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

13th Annual ARC Conference
May 15–16, 2007

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

Online registration is now closed.

For late or on-site registration, 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 15th 2007

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

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

Dennis Assanis
Professor and ARC Director, The University of Michigan

Dr. Walter Bryzik
Chief Scientist, U.S. Army TARDEC

Paul Skalny
Director, National Automotive Center, TARDEC

8:30 - 9:30 **MG William M. Lenaers**
Commanding General
TACOM Life Cycle Management Command

Dr. Thomas H. Killion
Deputy Assistant Secretary of the Army for Research and Technology
Chief Scientist

Question and Answer Session

9:30 - 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: **Charles E. (Charlie) Freese V**
Executive Director, Diesel Engine Engineering for GM Powertrain

Dan Kapp
Director, Powertrain R & A
Ford Motor Company

Dr. Andreas Truckenbrodt
Executive Director, Hybrid Development Center
DaimlerChrysler

Question and Answer Session

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

1:15 - 2:15 **Case Study 1**
Energy for Mobility of Military Vehicles: Alternative Fuels and Hybrid Propulsion

Speaker: **Thrust Areas 1, 4 and 5**
Prof. Dennis Assanis, Prof. Zoran Filipi and Prof. Huei Peng,
The University of Michigan

2:15 - 2:30 **Networking Break**

2:30 - 3:15 **Case Study 2**
Reliability Analysis and Design Optimization of Military Ground Vehicles Using TARDEC High Performance Computing

Speaker: **Thrust Area 3**
Prof. K. K. Choi, The University of Iowa
Prof. N. Vlahopoulos, The University of Michigan

3:15 - 3:30 **Networking Break**

3:30 - 4:15 **Case Study 3**
Development of a Load-Adapting HMMWV Rollover Warning System Using Combined Vehicle Dynamics and Driver Modeling

Speaker: **Thrust Areas 1 and 2**
Dr. Hosam K. Fathy and Dr. Omer Tsimhoni, The University of Michigan

4:15 - 4:30 **Wrap-Up and Q & A**

Dennis Assanis
Professor and ARC Director, The University of Michigan

4:30 **Adjourn**

△ Top of Page

<< Previous

ARC Conference Day 2 Schedule
Wednesday May 16th 2007

7:30 - 8:00am	**Registration and Continental Breakfast**
8:00 - 8:30	**Welcome** **Dennis Assanis** Professor and ARC Director, University of Michigan **Dr. Walter Bryzik** Chief Scientist, U.S. Army TARDEC
8:30 - 9:30	**Keynote Address:** **Peter Schihl, Ph.D., P.E.** ARC Technical Leader, U.S. Army TARDEC **Rolf Dreisbach** Head of Diesel and Powertrain Mechanics Engineering and Technology Powertrain Systems AVL

Question and Answer Session

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

Symposium I (abstracts)	**Vehicle Dynamics and Control**
Symposium II (abstracts)	**Human Centered Modeling and Simulation and Vehicle System Integration, Optimization and Robustness**
Symposium III (abstracts)	**High Performance Structures and Materials**
Symposium IV (abstracts)	**Advanced and Hybrid Powertrains**

Keynote Speakers

Biographies

Day 1 Speakers

(go to Day 2)

Major General William (Mike) Lenaers

Commanding General U.S. Army TACOM Life Cycle Management Command

Major General Mike Lenaers assumed command of the U.S. Army TACOM Life Cycle Management Command on 28 September 2004. Prior to this assignment, he served as the 32d Chief of Ordnance at Aberdeen Proving Ground, Maryland. He has commanded at every level from company through Corps Support Command. His extensive experience in supporting the Army's combat units, combined with his command of the Armament Research, Development and Engineer Command have made him a strong advocate for the combat units and the need for agile and responsive support across the complete life cycle of TACOM systems.

Major General Lenaers received an ROTC commission upon graduation from the University of Santa Clara with a Bachelor of Science Degree in Chemistry. He also holds a Master of Science Degree in Oceanography from Oregon State University. His military education includes the Command and General Staff College and the Army War College.

Major General Lenaers' previous assignments include: serving as the Technical Supply Officer and Shop Officer for the 699th Maintenance Company, 85th Maintenance Battalion, in Hanau, Germany; Aide-de-Camp to the Commander of the 3d Support Command (Corps) in Frankfurt, Germany; Transportation and Maintenance Officer for the Naval Support Force Antarctica at McMurdo Station, Antarctica; Commander of the 190th Maintenance Company, Armor Support Battalion, at Fort Hood, Texas; Associate Professor of Chemistry at the United States Military Academy; Chief of the Plans Branch for the Assistant Chief of Staff for Logistics, 21st Support Command in Kaiserslautern, Germany; Commander of the 707th Main Support Battalion, 7th Infantry Division, at Fort Ord, California; Commander of the 1st Infantry Division Support Command, at Fort Riley, Kansas; Commander, Armament Research Development and Engineering Center, at Picatinny Arsenal, New Jersey; Commander, 13th Corps Support Command, Fort Hood, Texas; three separate assignments as a General Staff Officer for the G4 at Headquarters, Department of the Army; and as the Deputy Chief of Staff for Ammunition, Headquarters, Army Materiel Command.

Major General Lenaers' awards include the Army Distinguished Service Medal, the Legion of Merit with three Oak Leaf Clusters, the Meritorious Service Medal with four Oak Leaf Clusters, the Army Commendation Medal, the Navy Commendation Medal, the Army Achievement Medal, the National Defense Service Medal, and the Antarctic Service Medal.

He and his wife, Lorel, are natives of the San Francisco Bay Area. They have one daughter, Nicole, who resides in Denver, Colorado.

Dr.Thomas H. Killion

Deputy Assistant Secretary of the Army for Research and Technology, Chief Scientist

In March 2004, Dr. Killion was designated as the Deputy Assistant Secretary for Research and Technology/Chief Scientist. He is responsible for the entirety of the Army's Research and Technology program, spanning 21 Laboratories and Research, Development and Engineering Centers, with approximately 8,600 scientists and engineers and a six year budget of $11.3 billion. He is responsible for developing a Science and Technology (S&T) strategy responsive to Army needs from the near-term (within the next five years) stretching out through the far-term (twenty years into the future). The Basic Research, Applied Research and Advanced Technology

Development programs and budgets that Dr. Killion builds for this strategy must be defended within the Army, to the DoD and to Congress. He is also the principal scientific advisor to both the Secretary of the Army and the Assistant Secretary of the Army for Acquisition, Logistics and Technology (ASA(ALT).

Prior to his designation, Dr. Killion served as the Director for Technology under the Deputy ASA for Research and Technology (DAS(R&T)). In this position, he was responsible for oversight and coordination for the majority of the Army's Applied Research (6.2) program and all of its Advanced Development (6.3) program. He also
co-chaired the Warfighter Technical Council and managed the Science and Technology Objective (STO) and Advanced Technology Demonstration (ATD) approval process for the DAS(R&T).

Prior to this assignment, Dr. Killion served as the Director for Personnel Technologies in the Office of the Deputy Chief of Staff, G-l, where he was responsible for policy, guidance, oversight and advocacy of the Army's MANpower and PeRsonnel INTegration (MANPRlNT) and Soldier Oriented Research and Development in Personnel and Training (SORD-PT) programs. Dr. Killion also served as the principal scientific advisor to the Deputy Chief of Staff, G-1.

Previously, Dr. Killion served as the U.S. Army Research Laboratory (ARL) Liaison to the Office of the DAS(R&T), where he assisted in shaping, advocating and defending Army Science and Technology (S&T) program investments and priorities to senior leaders in the Army and in DoD and to Congress. During this time, he also served as the Acting Deputy Director for Research for a year, with responsibility for oversight of the Army's Basic Research (6.1) program and substantial portions of the Applied Research (6.2) program. He also served as the manager for the Affi1Y's Dual Use S&T program.

Other key assignments in Dr. Killion's career include Technical Advisor in the Advanced Systems and Concepts Office at the Defense Threat Reduction Agency, ARL Liaison to the MANPRlNT Directorate, Executive Assistant to the Director of ARL, Technology Team Leader for the Unmanned Aerial Vehicles Joint Project, and Principal Scientist for Electronic Combat Training at the Air Force Human Resources Laboratory. He has authored numerous technical papers, open literature publications, and presentations on a diverse array of topics, including electronic combat training, computer-based training, unmanned aerial vehicle technology, dual use technology, Army basic research, Army S&T strategy, and MANPRINT.

