 2006, Beijing, China.

Program Committee Member of the 2005 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM 2005), July 24-28, 2005, Monterey, California, USA

Track Representative of Fluid Power Systems Technology Division (FPST) for IMECE 2005.

US Air Force Summer Faculty Fellow, AFRL, Wright-Patterson Air Force Base, 2005.

Faculty advisor to VUMotorsports student club, Vanderbilt University, 9/02 – present.

Collaborators & Other Affiliations

*Collaborators:*Andrew Alleyne, Ph.D., Department of Mechanical and Industrial Engineering, UIUC, Wayne Book, Ph.D., George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Michael Goldfarb, Ph.D., Department of Mechanical Engineering, Vanderbilt University, Monika Ivantysynova, Ph.D., Department of Mechanical Engineering, Purdue University, Suhada Jayasuriya, Ph.D., Department of Mechanical Engineering Texas A&M University, Perry Y. Li, Ph.D., Department of Mechanical Engineering, University of Minnesota, Nader Sadegh, Ph.D., George W. Woodruff School of Mechanical Engineering, Georgia Insitute of Technology, Corey Schumacher, Ph.D, AFRL/VACA, Wright Patterson Air Force Base, Kim A. Stelson, Ph.D., Department of Mechanical Engineering, University of Minnesota, Alvin Strauss, Ph.D., Department of Mechanical Engineering, Vanderbilt University, Roger Quinn, Ph.D., Dept. of Mechanical and Aerospace Engineering, Case Western Reserve University

Advisor: Harry Bingham (deceased), Ph.D., Department of Physics, University of California Berkeley, Ye-Hwa Chen, Ph.D., School of Mechanical Engineering, Georgia Institute of Technology, Aldo Ferri, Ph.D., School of Mechanical Engineering, Georgia Institute of Technology, Michael Goldfarb, Ph. D., Department of Mechanical Engineering, Vanderbilt University, Bonnie Heck, Ph.D., School of Mechanical Engineering, Georgia Institute of Technology, Nader Sadegh, Ph. D., School of Mechanical Engineering, Georgia Institute of Technology, George Vachtsevanos, Ph.D., School of Electrical Engineering, Georgia Institute of Technology, David Nygren, Ph.D., Physics, Lawrence Berkeley National Laboratory

Thesis Advisor to:, Taib Tariq Mohamad, M.Engineering. (2007), Dept. of Mechanical Engineering, Vanderbilt University, Yong Zhu, Ph.D. (2006), Department of Mechanical Engineering, Vanderbilt University, Navneet Gulati, Ph.D. (2005), Department of Mechanical Engineering, Vanderbilt University, Jose Riofrio, M.S. (2005), continuing Ph.D. Student, Dept. of Mech. Engineering, Vanderbilt University, Mark Adams, M.S. (2004), Department of Mechanical Engineering, Vanderbilt University, Chao Yong, Ph.D. Student, Dept. of Mechanical Engineering, Vanderbilt University, Justin Armstrong, M.S. Student, Dept. of Mechanical Engineering, Vanderbilt University, Mark Hofacker, M.S. Student, Dept. of Mechanical Engineering, Vanderbilt University

Wayne J. Book
George W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology

Professional Preparation

Massachusetts Institute of Technology	Mechanical Engineering	PhD.	1974
Massachusetts Institute of Technology	Mechanical Engineering	S.M.	1971
University of Texas, Austin	Mechanical Engineering	B.S.M.E.	1969

Appointments

2001 - present	HUSCO/Ramirez Chair in Fluid Power and Motion Control, Georgia Institute of Technology
1986 - present	Professor, Georgia Institute of Technology
1980 - 1986	Associate Professor, Georgia Institute of Technology
1974 - 1980	Assistant Professor, Georgia Institute of Technology
1987	Faculty Fellowship, Oak Ridge National Laboratory

Publications

1. Gao, Dalong and Wayne J. Book, “Steerability for Planar Dissipative Passive Haptic Interfaces,” to appear in IEEE/ASME Transactions on Mechatronics, v11 n2, April 2006.

2. Love, L.J. and W.J. Book, "Force Reflecting Teleoperation with Adaptive Impedance Control," IEEE Transactions on Systems, Man, and Cybernetics Part B: Cybernetics, v34, n1, pp.159-165, Feb. 2004.

3. Book, Wayne J. and Davin K. Swanson, “Reach Out and Touch Someone: Controlling Haptic Manipulators Near and Far,” Annual Reviews in Control, International Federation of Automatic Control, Elsevier Science (Oxford, UK), vol 28, pp 87-95, 2003.

4. Krauss, Ryan and Wayne Book, “Transfer Matrix Modeling of a Hydraulically Actuated Flexible Robot,” *International Journal of Fluid Power*, v8, n1, March 2007, pp 51-58.

5. Kontz, Matthew and Wayne Book, “Flow Control for Coordinated Motion and Haptic Feedback” *International Journal of Fluid Power* v8, n3, Nov 2007.

Synergistic Activities

Editorial Activities: Associate Editor, IEEE Transactions on Automatic Controls. Management Committee, Joint ASME-IEEE Transactions on Mechatronics, 1995-present. Chair for 1999.

Co-Founder of CAMotion, Inc. for commercialization of advanced motion control technology for automating manufacturing and material handling, 1997. Treasurer and consultant 1997 - present.

Steering and Advisory Committee service: Potomac Institute for Policy Studies NASA Computing And Communications Technology Advisory Group, 2004.

Collaborators & Other Affiliations (other than students listed)
*Collaborators:*Stephen Dickerson, Nader Sadegh, William Singhose, Christopher Paredis, Imme Ebert-Uphoff, David Rosen, Jarek Rossignac, Ari Glezer, Mark Allen, Kenneth Cunefare, Richard Salant, all from the Georgia Institute of Technology. Kim Stelson (U. Minnesota); Michael Goldfarb (Vanderbilt U.); Monika Ivantysynova (Purdue U.); Andrew Alleyne (U. Illinois);

Ph.D. Students Supervised: Noparat Punyapas, Viboon Sangveraphunsiri, Gordon Hastings, Thomas Alberts, Sabri Cetinkunt, Bau San Yuan, Jeh Won Lee, Dong Soo Kwon, Soo-Han Lee, J.J. Wang, Jae Lew, Jonathan Cameron, David Magee, Lonnie Love, John Hogan, Klaus Obergfell, Sungsoo Rhim, Saghir Munir, Lynnane George, Davin Swanson, Haihong Zhu, Lawrence Tognetti, Dalong Gao, Ho Ching, Amir Shenouda, Ryan Kraus, Benjamin Black, Patrick Op den Bosch.

Ph.D. and M.S. Adviosors: Ph.D.: Daniel Whitney, Dept. of Mechanical Engineering, Massachusetts Institute of Technology, M.S.: Russel Jones, Dept. of Civil Engineering, Massachusetts Institute of Technology.

Research visitors:
Jeha Ryu
Professor, Department of Mechatronics
GwangJu Institue of Science and Technology (GIST)
1 Oryong-dong, Buk-ku, GwangJu
500-712, Republic of Korea (South)
Re haptics

ACFR (Australian Center for Field Robotics) in Sydney Seminar, Tour about haptics for robotic devices

Dr. Fumitoshi Matsuno
Prof. of The University of Electro-Communications
Vice-President of NPO International Rescue System Institute
Steering Committee Chair of SICE Annual Conference.
SICE (The Society of Instrument and Control Engineers, Japan)
Rescue Robot discussion. Invitation to serve as Advisory Board Member of SICE 2008

24-25 September a researcher from the Swedish Forestry Research Institute
- Bjorn Lofgren will be at Georgia Tech. He studies trajectory planning and control for forestry machines with a basis in hydraulics / fluid power
very close connections to Komatsu as he serves on their
R&D advisory board for forestry

Thomas R. Chase
Department of Mechanical Engineering
University of Minnesota

Professional Preparation

Rochester Institute of Technology	Mechanical Engineering	B.S.	1977
Rochester Institute of Technology	Mechanical Engineering	M.S.	1983
University of Minnesota	Mechanical Engineering	Ph.D.	1984

Appointments

2003-present	Professor of Mechanical Engineering, Morse-Alumni Distinguished Teaching Professor of Mechanical Engineering, University of Minnesota
1991-2003	Associate Professor of Mechanical Engineering, University of Minnesota
1985-1991	Assistant Professor of Mechanical Engineering, University of Minnesota
1983-1985	Assistant Professor of Mechanical Engineering, University of Rhode Island

Publications

1. Rannow, M. B., Tu, Haink C., Li, Perry Y., and Chase, T. R., "Software Enabled Virtually Variable Displacement Pumps -Theoretical and Experimental Studies", Submitted to ASME Journal of Dyamic Systems, Measurement, and Control, submitted April 2007 (if accepted, publication anticipated in 2008).

2. Tu, H. C., Rannow, M. B., Van de Ven, J. D., Wang, W., Li, P. Y., and Chase, T. R., 2007, "High Speed Rotary Pulse Width Modulated On/Off Valve", Proceedings of the 2007 ASME IMECE, Paper No. 42559, vol. FPST.

3. Rannow, M. B., Tu, H. C., Li, P. Y., and Chase, T. R., 2006, "Software Enabled Variable Displacement Pumps: Experimental Studies", Proceedings of the 2006 ASME IMECE, Paper No. 14973, vol. FPST.

4. Li, Perry; Chase, Thomas; and Li, Yanhua, 2005, "Software Enabled Variable Displacement Pumps", Proceedings of the 2005 ASME IMECE, Paper No. 81376, vol. FPST.

5. Michael, D. G., et al. (including T. R. Chase), 2006, "Observation of Muon Neutrino Disappearance with the MINOS Detectors in the NuMI Neutrino Beam", Physical Review Letters, Vol. 97, No. 19, article #191801.

6. Adamson, P., et al. (including T. R. Chase), 2006, "First observations of separated atmospheric nμ and nμ events in the MINOS detector", Physical Review D (Particles and Fields), Vol. 73, No. 7, article #072002.

7. Chase, Thomas R., 2006, "A Note on the Waldron Construction for Transmission Angle Rectification", ASME Journal of Mechanical Design, Vol. 128, No. 2, pp. 509-512.

8. Langlais, T. E., Vogel, J. H., and Chase, T. R., 2003, "Multiaxial Cycle Counting for Critical Plane Methods", International Journal of Fatigue, Vol. 25, No. 7, pp. 641-647.

9. Adamson, P., Alner, J., Anderson, B., Chase, T., Dervan, P. J., Durkin, T., Falk, E., Harris, P. G., Michael, D. G., Morse, R., Nichol, R., Saakyan, R., Smith, C., Smith, P. N., Thomas, J., Webb, R., and White, R. F., 2002, "The MINOS Light Injection Calibration System", Nuclear Instruments and Methods in Physics Research A, Vol. 492/3, pp. 325-343.

Synergistic Activities

Associate Editor, ASME Journal of Mechanical Design, 9/1/04-present.

Level 3 Manager for Scintillator Module Design, NuMI Off-Axis ne Appearance (NOvA) Experiment, responsible for the design and purchase of approximately $2 million of components for neutrino detector modules (an experiment of the Fermi National Accelerator Laboratory).
Member-at-Large, ASME Systems & Design Group, 7/1/04-6/30/07.

Level 3 Manager for Scintillator Module Design, Main Injector Neutrino Oscillation Search (MINOS) Experiment, responsible for the design and purchase of over $1 million of components for neutrino detector modules. The MINOS Collaboration includes approximately 32 institutions internationally.

Member, Executive Committee, Design Engineering Division of the American Society of Mechanical Engineers, 1998-2004 (Chair, 2002-03).

Collaborators & Other Affiliations

Collaborators: A. Erdman (UMN), K. Heller (UMN), F. Kelso (UMN), P. Li (UMN), M. Marshak (UMN), E. Peterson (UMN), R. Poling (UMN), K. Ruddick (UMN).

Graduate advisors: Ph.D. Advisor: Professor Arthur G. Erdman, University of Minnesota
M.S.M.E. Advisor: Professor Richard Budynas, Rochester Institute of Technology

Graduate Advisees, 2002-2007: Ph.D. graduates: (None since 1999), MSME graduates: J. Brandts, 2007 (Hutchinson Technology, Hutchinson, MN) M. Meyer, 2006.

Current graduate advisees: A. Durand, K. McLennan, B. Nitti, M. Rannow, J. Robelia, H. Tu, R. Wang.

Total number of Ph.D. graduates: 5

Total number of MS graduates: 23

Douglas L. Cook
Applied Technology Center
Milwaukee School of Engineering

Professional Preparation

Milwaukee School of Engineering	Mechanical Engineering	B.S. 1998
Milwaukee School of Engineering	Electrical Engineering	B.S. 1998
Fachhochschule Luebeck	Dipl.-Ing. Elektrotechnik	1998
Milwaukee School of Engineering	Engineering	M.S. 2007

Appointments

2006 – Present	Research Engineer, MSOE, RP Research
2005 –2006	Principal Investigator, MSOE, ATC
1998 –2003	Graduate Rsch. Asst., MSOE, RPC
1996 –1998	Undrgrd. Rsch. Asst., MSOE, RPC

Publications

1. John R. Brauer, Douglas L. Cook, Thomas E. Bray "Finite-Element Computation of Magnetic Force Densities on Permeable Particles in Magnetic Separators" IEEE Transactions on Magnetics, Vol. 43, No. 8, August 2007 Ppg. 3483-3487 http://ieeexplore.ieee.org

2. Software – PlatyScan v1.0 – 4.2
   Douglas L. Cook, Nicole Gregor
   Developed for:
   Platypus Technologies, LLC
   Madison, WI
   http://www.platypustech.com

Synergistic Activities

Research and design of small, low-power, high-density end effector for extracting biomagnetic particles from suspension, for an undisclosed, world-wide corporation

Research and design of high-accuracy absolute-position encoder for use in uncontrolled environments, for an undisclosed, world-wide corporation

Liquid-crystal transmissivity studies for Platypus Technologies' new product developments, and software development for image analysis of such samples

Organized the last two, annual, workshops on campus for the FEA multi-physics software, COMSOL

Collaborators and Other Affiliations

Collaborators and Co-Editors: Vincent Anewenter MSOE, RPC, John Brauer, Ph.D. – Retired, Thomas Bray, MSOE, ATC, John Choren, MSOE, RPC, Vito Gervasi, MSOE, RPRsch., Sheku

Kamara, MSOE, RPC, James Mallmann, Ph.D. - MSOE, Physics and Chemistry, Vipin Paliwal, Ph.D. MSOE, Physics and Chemistry, Thomas Wanke MSOE, FPI

Graduate Advisors: Thomas Bray, MSOE, ATC, James Mallmann, Ph.D. MSOE, Physics and Chemistry, Steven Reyer, Ph.D., MSOE, EE and CS

Thesis Advisor and Postgraduate-Scholar Sponsor: N.A.

Kenneth A. Cunefare
George W. Woodruff School of Mechanical Engineering
The Georgia Institute of Technology

Professional Preparation

The University of Illinois at Urbana-Champaign	Mechanical Engineering	Bachelor of Science	1982
The University of Houston	Acoustical Engineering	Master of Science	1987
The Pennsylvania State University	Mechanical Engineering	Doctor of Philosophy	1990
The Technical University of Berlin	Structural Acoustics		1990-1991

Appointments

2006-present	Professor, Georgia Institute of Technology
1997-2006	Associate Professor, Georgia Institute of Technology
1990-1997	Assistant Professor, Georgia Institute of Technology
1990-1991	F.V. Hunt Postdoctoral Fellow, The Technical University of Berlin
1988-1990	NASA GSRP Fellow, The Pennsylvania State University
1987-1988	NASA GSRP Fellow, The University of Houston
1986-1987	Senior Engineer, Exxon Company U.S.A., Houston, Texas
1984-1986	Senior Project Engineer, Exxon Company U.S.A., Midland, Texas
1982-1984	Project Engineer, Exxon Gas Systems, Inc., Houston, Texas
1981	Intern, McDonnell Douglas Aircraft Corporation

Publications

1. Kenneth A. Cunefare, “Negative capacitance shunts for vibration suppression: wave based tuning and reactive input power,” paper A06_110, CD Proceedings, Active 2006, Adelaide, Australia, September 2006.

