Automotive Research Center
A U.S. Army Center of Excellence for Modeling and Simulation of Ground Vehicles
led by the University of Michigan

14th Annual ARC Conference
May 20th – 21st, 2008

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

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 20th 2008

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

8:00 - 8:30 **Welcome and Introductions**

Dennis Assanis
Professor and ARC Director, The University of Michigan

Paul Skalny
Director, National Automotive Center

8:30 - 9:15 **MAJOR GENERAL Roger A. Nadeau**
Commanding General
United States Army Test and Evaluation Command

Question and Answer Session

9:15 - 9:45 **Networking Break**

9:45 - 11:45 **Keynote Address:**

TOWARDS FUTURE VEHICLE CONCEPTS AND DESIGNS —
EFFICIENT AND RELIABLE VEHICLE SOLUTIONS FOR AN UNCERTAIN WORLD

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

Speakers: **Michael Wynblatt**
VP Engineering Technology Eaton Corporation

Peter J. Savagian
Director of Hybrid Powertrain Engineering
GM Powertrain, General Motors Corporation

Rani Finstad
Global PT Director Manufacturing Design
Simulation & Support, General Motors Corporation

Question and Answer Session

11:45 - 1:15pm **Lunch**

1:15 - 2:00	Case Study 1: **Simulation-Based Validation And Certification Of Vehicle Tests And Designs by Thrust Area 5** Speakers: Prof. Panos Papalambros, Dr. Michael Kokkolaras *The University of Michigan*
2:00 - 2:15	**Networking Break**
2:15 - 3:30	Case Study 2: **Alternative Energy and Power for Military and Commercial Vehicles** by Thrust Area 4 Prof. Dennis Assanis, Prof. Zoran Filipi, Dr. Dohoy Jung, *The University of Michigan* Prof. Naeim A. Henein*, Wayne State University*
3:30 - 3:45	**Networking Break**
3:45 - 4:30	Case Study 3: **New Technology Development for Integrated Survivability of Military and Commercial Vehicles** by Thrust Area 3 Speakers: Dr. Zheng-Dong Ma *The University of Michigan*
4:30 - 4:45	**Wrap-Up and Q & A** **Dennis Assanis** Professor and ARC Director, The University of Michigan
4:45	**Adjourn**

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ARC Conference Day 2 Schedule
Wednesday May 21st 2008

8:00 - 8:45am	**Registration and Continental Breakfast**
8:45 - 9:00	**Welcome** **Dennis Assanis** Professor and ARC Director, University of Michigan
9:00 - 9:30	**Keynote Address:** **Peter Schihl, Ph.D., P.E.** ARC Technical Leader, U.S. Army TARDEC

Question and Answer Session

9:45am - 4:15pm	**Technical Symposia** *Symposia Matrix and Abstracts to be announced.* *(Lunch from 12:05 to 1:30pm)*

Symposium I - Vehicle Dynamics and Control

9:45 - 11:00am	Hardware-In-Loop Simulation
11:15 - 12:05pm	Terrain Modeling
12:05 - 1:30	Lunch
1:30 - 2:20	Modeling and Control of Vehicle Systems I
3:00 - 3:50	Modeling and Control of Vehicle Systems II

Symposium II - Human Centered Modeling and High Performance Structures and Materials

9:45 - 11:00am	Human Centered Design
11:15 - 12:05pm	Survivability
12:05 - 1:30	Lunch
1:30 - 2:20	Reliability Based Design Optimization I
3:00 - 3:50	Reliability Based Design Optimization II

Symposium III - Simulation and Vehicle System Integration, Optimization and Robustness

9:45 - 11:00am	Optimal Design I
11:15 - 12:05pm	Optimal Design II
12:05 - 1:30	Lunch

1:30 - 2:20	Distributed Simulation and Packaging
3:00 - 3:50	Vehicle Safety

Symposium IV - Advanced and Hybrid Powertrains

9:45 - 11:00am	Diesel Injection and Combustion
11:15 - 12:05pm	Thermal Management
12:05 - 1:30	Lunch
1:30 - 2:20	Transient Operation and Hybrid Vehicle Power Management
3:00 - 3:50	Internal Combustion Engine Modeling

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Keynote Speakers

Biographies

Day 1 Speakers

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MAJ. GEN. Roger A. Nadeau

Commanding General
United States Army Test and Evaluation Command

Major General Roger A. Nadeau took command of the Army Test and Evaluation Command (ATEC) on June 28, 2007. Prior to accepting command of ATEC, he served as the commander of the U.S. Army Research, Development and Engineering Command from October 2004 to June 2007. His other significant assignments include Program Executive Officer for Ground Combat Systems; responsible for developing, acquiring, fielding and sustaining Army Ground Combat Systems; Program Executive Officer for Combat Support and Combat Service Support; Deputy for Systems Acquisition (DSA), Aviation and Missile Command (AMCOM), responsible for the development, fielding, sustainment, and divestiture of selected Army aviation and missile systems; Assistant Deputy for Systems Management and Horizontal Technology Integration in the Office of the Assistant Secretary of the Army for Acquisition, Logistics and Technology; and Chief of Staff to the Assistant Secretary of the Army (Acquisition, Logistics and Technology)/Army Acquisition Executive.

Major General Nadeau's troop time includes service as Battalion Executive Officer, 1st Battalion, 37th Armor, 1st Armor Division, United States Army Europe and Seventh Army, Germany and Southwest Asia during Desert Storm.

Major General Nadeau's awards and decorations include the Defense Service Medal; Legion of Merit (4 Oak Leaf Clusters); Bronze Star; Meritorious Service Medal (3 Oak Leaf Clusters); Army Commendation Medal; Parachutist Badge; Air Assault Badge; Ranger Tab; and Army Staff Identification Badge.

A nationwide command, ATEC has overall responsibility for all Army developmental and operational testing. The command plans, conducts, and integrates developmental testing, independent operational testing, independent evaluations, assessments, and experiments in order to provide essential information to decision makers. ATEC is the premier test and evaluation organization within DoD, valued by customers and decision makers for providing essential information that ensures war-fighters have the right capabilities for success across the entire spectrum of operations. (ref: http://www.atec.army.mil/leaders.htm)

Michael Wynblatt

VP Engineering Technology Eaton Corporation

Dr. Wynblatt is responsible for driving innovation processes and the development of new products, services and solutions that involve a wide range of technologies across the business groups and regions in Eaton. Wynblatt joined Eaton from Siemens, where he served as vice president and chief technology officer for its Technology-to-Business Center and prior to that as director of venture technology. Prior to working for Siemens, he held research and teaching positions at the State University of New York, Stony Brook.

Wynblatt holds a bachelor's degree in computer engineering from the University of Michigan and master's and doctorate degrees in computer science from the State University of New York.