Dr. Killion was born in Wichita, Kansas and received dual B.A.'s in Psychology and English from Saint Mary's College in Winona, MN, in 1974. He received his Ph.D. in Experimental Psychology from the University of Oregon, Eugene, OR, in 1978. Dr. Killion also graduated with highest distinction from the Naval War College in May 1997.

Charles E. (Charlie) Freese V

Executive Director, Diesel Engine Engineering for GM Powertrain

Charlie began his automotive career with Detroit Diesel Corporation in 1989 (DDC) where he started in the Advanced Engineering Department. Later he moved into Product Engineering where he helped develop the Series-60 on-highway, 2-cycle and a new family of 4-cycle off-highway diesel engines. Charlie became Chief Engineer of Advanced Automotive diesel engines where he led a development program which designed and prototyped a clean sheet light duty diesel concept in 228 days. He later assumed additional responsibilities as DDC's Director of Automotive Sales and Director of Advanced Programs. Charlie spent 2 years at Ford Motor Company where he served as Chief Engineer, diesel engines.

In 2003, Charlie joined General Motors, where he is responsible for global diesel engineering operations.

Charlie has a Bachelor of Science degree in mechanical engineering, a Master of Science degree in mechanical engineering and a Master of Science degree in engineering management, all from the University of Michigan. He has published numerous technical papers, holds 9 patents, and was honored in 2000 by the Automotive Hall of Fame with the Young Leadership and Excellence award.

Dan Kapp

Director - Powertrain Research & Advanced Engineering, Ford Motor Company

Dan Kapp is director, Powertrain Research & Advanced Engineering. He is responsible for research & advanced engineering of next generation concepts for engines and transmissions.

Prior to his current assignment, Kapp led the development of all engines and transmissions in

North America, including Ford's industry leading 6-speed automatic transmissions and the new award-winning Duratec 35 V-6.

In 2001, Kapp was appointed to his first executive position as director of Core and Advanced Powertrain Engineering responsible for powertrain controls, catalyst and emission systems, and calibration.

From the late 80's through the mid 90's, Kapp was involved in the design and development of the "Modular" V8 and V6 engines as Ford revamped its engine line-up to overhead cam designs. He was the program manager of the Triton V8 truck engines through their launch and then spent three years in the Truck Vehicle Center as the manager of Powertrain Systems Manager full-size trucks and SUV's.

Dan Kapp graduated from Michigan Technological University with a Bachelor of Science Degree in Mechanical Engineering.

Dr. Andreas Truckenbrodt

Executive Director, Hybrid Powertrain Programs, DaimlerChrysler

Dr. Andreas Truckenbrodt is responsible for the DaimlerChrysler Hybrid Development Center in Troy, Michigan. He was assigned this title in September of 2004. His position reports to a number of high level executives within DaimlerChrysler. Truckenbrodt is responsible for all DaimlerChrysler hybrid vehicle activity across multiple corporate brands such as Mercedes-Benz and Chrysler.

Dr. Andreas Truckenbrodt started his career at BMW Technik GmbH as project manager; he was responsible for the development of specialty cars and components. This position led to manager of experimental engineering with BMW Rolls-Royce, a German-British airplane engine manufacturer. His next call of duty was director at Daewoo Motor Engineering GmbH, where he was responsible for establishing a German Technical Center for the Korean headquarters. Truckenbrodt then worked with fuel cell supplier Ballard Power Systems and was in charge of Ballard's Transportation Division at the Nabern, Germany location as chairman of the board. Truckenbrodt re-joined DaimlerChrysler in January 2003 as head of DaimlerChrysler's Center for Fuel Cell and Alternative Powertrain Vehicles.

Dr. Truckenbrodt studied Aeronautics and Aerospace Engineering at the Technical University of Munich, Germany, and received his PhD in Mechanics and Control Systems in 1981.

Truckenbrodt was born in 1952.

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.

Rolf Dreisbach

Head of Diesel and Powertrain Mechanics Engineering and Technology Powertrain Systems, AVL

Education
- University of Technology Siegen, Germany (1982 - 1987)

Occupations
- 10 years Engine Development at MAN-Nutzfahrzeuge AG

- 5 years responsible for Performance and Emission Development at MAN-Nutzfahrzeuge AG
- During this time, 8 years Truck Race Engine Development

Publications

- Can the Technology for Heavy Duty Diesel Engines be Common for Future Emission Regulations in USA, Japan and Europe?" (SAE World Congress 2003)
- Technologies for Heavy-Duty Diesel Engines to Comply with EURO3 and beyond (33rd Meeting of Bus and Coach Experts, 2002)
- Light Commercial Vehicles - developed in China for EURO 3 (Engine China 2002)

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Symposia matrix is formatted to printout in "Landscape" format

Time	Symposium I	Symposium II	Symposium III	Symposium IV
	1A Proper Modeling Methodologies Chair: Jeff Stein	**2A Human Centered Design** Chair: Matt Reed	**3A Crashworthyness and Blast Protection** Chair: Zheng-Dong Ma	**4A Diesel Injection and Combustion** Chair: Zoran Filipi
9.45 - 10.10	Large-Scale HMMWV Model Parameterization Using an Activity-Guided Stochastic Search Algorithm	Adaptive Observers to Distinguish Driver Intent from Biodynamic Feedthrough	High-Frequency Shock Analysis for Composite Vehicles	Characterizing Transient Diesel Engine Behavior with Cycle-Resolved In-Cylinder Measurements
10.10 - 10.35	Approximate Similitude: Quantification and Use in Dynamic System Scaling	Using the Virtual Driver Cognitive and Physical Modeling Approach to Analyze Safety of In-vehicle Systems in FMTV Convoys	A Magic Cube (MQ) Approach for Crashworthy and Blast-Protective Structure Design Problems	A Model for Diesel Spray Behavior Under Supercritical Conditions
10.35 - 11.00	Structural Reduction of Dynamic System Models with Application to HMMWV Multibody Dynamic Model Reduction	Estimation of Body Links Transfer Functions in Vehicle Vibration Environment	Optimization of a Crash Energy Absorption Structure for Crashworthy Design of an Inflatable Morphing Body	Spray Characteization of Common Rail Injectors
11.00 - 11.15	**Break**			
	1B Terrain Modeling and Suspension Design Chair: Mehdi Ahmadian	**2B Distributed Simulation and Packaging** Chair: Greg Hulbert	**3B Reliability Based Design Optimization** Chair: K. K. Choi	**4B Hybrid Vehicle Modeling and Experiments** Chair: Dohoy Jung
11.15 - 11.40	Stochastic Modeling of Terrain Profile and Soil Characteristics	Integration Method of MBD and FEM Models in a Distributed Simulation Environment for HMMWV	Dimension Reduction Method (DRM) Based RBDO for Multidimensional Highly Nonlinear Systems	Maximizing the Benefits of the Hydraulic Hybrid Propulsion for the HMMWV with Optimal Power Management
11.40 - 12.05pm	Advanced Semi-Active Control Methods for HMMWV Primary Suspensions	Packaging with Shape Morphing - Status	Reliability Based Design Optimization with Dependent Input Variables Using Copula	Series Hybrid Vehicle Cooling System Simulation
12.05 - 1.30	**Lunch**			
	1C Hybrid Vehicles and Thermal Management Chair: Huei Peng	**2C Decomposition-based Vehicle Design** Chair: Michael Kokkolaras	**3C Tire-Terrain Interaction Modeling** Chair: Jonah E. Lee	**4C Modeling and Optimization of Engine Systems** Chair: Naeim E. Henein
1.30 - 1.55	Advanced Cooling Strategies for Internal Combustion Engines – Concept, Configurations, and Power Savings	An SLP Filter Algorithm for Probabilistic Analytical Target Cascading	Remote Sensing and Characterization of Snow-Covered Ground by Using Ground Penetrating Radar	Improving Performance of 2-stage Turbocharging System Through Advanced Bypass Valve Control
1.55 - 2.20	Modeling, Configuration Design, and Control Optimization of the Power-split Hybrid HMMWV	Design Adaptation for Dependable Vehicle Performance in Unknown Environments	Modeling of Non-Steady State Lateral Dynamics of Tires with Slip Angle and Turn Slip as Inputs	An Experimental Study for a Direct Measurement of the Piston-Assembly Frictional Losses in a Single Cylinder Test Rig
2.20 - 2.45	Parameterization of Fuel Cell Dynamics Using Stack-level Measurements	Optimal Partitioning and Coordination Decisions in Decomposition-based Design Optimization	The Development of Tire-Soil interaction Model for Off-Road Vehicle Simulation	Real-time, Self-learning Optimization of Diesel Engine Calibration
2.45 - 3.00	**Break**			
	1D Modeling and Control of Vehicle Systems Chair: Hosam Fathy	**2D Simulation-based Vehicle Design** Chair: Zissimos Mourelatos	**3D Design Optimization for Mixed Input Variables** Chair: Corina Sandu	**4D Engine Thermal Management & Alternative Fuels** Chair: Nabil G. Chalhoub
3.00 - 3.25	Multi-Wheel Vehicle Dynamics and Performance: Wheel Power Distribution and Driveline System Design	Optimal Engine Torque Management for Reducing Driveline Clunk using Time-Dependent Metamodels	Robust Design Concept in Possibility Theory and Optimization for System with Both Random and Fuzzy Input Variables	Numerical Modeling of Cross Flow Compact Heat Exchanger with Non-Uniform Cooling Air Distribution
3.25 - 3.50	Fuel Cell Hybrid Powertrain Optimization for Plug-In Electrical Power Generation	Simulation-based Vehicle Design Validation with Emphasis on Safety	Interval Analysis Using Maximal Failure Search Algorithm for Robust Design Optimization	Transient Heat Transfer in the EGR Cooler of a Diesel Engine
3.50 - 4.15	Probabilistic Combined Mass and C.G. Height Estimation for Onroad Vehicles	Optimal design of electric-hybrid powertrain cooling system	Nonlinear Methods for Modeling of Terrain Profiles	The Effect of High-Sulfur JP-8 on the Diesel Engine System