2. Jeff Badertscher, Kenneth A. Cunefare and Aldo Ferri, “Braking impact of normal dither signals,” accepted for publication, ASME Journal of Vibration and Acoustics, May, 2006.

3. Mark Holdhusen and Kenneth A. Cunefare, "Damping Effects on the State-Switched Absorber Used for Vibration Suppression," Journal of Intelligent Material Systems and Structures, **114**(9), pp. 551-561 2003.

4. Kenneth A. Cunefare, “State-switched absorber for vibration control of point-forced beams,” Adaptive Structures and Materials Symposium special issue of the Journal of Intelligent Material Systems and Structures, **13**(2), pp. 97-106, 2002.

5. Wayne M. Johnson and Kenneth A. Cunefare, “Structural Acoustic Optimization of a Composite Cylindrical Shell Using FEM/BEM,” ASME Journal of Vibration and Acoustics, **124** (July), pp. 410-413, 2002.

6. Kenneth A. Cunefare, “Feature variation and its impact on structural acoustic response predictions,” ASME Journal of Vibration and Acoustics, **125**(January), pp. 31-38, 2003.

Synergistic Activities

Member, National Committee on Education in Acoustics, Acoustical Society of America. 1998-2006.

Member, National Committee on Noise, Acoustical Society of America, 1999-2006.

Integration of NSF funded (ARI grant) laboratory into ME4055, Senior Experimental Methods class.

Active recruitment of women and minorities into my research program. Seven current or former students are women or under-represented minorities (Noelle Curry, Janeen Jones, Lisa Chang, Anne Marie Albanese, Wayne Johnson, Mawuli Dzirasa, and Tina Famighetti).

Collaborators and other Affiliations

Collaborators and Co-Editors: Dr. Krishan Ahuja (Georgia Tech), Dr. Mark Allen (Georgia Tech), Dr. Yves Berthelot (Georgia Tech), Scott Crane (General Electric), Brian Dater (Northrup-Grumman), Sergio DeRosa (University of Naples), Dr. Stephen Elliott (ISVR, Southampton, U.K.), Steve Engelstad (Lockheed Martin), Dr. Francesco Franco (Post Doc, University of Naples), Dr. Jerry Ginsberg (Georgia Tech), Dr. Ari Glezer (Georgia Tech), Dr. Marty Johnson (VPI), Dr. Greg Larson (Geogia Tech), Dr. Chris Lynch (Georgia Tech), Keith Oglesby (Ford Motor Co.), Dr. Huang Pham (Newport News Shipyard), Eugene Powell (Lockheed Martin), Dr. Nader Sadegh (Georgia Tech), Dr. Manuel Collet (CNRS), Dr. Chan Il Park (Kangnung National University)

Graduate and Post-Doctoral Advisors: Dr. Ashok Belegundu (Penn State), Dr. Courtney Burroughs (Penn State), Dr. Prof. Manfred Heckl (Post-Doctoral Sponsor, Technical University of Berlin, deceased), Dr. Gary Koopmann (Penn State), Dr. Alan Pierce (University of Boston).

Thesis Advisor and Postgraduate-Scholar Sponsor: Anne Marie Albanese (current MS/PhD student, NSF Fellowship recipient), Scott Crane (General Electric), Dr. Noelle Currey (Currey Acoustics), Brian Dater (Northrup-Grumman), Sergio DeRosa (Post-Doc, University of Naples), Muwali Dzirasa (Johns Hopkins), Jesse Ehnert (Arpeggio Acoustic Consulting), Mark Fowler (SY Technology), Dr.Francesco Franco (Post-Doc, University of Naples), Aaron Graf (General Motors), Dr. Mark Holdhusen (University of Wisconsin Marathon County), Dr. Wayne Johnson (Armstrong State University), Janeen Jones (NEETRAC), Dr. Heungsoeb Kim (post-doc, Hangyang University, Korea), Dr. Nila Montbrun (Post-doc, Universidad Simon Bolivar), David Moon (Ford Motor Company), Keith Oglesby (Ford Motor Company), Dr. Victor Rastelli (Post-doc, Universidad Simon Bolivar), Ryan Rye (Motorala), Dr. William Steven Shepard, Jr. (University of Alabama), Dr. Michael Michaux, Dr. Manuel Collet (post-doc, CNRS), Dr. Chan Il Park (post-doc, Kangnung National University), Tina Famighetti (Bose), Jeff Badertscher (current PhD student), Alex Michaud (current MS student), Ken Marek (current MS/PhD student), Mark Michener (current MS student).

Summary: 7 Ph.D., 20 M.S., 7 Post-Doc

Jane H. Davidson
Department of Mechanical Engineering
University of Minnesota

Professional Preparation

University of Tennessee	Engineering Science and Mechanics	M.S. 1975
University of Tennessee	Engineering Science and Mechanics	B.S. 1976
Duke University	Mechanical Engineering	Ph.D. 1984

Appointments

1999 – Present	Professor of Mechanical Engineering, University of Minnesota
2004-2005, Fall 2007	Visiting Professor, Mechanical and Process Engineering Department, Swiss Federal Institute of Technology, ETH Zurich
1993 – 1999	Associate Professor of Mechanical Engineering, University of Minnesota
1986 – 1993	Assistant & Associate Professor of Mechanical and Civil Engineering, Colorado State University
1984 – 1985	Assistant Professor of Mechanical and Aerospace Engineering, University of Delaware
1976 – 1982	Research Engineer, Oak Ridge National Laboratory and Research Triangle Institute

Publications

1. Kingsley, M.L., and Davidson, J.H., "Adsorption of Toluene onto Activated Carbons Exposed to Low-Concentration Ozone," Carbon, 44, 560-564, 2006.

2. Li, Z., Davidson, J.H., and Mantell, S.C., "Numerical Simulation of Flow and Heat Transfer of Streamlined Cylinders in Crossflow," ASME J. of Heat Transfer, 128, 564-570, 2006.

3. Su, Yan and Davidson, J.H., "Transient Natural Convection Heat Transfer Correlations for Tube Bundles Immersed in a Thermal Storage," ASME J. of Solar Energy Engineering, 129, 210-214, 2007.

4. Su, Y., and Davidson, J.H., "Multi-Zone Porous Medium Model of the Thermal and Fluid Processes during Discharge of an Inclined Rectangular Storage Vessel via an Immersed Tube Bundle," ASME J. of Solar Energy Engineering, 129, 449-457, 2007.

5. Mittleman, G., Davidson, J.H., Mantell, S.C, and Su, Y., in press, "Prediction of Polymer Tube Life for Solar Hot Water Systems: A Model of Antioxidant Loss," Solar Energy, doi:10.1016/j.solener.2007.10.002.

Synergistic Activities

Honors and Awards: Fellow American Society of Mechanical Engineering, American Solar Energy Society, 2007 ASES Charles Greeley Abbot Award, 2005 Distinguished Women Scholar Award in Science and Engineering, University of Minnesota, 2004 ASME John I. Yellott Award

for achievement in research, education and service in solar energy, 2003 ASME Dedicated Service Award, 2001 Outstanding Service Award, Solar Rating and Certification Board, 2000 John Tate Award for Excellence in Undergraduate Advising, University of Minnesota, 1990 Young Faculty Research Award, Colorado State University, ASME Solar Energy Division, Best Paper Awards, 1990, 1992, 1994, 1996, 1999, 2001

Teaching and Advising: Undergraduate Academic Advisor, 1995-2000, Faculty Advisor to student organizations SWE, ASHRAE., Presidential Minority Mentor 1999-2001., Responsible for laboratory development and teaching of the required undergraduate laboratory courses in Mechanical Engineering, 1994-present.

Outreach Activities: ME REU Co-director, 2005-Present, ASME Board of Women and Minorities, 2000-2003., Implemented "Explore Engineering" an outreach activity for Girls in Grades 2-9, 1994-1996, Funded by Northern States Power and Medtronic Star Foundation., University partner for middle school teacher in the Research Explorations for Teachers, 1995. Initiated the Colorado State University College of Engineering's High School Women in Engineering Program 1991., Teacher Engineering Camp for Denver Area Junior High students, 1990 and 1991.

Selected Service Activities: National Research Council Committee on Renewable Electricity ASME Climate Change Task Force, Editor in Chief, *Journal of Solar Energy Engineering*, 2000-2005, Board of American Solar Energy Society, 1998 – 2001., ASME Energy Committee, 2006-2010, Vice-Chair ASME Energy Resources Board, 1999-2000, Member-at-Large 1998-2001., ASME Distinguished Lecturer Program Committee, 1995-1998

Collaborators & Other Affiliations
Collaborators: Profs. Susan Mantell, Lorraine Francis, Francis Kulacki, and John Carmody University of Minnesota. Post-Doctoral Associates: Dr. T. Abu Hamed, Dr. G. Mittelman, Dr. D. Huang, Dr. M. Stolzerburg, University of Minnesota.

Graduate Advisors: E. J. Shaughnessy, Duke University; C.J. Remenyik, M.S. University of Tennessee

Thesis Advisor: Ph.D. Graduates: In the past 5 years - Junhong Chen, Asst. Prof. University of Wisconsin-Madison; Wei Liu, TSI; Mike Kingsley, SAIC, Syracuse, N.Y.; Zhihua Li, Intel Corp., AZ; Chunhui Wu, Abbot Spinal Research, Minneapolis; Yan Su, Asst. Prof.,Hong Kong University Sci. and Tech.: In Progress: Zhen Wu; Julia Haltiwager, Casey Briscoe. M.S. Graduates: Z. Li, Intel: Troy Pongratz, Science Museum of MN; Yana Wang, MIT Ph.D. candidate; Megan Kearney, 3M; Andy Freeman, University of MN researcher; Patty Sanft, Fuller Co.; Daniel Thomas, AIL Princeton NJ; Kakie McGill, Lozier, Omaha; Vishard Ragoonanan, Ph.D.candidate ME at UMN.; Mike Eggen, Ph.D. candidate Biomedical Engr., UMN; In progress: Ben Schoenbauer, Vinayak Kathare, Matt Royer, Derek Savela

William K. Durfee
Department of Mechanical Engineering
University of Minnesota

Professional Preparation

Harvard University	Eng. & Applied Physics	A.B., 1976
M.I.T.	Mechanical Engineering	M.S., 1981
M.I.T.	Mechanical Engineering	Ph.D., 1985

Appointments

2001-present	Professor and Director of Design Education, Dept. of Mechanical Eng., University of Minnesota
1993-2001	Associate Professor and Director of Design Education, Dept. of Mechanical Eng., University of Minnesota
1991-1993	Associate Prof. of Engineering Design, Dept. of Mech. Eng., MIT
1990-1991	Associate Professor, Department of Mechanical Engineering, MIT
1986-1988	Assistant Professor of Biomedical Eng., Dept. of Mech. Eng., MIT
1985-1990	Assistant Professor, Department of Mechanical Engineering, MIT
1978-1985	Research Assistant, Department of Mechanical Engineering, MIT
1976-1978	Project Engineer, Harvard-MIT Rehabilitation Engineering Center
1976	Laboratory Supervisor, Harvard University

Publications

1. Krebs, H., Hogan, N., Durfee, W., Herr, H., Rehabilitation robotics, orthotics, and prosthetics. In *Textbook of Neural Repair and Rehabilitation, Vol. II, Medical Rehabilitation*. Chap. 12, Selzer, Clarke, Cohen, Duncan, Gage, eds., Cambridge University Press, 2006.

2. Durfee WK, Savard L and Weinstein S, Technical feasibility of remote assessments for rehabilitation. *IEEE Trans. Neural Systems and Rehabilitation Engineering*, 15(1):23-29, 2007.

3. Durfee, W.K. and P.A. Iaizzo. Rehabilitation and muscle testing. In: *Encyclopedia of Medical Devices and Instrumentation, 2nd ed*. J.G. Webster, ed., Vol 6, pp 62-71, Hoboken, John Wiley & Sons, 2006.

4. Mallick DN, Adams C, Durfee WK, Erdman A, Iaizzo PA: An experiential approach to preparing students for leadership in managing technology. *Decision Line*, pp. 4-22 , July 2005.

5. Durfee W, Rivard A, Design and simulation of a pneumatic, stored-energy, hybrid orthosis for gait restoration. *J Biomechanical Eng*, 127(6):1014-1019, 2005.

Synergistic Activities

Work on passive and active exoskeletons for rehabilitation.

Collaborate with companies on product development, projects with: 3M, Micro-Medical, Devices, Toro, Aetrium, Augustine Medical, Donaldson, Spinal Designs, Honeywell, Select, Comfort, Sulzer Medica, Enhanced Mobility Technologies, Medtronics, EnduraTEC, Machine Magic, Scimed, Sulzer Spine Tech, Andersen Windows, Hormel, Introspective, Geodigm, VivaCare, Comedicus, Hearing Components, Newco, Cornelius.

Collaborators & Other Affiliations

Collaborators and Co-Editors: C. Adams, E. Bye, R. Cardozo, M. DeLong, A. Erdman, P. Iaizzo, A. Johnson, K. Johnson, D. Kittleson , K. LaBat , P. Li , D. Mallick , E. Stern, M. Wade, M. Zachariah (UMN); K. Dooley (ASU); E. Davis (Sister Kenny); T. Rosenthal (Systems Technology); J. Wachtel (Veridian Group); N. Huizenga (Courage Center); F. Pin (ORNL); R. Merletti (Politecnico di Torino); M. Rosen (National Rehabilitation Hospital); R. Beachy (Axiom).

Graduate and Postdoctoral Advisors: M.J. Rosen (National Rehabilitation Hospital).

Thesis Advisor and Postgraduate-Scholar Sponsor: B. Avula, D. Baker, J. Balik, P.M. Cheng, D. Chiu, T. Corrigan, R. Daga, B. Harrold, S. Hayden, C. Hendrix, R. Kim, K. Korkowski, K. MacLean, K. Merz, K. Oberjohn, J. Pavlovic, P. Ponde, J. Shakula, G. Varughese, R. Weathers.

Steven H. Frankel, Ph.D.
Mechanical Engineering
Purdue University

Professional Preparation

State University of New York at Buffalo	Mechanical/Aerospace Engineering	B.S. 1988
North Carolina State University	Mechanical/Aerospace Engineering	M.S. 1990
State University of New York at Buffalo	Mechanical/Aerospace Engineering	Ph.D. 1993

Appointments

2004-present	Professor, Purdue University, School of Mechanical Engineering, West Lafayette, IN
1999-2004	Associate Professor, Purdue University, School of Mechanical Engineering, West Lafayette, IN
1993-1999	Assistant Professor, Purdue University, School of Mechanical Engineering, West Lafayette, IN

Publications

1. Varghese, S. S. and Frankel, S. H., "Numerical Modeling of Pulsatile Turbulent Flow in Stenotic Vessels", Journal of Biomechanical Eng., 125, (4), pp. 445-460, 2003.

2. Xing, T., Li. Z., and Frankel, S. H., "Numerical Simulation of Vortex Cavitation in a Three Dimensional Submerged Transitional Jet", Journal of Fluids Engineering, 127, (4), pp. 714-725, 2005.

3. Varghese, S., Frankel, S. H., and Fischer, P., "Modeling Transition to Turbulence in Eccentric Stenotic Flows", Journal of Biomechanical Engineering, in press, 2007.

4. Varghese, S. S., Frankel, S. H., and Fischer, P., "Direct Numerical Simulation of Stenotic Flows, Part I: Steady Flow", Journal of Fluid Mechanics, 582, 253-280, 2007.

5. Varghese, S. S., Frankel, S. H., and Fischer, P., "Direct Numerical Simulation of Stenotic Flows, Part II: Pulsatile Flow", Journal of Fluid Mechanics, 582, 281-318, 2007.

6. Suh, J., Frankel, S. H., Mongeau, L., and Plesniak, M. W., "Compressible Large Eddy Simulation of Wall-Bounded Turbulent Flows Using a Semi-Implicit Numerical Scheme for Low Mach Number Aeroacoustics", Journal of Computational Physics, 215, pp. 526-551, 2006.

7. Chandy, A., Glaze, D. J., and Frankel, S. H., "Parallelizing the Discrete Ordinates Method (DOM) for Three-Dimensional Radiative Heat Transfer Calculations Using a Priority Queuing Technique", Numerical Heat Transfer, Part B: Fundamentals, 52, 33-49, 2007.

