15th Annual ARC Conference
May 12th – 13th, 2009

Held at the
Four Points by Sheraton Ann Arbor
3200 Boardwalk, Ann Arbor, Michigan 48108-1799 (*directions*)

Online registration is now closed.

For inquires, please email: arc-conference-inquiries@umich.edu

Organized by the
Automotive Research Center

U.S. Army Tank-automotive and Armaments Command (TACOM)
U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC)
National Automotive Center (NAC)

Automotive Research Center
2043 W.E. Lay Automotive Lab
1231 Beal Avenue
Ann Arbor, MI 48109-2133

ARC Conference Day 1 Schedule
Tuesday May 12th 2009

7:00 - 8:00am **Arrival and Continental Breakfast**

8:00 - 8:10 **Welcome and Introductions**

Dennis Assanis
Professor and ARC Director, The University of Michigan

Dr. Peter Schihl
U.S. Army TARDEC

8:10 9:40 **Keynote Address:**
Towards Future Fuel Efficient and Reliable Vehicle Solutions

Moderator: **Dennis Assanis**
Professor and ARC Director, The University of Michigan

Speakers: **Dr. Paul Rogers**
Executive Director, Research, U.S. Army TARDEC

Dr. David Gorsich
Chief Scientist, U. S. Army TARDEC

Kevin D. Beaty
Business Unit Manager – Eaton Corporation

Question and Answer Panel Session

9:40 - 10:00 **Networking Break**

10:00 - 11:00 Case Study 1:
Reliability-Based Design Optimization with Associated Confidence Levels under Input Model Uncertainties for Vehicle Weight Reduction
by Thrust Area 3

Speakers: Prof. K. K. Choi,
The University of Iowa

11:00 - 12:00 Case Study 2:
Internet-Distributed Hardware-in-the-Loop Simulation for Cyber-Enabled Concurrent Systems Engineering: A TARDEC/UM Case Study
by Thrust Areas 1 and 4

Speakers: Dr. Hosam Fathy, et. al.
The University of Michigan

12:00 - 1:30pm **Lunch**

1:30 - 2:30 Case Study 3:
The Road Map to Simulation-based Validation and Certification of Designs and Tests
by Thrust Area 5

Speakers Dr. Michael Kokkolaras, et. al.
The University of Michigan

2:30 - 3:00 **Networking Break**

3:00 - 4:15 **Parallel Technical Session I**
Click here for symposia matrix.

Symposium I	Symposium II	Symposium III	Symposium IV
IC Engines and Fuels	Powertrain Controls and Hybrid Vehicles	Vehicle Design Methodologies	Vehicle Mobility

ARC Conference Day 2 Schedule
Wednesday May 13th 2009

7:30 - 8:00am **Arrival and Continental Breakfast**

8:00 - 8:15 **Welcome and Introductions**

Dennis Assanis
Professor and ARC Director, The University of Michigan

Paul Skalny
Director, National Automotive Center

8:15 10:15 **Keynote Address:**

Moderator: **Dennis Assanis**
Professor and ARC Director, The University of Michigan

Speakers: **Dr. David Cole**
Chairman, Center for Automotive Research

General Paul J. Kern (U.S. Army, Retired)
President and Chief Operating Officer, AM General

Charles E. (Charlie) Freese V
Executive Director, Fuel Cell Activities, General Motors

Question and Answer Panel Session

10:45 - 4:25pm **Parallel Technical Session II**
Click here for symposia matrix.

Symposium I

10:45 - 12:00pm	Diesel Engine Combustion
12:00 - 1:30	Lunch
1:30 - 2:45	Engine Friction & Vehicle Energy
2:45 - 3:15	Networking Break
3:15 - 4:25	Thermal Management & Fuel Cells

Symposium II

10:45 - 12:00pm	Light Weight Structures and Materials
12:00 - 1:30	Lunch
1:30 - 2:45	Reliability Based Design Optimization I
2:45 - 3:15	Networking Break

3:15 - 4:25	Reliability Based Design Optimization II

Symposium III

10:45 - 12:00pm	Vehicle Design Methodologies
12:00 - 1:30	Lunch
1:30 - 2:45	Systems Optimization and Validation
2:45 - 3:15	Networking Break
3:15 - 4:25	Optimal Vehicle Design

Symposium IV

10:45 - 12:00pm	Terrain Modeling
12:00 - 1:30	Lunch
1:30 - 2:45	Vehicle Mobility
2:45 - 3:15	Networking Break
3:15 - 4:25	Human-In-The-Loop Testing

Keynote Speakers

Biographies

Day 1 Speakers

(go to Day 2)

Dr. Paul D. Rogers

Executive Director for Research and Technical Director,
U.S. Army Tank-Automotive Research, Development, and Engineering Center (TARDEC)

Selected to the Senior Executive Service in June 2007, Dr. Paul Rogers is currently serving in the dual-hat position as the Executive Director of Research and Technical Director, U.S. Army Tank-Automotive Research, Development and Engineering Center. The Center is the lead organization for Army research and development in Ground Vehicle Power and Mobility, Survivability, Intelligent Systems, Vehicle Electronic and Architecture Systems, and Platform Concept, Analysis, and System Simulation. As Executive Director, he manages the technology base programs and leads a 480 person workforce through six technical business area associate directors. He is also responsible for executive oversight for the Joint Center for Robotics. As Technical Director, Dr. Rogers serves as the key executive responsible for the Center's science and technology strategic planning, program selection, funding allocation, execution and transition to acquisition programs. Dr. Rogers leads programs to align ground-based systems science and technology research objectives with the Army's future war fighting and logistic needs.

Prior to this assignment, Dr. Rogers was the Deputy Associate Director for Mobility Research in TARDEC. He provided scientific and technical leadership and expertise for three Army Technology Objectives, 8 technical teams and over 90 associates. Dr. Rogers was largely responsible for transforming the subordinate teams and S&T programs to align more directly with customer needs and TARDEC executive guidance. Dr. Rogers led the formation of a Hybrid Electric Vehicle Experimentation and Assessment program to support future Tactical Wheeled Vehicle acquisition strategy.

Prior to joining Mobility, Dr. Rogers was activated and served in Iraq as the Battalion Commander for the 507th Engineer Battalion. His command included twelve separate companies/detachments at Balad, Iraq in support of Operation Iraqi Freedom 04-06. The 507th Eng Bn was a joint force consisting of deployed forces from the Active Army and Air Force, Army National Guard, Army Reserve, and Marines. He commanded a total of 823 soldiers, 139 marines, and 114 airmen in combat operations during the deployment. His mission responsibilities included military fixed bridging, offensive assault float bridging, rafting operations, riverine operations, vertical and horizontal construction, well drilling, and asphalt production/paving. He also organized, trained, and deployed an armored D9 dozer task force in support of division offensive operations. The 507th Eng Bn served in Iraq from 1 January 2005 to 6 December 2005. Dr. Rogers military awards and decorations include the Bronze Star, Army Meritorious Service Medal, Army Achievement Medal, Iraqi Campaign Medal, Airborne Badge and the Bronze Order of the de Fleury Medal. His previous military assignments include, Brigade and Battalion Operations Officer, Company Commander, and Platoon Leader.

Dr. Rogers has initiated multiple collaborative programs internal to TARDEC and external to DoD. Dr. Rogers served as Chief Research Engineer to the Associate Director for the Integrated Survivability Advanced Technology Demonstrator (ISATD). He formulated and lead a broad scale collaboration to demonstrate FCS integrated survivability. The IS ATD was the preeminent Army program for survivability and included participants from across the Army technology base. Dr. Rogers guided the efforts of four TARDEC product teams, multiple Army agencies (ARL, ARDEC, CERDEC) and numerous principle contractors supporting the IS ATD. Nationally, he has initiated collaboration with scientists from the National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center (GSFC) and Clemson University. He was an invited member of a Joint National Aeronautics and Space Administration (NASA)/European Space Agency (ESA) Two-Phase Thermal Management Workshop, an Army research lead for the Office of the Secretary of Defense - Electric Force Transformation Initiative, and a TARDEC Assistant Technical Project Officer for Data Exchange Agreements with Germany, the United Kingdom, and France. He previously served for six years as the ATPO for DEA 1182 with the Netherlands. Dr. Rogers is currently serving the External Advisory Boards for the Mechanical Engineering Departments at Michigan Technological University and the University of Michigan. He has served as an invited member of the Lawrence Technological University Mechanical Engineering Industrial Advisory Committee and an Adjunct Professor of Mechanical Engineering at LTU.

Dr. Rogers holds a Ph.D. in Mechanical Engineering-Engineering Mechanics from Michigan Technological University (MTU), a Masters of Strategic Studies from the U.S. Army War College, a Masters of Science in Engineering – Mechanical Engineering from the University of Michigan – Dearborn, and a Bachelors of Science in Mechanical Engineering from MTU. He is a graduate of the Army Engineer Officer Basic Course, Engineer Officer Advance Course, Combined Arms Services Staff School, Army Command and General Staff College and the U.S. Army War College.

Dr. Rogers is married to his wife Sally of 18 years and has three children Tim, Katie and Nicholas.

Dr. David J. Gorsich

Chief Scientist, U. S. Army TARDEC

Dr. David J. Gorsich was selected for a Scientific and Professional position in January 2009 and serves as the Army's Chief Scientist for Ground Vehicle Systems. His current research interests are vehicle dynamics and structural analysis, reliability based design optimization, underbody blast modeling, terrain modeling and spatial statistics.