Top of Page
<< Previous

Day 2, Wednesday , May 16, 2007
Symposium I Abstracts

1A Proper Modeling Methodologies

Session Chair: Jeff Stein

1A1 **Large-Scale HMMWV Model Parameterization Using an Activity-Guided Stochastic Search Algorithm**
Bryon Sohns, Hosam K. Fathy, and Jeffrey L. Stein

The goal of this project is to develop a method to efficiently parameterized high fidelity models of dynamic systems. One way to improve efficiency is to use activity to estimate the importance of different model parameters. Combining this technique with an appropriate optimization algorithm will greatly enhance the efficiency of the identification process. Since this problem is likely to be non-linear and have many local optima, an evolutionary optimization algorithm is an appropriate choice. This algorithm also has guaranteed convergence properties whether or not activity is used. In this presentation an activity-guided random walk optimization algorithm is described and compared to more traditional methods. It is shown that activity does have some relation to the importance of model parameters. Also, activity is combined with a random walk evolutionary algorithm to identify the parameters of a high-fidelity simulation model of a HMMWV. This model has roughly 20 rigid bodies and more than 100 parameters. Results show that the activity guided random walk efficiently converges to the locality of the global optima.

1A2 **Approximate Similitude: Quantification and Use in Dynamic System Scaling**
Burit Kittirungsi, Hosam K. Fathy, and Jeffrey L. Stein

Previous work has developed a generalized scaling framework which allows engineers to scale a proven design to satisfy new desired dynamic characteristics and simultaneously achieve adequate dynamic similitude. Such a framework employs dimensional analysis to derive scaling laws and add activity analysis to it to help discard the scaling of the least important parameters, thereby gaining more flexibility in scaling. Nevertheless, difficulties still remain and arise when the scaling laws identified as the more important ones cannot be followed exactly; thereby precluding absolute similitude. For this reason, this paper develops, for the first time, a generalizable metric which can quantify, on a continuous basis, the closeness of a design to achieving similitude. As a result, this metric allows the use of a multi-objective optimization problem to find design solutions representing trade-offs between design requirement satisfaction and dynamic similitude achievement. The viability of the method is demonstrated through two examples. The first one illustrates the use of the method to obtain optimal designs of a linear two-degree-of-freedom mass spring damper system. The second example highlights the applicability of the method to a fuel cell's nonlinear air supply system subjected to a set of design physical constraints.

1A3 **Structural Reduction of Dynamic System Models with Application to HMMWV Multibody Dynamic Model Reduction**
Tulga Ersal, Hosam K. Fathy, and Jeffrey L. Stein

The literature deems a model "proper", if it is only as complex as necessary to fulfill its purpose. Ensuring the properness of models is critical to efficient and successful design, analysis, and control of engineering systems, but it requires much time and expertise as systems become more complex, as exemplified by modern automobiles. Thus, there is a growing need for proper-modeling tools for complex systems. This talk will present a new method for reducing overly complex models to render them proper. This method has the following key characteristics: (1) It is energy-based and hence applicable to multidomain models. (2) It takes into account, for the first time, the correlations between the energy-flow patterns in the model. (3) It allows for not only order reduction, but also structural reduction. In mechanical domain, for example, this corresponds to a simultaneous reduction in dynamics and kinematics. (4) It does not require any state transformation, thereby preserving the physical meaning of the model. The modeling and reduction of a HMMWV will be presented to highlight the benefits of the proposed method.

1B Terrain Modeling and Suspension Design

Session Chair: Mehdi Ahmadian

1B1 **Stochastic Modeling of Terrain Profile and Soil Characteristics**
Mr. Lin Li, Dr. Corina Sandu, Dr. Alexander Reid, Mr. Dave Glemming

One fundamental difficulty in understanding the physics of the off-road traction and in predicting vehicle performance is the variability of the terrain profile and soil parameters. These 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. Soil parameters vary substantially from one type of soil to another. Moreover, for the same soil type, the parameters change with environmental conditions difficult to predict, for example the moisture content. 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 and soil behaviors on vehicle mobility are developed. A polynomial chaos approach is used to reconstruct one-dimensional (along longitudinal direction) stationary and non-stationary terrain profiles. Also, an efficient mathematical method based on the Karhunen-Loeve expansion is developed to reconstruct two-dimensional (along longitudinal and lateral direction) terrain profiles. To investigate the influence of parametric uncertainty of soil on vehicle performance, the polynomial chaos approach is used to establish stochastic shear stress-shear displacement relationship considering randomness in soil moisture, which can be combined with the stochastic pressure-sinkage relationship to explore the vehicle mobility on deformable soil and terrain.

1B2 **Advanced Semi-Active Control Methods for HMMWV Primary Suspensions**
Steve Southward, Mehdi Ahmadian

One promising means for achieving significant performance enhancement of a semi-active suspension control system is to incorporate an accurate non-linear inverse MR damper model in the controller. This strategy can provide a benefit to the Army for their existing semi-active control algorithms. Typically, MR dampers are characterized with signals such as DC current and sinusoidal relative velocity inputs, but these signals are not representative of a practical implementation. Although the resulting models or "maps" are relatively easy to invert, they are deficient for semi-active controller design. This deficiency can negatively impact the achievable performance. Experimental response data has been acquired on a COTS MR damper where band limited uncorrelated current and relative velocity signals are simultaneously input to the damper, representing realistic excitations. Direct comparison with a common static MR damper model clearly indicates the dynamic nature of the actual damper, and the deficiency of the static model. An adaptive real-time algorithm has been proposed for direct identification of a non-linear dynamic inverse model to empirically fit the MR damper response data. Future work will include dynamic characterization of an MR damper using the proposed algorithm, followed by a demonstration of semi-active performance enhancement on an actual HMMWV suspension mounted in a quarter-car rig.

1C Hybrid Vehicles and Thermal Management

Session Chair: Huei Peng

1C1 **Advanced Cooling Strategies for Internal Combustion Engines – Concept, Configurations, and Power Savings**
T. Mitchell, M. Salah, J. Wagner, and D. Dawson

Advanced thermal management systems for internal combustion engines can reduce parasitic losses and improve coolant temperature regulation, power consumption, and emissions by better regulating the combustion process with multiple computer controlled electro-mechanical components. The traditional wax-based thermostat valve, coolant pump, and clutch-driven radiator fan are upgraded with servomotor driven actuators. Advanced automotive thermal management systems use computer controllable electric or hydraulic actuators that must work in harmony so that desired thermal conditions can be accomplished in a power efficient manner. A comprehensive nonlinear control architecture has been developed for transient temperature tracking. In addition, four different thermostat configurations have been analyzed to investigate warm-up behaviors and thermostat valve operations. The cooling system configurations considered include factory, two-way valve, three-way valve, and no valve. An experimental system has been fabricated and assembled which features a variable position smart valve, adjustable speed electric coolant pump, variable speed electric radiator fan, 6.0L stationary engine block, and various sensors. In the configured system, the steam-based heat exchanger emulates the heat generated by the engine's combustion process. Representative numerical and experimental results are discussed to demonstrate the functionality of the thermal management system in accurately tracking prescribed temperature profiles and minimizing electrical power consumption, as well as to examine the effectiveness of each valve configuration in the engine cooling system.