8. Suh, J. and Frankel, S. H., "Numerical Simulation of Turbulence Transition and Sound Radiation of Flow through a Rigid Glottal Model", Journal of Acoustical Society of America, 121(6), 3728-3739, 2007.

9. Singh, K. P., Mongeau, L., Frankel, S. H., and Gore, J., "Effect of Co- and Counter-Swirl on Noise Emission from Swirling Non-reacting Flows and Flames", AIAA Journal, accepted for publication, 2007.

10. Thomson, S. L., Mongeau, L., and Frankel, S. H., "Flow over a Membrane-Covered, Fluid-Filled Cavity", Computers and Structures, Special Issue, accepted for publication, 2007.

Synergistic Activities

Collaborating with colleagues in Department of Mathematics – examining new subgrid-scale turbulence models and also new fluid-structure interaction computational approaches

Collaborators and Affiliations

Collaborators: Steve Wereley, Jie Shen, Steve Dong, Monika Ivanstoynova, (Purdue University); Chenning Tong (Clemson University**)**

*Graduate Advisors and Postdoctoral Sponsor:*Hassan Hassan, North Carolina State University (M.S. advisor); Peyman Givi, State University of New York at Buffalo (Ph.D. advisor)

Thesis Advisor and Postgraduate-Scholar Sponsor: Paul E. DesJardin, Kaimei Sun, Mitchell J. Zimberg, Greg S. Hertle, David M. Costura, David J. Glaze, Gang Li, Cheng Zhang, Sonu Sam Varghese, Nagendra Dittakavi, Sachin Khosla, Stephen Mattick, Stephane Poussou, Paul Smith, John Roach, Somesh Khandelwahl, (M.S.); Paul E. DesJardin, Ravi O. S. Prasad, Wei Zhao, Zhaoyan Zhang, Xing Tao, Scott Thomson, David Glaze, Sonu Varghese, Jungsoo Suh, Abhilash Chandy, Cheng Zhang, (Ph.D.)

Vito R. Gervasi
Applied Technology Center
Milwaukee School of Engineering

Professional Preparation

Milwaukee School of Eng	Manufacturing Eng Technology	B.S, 1996
Milwaukee School of Eng	Mechanical Engineering	M.S., 2003

Appointments

1993-present	Manager, Research & Development, Milwaukee School of Engineering
1985-1990	United States Air Force, honorable discharge

Publications

1. V.R. Gervasi, A. Schneider and J. Rocholl, "Geometry and Procedure for Benchmarking SFF and Hybrid Fabrication Process Resolution," *Rapid Prototyping J.*, **11**(1), 2005.

2. V.R. Gervasi and D.C. Stahl, "Design and Fabrication of Components with Optimized Lattice Microstructures," *Solid Freeform Fabrication Symposium Proceedings*, Austin, Texas, August 2004.

3. V.R. Gervasi, "Metrology Evaluation and Calibration Tool Kit for Rapid Tooling Processes," *Masters Thesis*, Milwaukee School of Engineering, April 2003.

4. D.C. Stahl, V. Gervasi and A. Schneider "Design and Fabrication of Components with Optimized Lattice Microstructures," *SME Rapid Conference Proceedings*, Chicago, May 2003.

5. L.M. Milkowski, V.R. Gervasi, S. Kumaresan and R.S. Crockett, "Development of a Mechanically Similar Composite Bone Replica," *Proceedings of the Annual Conference on Engineering in Medicine & Biology*, **1**, p. 495, 1999.

Synergistic Activities

Contributes to several sections of Wohler's Annual Rapid Prototyping, Tooling, and Manufacturing State of the Industry Worldwide Progress Report. Sections include RP academic program overview and Prototype Hard and Soft Tooling update. http://www.wohlersassociates.com/

Promotes the activities and education of the Rapid Prototyping Consortium (RPC) industrial membership in areas of Rapid Prototyping and Rapid Tooling. 1) Has educated and trained industrial members and MSOE community on RP related topics at consortium meetings as well as at member locations. 2) Has suggested and arranged numerous RPC guest speakers for monthly meetings. 3) Conducted applied research with consortium membership on numerous RP related projects http://www.rpc.msoe.edu/

Co-developed an algorithm to produce 3D models of complex protein molecules from .pdb files. The method combined with recent tooling developments is being used to produce the first low-

cost, highly complex protein model. Also, worked with the same small business to introduce the magnet enhanced WaterKit. http://www.rpc.msoe.edu/3dmd/water1.php

Participated in evolving SME's Rapid Prototyping Association (RPA) to the current Rapid Technologies and Additive Manufacturing (RTAM) Community, a significant progression for the education and integration of additive technologies toward the "factory of the future." Currently Chairing one of eight sub-groups formed under RTAM. http://www.sme.org/cgi-bin/communities.pl?/communities/rpa/rpahome.htm&&&SME& Also, assisted with planning and coordination of SME Technical Forum, "Direct Metal Systems In Rapid Manufacturing," Dearborn, Michigan, August 2003

Advisor for students in Research Experiences for Undergraduates (REU), advising manufacturing, rapid tooling, aerospace and mechanical engineering projects. 1997-present http://www.msoe.edu/reu/

Collaborators & Other Affiliations

Collaborators and Co-Editors: M. Batdorff, A. Bloor, T. Bray, D. Cook, S. John, S. Kamara , S. Kumpaty, J. Mallmann, J. Rocholl, A. Schneider, D. Stahl, T. Wanke, T. Labus (MSOE); G. Hillebrand, M. Mitchell (P&G); T. Herman (3DMD); J. Wellington (SME); B. Israel (Platypus Technologies, LLC).

Graduate and Postdoctoral Advisors: G. Hoffmann (MSOE)

Thesis Advisor and Postgraduate-Scholar Sponsor: None.

Michael Goldfarb
Department of Mechanical Engineering
Vanderbilt University

Professional Preparation

Massachusetts Institute of Technology	Mechanical Engineering	Ph.D. of Philosophy	1994
Massachusetts Institute of Technology	Mechanical Engineering	M.S.	1992
University of Arizona	Mechanical Engineering	B.S.	1988

Appointments

2005–present	Professor of Mechanical Engineering, Vanderbilt University
2000-2005	Associate Professor of Mechanical Engineering, Vanderbilt University
1994-2000	Assistant Professor of Mechanical Engineering, Vanderbilt University

Publications

1. Shen, X. and Goldfarb, M. Simultaneous Force and Stiffness Control of a Pneumatic Actuator. *ASME Journal of Dynamic Systems, Measurement, and Control*, vol. 129, no. 4, pp. 425-434, 2007.

2. Shen, X. and Goldfarb, M. Energy Saving in Pneumatic Servo Control Utilizing Inter-Chamber Cross-Flow. *ASME Journal of Dynamic Systems, Measurement, and Control*, vol. 129, no. 3, pp. 303-311, 2007.

3. Shen, X. and Goldfarb, M. On the Enhanced Passivity of Pneumatically-Actuated Impedance-Type Haptic Interfaces. *IEEE Transactions on Robotics*, vol. 22, no. 3, pp. 470-480, 2006.

4. Shields, B.L., Fite, K., and Goldfarb, M. Design, Control, and Energetic Characterization of a Solenoid Injected Monopropellant Powered Actuator, *IEEE/ASME Transactions on Mechatronics*, vol. 11, no. 4, pp. 477-487, 2006.

5. Al Dakkan, K.A., Barth. E.J., and Goldfarb, M. Dynamic Constraint Based Energy Saving Control of Pneumatic Servo Systems. *ASME Journal of Dynamic Systems, Measurement, and Control*, vol. 128, no. 3, pp. 655-662, 2006.

6. Shen, X., Zhang, J., Barth E.J., and Goldfarb, M. Nonlinear Model Based Control of Pulse Width Modulated Pneumatic Servo Systems. *ASME Journal of Dynamic Systems, Measurement and Control*, vol. 128, no. 3, pp. 663-669, 2006.

7. Fite, K.B., Goldfarb, M., and Rubio, A. Loop Shaping for Transparency and Stability Robustness in Time-Delayed Bilateral Telemanipulation. *ASME Journal of Dynamic Systems, Measurement, and Control*, vol. 126, no. 3, 2004.

8. Wu, J., Goldfarb, M., and Barth, E.J. On the Observability of Pressure in Pneumatic Servo Systems. *ASME Journal of Dynamic Systems, Measurement, and Control*, vol. 126, no. 4, 2004.

Synergistic Activities

Associate Editor, ASME Journal of Dynamic Systems, Measurement, and Control, 2001-2004.

Chair, ASME DSC Robotics Technical Panel, 1998-2000.

ASME Robotics Technical Committee, 2005-present.

ASME Mechatronics Technical Committee, 2006-present.

IEEE Technical Committee on Service Robotics, 1996-present

Faculty member volunteer for the Vanderbilt University Research Explorers lecture series, 1999-present.

Faculty member volunteer for Vanderbilt University/Cumberland Science Museum Science Frontiers NSF pilot study.

Collaborators and Other Affiliations

Collaborators and Co-Editors: Eric Barth, Ph.D., *Department of Mechanical Engineering, Vanderbilt University.* Hamayoon Kazerooni, Ph.D., *Department of Mechanical Engineering, UC Berkeley.* Alvin Strauss, Ph.D., *Department of Mechanical Engineering, Vanderbilt University.* Robert Labadie, M.D., *Department of Otolaryngology, Vanderbilt University.* Peter Konrad, M.D., Ph.D., *Department of Neurosurgery, Vanderbilt University.* Paul Pasquina, M.D., *Department of Physical Medicine and Rehabilitation, Walter Reed Army Medical Center.*

Graduate Advisors: William Durfee, Ph.D., *Department of Mechanical Engineering, University of Minnesota.* Woodie Flowers, Ph.D., *Department of Mechanical Engineering, M.I.T.* Robert Mann, Ph.D. (sadly deceased), *Department of Mechanical Engineering, M.I.T.* Thomas McMahon, Ph.D. (sadly deceased), *Division of Applied Sciences, Harvard University.*

Post-doctoral advisor: Xiangrong Shen 2006-present. Thomas Withrow, 2005-present. Kevin Fite, 2002-2006. Eric Barth, 2000-2002. Nicolae Lobontiu, 1999-2000.

Doctoral advisor: Farris, Ryan, Expected May 2011. Dalley, Skyler, Expect May 2011. Wait, Keith, Expected May 2009. Sup, Frank, Expected May 2009. Braun, David, Expected May 2009. Varol, Atakan, Expected May 2009. Li, Bo, Expected May 2008. Shen, Xiangrong, May 2006. Shields, Bobby, December 2004. Cox, Adam, August 2003. Al Dakkan, Khalid, August 2003. Fite, Kevin, B., December 2002. Siripanipipet, Taweedej, May 2002. Kilchenman, Marcia, August 2001. Speich, John E., August 2001.

Elizabeth T. Hsiao-Wecksler
Center for Autonomous Engineering Systems and Robotics
University of Illinois at Urbana-Champaign

Professional Preparation

Cornell University	Mechanical Engineering	BS	1987
Rochester Institute of Technology	Mechanical Engineering	MS	1994
University of California-Berkeley	Mechanical Engineering	PhD	2000
Harvard Medical School & Boston University	Rehabilitation Engineering	Post-doc	2000-2002

Appointments

2006	Affiliate, Center for Autonomous Engineering Systems and Robotics (CAESAR), University of Illinois at Urbana-Champaign
2005	Affiliate, Department of General Engineering, University of Illinois at Urbana-Champaign
2002	Affiliate, Department of Bioengineering, University of Illinois at Urbana-Champaign
2002-2003	Assistant Professor, Department of Mechanical Science and Engineering, University of Illinois at Urbana-Champaign
2000-2002	Post-doctoral Fellow, Integrated Rehabilitation Engineering Program, Boston University and Harvard Medical School
1987-1994	Senior Project Engineer, Low Volume Printers and Copiers Division, Xerox Corporation, Rochester, New York

Publications

1. Riemer, R., Hsiao-Wecksler, E.T. and Zhang, X. “Uncertainties in inverse dynamics solutions: a comprehensive analysis and an application to gait.” *Gait and Posture*, accepted.

2. Hsiao-Wecksler, E.T. “Biomechanical and age-related differences in balance recovery using the tether-release method.” *Journal of Electromyography and Kinesiology*, in press. *Invited Paper*.

3. Ramachandran, A.K., Yang, Y., Rosengren, K.S., and Hsiao-Wecksler, E.T. “Effect of Tai Chi on gait and obstacle crossing behaviors in middle-aged adults.” *Gait and Posture*, 26(2): 248-255, 2007.

4. Hsiao-Wecksler, E.T., and Robinovitch, S.N. “The effect of step length on young and elderly women’s ability to recover balance.” *Clinical Biomechanics*, 22(5): 574-580, 2007.

5. Doyle, R.D., Hsiao-Wecksler, E.T., Ragan, B.G., Rosengren, K.S. “Generalizability of center of pressure measures of quiet standing.” *Gait and Posture*, 25(2): p. 166-171, 2007.

Synergistic Activities

Course development: Modeling of Musculoskeletal Biomechanics. This course is an elective senior /first-year grad student lecture course for engineering and advanced kinesiology students. It explores various models of the human musculoskeletal system, ranging from the tissue (e.g., bone, muscle) to the whole body level (e.g., movement and balance). It is taught every fall semester since 2003.

Human and Robotic Locomotion Seminar: An interdisciplinary graduate seminar course with faculty and labs from Mechanical Engineering, Electrical Engineering, Kinesiology, Psychology, and Anthropology. Students in this course discuss issues and conduct interdisciplinary projects related to human locomotion and motor control using experimental and modeling techniques from biomechanics and robotics. It is taught every semester since 2003.

Development of research tools: Currently conducting projects to develop techniques for (a) quantitatively assessing patterns of motion in dynamic systems with specific interest in analyzing asymmetric gait behaviors, the focus of the current proposal, and (b) assessing postural responses to impulse perturbations.

Women & minorities in engineering: Research advisor to two undergraduate students who were 2004-2005 recipients of the Intel Undergraduate Research Program for Women and Minority Students. Course (ENG199W – Mentoring for Women Engineers): provide mentoring and advice to female undergraduate engineering students about career, course, and research opportunities. Academic advisor to eleven female and three minority (Hispanic) male Mechanical Engineering undergraduate students.

Undergraduate research advising: Since fall 2002, I have advised twenty-six undergraduate RAs in my lab (including eight women and two minority males). Thirteen have conducted independent study projects for course credit. One was an exchange student from Nagoya University, Japan. I was recognized in 2005 for this involvement of undergraduate researchers by receiving an Honorable Mention in the UIUC Campus Award for Excellence in Guiding Undergraduate Research.

Service: Session co-chair and reviewer American Society of Biomechanics conferences (2003, 2004, 2006, 2007) and International Society of Electromyography and Kinesiology Conference (2004). Reviewer for twelve journals. Ad-hoc reviewer for NIH – Musculoskeletal Rehabilitation Sciences study section, and NSF Graduate Research Fellowship Program – Bioengineering panel.

Collaborators and Other Affiliations

Collaborators: Andrew Alleyne, UIUC, Armand Beaudoin, UIUC, Sungjin Hong, UIUC, Gavin Horn, UIUC, IL Fire Service Inst, Peter Kurath, UIUC, Eric Loth, UIUC, John D. Polk, UIUC, Brian G. Ragan, U Northern Iowa, Karl S. Rosengren, UIUC, Jacob J. Sosnoff, UIUC, Yang Yang, UIUC, Xudong Zhang, UIUC

Graduate and Postdoctoral Advisors: Stephen N. Robinovitch, Simon Frasier Univ, Lewis A. Lipsitz, Harvard Medical School, James J. Collins, Boston University, D. Casey Kerrigan, University of Virginia

Thesis Advisor and Postgraduate-Scholar Sponsor: Total number of graduate students advised: 14 UIUC: Arun K. Ramachandran (MS), Matthew J. Major (MS), Kelly M. McHugh (MS), Brett A. Duiser (MS), K. Alex Shorter (MS/PhD), John Jang (MS), Raziel Riemer (PhD), Karthikeyan Rajendran (MS), Richard J. Doyle (PhD), Andrew Bosiljevac (MS), Louis DiBerardino (MS), Pilwon Hur (PhD), Kiwon Park (PhD), Robin Chin (MS)

Monika Ivantysynova, Ph.D
School of Mechanical Engineering & Agricultural and Biological Engineering
Purdue University

Professional Preparation

Slovak Technical University of Bratislava, CZ	Mechanical Engineering	M.S.E. 1979
Slovak Technical University of Bratislava, CZ	Mechanical Engineering	Ph.D. 1983

Appointments

2004-present	MAHA Professor Fluid Power Systems, School of Mechanical Engineering and Agricultural and Biological Engineering, Purdue University
1999-2004	Professor Mechatronic Systems, Institute for Aircraft Systems Engineering, Technical University of Hamburg-Harburg, Germany
1996-1999	Professor Fluid Power and Control, Department of Mechanical Engineering, Duisburg University, Germany
1992-1996	Senior Researcher and Manager of the Institute for Aircraft Systems Engineering at Technical University of Hamburg-Harburg, Germany
1990-1992	Project Leader at the Institute for Machine Design at Technical University of Hamburg-Harburg, Germany

Publications

1. Ivantysynova, M., Huang, Ch. and Behr, R. 2005. Measurements of elastohydrodynamic pressure field in the gap between piston and cylinder. Bath Workshop on Power Transmission and Motion Control PTMC 2005, Bath, UK, pp. 451 – 465 – Best paper award.