Peter J. Savagian

Director of Hybrid Powertrain Engineering
GM Powertrain, General Motors Corporation

Peter Savagian (suh vah' jhin) serves as Engineering Director of GM's Hybrid Powertrain Systems and Electric Motor Release Centers. For the past 8 years he has managed product development and advanced engineering for GM's hybrid systems, including hybrid architecture development, electric drive components, systems analysis and control algorithm development. Pete has worked on electric vehicle systems since 1990. Prior to his current assignment, Pete was Chief Engineer for GM's EV1 Electric Vehicle motors and power electronics at General Motors and Delco Electronics. In the past, he has worked at Hughes and Sundstrand in various engineering roles.

Pete holds a BS in Mechanical Engineering from the University of Wisconsin, a Masters in Engineering from the University of Southern California, and an MBA from Duke University.

Rani Finstad

Director of Advanced ME & ME Support
Global GMPT Manufacturing Engineering, General Motors Corporation

BS- Metallurgical Engineering - Michigan Technological University
MS- Metallurgical Engineering - University of Wisconsin - Madison

Rani has 29 years at GM, she started as a Co-op Student, Held positions as Project Engineer, Senior Project Engineer in Casting Development, Supervisor of Ferrous Casting Development. Rani held Director positions in Systems Engineering, Casting & Forging and Die & Stamping at GM's Advanced Engineering Staff. Rani became Director of Manufacturing Design, Simulation & Analysis when she joined GM Powertrain in 1997.

Her current responsibilities, is Director of Advanced ME & ME Support for GM Powertrain. Rani has responsibility for the use of sophisticated math based tools to simulate and analyze tools, equipment and process options for the engine, transmission and casting sectors. She manages the development of the math based tools supporting the ME organization. She directs the activities of the Powertrain pre-production operations and several support functions including Cutting Tools, Gages and Ergonomics. She most recently added responsibility for Advance Propulsion ME-supporting the growth in Hybrid, Electric and Fuel Cell systems.

Rani considers one of her strengths to be developing people and providing career growth and development opportunities.

Day 2 Speakers

(go to Day 1)

Dr. Peter Schihl

ARC Technical Leader, U.S. Army TARDEC

Dr. Schihl earned his Bachelor of Science and Master of Science degrees in Mechanical and Systems Engineering from Oakland University in 1989 and 1991, respectively. He received his Ph.D. from the University of Michigan in 1998. His research has concentrated on developing and experimentally validating simplified combustion and ignition models for direct-injection, quiescent chamber diesel engines. He has received the 'Best Paper in Session' award as the primary author at the 1996, 1998, 2000, 2004, and 2006 Army Science Conference Propulsion-Mobility technical sessions. He also received a Research and Development Achievement Award for his efforts. Dr. Schihl is a member of the Society of Automotive Engineers (SAE), the Combustion Institute, The Engineering Society of Detroit (ESD), and the American Society of Mechanical Engineers (ASME). Since 1998, he has been a reviewer at the annual Department of Energy CIDI (Compression Ignition Direct Injection) National Lab review.

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Symposia matrix is formatted to printout in "Landscape" format

Time	Symposium I	Symposium II	Symposium III	Symposium IV
	1A Hardware-In-Loop Simulation Chair: Jeff Stein	**2A Human Centered Design** Chair: Matt Reed	**3A Optimal Design I** Chair: Michael Kokkolaras	**4A Diesel Injection and Combustion** Chair: Zoran Filipi
9.45 - 10.10	Progress Towards Internet-Distributed Hardware-In-The-Loop Simulation	Convoy Driving with Secondary Tasks: Results of a Driving Simulator Experiment	Self-Learning Identification and Stochastic Optimal Control of Advanced Powertrain Systems	Autoignition, Combustion and Emission Characteristics of Soy Bean Based Biodiesel
10.10 - 10.35	Friction Modeling For Real Time Simulation	Three-Dimensional Joint Kinematics of the Upper Extremity in Reach Movements under Whole-Body Vibration Exposure	Consistency Constraint Allocation in Augmented Lagrangian Coordination	Impact of Alternative Fuels on Combustion, Emissions, and Efficiency
10.35 - 11.00	Hardware-In-The-Loop (HiL) Simulation Efforts On Vehicle Braking System And Electronic Stability Control	Analysis of Transparency in Teleoperation with Application to Steer-by-Wire	System Design with Geometric Considerations	Impact of Alternative Fuels on Combustion and Emissions during Transient Engine Operation
11.00 - 11.15	**Break**			
	1B Terrain Modeling Chair: Corina Sandu	**2B Survivability** Chair: Nick Vlahopoulos	**3B Optimal Design II** Chair: Michael Kokkolaras	**4B Thermal Management** Chair: Dohoy Jung
11.15 - 11.40	Stochastic Terrain Profile Modeling	High-Frequency Shock Analysis for Composite Vehicles	Optimal Design of Hybrid Electric Fuel Cell Vehicle Under Uncertainty	Vehicle Thermal Management System Design for FCS Series Hybrid Electric Vehicle
11.40 - 12.05pm	Modeling of Terrain Profiles and Characterization of the Roughness of Terrains	Predicting Effects of Component Damage on Structural Dynamic Response	Operation Optimization of Power-Split HEV Powertrains	Transient Fluid Flow and Heat Transfer in the EGR Cooler
12.05 - 1.30	**Lunch**			
	1C Modeling and Control of Vehicle Systems I Chair: Hosam Fathy	**2C Reliability Based Design Optimization I** Chair: K.K. Choi	**3C Distributed Simulation and Packaging** Chair: Greg Hulbert	**4C Transient Operation and Hybrid Vehicle Power Management** Chair: Naeim E. Henein
1.30 - 1.55	Online Mass Estimation of Off-road Vehicles	Selection of Copula to Generate Joint CDF for RBDO with Associated Confidence Level	Integration of Multibody Dynamics and Finite Element Analysis Models in D-Sim	Characterizing Transient Diesel Engine Behavior with Cycle-Resolved In-Cylinder Measurements
1.55 - 2.20	Improving High-CG Vehicle Rollover through Steering input Augmented Semiactive Suspensions	Reliability Estimation for Multiple Failure Region Problems using Importance Sampling and Approximate Metamodels	Physics-based Shape Morphing and Packing for Layout Optimization	A Stochastic Optimal Control Approach for Power Management in Plug-In Hybrid Electric Vehicles
2.20 - 3.00	**Break**			
	1D Modeling and Control of Vehicle Systems II Chair: Hosam Fathy	**2D Reliability Based Design Optimization II** Chair: Zissimos Mourelatos	**3D Vehicle Safety** Chair: Matt Castanier	**4D Internal Combustion Engine Modeling** Chair: Nabil G. Chalhoub
3.00 - 3.25	Lithium-Ion Battery Model Reduction in the Physical Domain for Combined Online State-of-Charge and State-of-Health Estimation	System Reliability-Based Design Optimization Using MPP-Based Dimension Reduction Method	An Innovative I-Bumper Concept and its FOA Model for Improved Survivability of Military and Commercial Vehicles	Computation of the Instantaneous Frictional Losses of Internal Combustion Engine Components
3.25 - 3.50	The Mechanical Properties of Snow as a Random Heterogenous Material	Model Validation for Simulation Based Design with Associated Confidence Level	Preliminary Study on an Innovative Reactive Restraint System for Improved Gunner Safety in Military Vehicles	Application of Variable Geometry Turbine in Dual-Stage Turbocharging System