1C2 **Modeling, Configuration Design, and Control Optimization of the Power-split Hybrid HMMWV**
Jinming Liu and Huei Peng

Interest in the pursuit for fuel-efficient technology runs very high in recent years due to the slow-but-sure depletion of crude oil supply, sudden rise in gasoline price, and continued environmental concerns. Hybrid electric propulsion seems to be one of the most promising technologies and is the only one that has been tested successfully on the commercial market. Among its many possible configurations, the power-split (i.e. parallel/series) configuration offers great design and control flexibility and achieves higher overall efficiency. Therefore, it gradually gains popularity in recent years. For example, almost all hybrid vehicles already available or are soon to become available from GM, Toyota, Lexus, and Ford, are of the power-split type. Many power-split hybrid vehicle designs have been suggested in recent development in the automotive industry. How to find the optimal control solution for them and with which to evaluate and compare these designs becomes a valuable research topic. In this research, a virtual power-split super HMMWV is constructed with optional powertrain designs to be analyzed. We will demonstrate a systematic approach to assess these different powertrain configurations by using dynamic programming. Then an optimal control solution is generated for the selected design candidate by using stochastic dynamic programming.

1C3 **Parameterization Of Fuel Cell Dynamics Using Stack-Level Measurements**
Denise McKay, Anna Stefanopoulou

Water management within proton exchange membrane fuel cell stacks is critical for optimizing cell performance. With adequate models for estimating the reactant and water dynamics within the fuel cell electrodes, the model must be parameterized and experimentally validated. Thus, an adequate performance metric must be selected which enables Real Time implementation of the fuel cell model. With estimations of the cell voltage, the performance variable most often selected, we focus on the voltage statistics for a multi-cell stack and the related tradeoffs associated with tuning a model based on the minimum, maximum, mean and median voltages. The variability in the voltage measurement is significantly larger during electrode flooding conditions, as compared to non-flooding conditions. This voltage variability presents a fundamental issue in parameterization and representation of flooding, where we have the largest measurement uncertainty. A combination of deterministic distributed parameter and stochastic models need to be developed to handle the representation of this behavior. This highly-critical and highly-uncertain operation is a ubiquitous characteristic of many systems of technological importance.

1D Modeling and Control of Vehicle Systems

Session Chair: Hosam Fathy

1D1 **Multi-Wheel Vehicle Dynamics and Performance: Wheel Power Distribution and Driveline System Design**
Vladimir V. Vantsevich

Dynamics and performance of vehicles with four or more drive wheels, multi-wheel drive vehicles, result from vehicle operational properties such as energy/fuel efficiency, mobility, tractive and velocity properties, vehicle turnability, and stability of motion and handling. No doubt, these vehicle operational properties considerably depend on total power applied to all the drive wheels. At the same time, the vehicle performance strongly depends on the distribution of total power among the drive wheels. In the given road/off-road conditions, the same vehicle with a constant total power at the drive wheels, but with different power distributions among the drive axles and left and right wheels of each axle will perform differently - the criteria of the above-listed operational properties will have different quantities. Power distribution to the drive wheels is largely determined by the vehicle driveline system, which is defined as a part of powertrain located after transmission. A driveline system includes a set of mechanisms and subsystems installed in power-dividing units (PDU). These units include transfer cases, interaxle reduction gears, and drive axles. A list of those mechanisms and subsystems may be formed by limited slip differentials with various torques biases, open and mechanically/electronically lockable differentials, NoSPINs, viscous clutches, torque management/vectoring devices, and many others. This presentation introduces analytical and experimental methods and achievements in designing mechanical and mechatronic driveline systems. The approach to designing driveline systems is that characteristics of a driveline system and a set of power dividing units are established through the inverse vehicle dynamics and vehicle performance analysis and optimization.

1D2 **Fuel Cell Hybrid Powertrain Optimization for Plug-In Electrical Power Generation**
Scott Moura, Dongsuk Kum, Huei Peng, Panos Papalambros, Hosam K. Fathy

Combined plant/control optimization is applied to a PEM hybrid fuel cell vehicle (HFCV) for vehicle to grid (V2G) applications. The HFCV model is developed from past control-oriented models. For the purposes of design optimization, three components (fuel cell stack, compressor, and battery) are made scalable. To construct a control scheme suitable for combined plant/control design optimization, a rule-based method is selected and framed in a manner such that several key parameters are formulated as design variables. Simulation based computations of the objective function are characterized by noise, and therefore inappropriate for gradient-based optimization algorithms. A surrogate modeling method is suggested using neural networks to approximate the physical model. Using the surrogate model, the combined design and controller HFCV model is optimized for maximum fuel economy for a given stationary power demand cycle. The solution is analyzed with respect to various optimality properties, such as constraint activity, Lagrange multipliers, interior & bounded solutions, and varying starting points. The trade-offs between optimal design solutions and constraints is observed and analyzed to analyze optimal design solutions for a PEM HFCV operating as an energy source to the power grid. Multi-objective optimization problems are formulated through parametric studies to elucidate trade offs between different design objectives. A resultant set of “design rules” are formulated to provide a physical engineering interpretation of the conclusions found.

1D3 **Probabilistic Online Estimation of On-road Vehicle Inertial Parameters**
Dongsoo Kang, Hosam K. Fathy, and Jeffrey L. Stein

The performance of active safety systems, especially in SUVs and trucks, depends strongly on uncertain loading conditions that cause significant discrepancies between real and modeled vehicles. In order to function well, they must be calibrated differently for different loading conditions. Calibrating active safety systems to worst-case loading conditions ensures safety over a wide range of loads but visibly sacrifices maneuverability. Alternatively, adapting safety systems to real loading conditions can enhance safety without unnecessarily penalizing maneuverability, but this necessitates online vehicle inertia estimations. Two specific critical vehicle inertial parameters that should be identified as part of such adaptation are vehicle mass and center of gravity height. The proposed vehicle inertial parameter estimation method is equipped with two supervisory processes: reduced Recursive Least Squares (RLS) parametric model through band-pass filtering, and conservative parameter error calculation through the probabilistic analysis. The RLS parametric model can be reconstructed with only a targeted vehicle parameter using minimum sensor packages under relatively high frequency conditions. The online estimated parameter is coupled with conservative upper and lower bounds on this estimate in the 3s sense. The proposed algorithm provides 99% conservative bounds of the parameter as well as the estimate value, and therefore enhances parameter reliability. A simulation example for a large SUV with additional rooftop loading is presented.

△ Top of Page
<< Previous

Day 2, Wednesday , May 16, 2007
Symposium II Abstracts

2A Human Centered Design

Session Chair: Matt Reed

2A1 **Adaptive Observers To Distinguish Driver Intent From Biodynamic Feedthrough**
Brent Gillespie and Taeyoung Shin

In previous studies, a model-based cancellation controller acting through a motorized joystick has been implemented to recover the manual tasking performance from the degradation caused by the biodynamic feedthrough vibration. Various attempts has been made to identify the such model, but only the off-line method that results in a driver specific model has been successfully implemented. In attempts to developing an adaptive method that can be implemented on-line, we have discovered that the conventional recursive algorithms cannot be directly applied because the biodynamic feedthrough vibration cannot be separately measured from the driver's intentional tracking command. To accurately model the biodynamic transmissibility from the measurement biased by the driver's intent, we have supplemented conventional recursive algorithm with a Kalman Filter that estimates both the feedthrough vibration and the driver's tracking command. The modified recursive algorithm successfully identifies the known linear plant even in the presence of additional signals in the measurement usually caused by driver's intent. Also the algorithm is applied to the pre-recorded human tracking data in a moving platform, and the compensated system with the developed algorithm suppresses high frequency peaks in the joystick force and thereby restores driver's intentional tracking command. For future work, convergence properties of this adaptive algorithms should be studied, and the real-time implementation of the algorithm should be tested to validate the method.

2A2 **Using The Virtual Driver Cognitive And Physical Modeling Approach To Analyze Safety Of In-Vehicle Systems In FMTV Convoys**
Omer Tsimhoni, Helen Fuller, Emily Servinsky, Matthew Reed

The overall goal of this project is to integrate a physical architecture of human motion (HUMOSIM) with a computational cognitive architecture (QN-MHP) to create a new, integrative approach to the analysis of human machine interaction. The presentation will focus on an experiment to test and validate the integrated model. A cognitive and physical task analysis of a driver using advanced in-vehicle information systems while following another vehicle in a convoy will be described alongside a driving simulator experiment with human subjects. Subjects operate an in-vehicle system while following a lead vehicle. Lead vehicle decelerations, simulating hard braking, are triggered stochastically to determine the consequences of alternative information system designs and driver scanning strategies on crash outcomes. The project aims to model the consequences of alternative information system designs and driver strategies on driver performance and crash outcomes.