2. Ivantysynova, M., Huang, Ch. and Japing, A. 2006. Determination of gap surface temperature distribution in axial piston machines. ASME International Mechanical Engineering Congress, Chicago, USA, IMECE2006-15249.- Best paper Award.

3. Grabbel, J. and Ivantysynova, M. 2005. An investigation of swash plate control concepts for displacement controlled actuators. International Journal of Fluid Power, Vol. 6 (2005), No.2 August 2005. pp. 19- 36.

4. Eggers, B.; Rahmfeld, R. and Ivantysynova, M. 2005. An energetic comparison between valveless and valve controlled active vibration damping for off-road vehicles. 6th JFPS International Symposium on Fluid Power. Tsukuba, Japan. pp. 275-283.

5. Hilaire, A. St., Ossyra J.C. and Ivantysynova, M. 2006. Pump controlled active roll stabilizer. International Journal of Fluid Power, Vol. 7 (2006), No.1 March 2006. pp. 27- 40.

Synergistic Activities

One of the world's leading expert in Hydrostatic Systems; Thrust leader ERC for compact and efficient fluid power; Founder and Editor-in-Chief of the International Journal of Fluid Power since 2000

Three new WebCT courses about "Theoretical Principles of Displacement Pumps" developed and taught for Maha Distance Education Centre at Purdue University. Five other new courses related to

fluid power education developed and taught at University of Duisburg and Technical University of Hamburg-Harburg.

Member of scientific board of first virtual network in fluid power, the Fluid Power Net International (http://fluid.power.net) and Member of European Fluid Power Research Centre FPCE, http://www.fpce.net and member of many scientific boards and a guest (plenary) lecturer at many conferences and work shops

Research proposal review for Natural Sciences and Engineering Research Council of Canada (NSERC), Academy of Finland, Research Council for Natural Sciences and Engineering, German Basic Research Foundation DFG and Academy of Italy; External Reviewer for Norwegian University of Science and Technology NTNU, Tampere University of Technology, Aalborg University of Denmark and Expert of the Centre of Excellence in Research IHA by the Academy of Finland

Collaborators and Other Affiliations

Collaborators: All PI's of the ERC for compact and efficient fluid Power (Kim Stelson, Perry Li and Will Durfee, University of Minnesota, Wayne Book and Richard Salant, Georgia Tech, Mike Goldfarb and Eric Barth, University of Vanderbilt, Andrew Alleyne and Eric Loth, University of Illinois, John Lumkes, Purdue University) a large number of people at Purdue University.
Outside of Purdue University: P. Aachten (INNAS), Mike Betz (Sauer_Danfoss), U. M. Boni (Mecalac), Wayne John Book (Georgia Institute of Technology), Richard Burton (University of Saskatchewan), Esteve Codina (Technical University of Catalonia), Finn Conrad (Technical University of Denmark), Peter John Chapple (NTNU Norwegian University of Science and Technology), U. Czarkowski (Actia), P. Drews (APS), Germano Franzoni (University of Parma), Jörg Grabbel (Blohm & Voss), Changchun Huang, Jonathan Liscouet (INSA Touluse), Lewis Kasper (Parker-Hannifin), William R. Kelley (BorgWarner Inc.), Richard Kimbel (Parker Hannifin), Joe Kovach (Parker-Hannifin), Petr Konarik (Technical University Ostrava), Noah Manring (University of Missouri), Jean-Charles Mare (INSA Toulouse), Nicola Nervegna (Politecnico di Torino), Takao Nishiumi (National Defense Academy, Japan), Petr Noskievic (Technical University of Ostrava), Hakan Olsson (Mid Sweden University, Sweden), E. Orlando (Mecalac), P. Nentwig (Sauer-Danfoss), Jean Claude Ossyra (Parker-Hannifin), Roberto Paoluzzi (IMAMOTER - C.N.R), Robert Rahmfeld (Sauer-Danfoss), Jari Rinkinen (Tampere University of Technology), Rudolf Scheidl (University of Linz), Scott Schuh (Bobcat), E. Skirde (Sauer-Danfoss), Jacek S. Stecki (Monash University), John Watton (Cardiff University), J. Weber (O&K), Franz Weingarten (Parker Hannifin), Andrzej Sobzyk (Krakow University), Matti Vilenius (Tampere University of Technology), Howard Zhang (Parker-Hannifin).

Thesis and Dissertation Advisor: Prof. Paciga (TU Bratislava)

Thesis or Dissertation Advisor in last five years: Florian Ahlers, Peter Altermann, , Dorothee Bauer, Andreas Berns, Robert Behr, Blake Adam Carl, Gang Chen, S.Carsten Collon, Sven Kelana Christiansen, Nicolas Ducat, Bastian Eggers, Henning Evert, Stefan Ernst, G. Fevre, Tobias Götz, Jörg Grabbel, Susan Hanke, Rene Herrmann, Anderson St. Hilaire, Salomon Ige, Arnd Kikker, Richard Klop, Kyle Williams, Christopher Wiliamson, Alexander Krauss, Rolf Lasaar, Christian Latinovic, J. Andrew Layer, Sebastian Lienkamp, Lars Olems, Jean Claude Ossyra, Matteo Pelosi, Marian Preisner, Robert Rahmfeld, Michael Oppermann, Volker Schlabs, Jan Steinhagen, Saravanan Subramanian, Uwe Wieczorek, Elmar Wulf, J. A. Yamah

Xiaochun Jiang, Ph.D.
Department of Industrial and Systems Engineering
North Carolina A&T State University

Professional Preparation

East China Institute of Technology, Nanjing, China	Mechanical Engineering	B.S.	1992
Nanjing University of Science & Technology, Nanjing, China	Manufacturing Engineering	M.S.	1998
Clemson University	Industrial Engineering (with a Minor in Experimental Statistics)	Ph.D.	2001

Appointments

2002-present	Assistant Professor, Industrial and Systems Engineering Dept., NC A&T State
2002	Human Factors Engineer & FAA contractor, Titan Systems /SRC Division, Mays Landing, NJ

Publications

1. Jiang, X., Gramopadhye, A. K., Melloy, B. "Theoretical Issues in the Design of Visual Inspection Systems", *Theoretical Issues in Ergonomics Science*, **5**(3), 232 – 247, 2004.

2. Jiang, X., Master, R., Gramopadhye, A. K., and Melloy, B.J., Grimes, L. (2003), Evaluation of Best System Performance: Human, Automated, and Hybrid Inspection Systems, *International Journal of Human Factors in Manufacturing*, 13(2), 137-152.

3. Jiang, X., Khasawneh, M. T.**,** Master, R., Bowling, S. R., Gramopadhye, A. K., Melloy, B. J., and Grimes, L., "Measurement of Human Trust in a Hybrid Inspection System Based on Signal Detection Theory Measures," International Journal of Industrial Ergonomics, 34(5), 407-419, 2004.

4. Master, R., Jiang, X., Khasawneh, M. T.**,** Bowling, S. R., Grimes, L., Gramopadhye, A. K., and Melloy, B. "Measurement of Trust over Time in Hybrid Inspection Systems" *International Journal of Human Factors in Manufacturing* , 15(2), 177-196, 2005.

5. Gripper, M., McBride, M., Osafo-Yeboah, B., and Jiang, X., "Using the Callsign Acquisition Test (CAT) to Compare the Speech Intelligibility of Air versus Bone Conduction", International Journal of Industrial Ergonomics, in Press.

6. Nuschke, P., and Jiang, X., **"**A framework for inter-organizational collaboration and sensemaking integrating communication and knowledge management tools," Proceedings of 12th ICCRTS, Newport, RI, 2007.

7. Jiang, X., Master, R., Kelkar, K. and Gramopadhye, A. K., "Task Analysis of Shift Change Activity in Aviation Maintenance Environment: Methods and Findings", *Human Factors and Aerospace Safety*, **2**(1), 45-69, 2002.

8. Jiang, X., Bingham, J., Master R. Gramopadhye, A. K and Melloy B., "A Visual inspection simulator for hybrid environments" *International Journal of Industrial Engineering: Theory, Applications and Practice*, **9**(2), pg. 123-132, June 2002.

9. Jiang, X., Srinivasan, Gramopadhye, A. K., Ferrell, W. J. "Modeling Errors In Sampling Inspection: Effect of Degraded Performance", *Quality Engineering*, **15**(1), 67-74, 2002.

Synergistic Activities

Co-chair of Human Factors and Ergonomics Track, 2007 Industrial Engineering Research Conference (IERC)

Co-chair of Human Factors and Ergonomics Track, 2008 Industrial Engineering Research Conference (IERC)

Editorial Board, International Journal of Industrial Ergonomics

Statistical Analyst, Assess the effectiveness of the NC-LSAMP project which aims to attract more underrepresented minority students to pursue advanced degrees in STEM related areas.

Collaborators and Other Affiliations

Collaborators: Dr. Anand K. Gramopadhye, Dr. Brian J. Melloy, Dr. Byung Rae Cho, Dr. Michael S. Leonard – Clemson University, Dr. Celestine Ntuen, Dr. Eui Park, Dr. Younho Seong, Dr. Daniel Mountjoy, Dr. Udoka, Dr. Bala Ram, Dr. Sanjiv Sarin, Dr. Salil Desai– North Carolina A&T State University, Dr. Mohammad T. Khasawneh -- State University of New York at Binghamton, Dr. Sittichai Kaewkuekool, -- King Mongkut's University of Technology Thonburi, Thailand, Dr. Kim Stelson – university of Minnesota, Dr. Wayne Book – Georgia Institution of Technology

Graduate and Postdoctoral Advisor: Dr. Anand K. Gramopadhye – Clemson University

Thesis Advisor and Postgraduate: Gilena Monroe (MS, 2004) NASA AMES Research Center, Mountain View, California, Edem Tetteh (MS, 2005) Continuing Lecturer, Purdue University Richmond Campus, James Davis (MS, 2004) Nescafe, Angela Smith (MS, 2006) Caterpillar Inc, Paul Nuschke (MS, 2007) Electronic Ink, Porsche Williamson (MS, 2007) GE, Asha Clinkscale (MS, 2007)

Matey G. Kaltchev
Department of Physics and Chemistry
Milwaukee School of Engineering

Professional Preparation

University of Sofia, Bulgaria	Engineering Physics	M.S., 1983
University of Wisconsin – Milwaukee	Phys Chemistry/ Surface Sci	Ph.D., 1999
University of Wisconsin – Milwaukee	Surface Science–Tribology	Postdoc 2000-2002

Appointments

2002 – Present	Assistant Professor, Department of Physics and Chemistry, Milwaukee School of Engineering
2000 – 2002	Research Associate in Surface Science, UW Milwaukee
1993 – 1999	Research Assistant, Department of Chemistry and Lab for Surface Studies, UW-Milwaukee
1984 – 1993	Research Fellow, Institute of Catalysis, Bulgarian Academy of Sciences, Sofia, Bulgaria
1983 – 1984	Research Scientist, Institute of Microelectronics, Sofia, Bulgaria

Publications

1. Kaltchev, M., Gao, F, Tysoe, WT "Study of the friction coefficient dependence of halide thin films and monolayers on applied load using atomic force microscopy (AFM)", in preparation for publication in *Tribology Letters* (2004).

2. Gao F, Wu G, Stacchiola D, Kaltchev M, Kotvis PV, Tysoe WT "The tribological properties of monolayer KC1 films on iron in ultrahigh vacuum: Modeling the extreme pressure lubricating interface", *Tribology Letters* 14 (2), 99-104 (2003).

3. Wu G, Gao F, Kaltchev M, Gutow J, Mowlem JK, Schramm WC, Kotvis PV, Tysoe WT "An investigation of the tribological properties of thin KCI films on iron in ultrahigh vacuum: modeling the extreme-pressure lubricating interface", *WEAR* 252 (7-8), 595-606 (2002).

4. Kaltchev M, Kotvis PV, Blunt TJ, Lara J, Tysoe WT, "A molecular beam study of the tribological chemistry of dialkyl disulfides", *Tribology Letters* 10 (1-2), 45-50 (2001).

5. Kaltchev M, Celichowski G, Lara J, Tysoe WT, "A molecular-beam study of the tribological chemistry of carbon tetrachloride on oxygen-covered iron", *Tribology Letters* 9 (3-4), 161-165 (2000).

Synergistic Activities

Reviewer, 2004 Hawaii International Conference on Sciences, 2003.

Consultant, Lucas – Milhaupt Co., Milwaukee, 2004.
Open House at Milwaukee School of Engineering, Physics and Chemistry representative, Winter 2002, Winter 2003.

Consultant, Advanced Analytical Facility, UW Milwaukee.

1st Annual Poster Session in Chemistry, judge, MSOE, Milwaukee 2003.

Collaborators & Other Affiliations

Collaborators and Co-Editors:

V. Boiadjiev (University of Tennessee Knoxville); F. Gao, D. Stacchiola, A. Thompson, W.T. Tysoe, Y. Wang (University of Wisconsin Milwaukee); J. Gutow (University of Wisconsin-Oshkosh); P. Kotvis (Benz Oil, Milwaukee); G. Wu (Valvoline Labs, Lexington, KY).

Graduate and Postdoctoral Advisors:

Wilfred T. Tysoe (University of Wisconsin Milwaukee).

Thesis Advisor and Postgraduate-Scholar Sponsor:

E. Manova, M.S. graduate student supervised at the Institute of Catalysis, Bulgarian Academy of Sciences, 1988-1989.

Medhat Khalil
MSOE Applied Technology Center
Milwaukee School of Engineering

Professional Preparation

Military Technical College, Cairo, Egypt	Mechanical Engineering	B.S., 1983
Cairo University, Cairo, Egypt	Mechanical Engineering	M.S., 1989
Concordia University, Montreal, Canada	Mechanical Engineering	Ph.D., 2003

Appointments

July 2005	Distinguished Lecturer and Scientist in Fluid Power and Motion Control Applied Technology Center, Milwaukee School of Engineering
2003 - present	Hydraulic System Simulation Software Developer, Power Systems Control and Simulation Department, CAE Inc., Montreal.
2003 - present	Adjunct Assistant Professor, Dept. of Mechanical and Industrial Engineering, Concordia University, Montreal.
2000-2003	Research Assistant, Center of Industrial Control, Department of Mechanical and Industrial Engineering, Concordia University, Montreal.
1996-2000	Technical Office and Training Manager, YFHE Co.
1996-2000	Egyptian Agent, Mannesmann Rexroth, Cairo, Egypt.
1986-1996	Lecturer, Mechanical Power & Energy Department, Military Technical College, Cairo, Egypt.
1983-1986	Maintenance Engineer, Army Vehicles Workshop, Cairo, Egypt

Publications

1. M.K. Bahr Khalil and Shajan John, "IESHYD010V01 - Hydraulic Components Sizing Calculator", International Journal of Fluid Power, Vol. 8 #3, pp. 65-67, November 2007 Germany.

2.M. K. Bahr Khalil, J. Svoboda and R.B. Bhat, "Modeling of Swash Plate Axial Piston Pumps with Conical Cylinder Blocks", Journal of Mechanical Design, ASME Transaction, Vol.126, pp 196-200, January 2004, USA.