Day 2, Wednesday , May 21, 2008
Symposium I Abstracts

1A Hardware-In-Loop Simulation

Session Chair: Jeff Stein

1A1 **Progress Towards Internet-distributed Hardware-in-the-loop Simulation**
Tulga Ersal, Hosam Fathy, Jeffrey Stein

To facilitate high-fidelity concurrent engineering, a research collaboration between TARDEC and UM seeks to integrate two hardware-in-the-loop setups over the internet, namely, the ride motion simulator in TARDEC, Warren, and the engine-in-the-loop setup in UM, Ann Arbor. Previous work by TARDEC achieved a similar integration of facilities at TARDEC and Santa Clara, CA, by employing observers of the hardware on both sides. This work investigates the possibilities to achieve this integration without relying on observers. This talk will present the initial studies of the potential challenges of such a setup. Specifically, the problem will be approached from a telerobotics perspective first, and some of the existing methods in that literature will be presented along with their limitations. Then, a simulation model will be presented that is being developed to investigate which of those limitations will be relevant in the proposed setup. Finally, simulation results will highlight the potential challenges future work needs to address.

1A2 **Friction Modeling for Real Time Simulation**
Rahul Ahlawat, Hosam Fathy, Jeffrey Stein

Accurate modeling of friction is desired in many applications, including those requiring real-time simulation, such as hardware-in-the-loop simulations. However, high fidelity representations of friction surfaces often lead to formulation problems concerning causality and to low computational speed and numerical issues during simulation. The problem is compounded when there are multiple friction surfaces present in the system, in which case simulation, if at all possible, is often computationally too expensive to run in real time. This talk will first present various friction models available in the literature and analyze them for their suitability for real time simulation. Then, it will be demonstrated on a simple example system containing friction surfaces how fidelity can be balanced with the desired computational efficiency for real time simulation. The talk will conclude with the presentation of the ongoing work on extending the demonstrated approach to a generic system.

1A3 **UMTRI INVITED TALK: Hardware-in-the-loop (HiL) Simulation Efforts on Vehicle Braking System and Electronic Stability Control**
Timothy J. Gordon

This presentation describes ongoing research efforts at the University of Michigan Transportation Research Institute (UMTRI) on hardware-in-the-loop (HiL) simulation of heavy truck braking systems using electronic systems for roll stability control (RSC) and yaw stability control (ESC). The research is sponsored by NHTSA, and is being used to evaluate control effectiveness and active safety performance. While HiL is not a new concept, the configuration described allows a great deal of flexibility to conduct large-scale high-fidelity vehicle simulation scenarios under a range of conditions and with a variety of electronic control units (ECUs). Case-by-case comparisons are possible due to the high level of repeatability in the vehicle and track conditions (from simulation) while real brake hardware and ECUs are directly implemented in the physical real-time environment. The hardware consists of an entire pneumatic braking system of a heavy truck, while the vehicle simulation software is based around TruckSim RT connected to Simulink RTW in co-simulation. TruckSim RT and Simulink

RTW both run as RT-Lab targets (real-time PCs) with a QNX operating system. A host PC supervises two real-time targets – one interfacing with the braking system and ECUs, the other running a real-time full-vehicle TruckSim simulation. In this application, steering commands are also obtained from TruckSim (from an internal lateral control algorithm) while longitudinal speed control is implemented via a customized driver control (brake/throttle) model in Simulink. The brake treadle is physically activated by an electric servo motor that accepts brake commands from the speed control model. All ten brake chamber pressures are measured and converted into wheel brake torques; which are fed back to the TruckSim dynamics solver along with the throttle inputs. All physical sensors which generate input signals to the electronic controllers are emulated by virtual sensors (sensor simulators) in the HiL simulation; which communicate with the ECUs via analog-digital conversion and CAN interfaces, and must be faithfully implemented to perform correctly and pass numerous self-diagnosis tests. This type of HiL simulation is applicable to a variety of civil and military purposes, and in the future will play an increasingly important role in the design and evaluation of active safety technologies.

1B Terrain Modeling

Session Chair: Corina Sandu

1B1 **Stochastic Terrain Profile Modeling**
Dr. Corina Sandu

One fundamental difficulty in understanding the physics of the off-road traction and in predicting vehicle performance is the variability of the terrain profile. The operating conditions are uniquely defined at a given spatial location and a given time. It is not practically feasible to measure them at a sufficiently large number of points to be able to accurately represent the terrain in models. This renders traditional analysis tools insufficient when dealing with rough terrain. In this study, mathematical tools to quantify the impact of uncertainties in terrain profile on vehicle mobility are developed. A polynomial chaos approach is used to reconstruct one-dimensional (along longitudinal direction) and two-dimensional (along longitudinal and lateral direction) stationary and non-stationary terrain profiles. The proposed mathematical methods calculate the autocorrelation of terrain profiles, solve eigenvalues and eigenvectors of the autocorrelation function, and obtain the corresponding orthogonal random variables directly. The schemes to choose the number of eigenvalues and eigenvectors are discussed. Another proposed method to model terrain profile is to use the finite difference approach in solving linear second-order stochastic partial differential equations. We currently use this approach to model non-stationary terrain profiles in two dimensions. In the proof of concept stage, certain assumptions are made for the values of the model coefficients to obtain the initial terrain profile. Further techniques will be derived to refine the model coefficients (i.e., to extract them from experimentally obtained terrain profile data) in order to realistically model the terrain for computer simulations of off-road vehicles.

1B2 **Modeling of Terrain Profiles and Characterization of the Roughness of Terrains**
J. Wei, T. Sun, D. Gorsich, M. Chaika and K. Alyass

We present 3 nonlinear methods for modeling of terrain profiles and we propose the following method for checking the fitness of the models from the mechanics point of view. We compute the histograms of the rainflow cycles of the oscillations of the simulated profiles from the models and compare them with that of the original terrain profile. It turns out that we can also use this histogram of the rainflow cycles of a terrain profile, or any quantities computed from it, as a measurement of the roughness of the terrain. The advantage of this new measurement is it does not require the assumption that the terrain profile is stationary and linear.

1C Modeling and Control of Vehicle Systems I

Session Chair: Hosam Fathy

1C1 **Online Mass Estimation of Off-road Vehicles**
Ben Pence, Jeffrey Stein

Active safety control strategies have been shown to decrease the probability of rollover-induced deaths and injuries. However, these strategies require accurate knowledge of vehicle inertial parameters, including vehicle mass, which varies significantly in military vehicles due to loading conditions. Thus, it is critical that the mass of the vehicle is estimated online. The current literature in the area of mass estimation has focused on on-road vehicles, and the results cannot be trivially applied to off-road driving conditions. In this talk, we will present a novel method for estimating online the mass of an off-road vehicle. The proposed method takes advantage of off-road conditions and uniquely combines base-excitation concepts with least-squares estimation to determine a mass estimate. We will present results from computer simulations and discuss the strengths and limitations of the proposed method. Finally, we will discuss future directions and strategies to overcome existing limitations.