Career Chronology:

- Dec 2008 – Jul 2003: Associate Director, Modeling and Simulation, Tank-automotive Research, Development and Engineering Center (TARDEC), Warren MI
- Jan 2008 – Jan 2007: Acting Director, Strategic Plans and Programs, TARDEC, Warren MI
- Jul 2003 – Sept 1998: Team leader, Robotics and Vehicle Intelligence, TARDEC, Warren MI
- Sept 1998 – Dec 1994: Research Scientist, TARDEC, Warren MI
- Dec 1994 – Jun 1990: Various assignments at ASA(ALT), AMC, ARL and TARDEC
- Jan 1990 – Dec 1988: Electrical Engineer, McGraw Commercial Equipment Corporation, Novi, MI

College:

- Ph.D., Applied Mathematics, M.I.T., Cambridge, MA, 2000
- M.S., Applied Mathematics, George Washington University, D.C., 1994
- B.S., Electrical Engineering, Lawrence Technological University, MI, 1990

Awards and Honors:

- Society of Automotive Engineers (SAE) Fellow, 2008
- Commanders Coin, CENTCOM, GEN Abizad, HMMWV Safety/Seat Experiments, 2005
- Commanders Coin, Chief of Staff, GEN Schoomaker, TARDEC M&S, 2005
- Commanders Coin, West Virginia National Guard, 2004
- Commanders Coin, US Army TACOM, MG Lenears, Army-SAE Partnership, 2004
- Commanders Coin, US Army TACOM, MG Thompson, Reliability, 2003
- SAE Technical Standards Board for three year term, TARDEC Quality Report, Sept 2005
- Army Research, Development and Aquisition Award, 1997, "Innovations in Ground Vehicle

Signature Research," A. Fenner Milton, 15 June 1998, Orlando, Fl
- Detroit Federal Executive Board Award, May 9, 2001

Professional memberships and associations:

- Adjunct professor and/or advisor at the following universities, serving as a scientific liaison with academia: College of Engineering, University of Iowa, IA: Mississippi State University; Kettering University; University of Michigan Transportation Institute
- Associate Editor of International Journal of Terramechanics and International Journal for Reliability and Safety.
- Co-President of Great Lakes section of Society of Industrial and Applied Mathematics (SIAM)
- Member, Sigma Xi M.I.T. Chapter
- Chair, SAE International Standards Committee for Ground Vehicle Reliability
- Member, SAE Material Parts and Processes Council
- Member, Senior Executives Association, ST Chapter

Major Publications:

Dr. Gorsich has published more than 140 scientific articles including over 30 peer review journal articles. He has published in the following peer review journals:

- Transactions of SAE
- International Journal of Vehicle Design
- Journal of Mechanical Design
- Journal of Commercial Vehicles
- Contemporary Mathematics
- Computational Statistics and Data Analysis
- Physical Review D
- Society of Automotive Engineers
- Journal of Multivariate Analysis
- Journal of Electronic Imaging
- Optical Engineering
- Pattern Recognition Letters
- Statistics and Computing
- IEEE Transactions on Pattern Analysis and Machine Intelligence

Kevin D. Beaty

Business Unit Manager – Eaton Corporation

Kevin Beaty joined Eaton Corporation as Business Unit Manager – Hybrid Electric Powertrains in March 2000 to lead a new group focused on developing the next generation of commercial truck drivetrain technology and products. His responsibilities include leading the development and implementation of the overall business strategy, technology and product development, and strategic OEM and partner relationships.

Prior to joining Eaton, Mr. Beaty held positions of Research Engineer, Senior Research Engineer and Group Leader with Southwest Research Institute (SwRI) in the Engine, Fuel, and Vehicle Research Division. While at SwRI, Mr. Beaty conducted engine R&D projects for the U.S. government, engine and vehicle manufactures, oil companies, gas utility companies, and a wide range of commercial clients aimed at improving engine performance, fuel efficiency and exhaust emissions. He has also previously been with Natural Fuels Corporation and Woodward Governor Company, and formed *kdb designs, inc.,* a firm specializing in helping clients bring engineered products and technologies into the market quickly and profitably.

Mr. Beaty's primary professional focus is on developing and deploying clean energy technologies, products and businesses.

Kevin holds a B.S. Degree in Mechanical Engineering from Texas A&M University. He is a Registered Professional Engineer, State of Texas and a Member of the Society of Automotive Engineers.

Day 2 Speakers

(go to Day 1)

David Cole

Chairman, Center for Automotive Research

David E. Cole is the Chairman of the Center for Automotive Research (CAR) in Ann Arbor, Michigan. He was formerly Director of the Office for the Study of Automotive Transportation (OSAT) at the University of Michigan Transportation Research Institute. He has worked extensively on internal combustion engines, vehicle design, and overall automotive industry trends.

Dr. Cole's recent research has focused on strategic issues related to the restructuring of the North American industry and trends in globalization, technology, market factors, and human resource requirements. He was formerly a member of the Energy Engineering Board of the National Research Council and the U.S.-Canada Free Trade Pact Select Panel. He is also a director of the Original Equipment Suppliers Association, as well as a director of seven automotive supplier companies. In addition, Dr. Cole is a member of the Executive Committee of the Michigan Economic Development Corporation (MEDC) and was recently appointed by Michigan's Governor to the Strategic Economic Investment and Commercialization Board and the Michigan Renewable Fuels Commission. He was named a co-chair of Detroit Renaissance's "Road to Renaissance" Project in the fall of 2006. At the University of Michigan he is a member of the Energy Research Council and Mechanical Engineering External Advisory Board. He is also a member of the Denso Foundation Board. Dr. Cole was formerly a director of the Automotive Hall of Fame and a member of the Board of Trustees of Hope College.

He is active in SAE, including serving two terms on the Board of Directors. In February 1986, he was named a fellow of SAE. He is also active in the Engineering Society of Detroit and was elected to fellow status in 1990. In 2000, he received the Engineering Society's highest award, the Horace H. Rackham medal. In 1993, he received the National Automobile Dealers Association Foundation's International Freedom of Mobility Award. In 1994, Design News selected Dr. Cole as one of eight engineering leaders, and he was also selected to receive Sweden's Order of the Polar Star.

In the fall of 1998, Dr. Cole was named as the Marketing Educator of the Year by the Society of Marketing Executives. Additionally, he received the 1998 Rene Dubos Environmental Award for his contributions to the industrial ecology of the automobile and in 1999, Chevalier of the National Order of Merit from France.

Dr. Cole also has been actively involved in the start-up of five different Ann Arbor-based companies. Dr. Cole's technical and policy consulting experience includes a variety of assignments for industry, labor, and government.

Dr. Cole received his B.S.M.E. and Mathematics, M.S.M.E. and Ph.D. from the University of Michigan.

General Paul J. Kern (U.S. Army, Retired)

President and COO, AM General

General Kern has a very distinguished record of service to our nation, including two tours of duty in Vietnam and service with the 24th Infantry Division during Desert Shield/Desert Storm.

- Commanding General, Army Materiel Command
- Military Deputy to the Assistant Secretary of the Army for Acquisition, Logistics & Technology
- Commander, 4th Infantry Division (Mechanized)
- Senior Military Assistant to the Secretary of Defense and Deputy Secretary of Defense

At the conclusion of his career General Kern led the investigation into Abu Ghraib and continues to work with the Center for Victims of Torture.

General Kern, a native of West Orange, New Jersey, was commissioned in 1967 as an armor lieutenant following graduation from the United States Military Academy at West Point. He earned master's degrees in both mechanical and civil engineering from the University of Michigan and was a Senior Fellow at the J.F. Kennedy School, Harvard University. He has been a member of the Society of Automotive Engineers since 1973 and was elected to the National Academy of Engineering in 2007. He serves on the Mechanical Engineering Advisory Board at the University of Michigan, as an Adjunct Professor at the University of Southern California, and recently held the Class of 1950 Chair for Advanced Technologies at West Point.

After retiring from the Army in January 2005, General Kern became a Senior Counselor of The Cohen Group where he will continue as an advisor. He was a member of CNA's Global Climate Change Military Advisory Board and Chairs their Energy Security Board. He also serves on the Boards of iRobot and Covant LLC.

Charles E. (Charlie) Freese V

Executive Director, GM Powertrain Engineering

Charles E. Freese V. is Executive Director, GM Powertrain Engineering, responsible for GM's Fuel Cell Activities.

Charlie has 20 years of experience in the automotive industry. He began his career at Detroit Diesel Corporation in 1989, where he held multiple positions in the Advanced Engineering, Product Engineering, and Sales organizations. As chief engineer, he led a team that designed and prototyped the company's first North American light duty diesel engine concept in 228 days. Charlie also served as Director of Automotive Sales and Director of Advanced Programs.

In 2001 Charlie assumed the position of Chief Engineer – Diesl Engines, for Ford Motor Company. At Ford he was responsible for new and current product development and quality.

In 2003 Charlie moved to General Motors Corporation, as Executive Director for Diesel Engineering. At GM Powertrain, Charlie was responsible for establishing and leading the Global Diesel Engineering organization. In 2008, Charlie assumed responsibility for GM's Fuel Cell Activities, as Executive Director. He is responsible for fuel cell R&D, product engineering, manufacturing, and strategic planning.

Charlie holds three degrees from the University of Michigan: Bachelor of Science in Mechanical Engineering, Master of Science in Mechanical Engineering and Master of Science in Engineering Management.

He has published multiple technical papers in the field of internal combustion engines, holds 9 patents, and was honored in 2000 by the Automotive Hall of Fame with the Young Leadership and Excellence Award.

