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

12th Annual ARC Conference
May 23–24, 2006

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

Registration closed.

For inquiries, 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

Day 1 Schedule
Tuesday May 23rd 2006

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

Dr. David Gorsich
Associate Director, TARDEC Ground Vehicle Simulation Laboratory

8:30 - 9:15 **Keynote Address:**

GEN Benjamin S. Griffin
Commanding General
United States Army Materiel Command

Question and Answer Session

9:15 - 9:30 **Networking Break**

9:30 - 11:45 **Keynote Address:**

Towards Efficient, Safe And Reliable Vehicle Concepts And Designs for the Future

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

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

MG William M. Lenaers
Commanding General United States Army Tank-automotive and Armaments Command

Gary J. Smyth
Director, Powertrain Systems Research Lab, GM Research and Development Center

Chuck Gulash
Vice-President for Research and Materials Engineering
Toyota Technical Center

Question and Answer Session

11:45 - 1:00 pm	**Lunch**
1:00 - 1:45	**Integrative Approach to Advanced Propulsion System Design Using Simulation and Engine-In-the-Loop** Speakers: **Thrust Areas 4 and 1** Dennis Assanis, Zoran Filipi
1:45 - 2:00	**Networking Break**
2:00 - 2:45	**A �System of Systems� Approach for Design (with Uncertainty) of Army Ground Vehicles** Speakers: **Thrust Areas 3 and 5** Gregory Hulbert
2:45 - 3:00	**Networking Break**
3:00 - 3:45	**Structures and Materials for Lighter, Safer, and More Reliable Vehicles** Speakers: **Thrust Area 3** Kyung K. Choi, Nick Vlahopoulos
3:45 - 4:00	**Wrap-Up and Q & A** **Dennis Assanis** Professor and ARC Director, The University of Michigan
4:00	**Adjourn**

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Day 2 Schedule
Wednesday May 24th 2006

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

8:00 - 8:05am **Welcome**

Dennis Assanis
Professor and ARC Director, University of Michigan

Paul Skalny
National Automotive Center Deputy Director

Symposia Matrix (link) and Abstracts (link)

Symposium I - Vehicle Dynamics and Control and Human Centered Modeling and Simulation

8:30 - 9:00am Introduction Speaker:
Michael Tiller
Vice-President of Modeling Research and Development
Emmeskay

9:00 - 10:00am **1A Vehicle Dynamics & Proper Modeling**
Session Chair: Jeff Stein (abstracts)

10:30 - 11:30am **1B Control of Hybrid Vehicles and Fuel Cells**
Session Chair: Huei Peng (abstracts)

1:00 - 2:20pm **1C Human Centered Design**
Session Chair: Matt Reed (abstracts)

2:50 - 3:50pm **1D Terrain Modeling and Vehicle Analysis**
Session Chair: Anna Stefanopoulou (abstracts)

Symposium II - Vehicle System Integration, Optimization and Robustness

8:30 - 9:00am Introduction Speaker:
David V. Strimling
Decision and Risk Analysis Process Lead
General Dynamics Land Systems

9:00 - 10:00am **2A Design and Control of Complex Systems**
Session Chair: Michael Kokkolaras (abstracts)

10:30 - 11:30am **2B Design Under Uncertainty I**
Session Chair: Panos Papalambros (abstracts)

1:00 - 2:20pm **2C Vehicle System Simulation**
Session Chair: Gregory Hulbert (abstracts)

2:50 - 3:50pm **2D Design Under Uncertainty II**
Session Chair: Zissimos Mourelatos (abstracts)

Symposium III - High Performance Structures and Materials

8:30 - 9:00am	Introduction Speaker: **Johann Pankau** Manager, NVH Engineering Continental North America
9:00 - 10:00am	**3A Structural Analysis and Design under Uncertainty** Session Chair: Matt Castanier (abstracts)
10:30 - 11:30am	**3B Reliability Based Design Optimization** Session Chair: K.K. Choi (abstracts)
1:00 - 2:20pm	**3C Blast Protection and Crashworthiness Analysis** Session Chair: Nick Vlahopoulos (abstracts)
2:50 - 3:50pm	**3D Vehicle-Terrain Interaction Modeling** Session Chair: Jonah Lee (abstracts)