2A3 **Estimation of Body Links Transfer Functions in Vehicle Vibration Environment**
Heon-Jeong Kim and Bernard J. Martin

Exposure of a driver to vehicle vibration is known to disrupt manual performances, and more specifically affect the speed and accuracy of reaching tasks associated with vehicle operation. The effects of whole body vibration (WBV) can be analyzed as a function of the vibration characteristics of each body link. This information can then be used to identify movement strategies and predict biodynamic responses. Conceptual principles derived from the understanding of human behavior in a vibratory environment can then be used for the design of controls or interfaces adapted for vehicle operation in this context. The transfer functions of individual upper body links were estimated to investigate their biodynamic properties as a function of vehicle vibration frequency and spatial location of targets to be reached. In the present study, fourteen seated participants performed pointing movements to eight targets distributed in the right hemisphere. WBV generated by a ride motion simulator (RMS) consisted of vertical and horizontal sinusoidal displacement of a vehicle cab at 2 Hz, 4 Hz, or 6 Hz. The results obtained for a subset of experimental conditions (vertical vibration, 5 selected targets) show that the transfer functions of the torso, upper arm, and lower arm-hand vary as a function of vibration frequency and target location.

2B Distributed Simulation and Packaging

Session Chair: Greg Hulbert

2B1 **Integration Method of MBD and FEM Models in a Distributed Simulation Environment for HMMWV**

Geunsoo Ryu, Zheng-Dong Ma, and Gregory M. Hulbert

A distributed simulation platform, called D-Sim, has been proposed in the past, which comprises three essential attributes: a general XML description for models suitable for both leaf and integrated models, a gluing algorithm, the T-T method, which only relies on the interface information to integrate subsystem models, and a logical distributed simulation architecture that can be realized using any connection-oriented distributed technology. This research focus on such D-Sim to integrate heterogeneous subsystem models, e.g., multibody dynamics subsystems models and finite element subsystems models for, e.g., detailed durability or NVH simulation and to conduct seamlessly integrated simulation and design tasks in a distributed computing environment. A Partitioned Iteration Method (PIM) is proposed in this research, which decouples the rigid body motion from elastic deformation of the simulated system using an iteration scheme, and it employs a CG-following reference frame for each deformable body in the distributed simulation of flexible multibody systems. The resultant simulation system can be used to integrate distributed deformable bodies in the D-Sim, while allowing large rigid body motions among the bodies or subsystems. It also enables using independent simulation servers; each of them runs standard or commercially available MBD and/or FEM codes. Examples are given in this research based on a two-dimensional beam model for verification of the new methodology which deals with an Euler-Bernoulli beam undergoing large rotation. The second example deals with a four-bar link in a distributed simulation environment for demonstrating how to decouple and integrate the rigid multibody motion and elastic deformation in the D-Sim using the gluing algorithm developed. The application of coupling FEM and MBD with Partitioned Iteration Method in three dimensional problems is on going research work.

2B2 **Packaging With Shape Morphing – Status**

Hong Dong, Georges Fadel, Vladimir Gantovnik

As hybrid vehicles with auxiliary power units (APUs), with large numbers of batteries or with alternative engine sizes become the norm, means to deal with the layout problem of the vehicle have to be developed. This work focuses on incorporating component shape design (morphing) into a vehicle layout design process. The main advantages of the proposed algorithm are improved design efficiency and reduced computational cost. Two different morphing methods are implemented and compared: parameterization-based morphing and mesh-based morphing based on a spring-mass physical model. In order to reduce the complexity of the design problem, an original problem is decomposed into system and component levels using a bi-level formulation. At the system level, the given functional objectives of the layout design problem are optimized with respect to component positions and orientations using the previously developed Packing GA. At the component level, the shapes of certain selected components are morphed to minimize the overlap with other objects and the enclosure. The original problem is solved by iterating between these two levels. The problem under investigation is that of a Ford Taurus underhood layout design. The related algorithms of CAD data extraction, data simplification and format conversion process are demonstrated.

2C Decomposition-based Vehicle Design

Session Chair: Michael Kokkolaras

2C1 **An SLP Filter Algorithm for Probabilistic Analytical Target Cascading**

Jeongwoo Han, Panos Papalambros

Designing a vehicle under uncertainty is a challenging task because it is a multidisciplinary system optimization problem. Subsystem interactions cause strong couplings, which may be amplified by uncertainty. Thus, effective coordination strategies can be particularly beneficial. Analytical target cascading (ATC) is a deterministic optimization method for multilevel hierarchical systems, which was recently extended to probabilistic formulations in the so-called probabilistic design. Solving the probabilistic optimization problem requires propagation of uncertainty, namely, evaluating or estimating the output distributions. This uncertainty propagation can be a very challenging and computationally expensive task for highly nonlinear functions. In order to overcome the general difficulty in uncertainty propagation, this article extends the use of the SLP algorithm to the probabilistic ATC formulation. By linearizing and solving a problem successively, the algorithm takes advantage of the simplicity and ease of uncertainty propagation for a linear system. A suspension strategy, developed for a deterministic SLP-based ATC strategy, is applied to reduce computational cost by suspending the analyses of subsystems that do not need considerable redesigns. The accuracy and effectiveness of the proposed SLP-based PATC strategy is demonstrated with several numerical examples.

2C2 **Design Adaptation for Dependable Vehicle Performance in Unknown Environments**
Michael Kokkolaras, Panos Papalambros, Zissimos Mourelatos

When vehicles are deployed in unknown environments, unexpected events require design changes to ensure safety and increased likelihood of mission accomplishment. Currently, these design changes are made in an “as needed,” ad hoc manner. More importantly, these design changes in some subsystems do not take into consideration interactions with other subsystems. Their impact on the overall system is thus unknown, and they may actually cause, instead of help to avoid, system (i.e., vehicle) failures. This talk will discuss the development of a methodology that accounts for subsystem dependability and interactions, so that design changes can be made without deteriorating overall system dependability. In this manner, design changes as reactions to unexpected events will not compromise vehicle safety and performance in other areas.

2C3 **Optimal Partitioning and Coordination Decisions in Decomposition- based Design Optimization**
James Allison, Michael Kokkolaras, Panos Papalambros

Solution of complex system design problems using distributed, decomposition-based optimization methods requires determination of appropriate problem partitioning and coordination strategies. A formal approach to simultaneous partitioning and coordination strategy decisions will be presented. This approach can provide insights on whether a decomposition-based method will be effective for a given problem. Pareto-optimal solutions are generated to quantify tradeoffs between the sizes of subproblems and coordination problems, as measures of the computational costs resulting from different partitioning-coordination strategies. Promising preliminary results with small test problems will be presented. The approach is illustrated on an electric water pump design problem.

2D Simulation-based Vehicle Design

Session Chair: Zissimos Mourelatos

2D1 **Optimal Engine Torque Management for Reducing Driveline Clunk using Time-Dependent Metamodels**
Daniel Wehrwein, Zissimos P. Mourelatos

Quality and performance are two important customer requirements in vehicle design. Driveline clunk negatively affects the perceived quality and must be therefore, minimized. This is usually achieved using engine torque management, which is part of engine calibration. During a tip-in event, the engine torque rate of rise is limited until all the driveline lash is taken up. However, the engine torque rise, and its rate can negatively affect the vehicle throttle response. Therefore, the engine torque management must be balanced against throttle response. In practice, the engine torque rate of rise is calibrated manually. This paper describes a methodology for calibrating the engine torque in order to minimize the clunk disturbance, while still meeting throttle response constraints. A set of predetermined engine torque profiles are calibrated in a vehicle and the transmission turbine speed is measured for each profile. The latter is used to quantify the clunk disturbance. Using the engine torque profiles and the corresponding turbine speed responses, a time- dependent metamodel is created using principal component analysis and Kriging. The metamodel predicts the turbine speed response due to any engine torque profile and is used in a subsequent optimization which minimizes a clunk disturbance measure while still meeting the throttle response target. The obtained optimal engine torque profile and the corresponding turbine speed were successfully validated experimentally. Compared with the production calibration, the clunk disturbance was reduced by thirty three percent and the throttle response was simultaneously improved by eleven percent.

2D2 **Simulation-based Vehicle Design Validation with Emphasis on Safety**
Harshit Sarin, Michael Kokkolaras, Greg Hulbert, Panos Papalambros

Virtual testing (VT) can be implemented to improve real-world safety beyond regulatory requirements. It can be achieved through the use of computer predictions to extend the range of protection to real-world crash conditions at speeds and configurations not addressed by regulations. Equally important, VT has the potential to reduce the number of tests conducted with physical prototypes. Consequently, VT is crucial to the automotive design process. To achieve fully the promises of VT, computer predictions need validation; in addition, the designs being modeled need to attain electronic certification (EC). This new concept of EC will assess the confidence level that the probability of a design will meet specified requirements. For an established set of validation metrics, reliability and confidence metrics can be developed to support the EC framework. This talk will discuss first efforts in improving and extending current metrics and processes as we are creating the building blocks that will enable VT and EC.