Symposia matrix is formatted to printout in "Landscape" format

Technical Symposia - Day 1

Time	Symposium I (*abstracts*)	Symposium II (*abstracts*)	Symposium III (*abstracts*)	Symposium IV (*abstracts*)
	1 IC Engines and Fuels Chair: Zoran Filipi	**2 Powertrain Controls and Hybrid Vehicles** Chair: Jeffrey L. Stein	**3 Vehicle Design Methodologies** Chair: Gregory Hulbert	**4 Vehicle Mobility** Chair: Hosam K. Fathy
3.00 - 3.25	Impacts of Alternative Fuel on Combustion Properties and Their Relation to Gaseous and Particulate Emissions	Interaction of Battery Size and Optimal Power Management in Plug-in Hybrid Electric Vehicles	Multi-scale Simulations for Developing Light Weight Vehicles with Increased Survivability to Loads from Explosions and High Velocity Projectiles	A Base-Excitation Approach to Polynomial Chaos Based Estimation of Sprung Mass for Off-Road Vehicle Suspension Models
3.25 - 3.50	Effect of Biodiesel Properties on Autoignition, Combustion and Emissions	Thermal Management System Architecture Design of Advanced Vehicles	Integration of Multibody Dynamics and Finite Element Models with Rigid and Flexible Gluing Joints in D-Sim	Exploration of Computational Techniques to Model Dynamic Sand-Tire Interaction: Discrete Element Method, Finite Element Method, and Meshless Method
3.50 - 4.15	Simulation-Based Assessment of Various Dual-Stage Boosting Systems in terms of Engine Performance Improvements	Utilizing 3D Aerial Terrain Maps for Improving Energy Management of Hybrid Vehicle	An Optimization Approach to Occupant Safety and Fuel Economy in Vehicle Design	Convoy Driving with Secondary Tasks: Modeling a Driving Simulator Experiment

Technical Symposia - Day 2

Time	Symposium I (*abstracts*)	Symposium II (*abstracts*)	Symposium III (*abstracts*)	Symposium IV (*abstracts*)
	1A Diesel Engine Combustion Chair: TBA	**2A Light Weight Structures and Materials** Chair: TBA	**3A Vehicle Design Methodologies** Chair: TBA	**4A Terrain Modeling** Chair: TBA
10.45 - 11.10	Comparing Heavy Duty and Medium Duty Engine Parameters using JP-8 and D2	Advanced Models for Predicting the Nonlinear Response of Complex Structures and Novel Sensor Placement Technology for Damage Identification	Modeling and Optimization of Hybrid Tubular SOFC and Gas Turbine Power Systems	A New Measure of the Roughness of a Terrain Profile
11.10 - 11.35	Diesel Engine Performance Operated by Alternative Fuels	Function-Oriented Material Design for an Innovative Gunner Restraint System	Risk-based Decisions under Aleatory and Epistemic Uncertainties in Engineering Design	A Stochastic PDE Approach to Terrain Modeling
11.35 - 12.00	Performance and Particulate Emissions of a Light-Duty Diesel Engine Operating on Soy-Based Biodiesel	A Reactive Structure Technology for Improved Survivability of Military and Commercial Vehicles	Research Issues Related to Packing Optimization	Exit Angle Influence on Energy Efficiency of Off-Road Tires
12.00 - 1.30	**Lunch**			
	1B Engine Friction & Vehicle Energy Chair: TBA	**2B Reliability Based Design Optimization I** Chair: TBA	**3B Optimal Vehicle Design** Chair: TBA	**4B Vehicle Mobility** Chair: TBA
1.30 - 1.55	Estimation of the Instantaneous Frictional Losses of Engine Components	Comparison Study Between Probabilistic and Possibilistic Approach for Problems with Correlated Input and Lack of Input Statistical Information	Representing and Accounting for Geometry in Optimal System Design	Vehicle-Terrain Interaction - Macroscopic and Microscopic Aspects
1.55 - 2.20	The Magnetostrictive Alternator: A New Concept for Energy Generation	Sequential Sampling Based Kriging Method with Dynamic Basis Selection for RBDO	Motor/Generator Downsizing Effect in Multi-mode Hybrid Powertrains	Advancements in Semi-Active Suspensions and Human-In-The-Loop Testing
2.20 - 2.45	Simulation-based Quantification of Power Harvesting from a Truck's Leaf Springs	Estimation of Confidence Level on Input Model Using Copula for Reliability-Based Design Optimization	An Interactive Modeling Environment for Automotive Exterior Design	Effects of Posture and Movement on Vibration Transmissibility Affecting Human Reach Performance under Vehicle Vibration
2.45 - 3.15	**Break**			

	1C Thermal Management & Fuell Cells Chair: TBA	**2C Reliability Based Design Optimization II** Chair: TBA	**3C Systems Optimization and Validation** Chair: TBA	**4C Human-In-The-Loop Testing** Chair: TBA
3.15 - 3.35	Vehicle Thermal Management – Alternative Cooling and Payload Temperature Control	A Simulation-Based RBDO Method Using Probabilistic Re-Analysis and a Trust-Region Approach	Incorporating Ease of Control into Sequential Optimization	Independent Hydrostatic Wheel Drives
3.35 - 4.00	Developing an Integrated Thermal Prediction Model for Vehicular Systems	Design for Lifecycle Cost Using Time-Dependent Reliability	Reduced Representations of Vector-Valued Coupling Variables in Decomposition-Based Design Optimization	Ultracapacitors for Power Boost in Heavy Vehicles
4.00 - 4.25	Vehicle Thermal Management System Design for Fuel Cell Vehicle	Requirements Modeling Lightweight Engineering	Sensitivity Study of Bayesian Model Validation	Effect of Pump Selection on Fuel Economy in a Dual Clutch Transmission Vehicle

Day 1, Tuesday, May 12, 2009
Symposium I Abstracts

(*click here for day 2 abstracts below*)

1 IC Engines and Fuels

Session Chair: Zoran Filipi

1A **Impacts of Alternative Fuel on Combustion Properties and Their Relation to Gaseous and Particulate Emissions**
Ashwin Salvi, Dennis Assanis, Zoran Filipi, the University of Michigan

The looming shortage of the global oil supply and a military based single-fuel forward policy provides a strong impetus for research aimed at developing solutions for increased use of alternative, renewable, and synthetic fuels in transportation and military applications. The physical and chemical properties of alternative fuels vary in a wide range, and this can have a significant impact on diesel engine combustion and emissions. Modern engines are highly optimized in order to meet the stringent emissions regulations while still providing outstanding efficiency making them increasingly sensitive to changes in fuel properties. Therefore, the objective of this work is to provide detailed insight into the effect of alternative fuels on diesel engine autoignition, combustion and emissions. The study characterizes the effect of the neat soy-based biodiesel (B100) and its blends (B20 and B50), petroleum based jet fuel (JP-8), and synthetic jet fuel (S-8), through comparisons with baseline diesel fuel in a V8 6L International medium-duty engine. The results include the measurements of the start of combustion, ignition delay, burn-rates, pressure rise rates, gaseous exhaust emissions, soot emissions, and particle size-number concentrations obtained using a differential mobility spectrometer.

1B **Effect of Biodiesel Properties on Autoignition, Combustion and Emissions**
N. A. Henein, W. Bryzik and Kaushik Acharya, Wayne State University

In an effort to reduce the dependence on petroleum derived fuels for land security and energy needs, biodiesel fuels are considered as extenders or even replacements of conventional diesel fuels. This presentation examines the effect of the differences in the properties of biodiesel from Ultra-Low-Sulfer-Diesel (ULSD) fuel on the basic combustion processes and their impact on engine performance, fuel economy and emissions. A detailed analysis of the rate of heat release showed the effects on fuel evaporation, endothermic reactions, premixed combustion fraction and mixing controlled and diffusion controlled combustion fractions. The experiments were conducted under controlled conditions on a single-cylinder, four-valve, high speed direct injection diesel engine and covered a wide range of injection pressures and swirl ratios. To ensure the proper combustion phasing, the injection timing was adjusted to keep the peak rate of heat release due to the premixed combustion fraction at a constant location with respect to the top dead center (TDC) under all the test conditions. The effects on fuel economy, peak cylinder pressures and NOx, particulate matter, HC and CO emissions are determined. The operating conditions that can increase or reduce NOx emissions, reported in the literature, are identified. Recommendations are made for adaptations needed for diesel engines for the efficient operation on Biodiesel or its blends with ULSD fuel.

1C **Simulation-Based Assessment of Various Dual-Stage Boosting Systems in terms of Engine Performance Improvements**
Byungchan Lee, Zoran Filipi, Dennis Assanis, the University of Michigan

In this study, several different types of dual-stage boosting systems are evaluated with a physics-based zero-dimensional Diesel engine system simulation in terms of their steady-state and transient performance characteristics and fuel economy improvements. The dual-stage boosting systems evaluated in the study include a boosting system with two fixed geometry turbochargers at both the high pressure and low pressure stages, and several hybrid boosting systems in which the high pressure turbocharger is replaced with a screw type supercharger, an electrical compressor, and a variable geometry turbocharger. A dual-stage boosting system with early intake valve closing (EIVC) strategy is also evaluated. Each alternative system exhibits unique tradeoffs and improvements in terms of performance and fuel economy compared to the dual-stage boosting system with fixed geometry turbochargers at both high and low stages.

Day 2, Wednesday , May 13, 2009
Symposium I Abstracts

1A Diesel Engine Combustion

Session Chair: TBA

1A1 **Comparing Heavy Duty and Medium Duty Engine Parameters using JP-8 and D2**
Dan Murray, Mike Smith, Zoran Filipi, Dennis Assanis, The University of Michigan

The advantages to moving the military to a single fuel for propulsion vehicles have previously been discussed. To support this effort the various effects of engine geometry, engine calibration and fuel delivery systems will need to be addressed to properly utilize the differences between fuels. This presentation will be comparing the impact on combustion, emissions and visual signature between two engines. The differences will determine aspects of the engine and its calibration that will need to be changed. The engines used were the Navistar 6.0 L V-8 and a Detroit Diesel Corporation 12.7 L I-6 engine. Various fuels were test on both a medium duty diesel engine and a heavy duty diesel engine to see the effects.

1A2 **Diesel Engine Performance Operated by Alternative Fuels**
Dinu Taraza, Wayne State University

Fleet operators and vehicle manufacturers are increasingly interested in assuring safe and efficient operation of diesel engines with different alternative and renewable fuels. For the army, an omnivore engine capable to run on any fuel available in the field is highly desirable. A high power diesel truck engine, the six cylinder common rail and turbocharged Mercedes 925 has been heavily instrumented and run on Ultra-low sulfur diesel fuel (ULSD), jet fuel JP8, synthetic fuel S8 and biodiesel blend B20. The engine was run at steady-state operating conditions for different speeds and loads and also tested for cold starting at room temperature.The engine behaved normally with all tested fuels, but differences have been noticed in the rate of heat release, engine efficiency and exhaust emissions. the behavior of the engine is analyzed based on the different physical and chemical properties of the utilized fuels and conclusion are presented for fuel injection optimization for each tested fuel. Further work will be conducted on different blends of biodiesel and a method of identifying, on board, the fuel used will be developed together with the adaptive control of injection strategy to assure safe and efficient operation.