1C2 **Improving High-CG Vehicle Rollover through Steering Input Augmented Semiactive Suspensions**

Mehdi Ahmadian, Steve Southward

This Presentation provides an analytical evaluation of how well skyhook control works for improving roll stability of vehicles with a high center of gravity (i.e., high-CG vehicles). After discussing the formulation for various semiactive control methods that have been suggested in the past for vehicle suspensions, the paper includes the implementation of a semiactive system on a high-CG vehicles. The vehicle is used for a series of road tests that includes lane change maneuvers, with different types of suspensions. The suspensions that are evaluated include passive suspensions, uncontrolled MR dampers, skyhook control, and a new semiactive control method called Steering Input Augmented (SIA) skyhook. SIA skyhook augments the conventional skyhook control with steering input, in order to account for the suspension requirements during a lateral maneuver. The results of the study show that although conventional skyhook control does not provide any significant roll stability, SIA skyhook can improve the suspension travel and lateral forces at the vehicle body during lateral maneuvers, therefore potentially providing improved vehicle stability.

1D Modeling and Control of Vehicle Systems II

Session Chair: Hosam Fathy

1D1 **Lithium-Ion Battery Model Reduction in the Physical Domain for Combined Online State-of-Charge and State-of-Health Estimation**

Joel Forman, Jeffrey Stein

As hybrid cars gain larger market share and both fuel cell and plug-in cars loom on the horizon, one realizes the need for improved battery management. Currently Lithium-Ion battery State-of-Charge (SOC) and State-of-Health (SOH) real-time estimation has been held back by the lack of computationally efficient models that can also account for battery degradation. This can be rectified by taking a model from the literature with battery degradation physics and reducing it to a computationally efficient form. This presentation introduces a research plan to reduce the model and leverage it to create a SOC/SOH estimator. By capturing the degradation physics such an estimator can also determine how battery use will affect battery life. Thus, the outcome of this research will enable battery management systems to make intelligent trade-offs between battery life and use.

1D2 **The Mechanical Properties of Snow as a Random Heterogenous Material**

Jonah Lee

Soft terrains such as snow and soils, can be classified as random heterogenous materials. The mechanical properties of soft terrains, important for vehicle-terrain interaction, can depend strongly on their microstructure. In this talk, we summarize our recent results in obtaining microstructure of sieved snow using 3-D X-Ray Microtomography (XMT) as well as constructing stochastic snow models based on the first and second moments of the real snow micrstructure using an efficient Gaussian Random Field approach. The elastic properties of real and reconstructed snow are then discussed such that the size of the Representative Volume Element (RVE) can be estimated. A physically-based viscoplastic ice model is then introduced and used for the ice matrix of snow represented as a two-phase composite material. Preliminary results of the viscoplastic properties of medimum-density snow are presented next. Future research directions in vehicle-terrain interactions will be discussed including: 1) obtain in-situ mechanical properties using XMT, a mechanical stage and a micropenetrometer for snow AND soils, 2) obtain tribological properties of compacted snow against rubber, 3) obtain micro-scale bond strengths of ice crystals to develop failure model of snow, 4) conduct numerical simulations of the mechanical and tribological properties of snow AND soils using the Material Point Method and compare simulation results with experimental data.

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Day 2, Wednesday , May 21, 2008
Symposium II Abstracts

2A Human Centered Design

Session Chair: Matt Reed

2A1 **Convoy Driving with Secondary Tasks: Results of a Driving Simulator Experiment**
Omer Tsimhoni, Helen Fuller, Matthew Reed

This project integrates a physical human model (HUMOSIM) with a computational cognitive model (QN-MHP) to create a tool to study complex human-machine interactions. The presentation will cover the results of a driving simulator experiment designed to calibrate the integrated model. Subjects of four statures entered information on a touch-screen display located in one of four positions while driving in a convoy, following a lead vehicle that changed speed continuously. Subjects drove a normal-weight vehicle and a heavy-weight vehicle. Driving performance and secondary task performance were analyzed as a function of display location, subject stature, and vehicle weight. Driving performance remained constant for all monitor positions, but secondary task performance declined as the monitor was moved farther from the subject, with the greatest declines among shorter drivers. As expected, driving performance was worse for the heavy-weight vehicle than for the normal-weight vehicle; the in-vehicle task time followed a similar pattern for both vehicle weights. The duration and frequency of eye glances made during the drives were affected by the location of the monitor. An analysis and model of the in-vehicle task will be presented and discussed.

2A2 **Three-Dimensional Joint Kinematics of the Upper Extremity in Reach Movements under Whole-Body Vibration Exposure**
Heon-Jeong Kim and Bernard J. Martin

Simulation of human reach movements is an essential component for proactive ergonomic analysis and computer-aided engineering of biomechanical models. Most studies on reach kinematics described human movements in a static environment, however the models derived from these studies cannot be applied to the analysis of human reach movements in vibratory environments such as in-vehicle operations. Earlier studies on reach performance under vibration exposure focused mainly on fingertip end-point accuracy. This study analyzes three dimensional joint kinematics of the upper extremity in reach movements performed in static and vibratory conditions. The ultimate goal is to develop an active biodynamic model capable of simulating reach movements in vibratory environments. Thirteen seated subjects performed reach movements to four target directions distributed in the right hemisphere. The results show differences and similarities in the characteristics of movement patterns of upper body segments for static and dynamic environments. Identification of movement patterns in terms of joint kinematics can be used to determine some biodynamic principles of upper body segments coordination in reach motion.

2A3 **Analysis of Transparency in Teleoperation with Application to Steer-by-wire**
Paul Griffiths, Brent Gillespie

In automotive steer-by-wire systems, the mechanical connection between the driver and steering gear is replaced by a control system that enables intelligent features including adaptive steering and active safety. Since the mechanical pathways for force and motion are broken, the control system must ensure tracking between the steering wheel and front road wheels, and must synthesize road feel using a motorized steering wheel. The capability of the steer-by-wire system to transmit road-feel correctly is termed transparency and can be analyzed in the framework of force-reflecting teleoperation. We introduce a novel measure of transparency which captures the error in the frequency domain and permits quantitative performance analysis not previously undertaken for force reflecting teleoperation. Design directives for the control system follow from analysis of distortion. Using this analysis, we also introduce a graphical design tool called a transparency diagram that relates distortion to key parameters in the design of the controller.