Symposium IV - Advanced and Hybrid Powertrains

8:30 - 9:00am	Introduction Speaker: **Dr. Mark A. Theobald** P.E., Technical Lead - Hybrid Engine General Motors Powertrain
9:00 - 10:00am	**4A Hybrid Vehicle Modeling** Session Chair: Naeim E. Henein (abstracts)
10:30 - 11:30am	**4B Diesel Injection and Combustion** Session Chair: Dohoy Jung (abstracts)
1:00 - 2:20pm	**4C Engine Systems Modeling** Session Chair: Zoran Filipi (abstracts)
2:50 - 3:50pm	**4D Engine Thermal Management** Session Chair: Dinu Taraza (abstracts)

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Keynote Speakers

Biographies

Day 1 Speakers

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BMG William M. 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.

Gary J. Smyth

Director, Powertrain Systems Research Lab, GM Research and Development Center

Smyth began his career with GM in 1989 as a senior project engineer with GM Advanced Product Engineering in Warren, Michigan. He has held numerous positions in the Advanced Powertrain organization and was named Engineering Director, Advanced Propulsion System Controls in 1999, with responsibilities including advanced diesel and advanced emission development. In September, 2004, he transferred to GM R&D as Director, Powertrain Systems Research Laboratory

Smyth attended The Queen's University of Belfast (QUB) in Northern Ireland. He studied Mechanical Engineering and completed his PhD in 1989.

Chuck Gulash

Vice-President for Research and Materials Engineering, Toyota Technical Center

E. Charles (Chuck) Gulash is Vice President of Research and Materials Engineering (RME) at Toyota Technical Center (TTC), located in Ann Arbor, Michigan. TTC, Toyota's North American R&D center, is a division of Toyota Motor Engineering & Manufacturing, North America, Inc. (TEMA). Mr. Gulash is responsible for the oversight of materials evaluation and development for prototype parts and materials destined for use in North American vehicles. Mr. Gulash also directs advanced material research focusing on establishing collaborations with leading universities and national labs for leading edge technologies such as advanced fuel cells and batteries.

Mr. Gulsah joined TTC in 1996 as General Manager of Vehicle Evaluation at the Arizona Proving Ground and has held a series of leadership roles in vehicle evaluation and performance development. He became Vice President of Vehicle Evaluation in 1999, Vice President of Vehicle Evaluation & Engineering in 2002, and Vice President of Research & Materials Engineering in 2006.

Prior to joining TTC, Mr. Gulash held various engineering and management positions during more than 20 years with General Motors Corporation, where he was involved with vehicle safety, design engineering and total vehicle development.

Mr. Gulash earned a Bachelor of Science degree in Mechanical Engineering and a Masters degree in Business Administration from the University of Michigan. He is a member of the Society of Automotive Engineers (SAE) and is a recipient of the SAE Arch T. Colwell Merit Award. He serves on the External Advisory Boards of the University of Michigan Mechanical Engineering Department and Transportation Research Institute as well as the Visiting Committee at the College of Engineering and Computer Science, University of Michigan – Dearborn.

Mr. Gulash resides in Ann Arbor, Michigan. His children, Joe and Liz, have graduated from the University of Arizona and work in southern California. His hobbies include cars, biking, hiking, yoga and digital things.

Day 2 Speakers

(go to Day 1)

Michael Tiller

Vice-President of Modeling Research and Development, Emmeskay

Michael Tiller graduated with a Ph.D. in Mechanical Engineering from the University of Illinois at Urbana-Champaign. His thesis work was in the area of analytical sensitivity analysis applied to optimization of large scale, finite element based, solidification models. After graduating from the University of Illinois, Dr. Tiller worked at Ford Motor Company where he spent 10 years in the area of powertrain research. While at Ford, Dr. Tiller worked on a range of different automotive systems including combustion and engine modeling, transmission modeling and anti-lock braking systems. He has several patents based on his work on the Ford Hybrid Escape. Dr. Tiller left Ford Motor Company in June, 2005 to become Vice-President of Modeling Research and Development at Emmeskay, Inc, a Plymouth Michigan based company specializing in advanced technology solutions. While at Ford, Dr. Tiller became involved in the Modelica modeling language. He is currently the Secretary of the Modelica Association, the non-profit organization that oversees the development of the Modelica modeling language. He is also the author of of the book"Introduction to Physical Modeling with Modelica".