1A3 **Performance and Particulate Emissions of a Light-Duty Diesel Engine Operating on Soy-Based Biodiesel**
Will Northrop, Dennis Assanis, The University of Michigan

Oxygenated fuels like biodiesel have shown to hold many benefits for diesel engines. Among these are lower emissions of soot, total hydrocarbons (THC) and carbon monoxide (CO). Biodiesel also has been reported to have higher oxides of nitrogen (NOX) emissions for a given injection timing and higher brake specific fuel consumption (BSFC) although thermal efficiency remains mostly unchanged. In this study, a thorough examination of particulate matter (PM) emissions was performed by comparing results from gravimetric filter analysis, filter smoke number (FSN) measurement, particulate spectrometry and an organic carbon versus elemental carbon (OCEC) technique. A light-duty diesel engine with common rail fuel injection was run in a conventional combustion mode utilizing a single pilot injection strategy. Five fuels were tested including soy-based biodiesel, two types of number 2 low sulfur diesel and 50% by volume blends of biodiesel with each of the petroleum fuels. All fuels were

run at a constant engine speed, load and combustion phasing as measured by location of 50% fuel mass fraction burned (CA50). As reported in the literature, BSFC increased and emissions of CO, THC and FSN decreased with increasing biodiesel concentration. The total PM mass as measured by the gravimetric analysis decreased less for biodiesel than that calculated from the FSN using an established empirical correlation. This difference was accounted for by a larger total organic carbon fraction (TOF) for biodiesel than the petroleum fuels. The particulate spectrometer showed that all fuels exhibited a bimodal particle size distribution. The larger PM mass for petroleum fuels could be accounted for by higher magnitudes of larger, agglomerated particles in the size range of 30-200 nm whereas the quantity of smaller particles from 10-30 nm was essentially the same for all fuels tested.

1B Engine Friction & Vehicle Energy

Session Chair: TBA

1B1 **Estimation of the Instantaneous Frictional Losses of Engine Components**

Giscard A. Kfoury, Nabil G. Chalhoub and Naeim A. Henein, Mechanical Engineering Department, Wayne State University

Robust observers suitable for handling nonlinear constrained systems provide the ground work for the development of schemes to compute the instantaneous frictional losses of engine components. In this study, a new robust observer has been introduced. Its capability in accurately estimating the state variables of constrained nonlinear systems has been demonstrated in the presence of both modeling uncertainties and external disturbances. This has lead to the development of an inverse dynamics approach for the computation of the instantaneous frictional losses of engine components. Its formulation is based on the differential-algebraic form of the equations of motion of the crankshaft/connecting-rod/piston mechanism. The implementation of the inverse dynamics scheme in conjunction with the proposed observer has been proven to be a viable approach for determining the instantaneous frictional losses of engine components over a wide range of engine speeds.

1B2 **The Magnetostrictive Alternator: A New Concept for Energy Generation**

Chris Stabler, Amin Bibo, Thiago Osorio, Mohammed F. Daqaq, John Wagner, and George Fadel, Clemson University

We present a dynamic model of a cam-driven magnetostrictive (MS) alternator designed for in- vehicle power generation. The model accounts for the dependence of the constitutive parameters on the magnetic bias (stator field) and pre-stress (axial load). Using the derived model, we study the effect of strain, drive speed, magnetic bias, and pre-stress on the output power. It is shown that, at optimal loading conditions, an MS rod subjected to 1500 microstrain at a drive speed of 3600 rpm has a power density of 50 Watt/cm3. To validate the theoretical model, an experimental prototype of the alternator is constructed. Experimental data is currently being generated.

1B3 **Simulation-based Quantification of Power Harvesting from a Truck's Leaf Springs**

Amin Bibo, Mohammed F. Daqaq, John Wagner, and George Fadel, Clemson University

Vibration-based energy harvesting has recently emerged as an effective means to transform otherwise wasted mechanical vibrations into useful electric power. This can be achieved by exploiting the ability of some active materials to generate an electric potential in response to mechanical strains emanating from external environmental vibrations. The current investigates the feasibility of utilizing such mechanisms to scavenge energy from the vibrations of an automotive vehicle. Specifically, this effort aims at quantifying the amount of power that can be scavenged from the vibrations of the leaf springs of a truck. To that end, we use the commercial software SIMPACK to model the dynamic behavior of a truck's leaf spring covered with piezoelectric layer that acts as an energy harvester. The piezoelectric layer is connected to a purely resistive load and the power dissipated in the load is used as a measure of the amount of power harvested. Results show that, under persistent harmonic excitations of different amplitudes that span low to high dynamic loadings of the leaf spring (deflections of 3-6 cm at the mid-point), it is possible to generate between 5-20 Watts of RMS power per leaf spring.

1C Thermal Management & Fuel Cells

Session Chair: TBA

1C1 **Vehicle Thermal Management – Alternative Cooling and Payload Temperature Control**
Lin Ma, John Wagner, Clemson University

The successful management of thermal loads within military vehicles (engine, payload) represents an important challenge given the increased presence of electronic equipment and hot weather operating environments. Two alternative cooling methods, phase change materials and metal suspension polymer, will be investigated to identify their benefits to offer additional heat removal. The introduction of electronics and human occupants in armored vehicles may require supplemental cooling to maintain an acceptable temperature; simulation tools are under development to study payload and engine cooling demands.

1C2 **Developing an integrated thermal prediction model for vehicular systems**
Mohammad Omar, Clemson University

This work describes the development of a thermal simulation model for a passenger vehicle heat generation sources and sinks, under different driving scenarios. The work presents the boundary condition extraction using infrared thermal detectors for vehicles and engines mounted on Chassis and engine dynamometers respectively. The module is established within a finite differencing commercial package (commercial name RadTherm) and include a complete vehicle drive-line, exhaust system and packaging accessories. The presentation shows initial results of the vehicle thermal signatures when manipulating the design of vehicle structure (body panel thickness and material) and road grade variations.

1C3 **Vehicle Thermal Management System Design for Fuel Cell Vehicle**
Sungjin Park, Dohoy Jung, The University of Michigan

Fuel cell system has been considered for military applications such as an Auxiliary Power Unit (APU) and power source to replace the internal combustion engine due to their higher efficiency, lower acoustic and thermal signatures, and more exportable power compared with conventional counterparts. Among the several types of fuel cells, Proton Exchange Membrane Fuel Cell (PEMFC) is under development for the propulsion of vehicles owing to its high power density and short start-up time. However, the Thermal Management System (TMS) of the PEMFC vehicle has been faced with technical challenges in packaging and performance because of the lower operating temperature of the PEMFC compared with that of the Internal Combustion Engine (ICE). In this study, numerical simulations of the VTMS for the FCV is developed and integrated with PEMFC stack model to investigate the thermal response and power consumptions of the VTMS. The results show that the VTMS has substantial impact on the performance of FCV and the integrated system analysis is necessary for the design of the VTMS of the FCV. It is also demonstrated that a numerical model of the VTMS of the FCV is an efficient tool to assess design concepts during the early stage of system development.

Day 1, Tuesday, May 12, 2009
Symposium II Abstracts

(click here for day 2 abstracts below)

2 Powertrain Controls and Hybrid Vehicles

Session Chair: Jeffrey L. Stein

2A **Interaction of Battery Size and Optimal Power Management in Plug-in Hybrid Electric Vehicles**
Scott J. Moura, Duncan S. Callaway, Hosam K. Fathy, Jeffrey L. Stein, the University of Michigan

This talk examines how varying battery size and optimal power management algorithm configurations impact performance, efficiency, and life cycle cost in plug-in hybrid electric vehicles (PHEVs). Existing studies examine this impact for power management algorithms derived using either rule-based or deterministic dynamic programming methods. This work extends research on PHEV battery energy capacity to PHEVs that use power management algorithms identified with stochastic dynamic programming (SDP). The work treats both PHEV trip duration and PHEV power demand over the course of a given trip as stochastic functions informed by drive cycle data and travel surveys. Furthermore, the talk examines two power management optimization objectives: one emphasizing fuel consumption only, and one that emphasizes the total cost of blending fuel and electricity. This approach is applied to a power-split hybrid configuration similar to the Toyota Prius, but is general to other configurations and component sizes. The results for this particular configuration indicate that blending provides significant benefits for batteries with low energy capacity, but this effect diminishes with increasing battery size.

2B **Thermal Management System Architecture Design of Advanced Vehicles**
Sungjin Park, Dohoy Jung, The University of Michigan

Series Hybrid Electric Vehicle (SHEV) systems have been considered for military applications due to their higher efficiency, lower acoustic and thermal signatures, enhanced low speed maneuverability, and more exportable power compared with conventional counterparts. The SHEV, however, needs additional powertrain components which make the Vehicle Thermal Management System (VTMS) more complicated. The powertrain of the SHEV has additional heat sources including a generator, driving motors, a battery pack, and a power controller. Thus, a more strategic approach is required when designing the VTMS for the SHEV. In this study, numerical simulations of the VTMS and the powertrain system of the SHEV are developed to investigate the thermal response and power consumptions of the VTMS. The output data from the powertrain system simulation are fed into the VTMS simulation to provide the operating conditions of powertrain components as input for the VTMS simulation. Although this simulation procedure is computationally efficient in design and optimization of the thermal management system, it has limitations with respect to predicting the fuel economy and the performance of the vehicle. Thus, the powertrain system simulation and VTMS simulation are integrated to evaluate the VTMS architecture design based on the fuel economy and performance of the vehicle. The results show that the VTMS architecture design of the advanced vehicle should be developed considering various cooling requirements of powertrain components, power management strategy, performance, parasitic power consumption, and the effect of driving conditions. It is also demonstrated that a numerical model of the VTMS of the advanced vehicle is an efficient tool to assess design concepts and architectures of the system during the early stage of system development.

2C **Utilizing 3D Aerial Terrain Maps for Improving Energy Management of Hybrid Vehicles**
Chen Zhang, Ardalan Vahidi, Pierluigi Pisu, and Georges Fadel, Clemson University

We present our findings on the role advanced knowledge of terrain information can have on fuel savings of a hybrid vehicle. The energy management strategy plays a critical role in the high fuel economy that modern hybrid electric vehicles can achieve; yet lack of information about future driving conditions is one of the limits in fulfilling the maximum fuel economy potential of hybrid vehicles. Today with wider deployment of vehicle telematics technologies, prediction of future driving conditions, e.g. road grade, becomes more and more realistic. This research evaluates the potential gain in fuel economy, if road grade information is integrated in energy management of hybrid vehicles. Real-world 3D terrain maps are provided to us by our industry partner Intermap Technologies. These maps are created using Airborne IFSAR mapping technology. Real-world road geometry information is utilized in power management decisions by using both Dynamic Programming (DP) and an Equivalent Consumption Minimization Strategy (ECMS). At the same time, two baseline control strategies without any future information are developed and validated for comparison purpose. Simulation results show that advance knowledge of future road terrain information enables fuel savings. The level of improvement depends on the cruise speed, the control strategy, the road profile, and the size of battery.