2B Survivability

Session Chair: Nick Vlahopoulos

2B1 **High-Frequency Shock Analysis for Composite Vehicles**
Nick Vlahopoulos

Capturing the propagation of power through a light weight composite vehicle structure due to impulsive operating loads or due to impact loads from threats allows identifying the survivability of the vehicle's electronics and the operational condition of the vehicle. Due to the short duration of such loads a high frequency content must be considered in the shock analysis. Energy finite element analysis (EFEA) has been proven to be an effective and reliable tool for evaluating the high frequency propagation of power through complex structural systems. In the past, EFEA has been utilized successfully for modeling structural-acoustic systems with isotropic structural material properties. Until recently, however, not much work has been done in modeling composite structures with EFEA. A new formulation for modeling the high frequency response of composite laminate plates is presented. The EFEA parameters are derived through a hybrid formulation. The power transmission characteristics at plate junctions of non-isotropic materials, including orthotropic plates and composite laminate plates are studied in order to obtain the power transmission coefficients at the junction. These coefficients are utilized to compute the joint matrix that is needed to assemble the global system of EFEA equations. The global system of EFEA equations can be solved numerically and the energy density distribution within the entire system can then be obtained. The results obtained from the EFEA formulation are validated initially through comparison with results from very dense FEA models.

2B2 **Predicting Effects of Component Damage on Structural Dynamic Response**
Sung Kwon Hong and Matt Castanier

This presentation will cover recent research in modeling, simulation, and reanalysis techniques for predicting the structural dynamic response of a vehicle that has suffered damage in a component. Component-level damage cases of interest include a crack due to fatigue and local deformation due to blast/impact. When a component in a vehicle structure suffers damage, a model of the healthy structure may no longer capture the system-level response and/or the loading on the component from the rest of the structure. Furthermore, being able to model and reanalyze the response of the damaged structure has important applications to damage detection and condition-based maintenance. In this talk, modeling techniques being developed in the ARC for predicting the effects of component-level deformation and cracking on the system-level structural response will be presented.

2C Reliability Based Design Optimization I

Session Chair: K.K. Choi

2C1 **Selection of Copula to Generate Joint CDF for RBDO with Associated Confidence Level**
Yoojeong Noh, K.K. Choi, Liu Du (Iowa), David Lamb (TARDEC)

In many RBDO problems, the input random variables such as material properties and fatigue properties, to name a few, are correlated. To solve the RBDO problems with the correlated input variables, a joint CDF (cumulative distribution function) of input variables should be obtained to transform the correlated input variables into the independent standard normal variables by using Rosenblatt transformation for the inverse reliability analysis. If the true input joint CDF is given, the Rosenblatt transformation is exact. However, since the true input joint CDF requires infinite data to obtain, it is hard to obtain the true joint CDF in practical industrial applications, where often only marginal CDFs and paired samples are available from limited experimental data. In this project, a copula, which is a link between a joint CDF and marginal CDFs, is proposed for generation of the joint CDF. The copula requires only marginal CDFs and correlation parameters to generate a joint CDF, so that the joint CDF can be readily obtained. To obtain the correct joint CDF type based on given information such as marginal CDFs and paired samples, it is necessary to find a copula that describes the paired samples well. For this study, Bayesian method, which selects an appropriate copula among candidate copulas based on samples, is used. A study is carried out to find out the necessary number of samples required to properly identify the right copula for the given data with different correlation coefficients. Using the identified copula, upper bound of confidence interval on the estimated parameter is used in RBDO because the copula with upper bound of the confidence interval provides the RBDO design with the associated confidence level. Numerical examples show how a right copula is identified and show that the upper bound of the confidence interval can be used to obtain the RBDO design with the associated confidence level.

2C2 **Reliability Estimation for Multiple Failure Region Problems using Importance Sampling and Approximate Metamodels**
Ramon C. Kuczera, Zissimos P. Mourelatos

An efficient reliability estimation method is presented for engineering systems with multiple failure regions and potentially multiple most probable points. The method can handle implicit, nonlinear limit-state functions, with correlated or non-correlated random variables, which can be described by any probabilistic distribution. It uses a combination of approximate or “accurate-on-demand,” global and local metamodels which serve as indicators to determine the failure and safe regions. Sample points close to limit states define transition regions between safe and failure domains. A clustering technique identifies all transition regions which can be in general disjoint, and local metamodels of the actual limit states are generated for each transition region. Importance sampling generates sample points only in the identified transition and failure regions, thus allowing the method to focus on the areas near the failure region and not expend computational effort on the sample points in the safe domain. A robust maximin “space-filling” sampling technique is used to construct the metamodels. Two numerical examples highlight the accuracy and efficiency of the method.

2D Reliability Based Design Optimization II

Session Chair: Zissimos Mourelatos

2D1 **System Reliability-Based Design Optimization Using MPP-Based Dimension Reduction Method**
Ikjin Lee, K.K. Choi, Liu Du, David Gorsich

Estimations of not only the component probability of failure but also the system probability of failure have been the main concern in structural reliability analysis for over three decades. According to the logical relationship of the failure modes of structures, structural systems can be divided into three types: series system, parallel system, and hybrid system. The reliability analysis of the series system is discussed in this study since it is the most frequently encountered in practical engineering applications. For accurate and reasonably efficient estimation of the system probability of failure, Ditlevsen’s second order upper bound, which consists of the sum of the component probability of failure and joint probability of failure, is used. For the component probability of failure calculation, MPP-based dimension reduction method (DRM) is used for accuracy. Based on the constraint function type, the joint probability of failure calculation can be calculated in three ways: (1) if two constraints are both concave, the joint probability of failure is ignored, (2) if two constraints are highly correlated, the joint probability of failure is the minimum of the two component probabilities of failure, (3) otherwise, FORM-based joint probability of failure is used. In addition to the accurate system reliability analysis, a system reliability-based design optimization (RBDO) with efficiency strategies, which are the mean value (MV) method for the identification of active constraints and new design closeness concept, is proposed.

2D2 **Model Validation for Simulation Based Design with Associated Confidence Level**
Liang Zhao, K.K. Choi, Liu Du, David Gorsich

Model validation is becoming an important issue these days in simulation based design. To validate a simulation model, one needs to estimate model accuracy based on previous physical response under input uncertainties. After the initial identification of the output uncertainties from the input uncertainties and the physical experiment measurement error, the simulation model prediction capability must be conducted. Traditional probability theories that use t-distribution are based on replicated experiments at the same testing point, which is not efficient and therefore not applicable to practical engineering problems. Also other linear/nonlinear regression methods highly depend on the regression basis functions, which also affect the prediction capability very much. The recent Bayesian method is more focused in calibrating the parameters instead of the model accuracy and also computationally expensive. In practical engineering problems, most of the time we only have limited data without replicated testing. A new method must be developed to construct the simulation model prediction with confidence by using limited unreplicated data. For this purpose, the Gaussian Process based model validation method is used to both estimate the measurement error and construct the prediction of the simulation model with confidence level. In this method, we separate the uncertainties in experimental response into several components; including the deterministic simulation response, deterministic trend of the model bias, the random effect in the bias, and the physical experiment measurement error. By applying the Gaussian Stochastic Process, we integrate these components together and construct the prediction with confidence level in untested design domain. Both mathematical and real engineering examples show accurate results of applying this method for the model validation.