3.M.K. Bahr Khalil, "Estimated versus Calculated Viscous Friction Coefficient in Spool Valve Modeling" Proceedings of the 51st National Conference on Fluid Power, International Fluid Power Exhibition, IFPE 2008 Technical Conference, March 2008, Las Vegas, NV., USA.

4.M.K. Bahr Khalil, "Innovative Tool for Custom Course Building and Delivery", Submitted for publication at the 11th Annual World Conference on Continuing Engineering Education, May 2008, Atlanta, USA. Abstract.

5.Khalil, M.K., Deping Li and Bhat, R.B. "Controlling of Rolling Mills Operating Conditions Using Variable Displacement Pump and Electro-Hydraulic Pressure Compensator". 12th International Conference on Applied Mechanics and Mechanical Engineering AMME-12, May 16-18, 2006, Military Technical College, Cairo, Egypt.

Synergistic Activities
Member of the "Continuing Education Committee," Canadian Society of Mechanical Engineering (CSME).

Member of the Professional Engineering Organization PEO, Ontario, Canada, Under Process.

Collaborators & Other Affiliations
Collaborators and Co-Editors: None

Graduate and Postdoctoral Advisors:
M.Sc.: S. Kassem (Cairo University)
Ph.D.: R. Bhat (Concordia University)

Thesis Advisor and Postgraduate-Scholar Sponsor: None

Perry Y. Li
Department of Mechanical Engineering
University of Minnesota

Professional Preparation

Cambridge University, England	Electrical & Information Sci.	B.A.(Hons.), 1987
Boston University, Boston	Biomedical Engineering	M.S., 1990
University of California, Berkeley	Mechanical Engineering	Ph.D., 1995

Appointments

2003-present	Associate Prof., Dept. Mechanical Engineering, Univ. of Minnesota
1999-present	Graduate Faculty in Control and Dynamic Systems (CDyS) Program, University of Minnesota
1997-2003	Nelson Assistant Prof., Dept. Mech. Engineering, Univ. of Minnesota
1995-1997	Member of the Research Staff, Xerox Wilson Center for Research and Technology
1990-1990	Research Engineer, Anesthesia Bioengineering Unit, Massachusetts General Hospital, Boston, Massachusetts
	Biomechanics Consultant, Reebok Corporation, Stoughton, MA

Publications

1. Q.Y. Yuan and P.Y. Li, "Using Steady Flow Force for Unstable Valve Design: Modeling and Experiments," To appear in the *ASME J. Dynamic Systems, Measurement & Control*.

2. P.Y. Li and K. Krishnaswamy, "Passive Bilateral Teleoperation of an Electrohydraulic Actuator Using an Electrohydraulic Passive Valve," *International J. Fluid Power*, Issue 13, pp. 43-59, 2004.

3. K. Krishnaswamy and P.Y. Li, "On the Use of Unstable Electrohydraulic Valves for Control," *ASME J. Dynamic Systems, Measurements & Control*, **124**(1), pp.183-190, 2002.

4. P.Y. Li, "Dynamic Redesign of a Flow Control Servovalve," *ASME J. Dynamic Systems, Measurement and Control*, **124**(3), pp. 428-434, 2002.

5. P.Y. Li, "Toward Safe and Human Friendly Hydraulics: The Passive Valve," *ASME J. Dynamic Systems, Measurements & Control*, **122**(3), pp. 402-409, 1999.

Synergistic Activities

Director of the industry supported "University of Minnesota Fluid Power Control Education and Research Initiative."

Developed a new U/G course "Fluid Power Controls Laboratory" to integrate systems dynamics, modeling and control concepts, with practical aspects of fluid power and controls.

Chair, Fluid Control Panel, in the ASME Dynamic Systems and Control Division.

PI of current NSF project: “Software Enabled Variable Displacement Pumps,” CMS-0409832.

Team Leader of a NFPA funded U/G project to build a hydraulic exoskeleton.

Co-PI on a NSF project to develop “Distributed Laboratory” for U/Gs learning systems dynamics. DUE/CCLI-0231121.

Associate Editor, *ASME Journal of Dynamic Systems, Measurement and Control*. 2003-present.

Collaborators & Other Affiliations

Collaborators and Co-Editors: W. Durfee, A. Erdman, S. Ramaswamy, K. Stelson (Univ. of Minnesota); E. Gross, E. Hamby (Xerox); G. Chiu (Purdue); S. Dianat (RIT); R. Horowitz (Berkeley); R. Ngwompo (Bath).

Graduate and Postdoctoral Advisors:
R. Horowitz (PhD, Berkeley); Z. Ladin (MS, Boston)

Thesis Advisor and Postgraduate-Scholar Sponsor: (all Univ. of Minnesota)
Graduates: C. Chen (MS); C. Zhong (MS); A. Shrivastava (MS); J. Li (MS); P. Bjegovic (MS); D. Rajala (MS); S. Saimek (PhD); D.J. Lee (PhD); K. Krishnaswamy (MS, PhD).
Current PhD students: Q. Yuan, Z. Liu, T. Sim, J. Longstregth, C.Y. Li.
Current MS students: R. Anderson, M. Stoner.

Eric Loth
Aerospace Engineering
University of Illinois at Urbana-Champaign

Professional Preparation

West Virginia University	Aerospace Engineering	B.S., 1983
Pennsylvania State University	Aerospace Engineering	M.S., 1985
University of Michigan	Aerospace Engineering	Ph.D., 1988

Appointments

2002-present	Willett Faculty Scholar, Univ. of Illinois College of Engineering
2002-present	Professor of Aerospace Engineering, Univ. of Illinois
1995-2002	Associate Prof. of Aeronatuical & Astronautical Eng., Univ. of Illinois
1990-1995	Assisitant Prof. of Aeronatuical & Astronautical Eng., Univ. of Illinois
1989-1990	Aerospace Engineer, Lab for Comp. Physics & Fluid Dynamics, Naval Res. Lab
1988-1989	Staff Scientist, Berekely Research Asssociates, Springfield VA

Publications

1. Dorgan and E. Loth, "Simulation of Particles Released Near the Wall in a Turbulent Boundary Layer," *Intl. J. Multiphase Flow* (to appear).

2. Y. Lee, E. Hafenricheter, J.C. Dutton and E. Loth, "Skin Friction Measurements for Recirculating Normal Shock/Boundary-Layer Interaction Control," *AIAA J.* (to appear).

3. E. Loth, W. Sherman, A. Aumann and C. Navarro, "A Virtual Technique for Multiphase Flows," *Int'l. J. Computational Fluids Dynamics*, **18**(3), pp. 265-275, 2004.

4. E. Loth, "Smart Materials for Mesoflap Bleed and Injection," (Invited Talk) *ASME Summer Fluids Engineering Meeting*, FEDSM2001-18277, New Orleans, May-June 2001.

5. T. Bocksell and E. Loth, "Random Walk Models for Particle Diffusion in Free-Shear Flows," *AIAA Journal*, **39**(6), pp. 1086-1096, 2001.

Synergistic Activities

Cambridge University (England), Engineering Department Visiting Scholar (fall 2004 sabbatical)

National Energy Technology Lab, ORISE Summer Faculty, Morgantown, WV (2002)

Brown University and University of California San Diego, Visiting Associate Professor (fall 1997 sabbatical)

Molten Metal Technology, Senior Research Engineer, Waltham, MA (summer 1996, 1997)

Naval Research Lab, Senior Fellow & ASEE Summer Faculty, Washington, D.C. (1995)

Arnold Engineering and Development Center**,** AFOSR Summer Faculty, TN (1993)

Science Applications Intl. Corp**.**, Senior Research Engineer, VA (summers 1990, 1991)

Collaborators & Other Affiliations

Collaborators and Co-Editors: A. Alleyne, M. Bragg, J.C. Dutton, P.Guebelle, P. Hrnjak, J. Molner, D. Tortorelli, S. White (UIUC); D. Davis, M. Potapczuk (NASA Glenn); D. Lankford (AEDC); S. McIlwain (StarCD); F. Roos (Boeing); W. Sherman (NCSA).

Thesis Advisor or Postgraduate-Scholar Sponsor:

Graduate students (total 24): Last 5 years includes P. Bhattacharjee, B. Field, R. Jaiman (UIUC); T. Bocksell (Pratt & Whitney); C. Bhargava (Madison Systems); A. Dorgan, D. Gefroh (Boeing); E. Hafenrichter (Sandia); S. Lee (Boston); J. Pan (Illinois State Water Survey).

Post-doctoral (total 27): S. Dug KIM (UIUC), S. McIlwain (Star-CD)

John H. Lumkes Jr. P.H.D., PE
Agricultural and Biological Engineering
Purdue University

Professional Preparation

Calvin College	Engineering	B.S.E, 1990
University of Michigan—Ann Arbor	Mechanical Engineering	M.S.E., 1992
University of Wisconsin—Madison	Mechanical Engineering	Ph.D., 1997

Appointments

2004-present Assistant Professor, Agricultural and Biological Engineering Department
Purdue University, West Lafayette, Indiana

2001-2004 Associate Professor, Mechanical Engineering Department
Milwaukee School of Engineering, Milwaukee, Wisconsin.

1997-2001 Assistant Professor, Mechanical Engineering Department
Milwaukee School of Engineering, Milwaukee, Wisconsin.

Publications

1. Lumkes, J., Control Strategies for Dynamic Systems, Design and Implementation, Marcel-Dekker Inc., 616 pages, 2002, ISBN: 0—8247—0661—7.

2. Hanks, T., and Lumkes, J. “Adaptive Control System for Electrohydraulic Camless Engine Gas Valve Actuator”, Proceedings of the 24th American Control Conference (ACC), June 8 to 10, 2005, Portland, Oregon.

3. Brauer, J., and Lumkes, J., “Coupled model of a magnetically-actuated valve controlling a hydraulic cylinder and load”, IEEE Transactions on Magnetics, March 2002, Vol. 38 Issue 2, p917.

4. Ficken, J., Labus, T., and Lumkes, J., “Electrohydraulics in the Undergraduate Curriculum”, Proceedings of the American Control Conference, Chicago, IL, June, 2000.

5. Van Doorn, W. and Lumkes, J., “Directional Stability Enhancement Of A Dual Path Front Hydrostatic Drive By Wire Off-Road Vehicle”, 2006 ASME International Mechanical Engineering Congress & Exposition, November 5-10, 2006, Chicago, IL USA.

7. Hadj-Kacem, N., and Lumkes, J., “Fuel Consumption Simulation on the Federal Urban Drive Cycle of a Hydrostatic Transmission Vehicle Modeled with Bond Graphs”, Proceedings of the 50th National Conference on Fluid Power (NCFP), March, 2005.
8. Lumkes, J., van Doorn, W., and Donaldson, J., “The Design and Simulation of a High Force Low Power Actuation System for Camless Engines”, Proceedings of 2005 ASME International Mechanical Engineering Congress and Exposition, November 5-11, 2005, Orlando, FL USA.

9. Batdorff, M., and Lumkes, J., "Virtually Variable Displacement Hydraulic Pump Including Compressibility And Switching Losses", 2006 ASME International Mechanical Engineering Congress & Exposition, November 5-10, 2006, Chicago, IL USA.

10. Holland, M., Harmeyer, K., and Lumkes, J., "Electrically Controlled Fixed-Displacement Pump, Variable-Displacement Motor Hydrostatic Transmission", 2006 SAE Commercial Vehicle Engineering Congress & Exhibition, October 31- November 2, 2006, Chicago, IL USA.

Synergistic Activities

Faculty Advisor, Purdue ASABE Chapter, American Society of Agricultural and Biological Engineers. Advisor for the ¼ Scale Student Design team. (2004-present)

SAE International Professional Society Activities: SAE Fluid Power Committee (2006-present), SAE Aerospace Program Office (APO) Committee (2003-present), SAE Aero Design Competition Rules Committee (2003-present), Board of Directors, Position of Vice Chair of Student Activities, Milwaukee Section of SAE (2003-2004), SAE Aero Design and Formula Design faculty advisor (1998-2004), SAE Chapter Faculty Advisor (1998-2004)

Musto, J., Lumkes, J., and Carnell, W., A Freshmen Programming Course for Mechanical Engineers Using Mechatronics Applications, Proceeding of the 2004 American Society for Engineering Education Annual Conference and Exposition, Salt Lake City, UT, June, 2004.

Lumkes, J., "The Integration of Student Design Competitions and Academic Curricula", accepted for presentation and publication at the 2006 ASME International Mechanical Engineering Congress & Exposition, November 5-10, 2006, Chicago, IL USA.

Lumkes, J., and Cesareo, V., The Use of Composites in Radio-Controlled Cargo Airplanes Designed for Student SAE Aero Design Competitions, 17th Technical Conference, American Society for Composites, October, 2002.

Collaborators & Other Affiliations

Collaborators: Tom Bray (Dean of Research, MSOE), John Brauer (Retired, formerly an employee of Ansoft and MSOE), Gary Krutz (Professor, ABE Dept. Purdue University), Monika Ivantysynova (Professor, ABE and ME Dept, Purdue University), Tom Wanke (Director of the Fluid Power Institute, MSOE)

Graduate Advisor: Ph.D. Advisor, Frank Fronczak, University of Wisconsin—Madison

Thesis Advisor: Tom Hanks (MSE), Josh Donaldson (MSE), Nabil Hadj-Kaceem (MSE), Howard Haugstad (MSE), Mark Batdorf (MSE), Bill VanDoorn (MSE)

Current Graduate Students: Mark Batdorff (Ph.D.), Jose Garcia (Ph.D.), Prashant Desai (MSE), John Mahrenholz (MSE), Cody McKinley (MSE), Greg Long (MSE)

Susan C. Mantell
Department of Mechanical Engineering
University of Minnesota

Professional Preparation

Stanford University	Mechanical Engineering	B.S.,	1977
Northeastern University	Mechanical Engineering	M.S.,	1987
Stanford University	Mechanical Engineering	Ph.D.,	1991

Appointments

2006-present	Professor and Design and Manufacturing Division Director, Department of Mechanical Engineering, University of Minnesota
2003-2006	Professor, Department of Mechanical Engineering, University of Minnesota
1998-2003	Associate Professor, University of Minnesota
1991-1998	Assistant Professor, University of Minnesota
1996-1997	Visiting Assistant Professor, Department of Mechanical Engineering, Massachusetts Institute of Technology
1982-1987	Design Engineer, CTI Cryogenics, Waltham, MA
1981-1982	Mechanical Engineer, GTE Sylvania, Westboro, MA
1979-1981	Internship (summers) for General Motors, Packard Electric Division, Youngstown, OH

Publications

1. Wu, C., Mantell, S.C., and J. Davidson, “Macroscopic Failure of Multilayered Viscoelastic Polymers,” to appear in Polymer Engineering and Science, (in press 2007).
2. Thomas, D., Mantell, S., Davidson, J., Goldberg, L., and Carmody, J., “Analysis of Sandwich Structures for a Self-supporting Residential Roof,” ASME J. of Solar Energy Engineering, **128**, 338-348, 2006.
3. Li, Z., Mantell, S., and Davidson, J. (2005). "Mechanical Analysis of Streamlined Tubes with Nonuniform Wall Thickness for Heat Exchangers." *Journal of Strain Analysis for Engineering Design*, 40(3), pp. 275-285.
4. Freeman, A., Mantell, S. C., and Davidson, J. (2005). "Mechanical Performance of Polysulfone, Polybutylene, and Polyamide 6,6 in Hot Chlorinated Water." *Solar Energy Journal*, 79, pp. 624-637. also appeared in Proceedings Solar World Congress, Orlando, FL.
5. Parthasarathy, S., Mantell, S.C., and Stelson, K., (2004), "Estimation, Control and Optimization of Curing in Thick-Sectioned Composite Parts", *ASME Journal of Dynamic Systems, Measurement and Control*, **126** (December), pp. 1-10.