Day 2, Wednesday , May 13, 2009
Symposium II Abstracts

2A Light Weight Structures and Materials

Session Chair: TBA

2A1 **Advanced Models for Predicting the Nonlinear Response of Complex Structures and Novel Sensor Placement Technology for Damage Identification**
Bogdan I. Epureanu, The University of Michigan

Modeling and reanalysis techniques are proposed for predicting the dynamic response of a complex structure that has suffered damage in one or more of its components. When such damages are present, the model of the healthy structure may no longer capture the system-level response or the loading from the rest of the structure on a damaged component. Hence, novel models that allow for an accurate reanalysis of the response of the damaged structure are needed in important applications, including damage detection. Herein, such models are obtained by using a reduced order modeling approach based on component mode synthesis. Because the resonant response of a complex structure is often sensitive to component uncertainties (in geometric parameters such as thickness, material properties such as Young's modulus, etc.), novel parametric reduced order models (PROMs) are developed for the general case of multiple substructures with uncertainties. Next, PROMs are exploited for sensor placement for structural dynamic analysis and damage detection. Cracked structures are of interest. The presence of cracks leads to changes in the mode shapes and resonant frequencies compared to the healthy structure. Because the overall goal is damage detection, the frequency range of interest is established by observing the frequencies of the mode shapes that are most sensitive to the crack. To quantify this sensitivity, a novel approach for characterizing the vibration of cracked structures has been developed. When a structure has a crack, it also exhibits nonlinear dynamics. This dynamics is caused by the periodic opening and closing of the crack surface (which leads to a piece-wise linear dynamics). Hence, standard modal analyses cannot be directly employed. To address this challenge, a novel technique to characterize the spatial correlations among the vibration of various points within the structure has been developed. These correlations are akin to mode shapes but they characterize the dynamics of the cracked (nonlinear) structure. This approach is based on the observation that, when the structure has a crack and vibrates at some (nonlinear) resonant frequency, two states can be identified: crack open and crack closed. These two states correspond to two shapes for the deformation of the structure at that frequency. Next, we assume that all the shapes the structure takes during its nonlinear vibration at a resonant frequency are linear combinations of these two shapes (open and closed at that resonant frequency). This novel approach is referred to as bilinear modal approximation. Numerical results are presented for simple cracked structures and for complex ground vehicle components. The number of required sensors is shown to

depend on the number of modes to be monitored, which in turn depends on the level of sensitivity of the monitored modes to the crack. The effectiveness of the approach is demonstrated and the effects of measurement noise are discussed. Three damage cases are considered: (1) severe structural deformation (dents), (2) missing material due to fracture, and (3) cracks.

2A2 **Function-Oriented Material Design for an Innovative Gunner Restraint System**
Guang Dong, Zheng-Dong Ma, Noboru Kikuchi, The University of Michigan

The objective of this research is to develop a fundamental design technology that can be used for the upfront design of new Gunner Restraint Systems (GRS) with improved solder safety, survivability, comfort, and ability to operate in current and future military vehicles. There are two major emphases in this research. The first one is to understand essential functions of the GRS and major factors that will affect the gunner dynamic response and safety performance. We have investigated gunners' safety performance under various vehicle operating conditions, including: rollover, severe braking, high-speed maneuvering, and rough terrain traversal. Among the key factors considered are consciousness of the gunner, bio-mechanical properties of the gunner's joints, and height of the gunners' center of gravity related to the vehicle. An MSC/ADAMS-based virtual prototyping model has been developed, which includes a prototypic military vehicle, gunner, and a GRS model for GRS development. Major up-to-date findings will be presented, which lead to new design strategies for the GRS. The second one is to develop a upfront design process that can be used to lay out innovative and optimum GRS design based on the available state-of-the-art technologies, which include, but are not limited to, supporting structures (such as seat, suspension, stand), restraint belts, air bags, retractors, and new active/reactive devices to be developed. The ARC-developed Function-Oriented Material Design (FOMD) process leads to a new hybrid-configuration design method based on topology optimization for optimum structural and material systems to meet the specific tasks demanded of GRS in military vehicles.

2A3 **A Reactive Structure Technology for Improved Survivability of Military and Commercial Vehicles**
Zheng-Dong Ma, The University of Michigan

We invented the term "Reactive Structure" to connote a smart structure that can react to external excitations (such as vibration, crash, blast and ballistic impacts) in a carefully designed way using the energy from the excitations to counteract the hazardous loading or perform other desired tasks. One such reactive structure employs a small amount of reactive material (such as TNT), which be used to enhance the reactivity of typical reactive structures. A new reactive structure concept, called Explosively Reconfigurable Structure (ERS), is investigated under this ARC research with a focus on feasibility and development of basic design methodologies and guidelines. The basic idea of this ERS is that it reactively reconfigures the structure with the assistance of a small amount of explosive for the purpose of mitigating blast impact. Two fundamental reactive mechanisms have been virtually tested using the LS-DYNA virtual prototyping platform: 1) Deforming the structure to form a desired V-shape so it can effectively deflect the blast shockwave 2)Altering critical load paths reactively so that less impact is transferred to the area where the protection is most needed. Our current effort is to understand how explosives can be used in a safe way and what potential guidelines can be laid out for designing innovative ERS systems. Finite element models have been developed and preliminary analysis of the developed ERS concepts has been conducted to determine feasibility and effectiveness of the ERS against land explosions.

2B Reliability Based Design Optimization I

Session Chair: TBA

2B1 **Comparison Study Between Probabilistic and Possibilistic Approach for Problems with Correlated Input and Lack of Input Statistical Information**
Ikjin Lee, K.K. Choi, Yoojeong Noh, David Gorsich and David Lamb, University of Iowa

Due to expensive experimental testing costs, in most industrial engineering applications, only limited statistical information is available to describe the input uncertainty model. It would be unreliable to use an estimated input uncertainty model, such as distribution types and parameters including the standard deviations for the distributions, that is obtained from insufficient data for the design optimization. Furthermore, when input variables are correlated, we would obtain non-optimum design if we use the assumption of independency for the design optimization. For problems with correlated input and lack of input statistical information, two approaches – reliability-based design optimization (RBDO) with confidence level on the input model and possibility-based design optimization (PBDO) – are compared using a mathematical example and Abrams roadarm of an M1A1 tank. The comparison study shows that the PBDO has more probability to provide an unreliable optimum design when the number of samples is very small and that it provides too conservative optimum design when the number of samples is relatively large. Furthermore, the optimum design does not converge to the true optimum design obtained using the true input distribution as the number of samples increases. On the other hand, the RBDO with confidence level on the input model provides a reliable optimum design in a stable and consistent manner, and the optimum design converges to the true optimum design obtained using the true input distribution as the number of samples increases.

2B2 **Sequential Sampling Based Kriging Method with Dynamic Basis Selection for RBDO**

Liang Zhao, K.K. Choi, Ikjin Lee, David Gorsich and David Lamb, University of Iowa

Traditional reliability-based design optimization (RBDO) requires the sensitivity for both the most probable point (MPP) search in inverse reliability analysis and design optimization. However, the sensitivity is often unavailable or difficult to compute in complex multi-physics or multidisciplinary engineering applications. Hence, the response surface method (RSM) is often used to calculate both function evaluations and sensitivity effectively. Researchers have been developing the RSM for decades, and yet are still searching for an approach with an efficient sampling method for fast convergence while meeting the accuracy criteria. We propose a new adaptive sequential sampling method to be integrated with the Kriging method with dynamic basis selection to solve RBDO problem. By using the bandwidth of the prediction interval from the Kriging method, a new sampling strategy and a new local response surface accuracy criteria are proposed. In addition, traditional Kriging methods, including ordinary Kriging and universal Kriging, use fixed polynomials basis functions to generate the mean structure. To overcome this disadvantage, a so-called Dynamic Kriging (D-Kriging) method is proposed to fit the true model more accurately. In this D-Kriging method, the mean structure is automatically decided by applying sequential feature selection to the candidate basis functions based on a new accuracy criterion. Both a highly nonlinear mathematical example and a vehicle durability engineering example show that the proposed RSM yields accurate RBDO results that are comparable to the sensitivity-based RBDO results, as well as significant savings in computational time for function evaluation and sensitivity computation.

2B3 **Estimation of Confidence Level on Input Model Using Copula for Reliability-Based Design Optimization**

Yoojeong Noh, K.K. Choi, Ikjin Lee, David Gorsich and David Lamb, University of Iowa

For obtaining correct reliability-based optimum design, an input model needs to be accurately estimated in identification of marginal and joint distribution types and in quantification of their parameters. However, in most industrial applications, only limited data on input variables are available due to expensive experimental testing costs. The input model generated using copula from the insufficient data might be inaccurate, which might lead to incorrect optimum design. In this presentation, reliability-based design optimization (RBDO) with a confidence level is proposed to offset the inaccurate estimation of the input model due to limited data by using an upper bound of the confidence interval of the standard deviation. In addition, using the upper bound of the confidence interval of the standard deviation, a confidence level on the input model can be assessed to assure the confidence level of the output performance, i.e. a desired probability of failure, through simulation studies. For RBDO, the estimated input model with an associated confidence level is integrated with the most probable point (MPP)-based dimension reduction method (DRM), which improves accuracy over the first order reliability method (FORM). A mathematical example and a fatigue problem are used to illustrate how the input model with confidence level yields a reliable optimum design by comparing it with the input model with the estimated input parameters.