Day 2, Wednesday , May 21, 2008
Symposium III Abstracts

3A Optimal Design I

Session Chair: Michael Kokkolaras

3A1 **Self-Learning Identification and Stochastic Optimal Control of Advanced Powertrain Systems**
Andreas Malikopoulos

Increasing demand for improving fuel economy and reducing emissions without sacrificing performance has stimulated significant research on and investment in advanced internal combustion engine technologies. These technologies have introduced a number of controllable variables that have enhanced our ability to optimize engine operation. Current engine calibration methods for deriving the values of the controllable variables generate a static tabular relationship between the variables and steady-state operating points or specific driving conditions (e.g., vehicle speed profiles for highway and city driving). These methods, however, seldom guarantee optimal engine operation for common driving habits (e.g., stop-and-go driving, rapid acceleration, or rapid braking). Each individual driving style is different and rarely meets those driving conditions of testing for which the engine has been calibrated to operate optimally. We present the theory and algorithms that succeed in making the engine of a vehicle an autonomous intelligent system capable of learning the optimal values of the controllable variables in real time while the driver drives the vehicle. The engine is treated as a controlled stochastic system, and engine calibration is formulated as a sequential decision-making problem under uncertainty that addresses the engine identification and stochastic control problem simultaneously. In various simulation-based case studies, including gasoline and diesel engine calibration, the engine was shown to progressively perceive the driver's driving style and eventually learn its optimal calibration for this driving style. Adapting this approach in a real vehicle may reduce considerably the existing discrepancy between the gas mileage estimate displayed on the vehicle's window sticker and the actual one. This would allow every driver to realize optimal fuel economy and pollutant emissions as fully as possible with respect to his/her driving habits.

3A2 **Consistency Constraint Allocation in Augmented Lagrangian Coordination**
James Allison

Many engineering systems are too complex to design as a single entity. Decomposition-based design optimization methods partition a system design problem into subproblems, and coordinate subproblem solutions toward an optimal system design. Recent work has addressed formal methods for determining an ideal system partition and coordination strategy, but coordination decisions have been limited to subproblem sequencing. An additional element in a coordination strategy is the linking structure of the partitioned problem, i.e., the allocation of constraints that guarantee that the linking variables among subproblems are consistent. There can be many alternative linking structures for a decomposition-based strategy which can be selected for a given partition, and this selection should be part of an optimal simultaneous partitioning and coordination scheme. This paper develops a linking structure theory for a particular class of decomposition-based optimization algorithms, Augmented Lagrangian Coordination (ALC). A new formulation and coordination technique for parallel ALC implementations is introduced along with a specific linking structure theory, yielding a partitioning and coordination selection method for ALC that includes consistency constraint allocation. This method is demonstrated using an electric water pump design problem.

3A3 **System Design with Geometric Considerations**
Kwang Jae Lee

A system consists of various components, each of which has its own shape. The configuration of these components and their geometries are important to system design because they can affect other system attributes. So far, however, this geometric aspect has not been considered when we design a system for one or multiple objectives such as performance, reliability, maintainability, safety and others. In this talk, an initial investigation of the design problem that considers geometry as well as performance will be discussed.

3B Optimal Design II

Session Chair: Michael Kokkolaras

3B1 **Optimal Design of Hybrid Electric Fuel Cell Vehicle Under Uncertainty**
Jeongwoo Han

System research on Hybrid Electric Fuel Cell Vehicles (HEFCV) explores the tradeoffs among safety, fuel economy, acceleration, and other vehicle attributes. In addition to engineering considerations, inclusion of business aspects is important in a preliminary vehicle design optimization study. For a new technology, such as fuel cells, it is also important to include uncertainties stemming from manufacturing variability to market response to fuel price fluctuations. This paper applies a decomposition-based multidisciplinary design optimization strategy to an HEFCV. Uncertainty propagated throughout the system is accounted for in a computationally efficient manner. The latter is achieved with a new coordination strategy based on sequential linearizations. The hierarchically partitioned HEFCV design model includes enterprise, powertrain, fuel cell, and battery subsystem models. In addition to engineering uncertainties, the model takes into account uncertain behavior by consumers, and the expected maximum profit is calculated using probabilistic consumer preferences while satisfying engineering feasibility constraints.

3B2 **Operation Optimization of Power-Split HEV Powertrains**
Kukhyun Ahn

The powertrain of a hybrid electric vehicle (HEV) can be managed in either power-boosting or energy-saving ways. The first is to cope with the driver's full-load demand and the second is to achieve as high fuel-efficiency as possible with the increased degrees of freedom of the HEV powertrain. Optimization problems for the two problems are defined and the design spaces are analyzed for general power-split architectures. Generalized optimization frameworks and optimization results are presented with examples of input- and compound-split cases. The investigations also reveal the relation between the two operation optimization problems or two design spaces, which can provide a wider perspective to the management of the operation states such as engine speed and torque. The discussion finally contributes to the definition of a new concept of HEV optimal operation which will fundamentally improve the conventional idea of the engine optimal operation line.

3C Distributed Simulation and Packaging

Session Chair: Georges Fadel

3C1 **Integration of Multibody Dynamics and Finite Element Analysis Models in D-Sim**
Guensoo Ryu, Zheng-Dong Ma, and Gregory M. Hulbert

A distributed simulation platform, denoted as D-Sim, has been developed at University of Michigan since 2001. The current research focus is to integrate heterogeneous subsystem models, e.g., multibody dynamics subsystems models and finite element subsystems models and to conduct seamlessly integrated simulation and design tasks in the distributed computing environment. A Partitioned Iteration Method (PIM) is proposed for modeling flexible bodies in the D-Sim, which decouples rigid body motion from elastic deformation using an iteration scheme. This method employs a CG-following reference frame for each deformable body in the distributed simulation of flexible multibody system. The resultant simulation capability can be used to integrate distributed deformable bodies in D-Sim, while allowing large relative rigid body motion among bodies and subsystems. It also enables using independent simulation servers; where each server can run commercially available or in-house MBD and/or FEM codes. Examples will be given to demonstrate the performance of the method and show how to decouple and integrate rigid body motion and elastic deformation using the developed gluing algorithm.

3C2 **Physics Based Shape Morphing and Packing for Layout Optimization**
G. Fadel, H. Dong

The packing problem, also named layout design, has found wide applications in the mechanical engineering field. In most cases, the shapes of the objects do not change during the packing process. However, in some applications, shape morphing may be required for some specific components (such as water and fuel reservoirs). The challenge is to fit a component of sufficient size in the available space in a crowded environment (such as the vehicle under-hood) while optimizing the overall performance objectives of the vehicle and improving design efficiency. This work is focused on incorporating component shape design into the layout design process, i.e. finding the optimal locations and orientations of all the components within a specified volume, as well as the suitable shapes of selected ones. The two major research issues are how to efficiently and accurately morph the shapes of components respecting the functional constraints, and how to incorporate component shape design into a layout design process. To morph objects whose shape can be changed arbitrarily, a mesh based morphing method based on a mass-spring physical model is developed. To handle the complete problem at once, decomposition and multilevel approaches are used. At the system level, a genetic algorithm (GA) is applied to find the approximate positions and orientations of the objects, while at the sub-system or component level, morphing is accomplished for select components. A gradient based local search is used for local perturbation of the positions of the objects after shape morphing. Practical examples of vehicle under-hood/underbody layout design with the mass-spring physical model based shape morphing are demonstrated to illustrate the proposed approach.