Synergistic Activities

Outreach/Design Education

STEPs summer camp for high school girls summer camp sponsored by the Society of Manufacturing Engineers, curriculum development and instructor for (2000-2002)

Design camp for high school students sponsored by the University of Minnesota Design Institute and College of Human Ecology, curriculum development and instructor (2000)

Young Scientists Round Table, Presentation on Composite Structures for Edina and Plymouth School Districts
Enquiring Minds, University of Minnesota, Poster session sponsored by the Graduate School
SWE Panel for high school girls considering the Institute of Technology, panelist (2000-2002)
Girl Scout Saturday sponsored by the Institute of Technology, curriculum development and instructor

Undergraduate advising activities
Iowa State University, Mechanical Engineering Department Advisory Council: member since 2001
Undergraduate advisor, upper division, Mechanical Engineering (2001-present)
Pi Tau Sigma: Mechanical Engineering Honor Society, faculty advisor U of MN student chapter (2002-2004)

Editor
Associate Editor *Journal of Composite Materials* (since December 2000)
Associate Editor *Journal of Materials Processing and Manufacturing Science* (August 1998 March 2003)

Collaborators & Other Affiliations
Graduate and Postdoctoral Advisors: Stanford University, George Springer (Ph.D.).

Thesis Advisor and Postgraduate-Scholar Sponsor:
Visiting Scholars: Joy Zhou
Post Graduates: Anand Rau, Dongsheng Wang, Gur Mittelman
Ph.D.: Li Cao, Robert Duh, Charles Hautamaki, Elizabeth Linstrom, Sanjay Parthasarathy, WeiChing Sun, Chunhui Wu, Tikeswar Naik, Liyong Sun, Zhihua Li

Collaborators: Jane Davidson (UMN), Ellen Longmire (UMN), Terry Simon (UMN), Kim Stelson (UMN), Beth Lanier (Chevron Phillips), Jay Burch (DOE), John Carmody (UMN)

Ashlie Martini
School of Mechanical Engineering
Purdue University

Education

Northwestern University	Mechanical Engineering	B.S. 1998
Northwestern University	Mechanical Engineering	Ph.D. 2007

Appointments

8/08 –	Assistant Professor, Mechanical Engineering, Purdue
8/07 – 5/08	Visiting Assistant Professor, Mechanical Engineering, Purdue
8/07 – 5/08	Visiting Postdoctoral Fellow, Mechanical Engineering, Northwestern

Selected Publications

Martini, A., Roxin, A., Wang, Q., Snurr, R.Q., and Lichter, S. “Molecular Mechanisms of Liquid Slip”, Journal of Fluid Mechanics, Accepted.

Martini, A., Zhu, D., and Wang, Q., 2007, “Friction Reduction in Mixed Lubrication”, Tribology Letters, 28, 109-222.

Martini, A., Velter, G., Keer, L.M., and Wang, Q., 2007, “Enhancement of a Simplified Model for Maximum Stress Prediction,” Tribology Letters, 23, 61-67.

Lichter, S., Martini, A., Snurr, R.Q., and Wang, Q., 2007, "Liquid Slip as a Rate Process," Physical Review Letters, 98, 226001.

Zhu, D., Martini, A., Wang, W., Hu, Y.H., Lisowski, B., and Wang, Q., 2007, “Simulation of Sliding Wear in Mixed Lubrication,” ASME Journal of Tribology, 129, 544-552.

Martini, A., Liu, Y.C., Snurr, R.Q., and Wang, Q., 2006, “Molecular Dynamics Characterization of Thin Film Viscosity for EHL Simulation,” Tribology Letters, 21, 217-225.

Synergistic Activities

Invited Participant, Atomic-scale Friction Research and Education Synergy Hub (AFRESH) project kick-off workshop (2007).

President, Northwestern University Mechanical Engineering Graduate Students’ Society (2006-2007).

Chairperson and Organizer, Northwestern University NSF-IGERT Annual Symposium on Virtual Tribology (2006).

Track Organizer, World Tribology Conference III, Student Poster Session (2005).

Coordinator, Preparing Future Engineering Faculty (2003-2004).

Graduate Student Representative and Scribe, NSF/ASME Workshop on the Future of Tribology (2004)

Graduate Advisors

Professor Q. Jane Wang, Northwestern University, Department of Mechanical Engineering, Evanston, IL

Professor Randall Q. Snurr, Northwestern University, Department of Chemical and Biological Engineering, Evanston, IL

Stephen L. McCary-Henderson
Curriculum and Instruction
North Carolina A&T State University

Professional Preparation

North Carolina A&T State University	Mathematics Education	B.S., 1983
North Carolina A&T State University	Professional Mathematics	B.S., 1983
University of Southern Mississippi	Mathematics Education	M. Ed., 1992
Union Institute and University	Team and Org. Devel.	Ph.D., 2001

Appointments

2003-present	Assistant Professor, North Carolina A&T State University
2002-2003	Adjunct Assistant Professor, North Carolina A&T State University
1988-2002	Mathematics Instructor/Freshman Academic Advisor, North Carolina A&T State University
1987-1988	Mathematics and Science Teacher, Charlotte-Mecklenburg School System, Charlotte, NC
Summers: 1987, 1989, 1990, 1993-1995	Mathematics/Physics/Computer Science, Accessing Mathematics-Based Careers (Intensive Summer Science Program), Bennett College

Publications

1. D. Massey, A. Graham, S. McCary-Henderson and E. Williams, "Creating Community Among African American Online Learners: A Case for Instructor Collaboration," Society for Information Technology and Teacher Education 15th International Conference (Atlanta, GA; March 1-6, 2003) p. 112.

2. K. Smith-Gratto, D. Leflore, S. McCary-Henderson and T. Olds, "Evaluating the Infusion of Technology into Teacher Education Curriculum," Society for Information Technology and Teacher Education 15th International Conference (Atlanta, GA; March, 1-6, 2003) p. 164.

3. "Tip for selecting a college major in a STEM discipline," Presented at the First Annual OPT-ED Alliance Day (Raleigh, NC; September 2002).

4. "Transitioning into STEM Disciplines: Tips on Selecting a College Major," Presented at the Sixth Annual Undergraduate Research Conference – North Carolina Louis Stokes Alliance for Minority Participation (Raleigh, NC; April 2002).

Synergistic Activities

National Council of Teachers of Mathematics

North Carolina Council of Teachers of Mathematics

Collaborators & Other Affiliations

Collaborators and Co-Editors: C. Caple (Virginia Tech); L. Edwards (Fayetteville State University); A. Graham, D. Leflore, S. Ricks T. Smith K. Smith-Gratto, (North Carolina A & T State University); D. Massey (University of Washington at Tacoma).

Graduate and Postdoctoral Advisors: Masters: H. Petticord (University of Southern Mississippi), Doctorate: E. Wingard (Union Institute and University)

Thesis Advisor and Postgraduate-Scholar Sponsor: None

Paul Michael
Fluid Power Institute
Milwaukee School of Engineering

Professional Preparation

University of Wisconsin, Milwaukee	Chemistry	B.S.	1987
DeVry University, Keller Graduate School	Business	M.B.A.	2001

Appointments

2005-present	Research Chemist, MSOE Fluid Power Institute, Milwaukee, WI
1987-present	Part-time Faculty, MSOE Fluid Power Institute, Milwaukee, WI
1993-2005	Technical Director, Benz Oil, Milwaukee, WI
1987-1993	Applications Chemist, Benz Oil, Milwaukee, WI
1978-1987	Laboratory Manager, Filmite Oil, Milwaukee, WI

Publications

1. P. Michael, "Lubrication in the Timber and Paper Industries," Handbook of Lubrication and Tribology, Vol.1, G.E. Totten Ed., Taylor & Francis, Boca Raton, 2006.
2. P. Michael, "In The Flow – How Viscosity Affects Grinding Oil Performance," *Cutting Tool Engineering*, 56(7) pp. 23-27, 2004.
3. W.A. Givens, P.W. Michael, "Hydraulic Fluids," ASTM Fuels & Lubricants Handbook, G.E. Totten Ed., ASTM International, West Conshohoken, PA, 2003.
4. P. Michael, "Standards For Hydraulic Fluid Testing," Handbook of Hydraulic Fluid Technology, G.E. Totten Ed., Marcel Dekker, NY, 2000.
5. S.N. Herzog, T.E. Marougy, P.W. Michael, "Fluid Viscosity Selection For Hydraulic Pumps and Motors," Proceedings of the 48th National Conference on Fluid Power – National Fluid Power Association, 2000.

Synergistic Activities

Society of Tribologists and Lubrication Engineers
Certified Lubrication Specialist, 1997

Massachusetts Institute of Technology
Summer Program in Tribology, 1992

American Society for Quality
Certified Quality Engineer, 1992

Society of Tribologists and Lubrication Engineers
Bearing Failure Analysis Course, 1988

Collaborators & Other Affiliations

National Fluid Power Association
Secretary, Fluids Committee
Project Chair / Co-Chair in authorship of:

NFPA T2.13.14 – 2006:
Recommended practice – Hydraulic fluid power – Use of environmentally acceptable fluids

NFPA T2.13.13 – 2002:
Recommended practice – Hydraulic fluid power – Fluids – Viscosity selection criteria for hydraulic motors and pumps

NFPA T2.13.1 – 1997:
Recommended Practice – Hydraulic fluid power – Use of fire resistant hydraulic fluids

American Society of Testing and Materials
Chairman of Hydraulic Fluid Industrial Applications Section D02.N02
Project Chair in authorship of:

ASTM D 5534
Test Method for Vapor-Phase Rust-Preventing Characterisitcs of Hydraulic Fluids

ASTM D 6547
Test Method for Corrosiveness of Lubricating fluid to a Bimettalic Couple

Saint V's Pantry
Food Pantry Director & Conference President, St.Vincent de Paul Society

Luc Mongeau
Department of Mechanical Engineering
Purdue University

Professional Preparation

University of Montreal	Mechanical Engineering	B.Sc.	1984
University of Montreal	Mechanical Engineering	M.Sc.	1986
The Pennsylvania State University	Graduate Program in Acoustics	Ph.D.	1991

Appointments

2006 – present	Professor, Mechanical Engineering, McGill University, Montreal, PQ, Canada Adjunct Professor, Purdue University, West Lafayette, IN, U.S.A.
2003 - 2004	Visiting Professor, Ecole Centrale de Lyon, Ecully, France.
2003 - 2006	Professor, School of Mechanical Engineering, Purdue University, West Lafayette, Indiana, U.S.A.
1998 - 2003	Associate Professor, School of Mechanical Engineering, Purdue University, West Lafayette, Indiana, U.S.A.
1998	Summer Intern, Boeing Commercial Airplane Group, Seattle, Washington, U.S.A.
1993- 1998	Assistant Professor, School of Mechanical Engineering, Purdue University, West Lafayette, Indiana, U.S.A.
1991-1992	Postdoctoral member of technical staff, AT&T Bell Laboratories, 600 Mountain Avenue, Murray Hill, New Jersey, U.S.A.
1987-1991	Research Assistant, Applied Research Laboratory, State College, Pennsylvania, U.S.A.
1986-1987	Instructor, Ecole Polytechnique, University of Montreal, Montreal, Canada.
1985-1986	Research Assistant, Ecole Polytechnique, University of Montreal, Montreal, Canada.

Publications

1. Park, J., Mongeau, L., and Siegmund, T., “An investigation of the flow-induced sound and vibration of viscoelastically supported rectangular plates: experiments and model verification,” *Journal of Sound and Vibration*, Vol. 275, No. 1, pp. 249-265, 2004.

2. Li, Y., Chiu, G.T.C., and Mongeau, L.G., “Dual-Driver Standing Wave Tube: Acoustic Impedance Matching With Robust Repetitive Control,” paper 2002-274, *IEEE Transactions on Control Systems Technology*, Vol. 12, No. 6, pp. 869-880, 2004.

3. Li, Y., Rotea, M.A., Chiu, G.T.-C., Mongeau, L.G., and Paek, I.S., “Extremum Seeking Control of a Tunable Thermoacoustic Cooler,” *IEEE Transactions on Control Systems Technology*, Vol. 13, No. 4, pp. 527-536, 2005.

4. Zanartu, M., Mongeau, L. and Wodicka, G. R., "Influence of acoustic loading on an effective single mass model of the human larynx", *J. Acoust. Soc. Am.*, Vol. 121, No. 2, pp. 1119-1129, 2007.

5. Cook, D.D., and Mongeau, L., "Sensitivity of a continuum vocal fold model to geometric parameters, constraints, and boundary conditions," *J. Acoust. Soc. Am.*, Vol. 121, No. 4, pp. 2247-2253, 2007.

6. Paek, I., Braun, J.E., and Mongeau, L., "Evaluation of standing-wave thermoacoustic cycles for cooling applications," *Int. J. Refrigeration*, Vol. 30, No. 6, pp. 1059-1071, 2007.

7. Thomson, S.L., Mongeau, L., and Frankel, S.H., "Flow over a membrane-covered, fluid-filled cavity," *Computers and Structures*, Vol. 85, No. 11, pp. 1012-1019, 2007.

8. Singh, K.K., Mongeau, L., Frankel, S.H., and Gore, J.P., "Effect of Co- and Counterswirl on Noise from Swirling Flows and Flames," *AIAA Journal*, Vol. 45, No. 3, pp. 651-661, 2007.

Synergistic Activities

Prof. Mongeau holds a Tier 1 Canada Research Chair in Flow-Induced Sound and Vibrations. He serves as Associate Dean for Academic Affairs for the Faculty of Engineering at McGill University. He is an active member of the Acoustical Society of America, the Institute for Noise Control Engineering, as well as the ASME, AIAA, and SAE.

Collaborators and Other Affiliations

At Purdue: S. Frankel, J. Braun, S. Bolton, R. Bernhard, T. Siegmund, M. Plesniak, G. Chiu, M. Franchek, A. Lyrintzis, C. Krousgrill, and P. Davies.

Outside Purdue: P. Blanc-Benon (E. Centrale Lyon, France), R. Scherer (Bowling Green State), R. Chan (Texas Southwestern), C. Duncan (Bowling Green State), David Freed (Exa Corporation).

Recent Ph.D. graduate students: P.T. Lew (Exa), I.S. Paek (Kangwon, Korea), J.B. Park (McGill), K. Singh (GE research), S. Thomson (BYU), Z. Zhang (UCLA), Y. Li (Wisconsin-Milwaukee), J. Park (Hanyang, Korea), F. Han (GE research), J. Kook (Hankook, Korea), S. Suh (Cummins).

Total number of students advised: 28 (and 5 postdoctoral scholars).

Daniel N. Mountjoy
Department of Industrial and Systems Engineering
North Carolina A&T State University

Professional Preparation

Wright State University	Systems Engineering/Human Factors	B.S., 1989
Wright State University	Systems Engineering/Human Factors	M.S. 1991
North Carolina State University	Industrial Engineering (Ergonomics)	Ph.D. 2001

Appointments

2000-2007	Assistant Professor, Industrial and Systems Engineering Dept., North Carolina A&T State University
1993-2000	Human Factors Engineer, Sytronics, Inc.
1991-1993	Research Associate, Anthropology Research Project, Inc.

Publications

1. Mountjoy, D. N., Russell, J., Ram, B. & Yu, X. Exploring the use of intelligent agents for manufacturing team training. Accepted for publication in *International Journal of Industrial Engineering.*

2. Mountjoy, D. N. (2005). Towards an understanding of risk taking in teleoperation. In *Proceedings of the IIE 2005 Annual Conference*. Norcross, GA: Institute of Industrial Engineers. CD ROM.

3. Seong, Y., Mountjoy, D. & Park, Y. (2005). Defining the decision zone considering a multitude of environmental factors. In *Proceedings of the IIE 2005 Annual Conference.* Norcross, GA: Institute of Industrial Engineers. CD ROM.

4. Mountjoy, D. N. (2004). Interface design and risk-taking in teleoperation. Accepted for publication in *Proceedings of the IIE 2004 Annual Conference*. Norcross, GA: Institute of Industrial Engineers.

5. Russell, J. D., Mountjoy, D. N., Yu, X., and Ram, B. (2003). Training teams through an agent-based simulation. In *Proceedings of the IIE 2003 Annual Conference*. Norcross, GA: Institute of Industrial Engineers.

Synergistic Activities

Currently advising undergraduate student in driving decision zone research for NC-LSAMP program

Collaborators & Other Affiliations

Collaborators and Co-Editors: M. Bikdash, A. Esterline, X. Jiang, C.A. Ntuen, A. Perry, B. Ram, Y. Seong (North Carolina A&T State University); S.A. Converse (NC State University); R. Koubek (Penn State University); W.P. Marshak (Sytronics, Incorporated); T. Smith-Jackson (Virginia Polytechnic Institute and State University).