David V. Strimling

Decision and Risk Analysis Process Lead, General Dynamics Land Systems

Mr. David V. Strimling is the Systems Engineering Decision and Risk Analysis Process Lead at General Dynamics Land Systems (GDLS) in Sterling Heights, MI. He has forty years of experience in development and application of state-of-the-art operations research, optimization and decision-support models. His work has successfully enabled operational, tactical, and strategic decisions in high technology product development environments. In his capacity as the GDLS Decision and Risk Analysis Process Lead, Mr. Strimling provides internal consulting services in his areas of expertise. Mr. Strimling developed the GDLS proprietary Armored Combat System Optimization Model (ACSOM) for system level optimization and trade studies. Prior to joining GDLS in 1982, Mr. Strimling was the senior Operations Research / Systems Analyst at U.S. Army Armor Center Directorate of Combat Developments at Fort Knox, Kentucky from 1974 – 1982. From 1966 – 1974, Mr. Strimling worked at the National Aeronautics and Space Administration George C. Marshall Space Flight Center in Huntsville, Alabama. Mr. Strimling has a Bachelors degree in Mathematics and a Masters degree in Operations Research. In addition to his professional experience, he has over twenty-eight years of part time graduate school teaching experience in Operations Research.

Johann Pankau

Manager NVH Engineering N. A., Continental

Johann Pankau holds a Master's Degree in Mechanical Engineering from the University of Darmstadt, Germany. Johann worked for over 16 years with ITT Teves, Continental Teves and Continental Tire on two continents, developing active and passive vehicle safety systems in both technical and managerial positions. Currently Johann is heading Continental's NVH Engineering

North America in Auburn Hills Michigan. His department services all company business units and external customers. Johann's technical experience ranges from conventional/electronic brake, tire and suspension development to integration and interaction of those components and systems within the vehicle. Furthermore, he posseses a thorough technical knowledge of NVH, CAE and CAD.

Dr. Mark Theobald

Technical Lead – Hybrid Engine, General Motors Powertrain

Dr. Mark Theobald has worked on hybrid vehicle technologies since 1994, beginning with the joint U.S. government/industry Partnership for a New Generation of Vehicles, and continuing with GM's internal advanced technology programs and technology management. Presently he is technical lead for hybrid engines in Hybrid Powertrain Systems at GM Powertrain. Mark is vice-chair of the SAE Hybrid Standards Committee, and co-organizer for technical sessions on hybrid powertrains at the annual SAE Congress. His earlier work in engine research at GM Research & Development was in the areas of variable valve actuation, diesel combustion, and emissions modeling. He holds degrees from Kalamazoo College, the University of Texas at Austin, Renselaer Polytechnic, and MIT. He is a Registered Professional Engineer and a Board-Certified Member of the Institute of Noise Control Engineering.

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Registration General Info Day 1 Sched. Day 2 Sched. Keynote Speaker Bios. Symposia Matrix