3D Vehicle Safety

Session Chair: Matt Castanier

3D1 **An Innovative I-Bumper Concept and its FOA Model for Improved Survivability of Military and Commercial Vehicles**
Dong Wook Lee, Zheng-Dong Ma, and Noboru Kikuchi

The greatest demand facing the automotive industry has been to provide safer vehicles with high fuel efficiency at minimum cost. Current automotive vehicle structures have one fundamental handicap: a short crumple zone for crash energy absorption. This leaves limited room for further safety improvement, especially for high-speed crashes. Breakthrough technologies are needed. One potential breakthrough is to use active devices instead of conventional passive devices. An innovative inflatable bumper concept, called the “I-bumper” has been developed by the authors for improved crashworthiness and safety of military and commercial vehicles. The proposed I-bumper has several active structural components, including a morphing mechanism, a movable bumper, two explosive airbags, and a morphing lattice structure with a locking mechanism that provides desired rigidity and energy absorption capability during a vehicular crash. It has additional innovative means for improving crashworthiness which is to use tubes filled with a granular material to absorb energy during the process of a crash. An analytical design model has also been developed in this research for optimal design of the I-bumper system, with a focus on up-front design. Major design variables include those for the explosive airbag, morphing lattice structure, and granular material used in the front posts for further energy absorption. The new design methodology has been implemented in Matlab, and validation has been conducted at a full vehicle level in order to demonstrate the effectiveness of the I-bumper for improved safety in a high-speed crash.

3D2 **Preliminary Study on an Innovative Reactive Restraint System for Improved Gunner Safety in Military Vehicles**
Guang Dong, Zheng-Dong Ma, and Noboru Kikuchi

A proper gunner restraint system (GRS) is essential for improving solder safety and shooting performance in military vehicles. In order to design an innovative GRS, it is necessary to fully understand the problem, identify design objectives and constraints, and develop proper designing tools and methodologies, which will lead to fundamental technology developments. In this preliminary study, we first interviewed 27 gunners for the need of an innovative and improved GRS. We then developed an integrated multi-body dynamics model for an existing HMMWV-GRS-gunner system to simulate gunner’s response in different maneuver conditions including severe braking, step steering, fishhook maneuvering, and rollover conditions. The study also considered gunner's consciousness, for example, with hand grasping or without hand grasping. The measurements used in the simulations include gunner's C.G. height, impact force between the gunner and turret fender, interaction forces between the gunner and GRS, and gunner's head acceleration. All of these were investigated for obtaining an understanding for developing the GRS. Some initial concepts of the GRS will also be discussed.

Day 2, Wednesday , May 21, 2008
Symposium IV Abstracts

4A Diesel Injection and Combustion

Session Chair: Zoran Filipi

4A1 **Autoignition, Combustion and Emission Characteristics of Soy Bean Based Biodiesel**
Naeim Henein, Mofaddel Dahodwala and Kaushik Acharya

Concerns about the depletion of petroleum reserves, air pollution, global warming and the rise in price of the crude oil are driving the development of alternate renewable sources of fuels needed for internal combustion engines, particularly in the transportation and national security sectors. Soy bean oil is one of the agricultural products that have been considered as a viable source biodiesel. Since the properties of biodiesel differ from the properties of petroleum derived diesel fuel, it is expected that all the processes that lead to fuel burning and engine lubrication will be affected. This points the need to examine the effect of biodiesel properties on autoignition, combustion, performance and emissions. Tests conducted on a single-cylinder high speed direct injection diesel engine covered a wide range of injection pressures, EGR rates and swirl ratios. A detailed analysis was made on the rate of heat release trace to determine the effect of using B20 (a blend of 20% soybean methyl ester biodiesel and 80% ultra low sulfur diesel fuel) on autoignition, combustion and engine out emissions at two different loads. An emphasis is made on the operating conditions that cause an increase or decrease in NOx emissions as has been reported in the literature and the reasons that contribute to these effects.

4A2 **Impact of Bio, Aviation and Synthetic Fuels on Diesel Engine's Combustion, Efficiency and Emissions**
Ashwin Salvi, Dennis Assanis and Zoran Filipi

The looming shortage of the global oil supply stimulates research aimed at developing solutions for increased use of renewable and synthetic fuels in transportation. The alternatives for diesel engines include bio-fuels, such as bio-diesel, and synthetic (gas-to-liquid or coal-to-liquid) fuels. While the military vehicles have to be designed to comply with the single fuels forward policy, i.e. the use of the aviation fuel, operating in different regions of the world might dictate using whatever is available locally. The physical and chemical properties of fuels mentioned above vary in a very wide range, and this can have a profound impact on combustion and emission formation processes in a diesel engine. Some of the properties of alternative fuels might be generally favorable, but given the fact the injection and combustion systems of modern diesel are highly optimized, variation of properties can also cause unexpected consequences. As an example, higher Cetane Number is very desirable, but if it increases from 42 (for JP8 aviation fuel) to 65 (for synthetic GTL fuel), the combustion process might change dramatically due to altered phasing and less premixed burning. This study characterizes the effect of Bio-diesel (B-20), Synthetic JP8, regular JP8, and regular Diesel on combustion phenomena and emissions of a diesel engine under steady-state conditions.

4A3 **The Impact of Alternative Fuels on Engine Response, Fuel Economy and Emissions Under In-vehicle Operating Conditions**
Rajit Johri, Ashwin Salvi, Dennis Assanis and Zoran Filipi

The initial results obtained at steady-state conditions indicate a significant impact of alternative fuel properties on diesel engine performance, combustion and emissions. However, engine operation in the vehicle leads to very dynamic variations of speed/load and frequent excursions from regular conditions determined by responses of key actuators. The objective of this work is to explore the interplay between the fuel properties and diesel engine processes under transient in-vehicle conditions by utilizing the Engine-In-the-Loop (EIL) facility. The EIL setup allows running the engine exactly as if it were in the vehicle, while having the benefits of complete engine diagnostics in the test cell. The instrumentation includes fast emissions analyzers for gaseous emissions, and measurements of smoke and particle size/number concentrations. The cyber driver attempts to follow the speed schedule regardless of the fuel energy content, therefore the history of engine command varies depending on the fuel selected. The experiments provide a unique insight into details of engine-driveline interactions and the effect of the fuel properties on vehicle attributes, such as fuel economy in miles per gallon or the visual signature resulting from the soot in the exhaust.