Graduate and Postdoctoral Advisors: S.A. Converse, North Carolina State University, J. Wilson, North Carolina State University, C.A. Ntuen, North Carolina A&T State University

Christiaan J.J. Paredis
School of Mechanical Engineering
Georgia Institute of Technology

Professional Preparation

Katholieke Universiteit Leuven, Belgium	Mechanical Engineering	B.S./M.S., 1983/1988
Université de Liège, Belgium	Business Administration	B.S. 1989/1991
Carnegie Mellon University	Electrical & Computer Eng	M.S./Ph.D., 1990/1996

Appointments

2002-present	Assistant Professor, School of Mechanical Engineering, Georgia Institute of Technology
1998-2002	Research Scientist, Institute for Complex Engineered Systems, Carnegie Mellon University
1996-1998	Visiting Research Engineer, Institute for Complex Engineered Systems, Carnegie Mellon University

Publications

1. R.J. Malak Jr and C.J.J. Paredis, "Validating Behavioral Models for Reuse," *Research in Engineering Design*, accepted for publication, to appear in 2007. (http://www.srl.gatech.edu/Members/rmalak/RED07_MalakParedis.pdf)

2. S.J. Rekuc, J.M. Aughenbaugh, M. Bruns, and C.J.J. Paredis, "Eliminating Design Alternatives Based on Imprecise Information," *SAE 2006 Transactions, Journal of Materials and Manufacturing*, paper no. 2006-01-0272, March 2007.

3. J.M. Aughenbaugh, and C.J.J. Paredis, "The Value of Using Imprecise Probabilities in Engineering Design," *Journal of Mechanical Design*. Vol. 128, No. 4, pp. 969–979, 2006.

4. [2] J.M. Ling, J.M. Aughenbaugh, C.J.J. Paredis, "Managing the Collection of Information under Uncertainty Using Information Economics," *Journal of Mechanical Design*. Vol. 128, No. 4, pp. 980–990, 2006.

5. [3] J. Schlosser, and C.J.J. Paredis, "Managing Multiple Sources of Epistemic Uncertainty in Engineering Decision Making," *Proceedings of the SAE 2007 World Congress*, paper no. 2007-01-1481, Detroit, Michigan, April 16–19, 2007.

6. J.H. Panchal, C.J.J. Paredis, J.K. Allen, and F. Mistree, "Simulation Model Refinement for Decision Making via a Value-of-Information Based Metric," *Proceedings of IDETC/CIE 2006*, paper no. DETC2006-99433, Philadelphia, PA, 2006.

Synergistic Activities

Co-advisor (with Prof. Wayne Book) of the RoboJackets, the Georgia Tech robotics club; the club mentors local high schools in the FIRST Robotics Competition (FRC), and participates in national and international robot competitions such as the Intelligent Ground Vehicles Competition and RoboCup. The club has about 40 active members and a $35K/year budget.

Education and Outreach Liaison at Georgia Tech for the NSF funded ERC for Compact and Efficient Fluid Power; organized "technology enrichment" sessions on fluid power for local high schools participating in robotics competition; mentored a teacher (NSF RET) and four of her students from Stone Mountain High School (89% African American) to develop an engineering design module related to fluid power.

Chair, ASME Computer and Information in Engineering Division, July 2007–June 2008; Executive Committee Member since 2002; Chair of the 2007 CIE Conference; Program Chair of the 2006 CIE Conference.

Associate director of the Product and Systems Lifecycle Management Center at Georgia Tech. Consortium for developing the next generation PLM methods and infrastructure, with the vision for "Georgia Tech-inspired PLM methods and tools to be used for managing product and process lifecycles in global supply chains to optimize profitability, customer service, and sustainability."

Developed undergraduate and graduate courses on Model-Based Design; received the 2007 *CETL/BP Junior Faculty Teaching Excellence Award* and the Society of Automotive Engineer's *2007 Ralph R. Teetor Educational Award* for excellence and innovation in teaching.

Collaborators & Other Affiliations

Collaborators and Co-Editors: J. Allen (GaTech), A. Alleyne (UIUC), E. Barth (Vanderbilt), W. Book (GaTech), B. Bras (GaTech), T. Bray (MSOE), R. Burkhart (Deere), T. Chase (UMN), K. Cunefare (GaTech), W. Durfee (UMN), S. Ferson (Applied Biomathematics), S. Frankel (UMN), S. Friedenthal (Lockheed Martin), P. Fritzson (Linköping U), V. Gervasi (MSOE), L. Ginzburg (Applied Biomathematics), M. Goldfarb (Vanderbilt), A. Griffin (GaTech), E. Hsiao-Wecksler (UIUC), M. Ivantysynova (Purdue), X. Jiang (NCAT), S. John (MSOE), M. Kaltchev (MSOE), M. Khalil (MSOE), D. Kittelson (UMN), P. Krus (Linköping U), P. Li (UMN), E. Loth (UMN), J. Lumkes (Purdue), S. Mantell (UMN), S. McCary- Henderson (NCAT), D. McDowell (GaTech), L. McGinnis (GaTech), P. Michael (MSOE), F. Mistree(GaTech), L. Mongeau (McGill), D. Mountjoy (NCAT), Z. Mourelatos (Oakland U), E. Park (NCAT), R. Peak (GaTech), D. Rosen (GaTech), M. Ruzzene (GaTech), R. Salant (GaTech), M. Shofner (GaTech), K. Stelson (UMN), S. Udoka (NCAT), J. Van De Ven (UMN), S. Wereley (Purdue), H. Zhu (GaTech).
Graduate and Postdoctoral Advisors: Pradeep Khosla (Carnegie Mellon University)

Thesis Advisor and Postgraduate-Scholar Sponsor: Khaled Al-Ajmi (Riyad Bank, Saudi Arabia), Jason Aughenbaugh (UT, Austin), Morgan Bruns (UT, Austin), Michael Collins (Software Engineering Institute), Antonio Diaz-Calderon (Jet Propulsion Laboratory), Soshi Iba (Honda R&D, Wako Research Center), Vei-chung Liang (NIST), Jay Ling (Nebraska Dept. of Transp.), Jitesh Panchal (Georgia Tech Savannah), Tarun Rathnam (Texas Instruments), Steven Rekuc (Royalox), Rajarishi Sinha (IC Mechanics).

Eui H. Park, Ph.D.
Department of Industrial and Systems Engineering
North Carolina A&T State University

Professional Preparation

Yonsei University	Korea Physics	B.S.	1972
Mississippi State	University Industrial Engineering	M.S.	1978
City University	Business Administration	M.B.A.	1980
Mississippi State	University Industrial Engineering	Ph.D.	1983

Appointments

1983 – present	Assistant/Associate/Full Professor, Department of Industrial and Systems Engineering, North Carolina A&T State University
1990 – 2005	Chairperson, Department of Industrial and Systems Engineering, North Carolina A&T State University
1978 – 1982	Senior Engineer, Division of Engineering Computing Systems, Boeing Commercial Airplane Company, Seattle, Washington
1985	Summer Faculty, Information Productions Division, IBM - Charlotte, NC
1983 – present	Consulted with ConVatec, Kaplan, Panel Concepts, Brayton International, Longwood, Guilford County Public Health, Korean Institute of Metals and Machinery, Hyundai, and Korean Management Association.

Publications

1. E. Park, P. deMattos, and J. Park, "Forecasting Resource Requirements at Hospital Emergency Department," 2007 IIE Lean and Quality, Atlanta, GA, September 2007.

2. E. Park, E. Idoya, and P. deMattos, "Improvement of Inventory Tracking System with Value Stream approach," Proceedings of the 2007 International Conference on Industry, Engineering, and Management Systems, Cocoa Beach, FL, March 2007.

3. Y. Seong, E. Park and Hwa-Ki Lee, "Sensemaking and Human Judgment Under Dynamic Environment," Journal of the Ergonomics Society of Korea, Vol. 25, No.3, pp. 1-12, August 2006.

4. Park, E. & C. Ntuen," A Model for Predicting Human Reliability under Workload and Skill Performance," 2006 INFORMS International Conference, Hong Kong, China, June 2006.

5. Ntuen, C. & E. Park, "Human Performance in Monitoring Linear Automation Behavior," Proceedings of 15th Triennial Congress of the International Ergonomics Association, Seoul, Korea, August 2003.

6. Ntuen, C. & E. H. Park "Supporting Courses of Action Planning with Intelligent Management of Battle Assets," Proceedings of Command & Control Symposium, National Defense University, July 2003.

7. Ntuen, C., S. Eastman & E. Park, "CAAD: The Commander's Battle Plan Assistance, Handbook of Human-Computer Interface for Military Application (M. Vassillious & T. Huang), Computer Society Press, Chapter 21, pp.237-257, 2001.

8. Okoye, C., A. Ntuen, E. Park & C. Plaisant **"**A Functionalist Approach to Usability Evaluation of Adaptive Learning Environment," Proceedings of 9th International Conference on Human-Computer Interaction New Orleans, Louisiana, August 2001.

9. Ntuen, C., C. Chi and E. Park, "An Interactive Display Decision Support System for Visualization of Battle Events," Proceedings of the 8th Annual Industrial Engineering Research Conference, Phoenix, Arizona, May 1999.

10. Park, E. and S. J. Udoka, "Traversing The Real-Virtual Continuum: A Comparison of Augmented Reality Vs. Virtual Reality For Adaptations To Manufacturing Applications, Research Trends in Design and Manufacturing (Chapter 10), Korean Science & Engineering Foundation, Nov. 1998, pp. 10-1 – 10-32.

11. Ntuen, C. and E. Park, "Collaborative Planning Agents for Supervisory Control of Advanced Manufacturing Systems," Proceedings of the International Conference on Hybrid Automation and Ergonomics, Hong Kong, July 1998, IEA Press, pp.391-395.

12. Ntuen, C., E. Park and D. Speller, "An Open Shop Scheduling Simulation Using Expert Database," Proceedings of the 7th IE Research Conference, IIE Press, Banff, Canada, May 1998.

13. Park, E., Y. Park and K. Han, "Environmentally Conscious Manufacturing Using Concurrent Engineering," Proceedings of the 7th IE Research Conference, Banff, Canada, May 1998.

Synergistic Activities

Fellow, Institute of Industrial Engineers, since 2000

Board of Directors, Member, Piedmont Triad Center for Advanced Manufacturing, 1997 – 2005

Director, Manufacturing Initiatives, North Carolina A&T State University, 1989 – 1995

Co-Program Chair, Symposium on Human Interactions with Complex Systems, five times since 1991.

Principle Investigator in 19 awarded funded research projects totaling over $5 million in the past ten years.

Collaborators & Other Affiliations

Collaborators: Dr. Richard Sisson – Mechanical Engineering, Worcester Polytechnic Institute, Dr. Albert George – Mechanical Engineering, Cornell University, Dr. Celestine Ntuen, Dr. Bala Ram, Dr. Sanjiv Sarin and Dr. Jung Kim – Industrial & Systems Engineering, North Carolina A&T State University, Dr. Earl Barnes and Dr. Don Ratliff – School of Industrial & Systems Engineering, Georgia Institute of Technology, Dr. Wayne Book – School of Mechanical Engineering, Georgia Tech, Dr. Gary Rubloff – Institute of Systems Research, University of Maryland

Graduate Advisors:

Drs. Larry Brown and Fazli Rabbi (Mississippi State University); Dr. Joe Tanchoco (Purdue University)

Richard F. Salant
Department of Mechanical Engineering
Georgia Institute of Technology

Professional Preparation

Massachusetts Institute of Technology	Mechanical Engineering	BS	1963
Massachusetts Institute of Technology	Mechanical Engineering	MS	1963
Massachusetts Institute of Technology	Mechanical Engineering	ScD	1967

Appointments

2001- Present	Georgia Power Georgia Institute of Technology Distinguished Professor
1987 – 2001	Professor Georgia Institute of Technology
1972 – 1987	Manager - Fluid Mechanics Borg Warner Research Center & Heat Transfer Dept.
1972	Associate Professor, M.I.T.
1968 – 1972	Assistant Professor, M.I.T.
1966 – 1968	Assistant Professor, University of California/Berkeley

Publications

1. Salant, R. F. and Rocke, A., "Hydrodynamic Analysis of the Flow in a Rotary Lip Seal Using Flow Factors, Journal of Tribology, vol. 126, pp. 156-161, 2004 and STLE/ASME Tribology Conference, pp. 2003-Trib-118, 2003.

2. Rocke, A. H. and Salant, R. F., "Elastohydrodynamic Analysis of a Rotary Lip Seal Using Flow Factors, Tribology Transactions, vol. 48, pp. 308-316, 2005 and 60th Annual Meeting, STLE, 2005.

3. Shen, D. and Salant, R. F., "An Unsteady Mixed Soft EHL Model, with Application to a Rotary Lip Seal," Tribology International, vol. 40, pp. 646-651, 2007.

4. Shen, D. and Salant, R. F., "A Transient Mixed Lubrication Model of a Rotary Lip Seal with a Rough Shaft," Tribology Transactions, vol. 49, pp. 621-634, 2006 and 61st Annual Meeting, STLE, 2006.

5. Salant, R. F., Maser, N. and Yang, B., "Numerical Model of a Reciprocating Hydraulic Rod Seal," Journal of Tribology, Vol. 129, pp. 91-97, 2007 and STLE/ASME Tribology Conference, San Antonio, pp. Trib-06-1052, 2006.

6. Shi, F. and Salant, R. F., "Numerical Study of a Rotary Lip Seal with a Quasi-Random Sealing Surface," Journal of Tribology, vol. 123, pp. 517-524, 2001.

7. Harp, S. R. and Salant, R. F., "An Average Flow Model of Rough Surface Lubrication with Inter-Asperity Cavitation, Journal of Tribology, vol. 123, pp. 134-143, 2001.

8. Harp, S. R. and Salant, R. F., "Inter-Asperity Cavitation and Global Cavitation in Seals: An Average Flow Analysis," Tribology International, vol. 35, pp. 113-121, 2002.

9. Salant, R. F. and Shen, D., "Hydrodynamic Effects of Shaft Surface Finish on Lip Seal Operation," Tribology Transactions, vol. 45, pp. 404-410, 2002.

10. Shen, D. and Salant, R. F., "Elastohydrodynamic Analysis of the Effect of Shaft Surface Finish on Rotary Lip Seal Behavior," Tribology Transactions, vol. 46, pp. 391-396, 2003.

Synergistic Activities

Associate Editor, Journal of Fluids Engineering (1984-1987)

Associate Editor, Journal of Tribology (1993-1999)

Member of the Editorial Board, Sealing Technology, Elsevier (1993-present)

ASME – Fellow (1990), Henry R. Worthington Medal (1996), Machine Design Award (2003).

STLE – Fellow (1997), Edmond E. Bisson Award (2000), Frank P. Bussick Award (2002, 2005, 2007)

Collaborators & Other Affiliations

Collaborators: Alajbegovic, V. (Freudenberg-NOK); Bair, S.; Cao, B.; Cowan, R.; Danyluk, S.; Dong, J. (Rockwell Automation); Flitney, R. (BHR Group); Gomez, S. (Schlumberger); Green, I.; Poll, G. (U. Hannover); Rocke, A.; Shen, D.(Maxxis); Streator, J.; Sullivan, E. (Hughes Christensen); Wilkinson, C. (Schlumberger); Winer, W.

Graduate Advisor: Tau-Yi Toong, MIT (retired)

Thesis Advisees: Shen, D. (Maxxis); Ramirez, A. (Sandia); Alajbegovic, V. (Freudenberg-NOK); Rocke, A (McKim & Cree); Maser, N. (Pratt and Whitney); Wang, L.; Yang, B.; Thatte, A.