2C Reliability Based Design Optimization II

Session Chair: TBA

2C1 **A Simulation-Based RBDO Method Using Probabilistic Re-Analysis and a Trust-Region Approach**

Ramon C. Kuczera, Zissimos P. Mourelatos, Jing Li, Oakland University

A simulation-based, system reliability-based design optimization (RBDO) method is presented which can handle problems with multiple failure regions. The method uses Probabilistic Re-Analysis (PRRA) in conjunction with a trust-region optimization approach. PRRA calculates very efficiently the system reliability of a design by performing a single Monte Carlo (MC) simulation. Although PRRA is based on MC simulation, it calculates “smooth” sensitivity derivatives, allowing therefore, the use of a gradient-based optimizer. The PRRA method is based on importance sampling. It provides accurate results, if the support (set of all values for which a function is non zero) of the sampling PDF contains the support of the joint PDF of the input random variables and, if the mass of the input joint PDF is not concentrated in a region where the sampling PDF is almost zero. A sequential, trust-region optimization approach satisfies these two requirements. The potential of the proposed method is demonstrated using the design of a vibration absorber, and the system RBDO of an internal combustion engine.

2C2 **Design for Lifecycle Cost Using Time-Dependent Reliability**

Amandeep Singh, Zissimos P. Mourelatos, Jing Li, Oakland University

Reliability is an important engineering requirement for consistently delivering acceptable product performance through time. As time progresses, the product may fail due to time phenomena such as time-dependent operating conditions, component degradation, etc. The degradation of reliability with time may increase the lifecycle cost due to potential warranty costs, repairs and loss of market share. In design for lifecycle cost, we must account for product quality, and time-dependent reliability. Quality is a measure of our confidence that the product conforms to specifications as it leaves the factory. Reliability depends on 1) the probability that the system will perform its intended function successfully for a specified interval of time (no hard failure), and 2) on the probability that the system response will not exceed an objectionable by the customer or operator, threshold for a certain time period (no soft failure). Quality is time-independent, and reliability is time-dependent. A design methodology is presented to determine the optimal design of time-dependent, multi-response systems, by minimizing the cost during the life of the product. The conformance of multiple responses is treated in a series-system fashion. The lifecycle cost includes a production, an inspection, and an expected variable cost. All costs depend on quality and/or reliability. The key to our approach is the calculation of the so-called system cumulative distribution function (time-dependent probability of failure). For that we use an equivalent time-invariant “composite” limit state which is accurate for monotonic or non-monotonic in time systems. Examples highlight the calculation of the cumulative distribution function and the design methodology for lifecycle cost.

2C3 **Requirements Modeling Lightweight Engineering**

Michael McLellan, Jonathan Maier, Gregory Mocko, Georges Fadel, Clemson University
Mark Brudnak, TARDEC

Lighter weight vehicles have the potential to dramatically decrease fuel costs, material costs, deployment, and other logistical costs of the Army. Analyzing vehicle requirements has the greatest potential for impacting the mass of final vehicle designs since requirements are defined in the earliest stage of the development process. Requirements affect functionality, physical architecture, working solutions, and component and assemblies within the system. The primary objectives in this project are (1) to develop a formal representation and method for increasing the consistency of stating for stating requirements, (2) to formulate a set of rules for reducing mass based on requirements analysis, and (3) to track the changes of requirements and how they impact vehicle systems. The proposed approach is based on benchmarks of current Department of Defense (DoD) requirements definition and modeling practices. Additionally, commercially available software, including Telelogic DOORS and FocalPoint, SysML, and MagicDraw, are evaluated. Further, requirements modeling and analysis techniques in the domain of software engineering are extended to mechanical systems. A formal requirements representation is developed based on protocol and best practices proposed in DoD documents. The representation uses grammar, parts-of-speech (POS), and natural language processing (NLP) for representing requirement statement in a consistent and clear form. The representation is exercised on several DoD, Army, and consumer requirements. Accompanying the formal restatement of requirements are methods and guidelines to state requirements in such a way as to reduce the mass of the systems they ultimately entail. The formal syntax and mass reduction methods are being demonstrated on the cooling system of the Family of Medium Tactical Vehicles (FMTV). Current efforts are focused on the development of computer models of the vehicle requirements, processing into the formal syntax, and application of the mass reduction methods. SysML, matrix models, and parametric models are all being explored. The final software scheme will be demonstrated on additional vehicle systems.

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Day 1, Tuesday, May 12, 2009
Symposium III Abstracts

(click here for day 2 abstracts below)

3 Vehicle Design Methodologies

Session Chair: Gregory Hulbert

3A **Multi-scale Simulations for Developing Light Weight Vehicles with Increased Survivability to Loads from Explosions and High Velocity Projectiles**
Nick Vlahopoulos, the University of Michigan

The U.S. Armed forces face the need for rapid deployment from the United States in order to engage regional threats decisively on a global basis. Size and weight are paramount factors for Army vehicles supporting this force projection structure. Lighter weight vehicles is an enabling factor for faster transport, higher mobility, fuel conservation, and a reduced ground footprint of supporting forces. At the same time high levels of protection must be offered by the vehicle to its occupants against combined loads from explosions and high velocity fragments and projectiles. Weight reduction and high levels of survivability are mutually competing objectives. Composite materials provide some of the most viable options for manufacturing such lightweight vehicles provided that they can offer the desirable level of protection. Multi-scale simulations can be engaged for designing such materials and for evaluating the overall vehicle survivability. NASA Glenn has developed the ImMAC suite codes which enable coupled multi-scale analysis of advanced composite structures. In this project the ImMAC simulation capability is combined with a readily available code for simulating the response of a target structure subjected to loads from explosion/fragmentations in order to develop a new multi-scale simulation method suitable for Army vehicle analysis. The work completed up-to-date demonstrates the feasibility of designing light weight vehicles with high resistance characteristics to loads from explosive threats.

3B **Integration of Multibody Dynamics and Finite Element Models with Rigid and Flexible Gluing Joints in D-Sim**
Geunsoo Ryu, Zheng-Dong Ma, Gregory Hulbert, the University of Michigan

A distributed simulation platform, denoted as D-Sim, has been developed in our research group since 2001. The current research focused on the integration of heterogeneous subsystem models including multibody dynamics and finite element subsystem models, and conducting seamlessly integrated simulation for design tasks in a distributed computing environment. With Partitioned Iteration Method (PIM), D-sim can be used to integrate distributed deformable bodies while allowing large rigid body motions among the bodies or subsystems. It also enables using independent simulation servers; where each server can run commercially available or research-based MBD and/or FEM codes. Gluing algorithm plays a critical role in integrating the distributed subsystems and components. However, it is still a challenge to apply the gluing algorithm to general simulation models, which may be assembled by diverse connecting methods, including spot welding, bolting, bushing, and other physical connections. Flexible gluing joints can deal with various connections between subsystems, and can account for linear and non-linear flexibility at these connections. This not only improves the accuracy of the simulation to represent the real physical system, but also can improve the convergence of multibody dynamics simulation. Examples are provided that the integration of FEM and MBD with flexible gluing demonstrates the performance of the method and also how to decouple and integrate rigid body motion and elastic deformation using the developed gluing algorithm.

3C **An Optimization Approach to Occupant Safety and Fuel Economy in Vehicle Design**
Steven Hoffenson, the University of Michigan

A major challenge in automotive design is the creation of safe vehicles with minimal environmental impact. This study presents a modeling framework for evaluating and optimizing body designs for improved occupant safety and fuel efficiency. Vehicle body mass is considered as the main link between safety and sustainability. The modeling framework includes frontal crash energy absorption, restraint system design and fuel economy. Preliminary results indicate a Pareto-optimal curve between safety and sustainability may exist when other factors are not taken into account. A more complete modeling framework that includes more sophisticated sustainability and safety metrics, cost and other market considerations, is suggested in order to support better design and regulatory decisions.

Day 2, Wednesday , May 13, 2009
Symposium III Abstracts

3A Vehicle Design Methodologies

Session Chair: TBA

3A1 **Modeling and Optimization of Hybrid Tubular SOFC and Gas Turbine Power Systems**
Soryeok Oh and Jing Sun, The University of Michigan

Turbo-charging an SOFC (solid oxide fuel cell) system is a natural and effective way to enhance the efficiency of SOFC systems, given the high energy content in the exhaust gas of SOFC stacks. For mobile applications, however, a set of challenges exist in managing transient operations. In this work, we build on our earlier research on combined SOFC and gas turbine systems. A tubular SOFC system, integrated with a twin-shaft GT, is investigated for its dynamic characteristics and load following capabilities. Dynamic model has been developed to facilitate model-based analysis and future control design. Model-based optimization has also been performed to shed lights on the transient capabilities of the proposed hybrid SOFC/GT system.

3A2 **Risk-based Decisions under Aleatory and Epistemic Uncertainties in Engineering Design**
Dimitri Nowak (1), Sravya Thoomu (2), Sundeep Samson (2), Georges M. Fadel (2), James A. Reneke (1) and Margaret M. Wiecek (1)
(1) Department of Mathematical Sciences (2) Department of Mechanical Engineering

The problem of design selection from among competing alternatives has been identified as central in engineering design. Uncertain design parameters and operating environments complicate the decision-making process. A risk-based decision making methodology with both aleatory and epistemic uncertainties is demonstrated on a simple spring system and applied to a side-impact crashworthiness problem. Non-quantifiable variability resulting from lack of knowledge is treated as epistemic uncertainty and quantifiable variability caused by random influences is treated as aleatory uncertainty. Risk is quantified using aleatory uncertainty for fixed values of epistemic uncertainty. Three cases for the spring system are studied. A deterministic case with epistemic uncertainty is followed by two stochastic cases, one without and one with epistemic uncertainty. In each stochastic case, a finite number of alternatives are evaluated in terms of decision criteria balancing the expected performance and risk over the range of uncertainties. The traditional crashworthiness problem is extended by recognizing epistemic uncertainty in the experimental setup. The proposed methodology identifies a robust design that is the least-risk design over the range of uncertainties. The results are compared with traditional RBDO and SORA methods which only consider aleatory uncertainty. The study shows unique features of this approach in which risk-based design decisions are made under both aleatory and epistemic uncertainties, without assuming a distribution for epistemic uncertainty.