2D3 **Optimal Design Of Electric-Hybrid Powertrain Cooling System**
Andreas Malikopoulos, Michael Kokkolaras, SungJin Park, and Dohoy Jung

This talk discusses the optimization of a cooling system configuration, as well as sizing of its key components, for a series, electric-hybrid powertrain. The scope of this research is to address thermal management issues that are not arisen when dealing with conventional powertrains. Models for all critical system components have been developed (and presented in a modeling counterpart talk in Symposium IV). The cooling system model predicts quantities such as coolant temperatures, flow rates, and pressure drops across individual components. It has been integrated with a full vehicle simulation model, and used to optimize the cooling system for performance and efficiency when it is subject to extreme thermal loads.

△ Top of Page
<< Previous

Day 2, Wednesday , May 16, 2007
Symposium III Abstracts

3A Crashworthiness and Blast Protection

Session Chair: Zheng-Dong Ma

3A1 **High-Frequency Shock Analysis for Composite Vehicles**
Xioyan Yan, Nick Vlahopoulos

In an effort to make Army vehicles more lightweight for increased fuel efficiency, composite materials can be used for their construction. However, composite vehicles or vehicles with composite components are more vulnerable than conventional vehicles to shock loads because they are more flexible. This presentation will cover recent work on developing a simulation capability that will allow assessing the high-frequency shock response and damage of a lightweight composite vehicle due to a shock induced by a projectile impact, from a blast load, from operating loads when traveling at high speeds over rough terrain, or from firing the vehicle's gun. This new effort utilizes the technical foundation offered by the Energy Finite Element Analysis (EFEA) developments completed in previous ARC research. EFEA allows very fast computations at high frequencies because the primary variables of the formulation are energy-based. Thus, in contrast to traditional, displacement-based FEA, a relatively coarse mesh with a small number of finite elements is sufficient for analyzing even large structures at high frequencies. However, currently EFEA can only model structures made out of metal. The new developments are focused on methods for prescribing the shock loads in EFEA, modeling components made out of composite materials, and providing the results in a manner meaningful for assessing vehicle damage and equipment failure.

3A2 **A Magic Cube (MQ) Approach for Crashworthy and Blast-Protective Structure Design Problems**
Chang Qi, Zheng-Dong Ma, and Noboru Kikuchi

Crashworthy design is one of the most challenging problems in automotive product development, while blast-protective structure design is crucial for military operations. Challenges still remain, which include developing a reliable and systematic approach for general crashworthiness and blast-protective structure design problems, which can be used to design an optimum crashworthy or blast-protective structure in terms of topology, shape, and size, and for both structural and material layouts. In this presentation, we present an advanced and systematic approach, the Magic Cube (MQ) approach, and demonstrate its effectiveness in real vehicle structure design problems with focus on a blast-protective structure for HMMVW.

3A3 **Optimization of a Crash Energy Absorption Structure for Crashworthy Design of an Inflatable Morphing Body**
Dong-Wook Lee, Zheng-Dong Ma, and Noboru Kikuchi

An "inflatable morphing body" design concept has been proposed by the authors for crashworthiness and improved safety of military and commercial vehicles. The proposed inflatable body has several key components including a morphing mechanism, active structural components, and a crash energy absorbing (CEA) lattice structure with a locking mechanism to provide desired rigidity and energy absorption capability during a vehicular crash. In this presentation, we focus on the design of the CEA structure. The layout of the CEA structure and major design variables will be identified and an analytical design model for the design problem will be developed. Optimization of the CEA structure will then be conducted in order to maximize the crash energy absorption under given design constraints including allowable maximum crash force and crash distance. The proposed CEA structure is composed of a lattice structure with movable plates for morphing purposes, which will be locked in designated positions before or during the crash. We will describe how to determine the optimal size and shape of the plates as well as their configuration and positioning in order to maximize energy absorption during the crash.

3B Reliability Based Design Optimization

Session Chair: K.K. Choi

3B1 **Dimension Reduction Method (DRM) Based RBDO for Multidimensional Highly Nonlinear Systems**
Ikjin Lee, K.K. Choi, and Liu Du

There are two commonly used reliability analysis methods: linear approximation - First Order Reliability Method (FORM); and quadratic approximation - Second Order Reliability Method (SORM), of the performance functions. The reliability analysis using FORM could be acceptable for mildly nonlinear performance functions, whereas the reliability analysis using SORM is usually necessary for highly nonlinear performance functions of multi-variables. However, SORM requires the second-order sensitivities, and thus, the SORM-based inverse reliability analysis is very difficult to develop. An inverse reliability analysis method is proposed for multi-dimensional highly nonlinear systems to obtain very accurate failure rate calculation without requiring the second order sensitivities and an RBDO method using the inverse reliability analysis result. For this purpose, the univariate dimension reduction method (DRM) is used. Since the FORM-based reliability index (ß) could be inaccurate for the most probable point (MPP) search, a three-step computational process is proposed to carry out the inverse reliability analysis: constraint shift, reliability index update using DRM, and MPP search using the updated reliability index. Using the three steps, a new DRM-based MPP is obtained, which estimates the failure rate of the performance function more accurately than FORM and more efficiently than SORM. The DRM-based MPP is then used for the next design iteration of RBDO, and thus yields an accurate optimum design even for highly nonlinear system. Since the DRM-based RBDO requires more function evaluations, the enriched performance measure approach (PMA+) with new tolerances for constraint activeness and reduced rotation matrix is used to reduce the number of function evaluations.

3B2 **Reliability Based Design Optimization with Dependent Input Variables Using Copula**
Yoojeong Noh, K.K. Choi, and Liu Du

For the performance measure approach (PMA) of RBDO, a transformation between the input random variables and the standard normal random variables is required to carry out the inverse reliability analysis. Since the transformation uses the joint cumulative density function (CDF) of input variables, the joint CDF should be known before carrying out RBDO. In many industrial RBDO problems, even though the input random variables are dependent, they are often assumed to be independent because only marginal distribution and covariance are practically obtained and the joint CDF is very difficult to obtain. With the assumption of independent input variables, it is easy to construct the joint CDF, and Rosenblatt transformation, which transforms the conditional CDF of input variables into the standard normal distribution, has been used for RBDO. However, when input variables are dependent, Rosenblatt transformation cannot be directly used because it is hard to obtain the joint CDF of dependent variables. On the other hand, Nataf transformation can be used for dependent input variables because it only requires marginal distribution and covariance. However, since Nataf transformation uses Gaussian copula, which joins multivariate normal and marginal distributions, it cannot be used for input variables with non-Gaussian joint distribution. In this study, a new transformation that uses a non-Gaussian copula, such as Clayton copula, as the joint CDF of dependent input variables, which is then followed by Rosenblatt transformation, is proposed for non-Gaussian correlated variables. In addition, it is shown that the dependency between input variables significantly affect RBDO results and different transformations such as Nataf transformation using Gaussian copula and the new transformation using non-Gaussian copula (Clayton copula) provide different RBDO results.

3C Tire-Terrain Interaction Modeling

Session Chair: Jonah E. Lee

3C1 **Remote Sensing and Characterization of Snow-Covered Ground by Using Ground Penetrating Radar**
Jonah Lee and Wei Wang

Vehicle mobility in cold regions is greatly affected by snow properties and snow depth. For navigational purpose, it is highly desirable to obtain snow parameters beforehand in the sense of remote sensing and preferably non-contact such that snow is not disturbed. Ground penetrating radar (GPR) has been actively developed during the past few decades and has shown much potential in obtaining geometric and electromagnetic properties of soft terrain including snow-covered ground. The dielectric constant of snow is a function of density and microstructure. On the other hand, the mechanical properties of snow are also known as a function of density and microstructure. It is highly likely that the mechanical properties of snow can be correlated to the dielectric constant of snow for a given density and microstructure. This talk presents preliminary results to obtain, for layered dry snow, the dielectric constant and depth using GPR, and the hardness using rammsonde. The main focus is to interpret GPR data in the field as well as to assess the predictive capability of numerical models. We used single- and multiple-layered snow (of which density is varied in a wide range in its natural state), as well as sieved snow for the measurements. Given depth and dielectric constant of snow, one can simulate the GPR signals in a layered medium, i.e., forward modeling. Also backward modeling is discussed that determinates depth and dielectric constant for given GPR signals. For forward modeling, we employ the Finite Difference Time Domain program GPRMAX as well as the transmission line theory. For backward modeling, we adopt the layer-stripping method using the field data as well as the output from forward modeling. Comparisons of results from experiments and numerical models indicate that GPR has a strong potential for the characterization of snow cover for cold-regions vehicle mobility.