Symposia matrix is formatted to printout in "Landscape" format

Time	Symposium I	Symposium II	Symposium III	Symposium IV
	Introduction			
8:30am - 9:00	**Michael Tiller** Vice-President of Modeling Research and Development, Emmeskay	**David V. Strimling** Decision and Risk Analysis Process Lead, General Dynamics Land Systems	**Johann Pankau** Manager NVH Engineering N.A., Continental	**Dr. Mark A. Theobald** P.E., Technical Lead - Hybrid Engine, General Motors Powertrain
	1A Vehicle Dynamics & Proper Modeling	**2A Design and Control of Complex Systems**	**3A Structural Analysis and Design under Uncertainty**	**4A Hybrid Vehicle Modeling**
9.00 - 9.20	Virtual Powertrain Scaling for Advanced Engine-in-the-Loop Simulation	Analysis of Single-Level Formulations for Complex System Design Optimization	Structural Reduced-Order Modeling Methods for Distributed Simulation, Uncertainty Analysis, and Design	Analysis of the Series Hydraulic Hybrid Propulsion for the HMMWV Using Simulation and Engine-in-the-Loop Testing
9.20 - 9.40	Rapid Identification of Critical Chassis Parameters Through the Use of Model Reduction Techniques	Real-time optimization for engine calibration	Maximal Failure Search Method for Mixed Random and Fuzzy Variables Design Optimization	Simulation Study of the Power Split Hydraulic Hybrid Propulsion System
9.40 - 10.00	Development of Proper Vehicle Level Models of HMMWV for Engine-in-the-Loop Simulation	Optimal Design of Fuel Cell Hybrid Vehicles	Dynamic Tire Model: Parameter Identification Via Virtual Tests And Validation In Real And Virtual Environments	Control Analysis of a Hybrid Electric HMMWV
10.00 - 10.30	**Break**			
	1B Control of Hybrid Vehicles and Fuel Cells	**2B Design Under Uncertainty I**	**3B Reliability Based Design Optimization**	**4B Diesel Injection and Combustion**
10.30 - 10.50	An Efficient Scaling Methodology for Dynamic Models Using Dimensional and Activity Analyses	Optimal Design with Non-Normally Distributed Random Parameters, Conditional Probability, and Joint Constraint Reliabilities: A Case Study in Vehicle Emissions Regulations to Achieve Ambient Air Quality Standards	Dimension Reduction Method for Reliability-Based Robust Design Optimization	Spray Dynamics and Breakup Mechanisms for Transient and Short Pilot Injections
10.50 - 11.10	Control of electric architecture for fuel cell electric auxiliary power unit	Decision-making for Complex Systems under Uncertainty and Risk: Application to an Engineering Selection Problem	Reliability-Based Design Optimization with Correlated Input Parameters	A Simulation-Based Cold-Start Control-Strategy for a Common Rail Diesel Engine at different Ambient Temperatures
11.10 - 11.30	Modeling and Validation of a Membrane Humidifier for Dynamic Fuel Cell Power and Fuel Processing	A Single-Loop Approach for System Reliability-Based Design Optimization	Weight Minimization of Stryker A-Arm and Morpher-Based RBDO of M1A1 Roadarm for Durability	Impact of transient diesel engine operation on visual signature
11.30 - 1.00pm	**Lunch**			
	1C Human Centered Design	**2C Vehicle System Simulation**	**3C Blast Protection and Crashworthiness Analysis**	**4C Engine Systems Modeling**
1.00 - 1.20	Fitting biomechanical and regression models to human-vehicle interaction data: a simulation study and initial experiment -------------------------- Simulating reach trajectories perturbed by vehicle ride motion -------------------------- Simulating human movement coordination for sequences of tasks -------------------------- The Virtual Driver: Integrating Cognitive and Physical Models of Driver Performance -------------------------- Alteration of movement coordination under vehicle vibration exposure	Investigation of Rollover, Ride, and Obstacle Avoidance Maneuvers of Tactical Vehicles	EFEA developments for high frequency shock analysis of composite structures subjected to blast loads	Transient Engine System Simulation using a Quasi-Dimensional Diesel Spray combustion model.
1.20 - 1.40		A Distributed Simulation Platform for HMMWV using the Gluing Algorithm	An innovative Inflatable Morphing Body Structure for Crashworthiness of Military and Commercial Vehicles	Simulation-based Analysis of Two-Stage Hybrid Turbocharging Systems
1.40 - 2.00		Underhood/Underbody Layout Design With Shape Morphing	HMMWV Rollover Case Study Simulation	High Power Density Diesel Engine Dynamics and Cycle Simulation
2.00 - 2.20		Performance Tradeoffs and System Sensitivity in Multicriteria Design Optimization	A Magic Cube Approach for Crashworthiness Design	Engine Friction Model for Transient Operation of Turbocharged, Common Rail Diesel Engines
2.20 - 2.50	**Break**			
	1D Terrain Modeling and Vehicle Analysis	**2D Design Under Uncertainty II**	**3D Vehicle-Terrain Interaction Modeling**	**4D Engine Thermal Management**
2.50 - 3.10	Large Scale 3D Terrain Modeling	Interval analysis in multilevel system design	Current Developments in Tire-Snow Interfacial Forces: Effects of Density with Uncertainty and Depth, Validation and Terrain Characterization	Advanced Thermal Management for Internal Combustion Engines
3.10 - 3.30	Naturalistic analysis of drivers' lateral performance and behavior using the ACAS Database	A Bayesian Approach to Reliability-Based Optimization with Incomplete Information	Time-Varying Off-Terrain Traction Forces Modeling Methodology and Frequency Response within Tire and Snow-Covered Ground Interface	Airflow management for the cooling system performance
3.30 - 3.50	Initial conditions of a simple, passive-dynamic walker	A Sequential Algorithm for Possibility-Based Design Optimization	Two Examples of Statistical Modeling of Terrain Profiles	Thermal management analysis for a high performance large active area PEMFC system