3A3 **Research issues related to Packing Optimization**
Vidhya Sagar Reddy Arumalla, Karthik Ravindranath, Robert Boyd, Sriram Sridharan, Santosh Tiwari, Sundeep Samson and Georges Fadel , Clemson University

This presentation summaries the current status of our work in generalized packing which continues to be a major part of industry as it strives to efficiently pack; from people, bags, boxes, etc. within a vehicle to multiple vehicles within an aircraft. Current underhood packing approaches do not incorporate the heat transfer information which could play a vital part in the placement of components. An Agent-Based implementation of a multiple criteria underhood packing strategy is under development. It will be described conceptually. The aim is to be able to consider Dynamic Behavior, Survivability, Accessibility and Operational Temperature as the four objectives. Each component under the hood is treated as an autonomous agent that will interact, cooperate, coordinate and negotiate with the others to achieve the overall system objective. Furthermore, the state-of-the packing algorithms developed for rigid objects fails to efficiently deal with deformable objects. A modified morphing algorithm in additions to the packing algorithm is under development to incorporate deformable objects in the packing scenario. No assumptions on the deformable objects' final deformed shape are made. Initial results are presented and discussed.

3B Systems Optimization and Validation

Session Chair: TBA

3B1 **Representing and Accounting for Geometry in Optimal System Design**
Kwang Jae Lee, The University of Michigan

System design is tied to both functionality and geometric realization. The former is pertinent to system performance, and the latter is related to packaging. Packaging process is very important in system as well as component design. When the components do not fit into the allocated space at the packaging stage, the design engineers must make modifications that can affect the performance of the system and result in increased delivery time and development costs. Therefore, if we can account for packaging at the preliminary design stage, manufacturing and design costs should be reducible. In this talk, the requisite geometry representations, initial efforts to address the combined packaging and optimal system design, development of a computational environment that enables these investigations, and a demonstration example will be presented.

3B2 **Motor/Generator Downsizing Effect in Multi-mode Hybrid Powertrains**
Kukhyun Ahn, The University of Michigan

Multi-mode hybrid powertrains are known to achieve better dynamic performance with smaller motor/generator (M/G) units than single-mode ones. This research investigates a full-load performance optimization problem to explain the mechanism that leads to this improvement. A three-dimensional operation space analysis and a synchronous mode shift scheme for the multi-mode powertrain are presented. This optimization is then integrated into a powertrain design optimization problem, where M/G characteristics and gear ratios are optimized. The optimization results show significant improvement in dynamic performance at reduced M/G capacities.

3B3 **An Interactive Modeling Environment for Automotive Exterior Design**
Yi Max Ren, The University of Michigan

This work presents a three-dimensional surface parametric modeling environment for representing basic exterior vehicle shapes. Google SketchUp is used to develop the representation because it allows rapid modeling through coding. Parametric representation allows shapes to be modified quickly and inexpensively based on user preference input. This representation is then used in conjunction with an Interactive Genetic Algorithm to demonstrate its value in eliciting user shape preferences. The developed interacting modeling environment is a building block towards a system optimization capability that integrates engineering attributes with customer shape preferences in automotive product development.

3C Optimal Vehicle Design

Session Chair: TBA

3C1 **Incorporating Ease of Control into Sequential Optimization**
Diane Peters, The University of Michigan

Optimal design of vehicle systems requires both system design and controller design. In many cases where there are separate objectives for the physical system and its controller, there is a tradeoff present between these two objectives. Conventional sequential optimization will generate a design which is optimal for one objective, but not for the other. Solution of a simultaneous optimization problem, incorporating both objectives, will find optimal solutions to the system; however, the simultaneous problem is larger, more computationally intensive, and operationally inconvenient to formulate and execute. A new, modified sequential optimization formulation is proposed, incorporating ease of control into the design of the physical system. The presentation addresses characteristics of an effective surrogate function for ease of control, and discusses possible surrogates effective for particular problem formulations.

3C2 **Reduced Representations of Vector-Valued Coupling Variables in Decomposition-Based Design Optimization**

Michael Alexander, The University of Michigan

Decomposition-based methods for system design optimization introduce consistency constraints, which contain coupling variables communicated between adjacent subproblems and link them together. When these variables are vector-valued (e.g., dynamic responses), the problem size can increase dramatically and make such methods impractical. Therefore, it is necessary to represent these vector-valued coupling variables with a reduced representation that will enable efficient optimization while maintaining an acceptable level of accuracy with respect to the original representation. This study investigates two representation techniques, radial-basis function artificial neural networks and proper orthogonal decomposition, and implements each in an analytical target cascading problem formulation for electric vehicle powertrain system optimization. Implementation of each representation technique is demonstrated and the techniques are assessed in terms of efficiency (decision vector dimensionality) and accuracy.

3C3 **Sensitivity Study of Bayesian Model Validation**

Yogita Pai, The University of Michigan

With the need to bring reliable products to market under shorter development times, validation of both experimental and simulation results is playing a critical role. Of particular challenge are multivariate, inhomogeneous time-series data. One promising method is the application of Probabilistic Principal Component Analysis (PPCA) followed by interval?based Bayesian hypothesis testing (IBHT). To gain confidence in this approach, the robustness of the methods to scaling and to the prescribed interval must be evaluated. In this talk, we present our current research towards sensitivity analyses of PPCA and IBHT using real-world data sets.

Day 1, Tuesday, May 12, 2009
Symposium IV Abstracts

(click here for day 2 abstracts below)

4 Vehicle Mobility

Session Chair: Hosam K. Fathy

4A **A Base-Excitation Approach to Polynomial Chaos Based Estimation of Sprung Mass for Off-Road Vehicle Suspension Models**
Benjamin L Pence, Hosam K. Fathy, Jeffrey L Stein, the University of Michigan

This talk presents novel methods for identifying in real-time the sprung mass of off-road vehicles. It is motivated by the need to determine the mass of off-road vehicles whose loading conditions vary significantly from one trip to the next. The online estimate is to be used by vehicle control strategies such as safety control, powertrain control, and traction control. Existing sprung mass estimation strategies based on suspension dynamics require either known suspension force actuation or prior knowledge of terrain characteristics. This talk proposes three methods, each of which is founded on a base excitation model of a quarter-car suspension. The base excitation formulation treats unsprung mass motions as measured base excitations, thus eliminating the need for ground disturbance measurement or suspension actuation. The methods uniquely combine the base-excitation concept with online estimation strategies. These strategies include recursive least squares, recursive total least squares, and polynomial chaos estimation. The talk demonstrates the methods via computer simulations and concludes that each method provides a potential solution for real-time, sprung mass estimation for off-road vehicles.

4B **Exploration of Computational Techniques to Model Dynamic Sand-Tire Interaction: Discrete Element Method, Finite Element Method, and Meshless Method**
Timothy Reeves*, Avinash Kolla, Marisa Orr, Jianfeng Ma, Balajee Ananthasayanam, Sherrill Biggers, Paul Joseph, Joshua D. Summers**, Clemson University
**Presenting Author ** Corresponding Author*

This research examines and compares approaches for modeling the behavior of sand under various loading conditions as a critical first step in developing computational tools to aid in designing new tire-sand interaction systems for improved traction. Sand is a challenging material to be modeled computationally due to its unusual behavior, sometimes resembling a fluid and sometimes behaving more like a solid, yet never truly behaving as either. This behavior arises from the particulate nature of sand, which, in contrast to the systems typically modeled in continuum mechanics, is not readily represented by continuum models. In sand, elements (i.e. particles) do not have permanent associations with neighboring elements as they do in most continua, but rather are free to migrate anywhere in the domain according with their interactions with other elements. The Discrete Element Method (DEM) is a numerical technique designed to model the dynamics of particulate systems and is being used to develop an understanding of the behavior of certain sand systems. The number and complexity of particles in a DEM simulation are limited by computational resources. Therefore, to realistically approximate complex systems such as sand, the parameters of the particles in a DEM system must be calibrated experimentally. Once this has been performed, it is anticipated that DEM simulations will provide benchmarks for validating new continuum models to be implemented in Finite Element Method (FEM) or in Meshless Integral Method (MIM) simulations. FEM and MIM are less computationally intensive than DEM as they use simpler approximations of the behavior of sand as it interacts with loading sources, such as tires. This presentation introduces the capabilities of DEM and

presents initial studies in both FEM and MIM approaches to modeling the behavior of sand and tire interactions. Finally, to demonstrate the future directions, experimental results from traction system prototyping based on an undergraduate design team's three month effort is illustrated.

4C **The Virtual Driver: Modeling the Experimental Results of Convoy Driving with a Secondary In-Vehicle Task**

Helen Fuller, Matthew Reed, Yili Liu, the University of Michigan

Digital human models (DHMs) are vitally important tools for studying tasks that occur in environments that are too complex or dangerous to investigate experimentally. Many tasks have significant physical and cognitive components, necessitating a DHM that can interact both physically and cognitively with its environment. One example is driving while performing an in-vehicle task, such as tuning a radio, entering coordinates into a GPS system, or operating a communications device in a military vehicle. The goal of this project is to integrate a physical human model (HUMOSIM Framework running in the Jack human modeling environment) with a computational cognitive model (QN-MHP) to study complex human-machine interactions. A driving simulator experiment was conducted to generate data that will be used to tune and validate the integrated model. Men and women with a wide range of body size followed a lead vehicle that changed speed continuously as they entered information on a touch-screen display located in each of four positions. Driving behavior and secondary task performance results will be presented, along with strategies that subjects used to share resources between the two tasks. In addition, methods for modeling the combined task and preliminary modeling work will be discussed.

Day 2, Wednesday , May 13, 2009
Symposium IV Abstracts

4A Terrain Modeling

Session Chair: TBA

4A1 **A New Measure of the Roughness of a Terrain Profile**

T. C. Sun, D. Gorsich, M. Chaika, J. Wei, S. Qiu and K. Alyass, Wayne State University

In this paper we shall propose a new measure of roughness of a terrain using the idea from the linear damage theory in fracture mechanics and the concept of rainflow count of the oscillation cycles from a terrain profile. We believe that this new measure can be used as a complement to the old method of using the root mean square (rms) as measure of roughness of a terrain. We welcome comments and discussions from peers.