3C2 **Modeling of Non-Steady State Lateral Dynamics of Tires with Slip Angle and Turn Slip as Inputs**

Qing Liu and Jonah Lee

Lateral dynamics of tires determines vehicle understeer gradient and vehicle handling performance and has great impact on vehicle stability and mobility. Wheeled vehicle's lateral acceleration, yaw rate and roll angle are closely associated with lateral dynamics of tires. Vehicle active safety analysis and controls need lateral dynamics models of tires to capture tire dynamics properties under general operating conditions. In non-steady state (NSS) operating conditions, the lateral inputs of tires are time-varying (time-dependent) that represents vehicular transient process and tire's lag properties. There are deterministic geometric relationships between two independent groups of lateral inputs, i.e. displacement-based inputs (lateral displacement and yaw angle) and slip-based inputs (turn slip and slip angle). Two reference frames are established to describe geometric deformation of tires, including local reference frame fixed on contact center and global reference frame fixed to the ground. Lateral deformations are analyzed and derived from geometric relationships and transient identities of contact patch based on two representative tire deformation assumptions - one is Pacejka's string-based assumption with lateral relaxation, and another one is TBT-based carcass deformation with consideration of carcass translating, bending and twisting deformations in lateral direction. The effect of tire width due to longitudinal deformation is further taken into account. Modeling methodology of NSS tire models with slip angle and turn slip as inputs are presented. Model reductions, the effects of tire parameters on frequency responses and comparisons between NSS TBT-based model and string-based model are discussed.

3C3 **The Development of Tire-Soil interaction Model for Off-Road Vehicle Simulation**

Youngwon Hahn, Qing Liu, Gregory M. Hulbert, Zheng-Dong Ma, Jonah Lee

In this research, tire-soil interaction model is developed and tested following predictive semi-analytical model with ADAMS. The predictive semi-analytical model was already proposed by Liu for tire-snow interaction. The proposed model is well defined and provided good prediction for tire-snow interaction (SAE 2005-01-0932): Bekker's pressure sinkage equation is used to calculate normal pressure and Longitudinal and lateral force are only function of sinkage, normal force and slip ratio. Using commercial software ADAMS, the proposed tire-soil interaction model is implemented and simulated using HMMWV model. The Fiala tire model is used in this research. Two cases are simulated and compared with flat road. Each case has two maneuvers, straight-line brake and step steer (J-turn). First, tire-soil interaction model and conventional on-road tire model are simulated on the flat road of the same frictional coefficient. The proposed tire-soil interaction model provided larger force under the same slip ratio. Second, the same maneuvers are performed with real off-road frictional coefficient. The results are discussed with those of on-road tire model.

3D Design Optimization for Mixed Input Variables

Session Chair: Corina Sandu

3D1 **Robust Design Concept in Possibility Theory and Optimization for System with Both Random and Fuzzy Input Variables**
Liu Du, K.K. Choi, and Ikjin Lee

Structural analysis and design optimization have recently been extended to the stochastic approach to consider various types of uncertainties. However, in areas where it is not possible to produce accurate statistical information for input data, the possibility-based (or fuzzy set) methods have recently been introduced in structural analysis and design optimization. The maximal failure search (MFS) method was developed to carry out the inverse analysis for mixed (random and fuzzy) variable design optimization (MVDO). To improve both reliability and quality, the robustness part of the reliability-based robust design optimization (RBRDO) was formulated and solved by the performance measure integration (PMI) or dimension reduction method (DRM). However, the robust design concept has not been developed in the possibility theory in the literature. This study investigates the similarity of the membership function of a fuzzy variable and the cumulative distribution function of a random variable. Based on the probability-possibility consistency principle, a random variable corresponding to the fuzzy variable is introduced in this study in order to define the robust design concept for the fuzzy variable. For the system with both random and fuzzy input variables, the robustness measure of the output performance is computed using the performance measure integration (PMI)-like method, while the integration points are obtained from the inverse possibility analysis by using MFS. The proposed robust design concept in the possibility theory is used to formulate a new mixed (random and fuzzy) variable robust design optimization (MVRDO) method. Several numerical examples are used to verify the robust design concept in the possibility theory and the MVRDO formulation.

3D2 **Interval Analysis and Mixed Random, Fuzzy, Interval variable Design Optimization Using Maximal Failure Search Algorithm**
Liu Du, K.K. Choi, and Ikjin Lee

The probability approach to structural analysis and design optimization requires full input stochastic distribution information for input uncertainties. If the system has limited input information, a possibility approach was recently proposed to provide conservative optimal designs. If the only information of input uncertainty is just lower and upper bounds as interval variables, then the interval analysis needs to be carried out for the worst case structural analysis and design optimization. This study proposes to use the maximal possibility search algorithm with interpolation (MPS) algorithm if input uncertainties are all interval variables. On the other hand, if input uncertainties are mixed random, fuzzy, and interval variables, then it is proposed to use the maximal failure search (MFS) algorithm for worst case analysis and design optimization. In addition, to improve the design quality by using robust design optimization, this study proposes to calculate the output robustness measure of system with input interval variables using the MPS and MFS algorithms. Several numerical examples are used to verify the worst case and robust design optimization formulation of the system with input interval variables.

3D3 **Nonlinear Methods For Modeling Of Terrain Profiles**
T. C. Sun, M. Chaika, D. Gorsich, J. Wei and K. Alyass

Many terrain profiles have nonlinear statistical structures and hence can not be modeled as linear processes. In this talk we propose three nonlinear methods to model these type of terrain profiles. (1) ARMA+GARCH Method. (2) Empirical Mode Decomposition (EMD) Method. (3) Threshhold Autoregressive (TAR) Method. We shall discuss and compare these three methods and also apply them to the Perryman3 terrain profiles. The purpose of this talk is to draw the attention of engineers from all areas to apply these methods to the modeling of their own terrain profiles.

△ Top of Page

<< Previous

Day 2, Wednesday , May 16, 2007
Symposium IV Abstracts

4A Diesel Injection and Combustion

Session Chair: Zoran Filipi

4A1 **Characterizing Transient Diesel Engine Behavior with Cycle-Resolved In-Cylinder Measurements**
Jonathan Hagena, Zoran Filipi, Dennis N. Assanis

Engine behavior during transient operation is not well understood. Because engine subsystems have different response times the amount of fuel, air, EGR, and residual changes continuously and therefore cause consecutive combustion cycles to vary significantly. To better understand transient engine behavior, an experimental technique is introduced which combines cycle-resolved in-cylinder and exhaust manifold gas measurements as well as crank-angle resolved pressure data to determine the mass of fuel, air, EGR, and residual for each cycle. This information is then used to help explain transient engine behavior and then to develop transient control strategies that improve engine operation.

4A2 **A Model For Diesel Spray Behavior Under Supercritical Conditions**
Anametra Bhattacharyya, Naeim A. Henein and Walter Bryzik

Diesel engines are required to meet stringent standards for exhaust emissions including NOx and particulate matter, without penalty in their superior fuel economy and low green house gas emissions. To meet these challenges, there is a need to gain more insight and a better understanding of the behavior of sprays of actual diesel fuels, which is composed of several types of hydrocarbons, under supercritical conditions in diesel engines. Since advanced diesel engines apply fairly high injection pressures, spray penetration increased and fuel impingement on the combustion chamber walls became an important parameter that affects fuel evaporation, combustion and emission formation. In this study, a computer simulation model is developed for two-component diesel fuel sprays under conditions typical to high speed direct injection turbo charged diesel engines. The analysis considered sprays of two-component fuels of different molecular structures, having different combinations of C_9H_{20}, $C_{12}H_{26}$, and $C_{18}H_{38}$. A comparison is made the behavior of the two-component fuel and the each of the single components. The model is applied to investigate the spray behavior in the combustion chamber of a small-bore, high-speed, direct-injection diesel engine running at 1500 rpm and IMEP = 3 bar. The effect of increasing the injection pressure from 600 bar to 1200 bar on wall impingement is determined. The analysis showed clearly that while Sauter Mean Diameter (SMD), commonly used is an indicator of spray evaporation, is not a proper indicator of the spray penetration. The droplets that impinge on the wall have diameters at least 30% larger than Sauter Mean Diameter. The model predictions agreed with the results of a detailed analysis of the fuel distribution in the combustion chamber, based on the rate of heat release under different injection pressures.