***** If no affiliation is given, the affiliation is Georgia Tech.

Kim A. Stelson
Department of Mechanical Engineering
University of Minnesota

Professional Preparation

Stanford University	Mechanical Engineering	B.S.,	1974
Massachusetts Institute of Technology	Mechanical Engineering	S.M.,	1977
Massachusetts Institute of Technology	Mechanical Engineering	Sc.D.,	1982

Appointments

2006-present	Director, NSF Engineering Research Center for Compact and Efficient Fluid Power
1994-2006	Director, Design and Manufacturing Division, Department of Mechanical Engineering, Univ. of Minnesota
1994-present	Professor, Dept. of Mechanical Engineering, Univ. of Minnesota
2001-2002	Visiting Professor, Univ. of Bath, United Kingdom
1996	Visiting Associate Professor, Univ. of Auckland, New Zealand
1987-1994	Associate Professor, Dept. of Mechanical Engineering, Univ. of Minnesota
1992-1993	Visiting Senior Lecturer, Hong Kong Univ. of Science and Technology
1981-1987	Assistant Professor, Department of Mechanical Engineering, Univ. of Minnesota

Publications

1. Yu, X., R. Rajamani, K. A. Stelson, and T. Cui, "Carbon Nanotube Based Transparent Thin Film Acoustic Actuators and Sensors," *Sensors and Actuators A: Physical*, Vol. A132, pp. 626-631, Nov. 2006.

2. Groepper, C., T. Cui, P. Y. Li and K. A. Stelson, "Design of Integrated Pressure, Flow and Temperature Sensor for Hydraulic Systems," *Bath Symposium on Power Transmission & Motion Control, PTMC 2006,* 13-15 September 2006, pp. 321-334.

3. S. Parthasarathy, S.C. Mantell and K.A. Stelson, "Estimation, Control and Optimization of Curing in Thick-Sectioned Composite Parts," *Transactions of ASME, Journal of Dynamic Systems, Measurement and Control*, **126**(4), 2004.

4. H. Zhu, R. Rajamani and K.A. Stelson, "Development of Thin Panels for Active Control of Acoustic Reflection, Absorption and Transmission," *Journal of the Acoustical Society of America,* **113**(2), pp. 852-870, 2003.

5. D.R. Youtt, R. Rajamani and K.A. Stelson, "Passive and Active Vibration Isolation for a Variable Displacement Axial Piston Pump," *Power Transmission and Motion Control*, pp. 307-318, 2002.

Synergistic Activities

Director, NSF ERC for Compact and Efficient Fluid Power, 2006-present
Director of Graduate Studies, M.S. in Manufacturing Systems, 1997-2001. A master's degree program for full-time employees in industry.

Director, STEPS Summer Camp for Girls, 2000-2002. A program for high school girls that motivates an interest in engineering by building and launching a rocket.

Associate Technical Editor, *ASME Journal of Manufacturing Science and Engineering*, 1995-2001; *SME Journal of Manufacturing Processes*, 1999-present; and *ASME Journal of Dynamic Systems, Measurement and Control*, 2003-present.

Editorial Board, *Transaction on Control, Automation and Systems Engineering*, 2000-present; and *IMechE Journal of Engineering Manufacture*, 2000-present. Scientific Committee, *Transactions of the North American Manufacturing Research Institute of SME*, 1999-present.

Collaborators & Other Affiliations

Graduate and Postdoctoral Advisors: Massachusetts Institute of Technology S.M. thesis advisor, Shawn Buckley; Massachusetts Institute of Technology Sc.D. thesis advisor, David Gossard.

Thesis Advisor and Postgraduate-Scholar Sponsor: M. Bhattacharya (U. of Minn.); X. Cheng (U. of Missouri-Rolla); J. Dudney (St. Jude Medical); K.A. Edge (U. of Bath); D. Fronimidis (U. of Bath); S. Kidane (U. of Minn.); A. Kramer (U. of Braunschweig); D. Liu (Guidant); H. Lou (Seagate); Y.P. Mei (Seagate); A.R. Mileham (U. of Bath); A. Sen (U. of Minn.); M.A. Sokola (U. of Bath); N. Sun (U. of Minn.); W.C. Sun (Formosa Plastics); V.R. Voller (U. of Minn.); D. R. Youtt (Eaton).

Zongxuan Sun
Department of Mechanical Engineering
University of Minnesota

Professional Preparation

University of Illinois at Urbana-Champaign	Mechanical Engineering	Ph.D. 2000
University of Illinois at Urbana-Champaign	Mechanical Engineering	M.S. 1998
Southeast University, China	Automatic Control	B.S. 1995

Appointments

2007 – present	Assistant Professor, Department of Mechanical Engineering, University of
2006 – 2007	Staff Researcher, Research and development Center, General Motors Corp.
2000 – 2006	Senior Researcher, Research and Development Center, General Motors Corp.
1999 – 2000	Senior Engineer, Western Digital Corp.
1996 – 2000	Research Assistant, University of Illinois at Urbana-Champaign

Publications

1. Sun, Z. and Kuo, T., "Electro-Hydraulic Fully Flexible Valve Actuation System for Advanced Combustion Development", Proceedings of the 2006 FISITA World Congress, Yokohama, Japan, F2006P287, Oct., 2006.

2. Sun, Z. and Miao, H., "Hydraulic Assist Power System", Proceedings of the 2006 International Mechanical Engineering Congress and Exposition, Chicago, IL, IMECE2006-13704, Nov., 2006.

3. Sun, Z., "Self-Regulating Electro-Hydraulic Valve Actuator Assembly", US patent 6,928,966, 2005.

4. Sun, Z., "Engine Valve Actuator Assembly with Dual Automatic Regulation", US patent 6,959,673, 2005.

5. Sun, Z. and Tsao, T.-C., "Adaptive Control with Asymptotic Tracking Performance and Its Application to an Electrohydraulic Servo System", ASME Transactions on Journal of Dynamic Systems, Measurement and Control, Vol.122, pp. 188-195, 2000.

Synergistic Activities

Guest editor, "Active Automotive Safety Systems", IEEE Control System Magazine.

Invited session organizer, "Dynamics and Control of Flexible Engine Valve Actuation", The 2003 American Control Conference, Denver, CO.

Invited session organizer, "Advance in Modeling and Control of Powertrain and Its Subsystems", The 2003 American Control Conference, Denver, CO.

Invited session co-organizer, "Alternative Automotive Propulsion and Actuation Technologies", The 2003 American Control Conference, Denver, CO.

Invited session co-organizer, "Automated Highway Systems", The 2003 American Control Conference, Denver, CO.

Invited session co-organizer, “Modeling and Control of Transportation Systems”, The 2003 American Control Conference, Denver, CO.

Collaborators & Other Affiliations

Collaborators and Co-Editors: Hsu-Chiang Miao, Burak Gecim, Shih-Ken Chen (GM), T.-C. Tsao (UCLA), G. Zhu (MSU)

Thesis Advisor or Postgraduate-Scholar Sponsor: J. Dixon, Y. Wang, X. Song, A. Zulkefli (U of Minn)

Silvanus Johnson Udoka, Ph. D.
Department of Industrial and Systems Engineering and Department of Business Administration
North Carolina A&T State University

Professional Preparation

Weber State University	Manufacturing Engineering Technology	B.S., 1982
Oklahoma State University	Industrial Engineering & Management	M.S., 1984
Oklahoma State University	Industrial Engineering & Management	Ph.D., 1989

Appointments

1997 - Present	Associate Professor (Tenured), Department of Industrial & Systems Engineering and Department of Business Administration (Joint Appointment), NC A&T State University.
2000	Summer Faculty Intern, Consilium, An Applied Materials Company, Mountain View, CA.
1999	Summer Faculty Research Fellow, GE Corporate Research and Development, Niskayuna, NY
1992 - 1997	Assistant Professor, Department of Industrial & Systems Engineering and Department of Business Administration (Joint Appointment), NC A&T State University.
1989 - 1992	Assistant Professor, Department of Industrial Engineering, University of Wisconsin-Platteville, Platteville, WI.
1985 - 1989	Instructor of Industrial Engineering & Management Oklahoma State University, Stillwater, OK
1984 - 1985	Distribution Manager, Sunmark Inc., Carrolton, TX

Publications

1. Sanders, J. H. and S. J. Udoka "A Step-Wise Search for Statistical Significance in Establishing a Manufacturing Process Window. " To be Presented at the FAIM 2007 Conference, Philadelphia, PA, June 17-20, 2006.

2. Huff, Jimmy and S. J. Udoka "Analysis of Peak Picked Detections of Sonar Signals Derived From Simulations of Sonar Beam Intensities." To be presented at the 2007 Industrial Engineering Conference, Nashville, TN, May 19-23, 2007.

3. Udoka, S. J. "Lean Six Sigma: A Roadmap to Systematic Process Improvement." Proceedings of the 7th Africa-USA International Conference on Manufacturing Technology" Port Harcourt, Nigeria, July 12-14, 2004.

4. Udoka, S. J. "A Framework for a Confluence Of Six-Sigma, Lean Strategies and SCOR." Proceedings of the 2004 Industrial Engineering Conference (IERC), Houston, TX. May 15-19, 2004.

5. McGee, A. A. and S. J. Udoka, "A Process Model for Interdisciplinary Virtual Teams," Proceedings of the 2003 Industrial Engineering Research Conference (IERC), Portland, Oregon, May 17-21, 2003.

6. Sanders, J. and S. J. Udoka, "Development of the "Science" of Micro Lithography Glass Grinding & Polishing Using Virtual Manufacturing." Proceedings of the 13th International Conference one Flexible Automation & Intelligent Manufacturing (FAIM) 2003, June 9-11, 2003, Tampa Florida.

7. Franceschini, Ricardo J., Silvanus J. Udoka, and Frederick Ferguson, "A Rational Standard for Design of Living and Experimental Modules for Sustained Space Habitation." Proceedings of the 2001 Industrial Engineering Research Conference (IERC), Dallas, TX, May 20-22, 2001.

8. Udoka, S. J., E. H. Park and C. A. Ntuen "Adaptations of Virtual Reality and Augmented Reality to Manufacturing Applications: Implications for Developing Economies." Proceedings of the 5Th Africa-USA Conference on Manufacturing Technology, Abuja, Nigeria, July 10-14, 2000., pp. 38-45.

Synergistic Activities

"*A Framework for Optimizing Manufacturing Task Performance Utilizing a Virtual Environment."* Doctoral Dissertation under my supervision (Janet H. Sanders, Ph.D. Candidate)

"Mixed Reality Development in a Scalable Visualization Environment." A Project funded under Title III Grant for Ph. D. student development.

Interdisciplinary Learning, Discovery and Engagement of Students through Integrated Virtual Team Projects: The Interdisciplinary Virtual Team (IVT) Project was initiated and implemented starting in the 2002-2005 academic year and is ongoing in my courses in the Department of Industrial and Systems Engineering in cooperation with Dr. Chi Anyansi-Archibong in courses in the Department of Business Administration.

Collaborators and Other Affiliations

Collaborators: Dr. Marc Goetschalckx – Georgia Institute of Technology, Dr. Paul Stanfield – North Carolina A&T State University

Graduate Advisors: Dr. John W. Nazemetz – Oklahoma State University, Dr. Allen C. Schuermann – Oklahoma State University, Dr. David E. Mandeville – Oklahoma State University

Graduate Students Supervised (As Chair) For Thesis Or Project: Kula Bwamba – Masters Project (Completed May 1997), Charles Ehule – Masters Project (Completed April 1998), Ricardo Franceschini – Masters Thesis (Completed July 2000), Aquaris Moore - Masters Thesis (Completed June 2000), Kristin E. Bell - Masters Thesis (CompletedJune 2001), Alecia A. McGee – Masters Project (Completed - May 2003), Nicole Champion – Masters Project (Completed July 2004), Janet Sanders – Ph. D. Dissertation (Completed July 2007), Jimmy Huff - Ph. D. Dissertation (In Progress)

Steven T. Wereley, PH.D.
Department of Mechanical Engineering
Purdue University

Professional Preparation

Lawrence University	Physics	B.A.	1990
Washington University	Mechanical Engineering	B.S.	1990
Northwestern University	Mechanical Engineering	M.S.	1992
Northwestern University	Mechanical Engineering	Ph.D.	1997
University of California, Santa Barbara	Post Doctoral Scholar Experimental Microfluidics		1997-1999

Appointments

2005-Present	Associate Professor, Purdue University, School of Mechanical Engineering, West Lafayette, IN
1999-2005	Assistant Professor

Publications

1. M. Raffel, C. Willert, S. Wereley, J. Kompenhans, *Particle Image Velocimetry: A Practical Guide*, Springer, New York (2007).

2. N.T. Nguyen and S.T. Wereley, *Fundamentals and Applications of Microfluidics (2nd edition)*, Artech House, Boston, 2006.

3. S.T. Wereley and C.D. Meinhart, "Electrokinetics in Microdevices" in Complex Systems Science in BioMedicine, eds. Deisboeck, Kresh and Kepler, Kluwer, Boston (2006).

4. A.R. De Carlo, M. Rokkam, A. ul Haque, S.T. Wereley, P.P. Irazoqui, H.W. Wells, W.T. McLamb, S.J. Roux, D.M. Porterfield, "Development of a Microfluidic Ion Sensor Array (MISA) to Monitor Gravity-Dependent Calcium Fluxes in Ceratopteris Spores," Gravit. and Space Biol. Bull., Vol 19, pp. 123-124 (2006).

5. R. Gomez, R. Bashir, A. Sarakaya, M.R. Ladisch, J. Sturgis, J.P. Robinson, T. Geng, A.K. Bhunia, H.L. Apple, and S.T. Wereley, "Microfluidic Biochip for Impedance Spectroscopy of Biological Species," J. Biomedical Microdevices, Vol. 3, No. 3, 201-209 (2001).

6. A. ul Haque, A. R. De Carlo, M. Rokkam, S.T. Wereley, H.W. Wells, W.T. McLamb, S.J. Roux, D.M. Porterfield, "Design, fabrication and characterization of an in silico cell physiology lab for measuring cellular responses to microgravity," J. Phys: Conf. Ser., Vol. 34, pp. 740–746, (2006).

7. H. Sagi, Y. Zhao, and S.T. Wereley, "Wide Range Flow Sensor—Vacuum through Viscous Flow Conditions," J. Vac. Sci. and Tech. A, Vol. 22, No. 5, pp. 1992-1999 (2004).

8. S. Devasenathipathy, J.G. Santiago, S.T. Wereley, C.D. Meinhart, and K. Takehara, "Particle imaging techniques for microfabricated fluidic systems," Exp. Fluids, Issue: Vol. 34, pp 504-514 (2003).

9. C.D. Meinhart, S.T. Wereley, and J.G. Santiago, "Micron-Resolution Velocimetry Techniques," *Developments in Laser Techniques and Applications to Fluid Mechanics*, R. J. Adrian et al. (Eds.), Springer-Verlag, Berlin, pp. 57-70, (2000).

10. S.T. Wereley and R.M. Lueptow, "Inertial particle motion in a Taylor Couette rotating filter," Phys. Fluids, Vol. 11, No. 2, 325-333, (1999).

Synergistic Activities

Member of Purdue Engineering-wide group reforming the first year curriculum to include nano science and nanotech topics.

Collaborated with an electrical engineering professor at Nanyang Technical University in Singapore to write a microfluidics textbook currently being used at several universities to instruct micro systems/fluidics classes.

Developed a micro-Particle Image Velocimetry (□PIV) software package that is currently used in several universities and industrial settings.

Collaborators and Affiliations

Collaborators: Purdue University: Heather Apple, Rashid Bashir, A.K. Bhunia, Stuart Bolton, George Chiu, T. Geng, Lichuan Gui, Steve Frankel, Rafael Gomez, Mike Ladisch, Mike Plesniak, J.P. Robinson, A. Sarakaya, Paul Sojka, J. Sturgis; UC Santa Barbara: Rich Chiu, Mike Gray, Carl Meinhart, Shannon Stone; Stanford: Shankar Devasenathipathy, Juan Santiago; Northwestern University: Rich Lueptow; University of Illinois: Ron Adrian; University of Wisconsin: Dave Beebe

Graduate Advisors and Postdoctoral Sponsors: M.S. and Ph.D. advisor: Rich Lueptow, Northwestern University. Postdoctoral Sponsor: Carl Meinhart, UC Santa Barbara

Thesis Advisor and Postgraduate-Scholar Sponsor: Professor Wereley has or is currently advising 9 Ph.D. and 8 Masters Students: M.S. Jinhua Cao, Pramod Chamarthy, Andrew Ewing, Venu Gorti, Choongbae Park, Aeraj ul Haque, Ira Whitacre, Yabin Zhao Ph.D. Jinhua Cao, Pramod Chamarthy, Oswald Chuang, Jaesung Jang, Aloke Kumar, Sang-Youp Lee, Radha Muddu, Craig Snoeyink, Stuart Williams