4A2 **A Stochastic PDE Approach to Terrain Modeling**

Richard Lee and Corina Sandu, Advanced Vehicle Dynamics Laboratory, Virginia Polytechnic Institute and State University

For realistic predictions of vehicle performance in off-road conditions, it is critical to incorporate in the simulation accurate representations of the variability of the terrain profile. Terrain geometry and soil characteristics highly affect vehicle mobility and handling. It is not practically feasible to measure the terrain at a sufficiently large number of points, or, if measured, to use such data directly in the simulation. Dedicated modeling techniques and computational methods that realistically and efficiently simulate off-road operating conditions are thus necessary. Many studies have been recently conducted to identify effective and appropriate ways to reduce experimental data in order to preserve only essential information needed to re-create the main terrain characteristics, for future use. In this study, terrain profiles are modeled using the finite difference approach for solving linear second-order stochastic partial differential equations. We currently use this approach to model non-stationary terrain profiles in two dimensions (i.e., surface maps). Certain assumptions are made for the values of the model coefficients to obtain the terrain profile through the fast computational approach described, while preserving the stochastic properties of the original terrain topology. The technique developed is illustrated to recreate the stochastic properties of a sample of terrain profile measured experimentally. To further analyze off-road conditions, stochastic soil properties are incorporated into the terrain topology. The polynomial chaos method is applied to Bekker's pressure-sinkage relation to analyze

the uncertainties within the soil models. Simulations have been created on a surface map for different case studies. These case studies had various combinations of stochastic or deterministic terrain profile, a stochastic or deterministic soil model, and an object to run across the surface (e.g., deterministic terrain profile, stochastic soil model, rigid wheel).

4A3 **Exit Angle Influence on Energy Efficiency of Off-Road Tires**

Carmine Senatore and Corina Sandu, Advanced Vehicle Dynamics Laboratory, Virginia Polytechnic Institute and State University

Fuel economy of land vehicles depends on four main factors: thermal losses in the engine, friction of moving parts (engine, transmissions, joints), aerodynamic resistance, and tire friction. We focus our analysis on the tire-soil interaction and, starting from the model developed by Chan and Sandu (2007), we conduct a thorough analysis to understand the factors that affect the tire performance and its energy efficiency. Common tire models like the Friction Ellipse Model and the Magic Formula Model are mainly intended for on road tires and don't provide a detailed description of the contact patch dynamics. The models proposed by Wong, Reece, Muro, Karafiath, and Chan are intended for flexible tires on flexible terrain and give a more detailed description of the soil-tire interaction at the contact patch. These models, though, lack the capability to uniquely predict or identify the exit angle of the trailing edge. In this study we conduct a sensitivity analysis and compare different implementations of the exit angle, as well as its impact on the energy efficiency of the vehicle. We consider that the vehicle travels at constant speed on a flat off-road (soft homogeneous soil) surface. We vary the implementation of the exit angle and we run simulations for different vehicle mass, tire radius, inflation pressure, and tire width. The exit angle influences the contact patch length and location and therefore has a strong impact on the tire performance. As an initial assumption, we consider the exit angle a function of the vertical force. The trend in the absorbed power versus tire radius and absorbed power versus vehicle mass shows that the exit angle dependence upon the vertical force is reasonable but also suggests that a correlation with tire radius and width exists.

4B Human-In-The-Loop Testing

Session Chair: TBA

4B1 **Vehicle-Terrain Interaction - Macroscopic and Microscopic Aspects**

Jonah Lee, University of Alaska-Fairbanks

In this talk, we first present UAF's vision of vehicle-terrain interaction research - in collaboration with many partners -- with a brief chronological review of accomplishments, challenges and needs in the three interrelated areas: macroscopic aspect, uncertainty characterization and microscopic aspect. The need of validation of models is emphasized throughout our presentation. Although our focus has been on vehicle-snow interaction, it is hoped that the methodology we have developed can be adapted for other soft terrains as well. For the macroscale aspect, we will discuss a range of models from semi-analytical and high-fidelity finite element models for smooth and treaded tires, indentation tests, under quasi-static as well as time-dependent conditions. The work done for mobile-scanning using Ground Penetrating Radar was also touched upon. For uncertainty characterization, we will discuss models using interval analysis and polynomial chaos approach. For the microscale aspect, we will discuss stochastic characterization of snow microstructure, microscale indentation tests using the meshless Generalized Interpolation Material Point (GIMP) method implemented in the software package Uintah. We close the presentation with exciting and challenging future work including laboratory traction tests, field studies such as terrain characterization towards the validation of vehicle-terrain interaction models.

4B2 **Advancements in Semi-Active Suspensions and Human-In-The-Loop Testing**

Steve Southward and Dan Reader, Virginia Polytechnic Institute and State University

Mobility and performance of an HMMWV or equivalent military transport vehicle is strongly dependent on the primary suspension effectiveness. Semi-active suspension technology represents a proven control solution for improving vehicle performance because they are lighter, less expensive, more reliable, and offer near equivalent performance compared to fully-active solutions. This research has focused on two advancements. In the first phase, which is now complete, a non-linear forward model of a Magneto-Rheological (MR) fluid damper has been developed including a turn-key method for generating model parameters using a shock dynamometer. This model was constructed to admit an inverse model solution that has been shown to enhance the performance of most semi-active suspension control algorithms. An example simulation of this advancement was demonstrated with Skyhook control. The second phase of this research, which is ongoing, was to develop a Human-In-the-Loop (HIL) test platform for evaluating semi-active suspension technology. A demonstration of an example transport vehicle will be presented on a 6-DOF full motion driving simulator for a passive suspension. MR damper models with the inverse-based semi-active control advancement are currently being incorporated into the vehicle model for human evaluation studies.

4B3 **Effects of Posture and Movement on Vibration Transmissibility Affecting Human Reach Performance under Vehicle Vibration**

Heon-Jeong Kim and Bernard J. Martin, the University of Michigan

Vibration transmissibility to the human body is a function of both vehicle vibration characteristics and postures associated with the performance of movements. The majority of earlier studies investigating upper body vibration transmissibility considered only a static posture excluding dynamic limb movements (Amirouche, 1987; Wei and Griffin, 1998; Rosen and Arcan, 2003; Yoshimura et al, 2005; Liang and Chiang, 2006). A few recent studies reported the effect of vehicle vibration on arm reaching movements through the description of fingertip deviation from a desired trajectory (Rider and Chaffin, 2003, 2004). The present work investigates the variation of vibration transmissibility to upper extremities as a function of dynamic posture changes along the intended reach trajectory. Dynamic reach movements in the direction of targets distributed in the right hemisphere of a vehicle operator are analyzed as a function of vibration characteristics and movement directions.. Thirteen subject performed right hand reach movements in various directions to final/end target location as well as intermediate target locations selected along the trajectory of movement performed to the end target. The established database of upper body segments transmissibility is used to develop an active biodynamic human model.

4C Vehicle Mobility

Session Chair: TBA

4C1 **Independent Hydrostatic Wheel Drives**

Sisay Molla, Indrasen Karogal and Beshah Ayalew, Clemson Univeristy - International Center for Automotive Research

This work presents an investigation of vehicle stability enhancement strategies using independent hydrostatic wheel drives. The goal is to capitalize on the high power density of hydraulic pump/motor units. These units are small enough to be mounted on/at the wheels of off-road military vehicles where they can contribute to savings in weight and/or space. The approach can also achieve powertrain fuel efficiency gains from the hybridization and modularity of the drive system, where either the engine or part of the hydrostatic system can be operated intermittently. This research work was conducted in two parts. The first part dealt with developing upper level vehicle stability control strategies. The corrective yaw moment required to maintain driver-solicited vehicle responses is computed from yaw rate and/or lateral acceleration feedback. From this, the upper level torque distribution strategies develop the independent tractive/braking torque requests. A combination of 4 torque distribution strategies and 3 feedback controllers were evaluated where most of them were found to work well in standard handling test maneuvers. The second part of the work dealt with the development of simulation models for the modular hydrostatic drive system comprising of the four hydraulic pump/motors, an IC engine, hydraulic lines, valves and a set of hydropneumatic accumulators. We will outline these models and their integration into the vehicle stability control framework. We also outline our continuing work for validation by implementing a hardware-in-the-loop simulation of the system comprising of the hydrostatics hardware on a 4x4 chassis dynamometer and the dynamics of a HMMWV simulated in a dSPACE hardware.

4C2 **Ultracapacitors for Power Boost in Heavy Vehicles**

Seneca Schepmann, Dean Rotenberg, Ardalan Vahidi, John Wagner, and Georges Fadel, Clemson University

Through numerical simulations, the potential of ultracapacitors to serve as a stand-alone auxiliary power source for vehicles is investigated. A mild parallel hybrid powertrain is considered in which an electric motor and an ultracapacitor-based energy source assist the combustion engine during periods of high power demand. The ultracapacitor is recharged by the engine during periods of low demand,

and through regenerative braking. Standard city-cycle simulations on a detailed model of the powertrain illustrate 5 to 15 percent improvement in fuel economy enabled by the ultracapacitor-based mild hybrid configuration.

4C3 **Effect of Pump Selection on Fuel Economy in a Dual Clutch Transmission Vehicle**
Rahul Ahlawat, the University of Michigan

Positive displacement pumps are used in automotive transmissions to provide pressurized fluid to various hydraulic components in the transmission and also to lubricate the mechanical components. The output flow of these pumps increases with speed, almost linearly, but the flow requirements often saturate at higher speeds resulting in the excess flow draining back to the sump. This represents a parasitic loss in the transmission leading to a loss in fuel economy. To overcome this issue, variable displacement pumps have been used in the transmission, where the output flow is reduced by controlling the displacement of the pump. The use of these pumps in automatic transmissions, has resulted in better fuel economy as compared to some types of fixed displacement pumps. However, the literature does not fully explore the benefits of variable displacement pumps to a specific type of transmission namely, dual-clutch transmission, that has different pressure & flow requirements than an epicyclic gear-train. This talk presents an analysis on the effect of pump selection on fuel economy in a five speed dual clutch transmission of a commercial vehicle. The talk will focus on the development of models, and their parameterization using the experimental data, and then conclude with some results comparing the fuel economy benefit obtained by the use of the variable displacement pump in a dual clutch transmission to that of an automatic transmission.