4B Thermal Management

Session Chair: Dohoy Jung

4B1 **Vehicle Thermal Management System Design for FCS Series Hybrid Electric Vehicle**
Sungjin Park, Dohoy Jung, Zoran Filipi, and Dennis N. Assanis

Series Hybrid Electric Vehicles (SHEVs) are under development for the automotive platform of Future Combat System (FCS) owing to their improved fuel economy, exportable electric power, enhanced low speed maneuverability, and low acoustic signature for stealth operation. Compared with conventional vehicles, SHEVs need additional powertrain components such as a generator, driving motors, a battery pack, and a power bus, all of which make the thermal management system more complicated. Moreover, combat vehicles need more reliable thermal management system for the vehicle's survivability because combat vehicles are operated under desert-like conditions allowing a high tractive effort to weight ratio. Thus, a more strategic approach is required when designing a thermal management system for combat SHEVs. In this study, numerical simulations of the vehicle thermal management system and the vehicle powertrain system of a virtual heavy duty tracked SHEV for FCS is developed to investigate the thermal responses and power consumptions of the thermal management system. The output data from the powertrain system simulation are fed into the thermal management system simulation to provide the operating conditions of powertrain components. Three different thermal management system architectures with different concepts are modeled and the factors that affect the performance and power consumption of each cooling system are identified and compared with each other. The results show that the cooling system architecture of the SHEV should be developed considering various cooling requirements of powertrain components, power management strategy, performance, parasitic power consumption, and the effect of conditions. It is also demonstrated that a numerical model of the SHEV cooling system is an efficient tool to assess design concepts and architectures of the system during the early stage of system development.

4B2 **Transient Fluid Flow and Heat Transfer in the EGR Cooler**
Radu Florea, Dinu Taraza., Naeim A. Henein

Turbocharged diesel engines are characterized by highly pulsating pressure in the exhaust manifold. Under these conditions the flow of the Exhaust Gas Recirculation (EGR) from the exhaust manifold to the inlet manifold becomes highly unsteady. The periodic variation of the pressure in the manifolds leads to situations when the intake manifold pressure becomes higher than the exhaust manifold pressure. Especially at high speed and high load, when pressure pulses increase, the inertia of the flowing gas is no more capable to overcome the pressure difference and reverse flow occurs. This situation has a significant influence on the heat transfer in the EGR cooler and the amount of exhaust gas flowing in the intake manifold. Because the exhaust gas flow cannot be measured under these conditions, complex simulation using FIRE code from AVL is used to predict the unsteady flow and heat transfer. Validation is obtained by the measured temperature of the EGR before and after the cooler.

4C Transient Operation and Hybrid Vehicle Power Management

Session Chair: Naeim E. Henein

4C1 **Cycle-resolved In-Cylinder Diagnostics During Transient Diesel Engine Operation**
Rob Prucka, Jonathan Hagena, Zoran Filipi, Dennis Assanis

This study introduces an experimental technique to quantify cycle-resolved values of pre-combustion in-cylinder compositions during transient engine operation. The work is motivated by the need to characterize diesel engine response, including combustion and emission formation, during transient operation. The excursions of operating parameters during transients can have significant impact on dynamic response and driveability, as well as cumulative diesel emissions. The technique provides data on a cycle-by-cycle basis, a resolution that is unattainable with traditional test cell hardware. One cylinder of a 6.0L V-8 diesel engine is instrumented to obtain cycle-resolved masses of three in-cylinder pre-combustion constituents: fuel, air, and stoichiometric combustion products. Cycle-by-cycle air mass is determined through calculation of the air/fuel ratio from measurements of CO_2 concentrations in the exhaust and in the cylinder. Stoichiometric combustion product mass is quantified through the pre-combustion in-cylinder measurement of CO_2. Experiments demonstrate that during the first few cycles of intense accelerations, excessive levels of over-fueling occur, resulting in cycles with equivalence ratios as high as 1.4. These cycles cause extremely high particulate emissions. High levels of NO emissions occur 3-4 cycles into strong accelerations and are attributed to intensely-premixed combustion with high levels of in-cylinder oxygen. In summary, this study demonstrates that tighter cycle-resolved control of fuel injection and EGR systems, including internal residual, are necessary prerequisites for realizing the full potential of low-emissions transient engine operation strategies.

4C2 **A Stochastic Optimal Control Approach for Power Management in Plug-In Hybrid Electric Vehicles**

Scott J. Moura, Hosam Fathy, Duncan Callaway, and Jeffrey Stein

This talk features ARC-leveraged research sponsored by the NSF Graduate Research Fellowship Program. We examine the problem of optimally splitting driver power demand among the different actuators (i.e., the engine and electric machines) in a plug-in hybrid electric vehicle (PHEV). Existing studies focus mostly on optimizing such PHEV power management for fuel economy, subject to charge sustenance constraints, over individual drive cycles. This work introduces three original contributions to this literature. First, it uses stochastic dynamic programming to optimize PHEV power management over a distribution of drive cycles, rather than a single cycle. Second, it explicitly trades off fuel and electricity usage in a PHEV, thereby systematically exploring the potential benefits of controlled charge depletion over aggressive charge depletion followed by charge sustenance. Finally, it examines the impact of variations in relative fuel-to-electricity costs on optimal PHEV power management, for the first time. The talk will focus on a single-mode power-split PHEV configuration for mid-size sedans, but its approach is extendible to other configurations as well.

4D Internal Combustion Engine Modeling

Session Chair: Nabil G. Chalhoub

4D1 **Computation of the Instantaneous Frictional Losses of Internal Combustion Engine Components**

Giscard Kfoury, Nabil Chalhoub and Naeim Henein

The current work aims at determining the instantaneous frictional losses associated with moving components of internal combustion engines, operating at high speeds and under transient conditions. Some of the results will focus on the hydrodynamic lubrication regime between the piston-assembly and the cylinder liner. They are generated by considering the piston secondary motions along with the solid-fluid interaction between the piston-assembly and the lubricating oil film. The oil pressure is determined by implementing the 3-D Reynolds' equation. Other results will rely on an inverse dynamics scheme to determine the instantaneous frictional losses at the component level. This work requires a detailed model for the crankshaft/connecting-rod/piston-assembly. The effect of higher order dynamics inherent in the motion measurements of the crank-slider mechanism has been attenuated herein by using estimated rather than measured state variables in the computation of the instantaneous frictional losses. This task was accomplished by developing a nonlinear robust observer suitable for handling constrained systems. The simulation results illustrate the viability of the proposed approaches.

4D2 **Application of Variable Geometry Turbine in Dual-Stage Turbocharging System**

Byungchan Lee, Dohoy Jung, Zoran Filipi, and Dennis Assanis

In a dual-stage turbocharging system, it is desirable to have a small high pressure turbocharger in order to improve system transient response to sudden changes in speed and load. On the other hand, the small high pressure turbocharger restricts the gas flow at higher engine speed, and, typically, some of the gas flow must be bypassed to prevent choking. However, a variable geometry turbine (VGT) can effectively eliminate the need for bypassing and improve the transient characteristics of the system at the same time by adjusting the vane position. In this study, a interpolation-based methodology is applied to the VGT modeling, and the boosting characteristics of the dual-stage system with the VGT in high pressure stage is analyzed using a high-fidelity Diesel engine system simulation.