4A3 **Spray Characterization of Common Rail Injectors**
Xingbin Xie, M.-C. Lai.

Examples of high-speed visualization to characterize the sprays from nozzles used in Common Rail Fuel Injection System are presented. These include a double-hole nozzle for LD application, and various mini-sac and VCO nozzles for locomotive applications. In addition, sprays from single-hole nozzles are characterized using high-speed phase-contrast X-ray visualization. It was shown Spray symmetry and spray structure were found to depend significantly on the nozzle geometry and the operating conditions.

4B Hybrid Vehicle Modeling and Experiments

Session Chair: Dohoy Jung

4B1 **Maximizing the Benefits of the Hydraulic Hybrid Propulsion for the HMMWV with Optimal Power Management**
Young-Jae Kim, Zoran Filipi

Novel approaches are needed to provide propulsion options capable of dramatically improving fuel economy, while preserving or even improving performance. In case of trucks, the task is particularly challenging since heavy vehicles already use efficient, highly optimized diesel engines, and due to severe limitations in pursuing weight and/or aerodynamic drag reduction. Hence, hybridization is the only avenue towards achieving significant breakthroughs in truck fuel economy, at least in near and mid-term. Our previous study of the advanced propulsion options for the HMMWV has shown that hydraulic energy conversion and storage components can be very attractive, due to their high power-density and efficiency. Two architectures are the top contenders, the full series and a power split system. They both allow great flexibility in controlling engine operation, although using very different means. Hence, the power management strategy has a critical impact on vehicle performance and efficiency. This study presents development of the integrated propulsion system simulation and its use for optimizing both systems. Deterministic dynamic programming techniques are applied to find benchmark control trajectories, and the results are subsequently analyzed to extract implementable rules and evaluate the fuel economy benefits.

4B2 **Series Hybrid Vehicle Cooling System Simulation**
Sungjin Park, Dohoy Jung, Dennis N. Assanis

The cooling system of hybrid vehicle is more complicated than that of conventional vehicle due to the various requirements for different components. This makes the design and the configuration of hybrid vehicle cooling system difficult and challenging. Thus, numerical model of cooling system for hybrid vehicle can be useful for designing and optimizing the system. In this study, the series hybrid vehicle cooling system model has been developed to simulate the thermal response of the cooling system during vehicle driving cycle. The simulation is conducted in two steps. First, driving cycle simulation of a series hybrid vehicle is performed using a VESIM (Vehicle-Engine SIMulation) model. And then, the results from cycle simulation are fed into the cooling system model for cycle simulation of the cooling system. The model is used for designing components of cooling system and a comparative study between configurations of the series hybrid vehicle cooling system. It is found that, in series hybrid vehicles, heat rejection from electric components is considerable compared to the heat from the engine and that configuring proper cooling system is important for the series hybrid vehicle because electric components of the vehicle works independently and have different operating temperatures.

4C Modeling and Optimization of Engine Systems

Session Chair: Naeim E. Henein

4C1 **Improving Performance of 2-Stage Turbocharging System Through Advanced Bypass Valve Control**
Byung-chan Lee, Zoran Filipi, Dennis Assanis

Two-stage turbocharging can dramatically improve power density of the engine because of its much higher boost level compared to the single-stage system. However, the two-stage turbocharging system often exhibits excessive backpressure at high speed as the smaller high pressure turbocharger reaches its maximum flow capacity. In addition, the turbocharger efficiency at part-load operating condition is lower than that of single-stage system because each individual turbocharger operates on a lower pressure ratio. In order to improve performance in such operating conditions, advanced bypass valve control system has been developed. It allows the two-stage turbocharging system to completely bypass low pressure turbocharger in order to improve part load and transient performance, and to operate only low pressure turbocharger at high engine speed in order to reduce excessive backpressure.

4C2 **An Experimental Study for a Direct Measurement of the Piston-Assembly Frictional Losses in a Single Cylinder Test Rig**
Giscard A. Kfoury, Nabil G. Chalhoub, Naeim A. Henein and Walter Bryzik

Characterization of the lubrication regimes and quantification of the frictional losses are very important factors for the design of durable IC engines with an improved fuel economy. The purpose of the current study is to develop a tribology test rig that allows direct measurement of the instantaneous frictional losses between the piston-assembly and the cylinder liner. The effects of oil grade and engine speed on the lubrication regimes in the piston-assembly have been examined in this study. Moreover, theoretical calculations of the oil film thickness between the cylinder liner and the piston rings are provided.

4C3 **Real-time, Self-learning Optimization of Diesel Engine Calibration**
Andreas Malikopoulos, Panos Papalambros, Dennis Assanis

Advanced diesel engine technologies enable superior fuel economy combined with durability. Technologies, such as fuel injections systems, variable geometry turbocharging (VGT), and exhaust gas recirculation (EGR), have enhanced the number of accessible engine controllable variables and our ability to optimize engine operation. In particular, the determination of the optimal values of these variables, referred to as engine calibration, is especially critical for coordinating optimal performance of several specified indices, e.g., fuel economy, emissions, or engine power with respect to the engine's controllable variables. State-of-the-art methods of engine calibration rely on deriving static tabular relationships between a small number of steady-state operating points and the optimal values of the controllable variables. These relationships are incorporated into the electronic control unit of the engine to control engine operation, so that optimal values of the specified indices are maintained. While the engine is running, values in the tabular relationships are being interpolated to provide the values of the controllable variables for each operating point. Such methods, however, seldom guarantee continuously optimal engine operation, especially during transient cases. Pre-specifying the entire transient engine operation is impractical, and thus the existing methods cannot generate optimal values for transient operation a priori. We present the theoretical framework and algorithmic implementation for allowing the engine to learn the optimal set values of accessible controllable variables in real time while running a vehicle. Through this new approach, the engine progressively perceives the driver's driving style and eventually learns to operate in a manner that optimizes specified performance indices. The effectiveness of the approach is demonstrated through simulation of a diesel engine, which learns to optimize fuel economy with respect to two controllable variables, i.e., injection timing and VGT blade position. The engine is shown capable of learning the optimal control policy (timing and blade position) by means of sensory observations representing states (engine operating points) in real time to minimize brake-specific fuel consumption.

4D Engine Thermal Management & Fuel Interactions

Session Chair: Nabil G. Chalhoub

4D1 **Numerical Modeling of Cross Flow Compact Heat Exchanger with Non-Uniform Cooling Air Distribution**
Jaskirat Singh, Dohoy Jung and Dennis N. Assanis

Compact heat exchangers have been widely used in various applications in thermal fluid systems including automotive thermal management systems. Radiators for engine cooling systems, evaporators and condensers for HVAC systems, oil coolers, and intercoolers are typical examples of the compact heat exchangers that can be found in ground vehicles. Among the different types of heat exchangers for engine cooling applications, cross flow compact heat exchangers with louvered fins are of special interest because of their higher heat rejection capability with the lower flow resistance. In this study, a predictive numerical model for the cross flow type heat exchanger with louvered fins has been developed based on the thermal resistance concept and the finite volume method in order to provide a design and development tool for the heat exchanger. The model incorporates a non-uniform air distribution, which can be given as input and has the capability to simulate any Inlet Air Profiles. The model was validated with the experimental data from an engine-cooling radiator. As a case study, the current numerical model was used to simulate a uniform air profile on a Heat Exchanger and the result was compared with existing data. Simulations were also done on a Heat Exchanger using single fan and dual fans and comparisons were drawn. Further critical parameters were identified in defining the non-uniformity of the inlet air profile.

4D2 **Transient Heat Transfer in the EGR Cooler of a Diesel Engine**
Radu Florea, Dinu Taraza, Naeim A. Henein, Walter Bryzik

EGR is a proven technology used to reduce NOx formation in both compression and spark ignition engines by reducing the combustion temperature In order to further increase its efficiency the recirculated gases are subjected to cooling. However, this leads to a higher load on the cooling system of the engine, thus requiring a larger radiator. An accurate simulation model of the heat transfer in the EGR cooler could be used to improve the efficiency of this decice. The current research presents a method of determining the highly pulsating flow field and instantaneous heat transfer in the EGR heat exchanger of a 2.5 liter, four cylinder, common rail diesel engine. The processes are simulated using the CFD code FIRE (AVL) and the results are subjected to validation by comparison with the experimental data obtained on the 2.5 liter four cylinder diesel engine.

4D3 **The Effect of High-Sulfur JP-8 on the Diesel Engine EGR Cooler Condensate**
Mike Smith, Zoran Filipi, Dennis N. Assanis

△ Top of Page

<< Previous