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Day 2, Wednesday , May 24, 2006
Symposium I Abstracts

1A Vehicle Dynamics & Proper Modeling

Session Chair: Jeff Stein

1A1 **Virtual Powertrain Scaling for Advanced Engine-in-the-Loop Simulation**
Hosam K Fathy and Jeffrey L. Stein

The use of engine-in-the-loop (EIL) simulation to compare conventional and hybrid powertrains poses an interesting problem, namely, the difficulty of physically downsizing the engine for the hybrid powertrains. This talk will briefly survey the engine scaling literature, concluding with the development of a method for “virtually” scaling an engine within an EIL setup. The talk will then proceed to explore the ramifications of such virtual scaling on the remaining subsystems in a conventional HMMWV powertrain. Specifically, the talk will derive, from first principles, scaling laws that can downsize the torque converter and transmission of a conventional HMMWV to match the downsized engine. Numerical and experimental demonstrations of this scaling methodology will be discussed, and future work directions will be explored.

1A2 **Rapid Identification of Critical Chassis Parameters Through the Use of Model Reduction Techniques**
Bryon Sohns, James Allison, Hosam K Fathy, and Jeffrey L. Stein

Identifying models of multi-body dynamic systems from experimental data is a common problem in the army and in industry. However, as our knowledge and computing power grows, so does the size of the models created. As a model grows in size, the time required to identify all of the model’s parameters suffers from combinatorial explosion. There are techniques, including parameter sensitivity analysis, which can help alleviate this problem somewhat. However, for larger models even these techniques suffer from the same inefficiency due to combinatorial explosion. In this presentation an energy metric called activity is used to accelerate the identification of a dynamic model from experimental data. This project explores the viability of an energy metric from previous ARC projects in model reduction, called activity, as an estimator of parameter sensitivity. This is done through numerical exploration using a quarter-car suspension model in pure simulation. It is found that activity does have a strong correlation with parameter sensitivity, with a marked increase in the efficiency of the identification problem. A theoretical examination of the connection between activity and sensitivity is also made. In the future this method will be applied to a HMMWV model currently in use by TARDEC.

1A3 **Development of Proper Vehicle Level Models of HMMWV for Engine-in-the-Loop Simulation**
Rahul Ahlawat, Hosam K. Fathy, and Jeffery L. Stein

Engine-in-the-Loop (EIL) simulation offers an accurate way to measure the response of the engine in a vehicle following a driving cycle. As a result of last year’s work, a first attempt at the development of vehicle-level models of HMMWV was made and some critical integration issues in the setup were sorted out. However, the vehicle was unable to brake all the way to zero velocity due to the use of classical brake friction models. This talk will present the development of brakes based on Karnopp’s friction model which more accurately represents the dynamics of stick-slip friction, and makes the vehicle brake to zero velocity. Also, the previous transmission model represented the dynamics of gear shifting by a blending function. This talk will present the development of a full physics-based model of the transmission from the literature and the continuing work for its reduction to get a proper model for EIL simulation which has sufficient accuracy and real time capability. Such ‘proper’ vehicle level models will ensure the accuracy of the engine response in the EIL simulation and will also allow physics-based dynamic scaling of the system.

1B Control of Hybrid Vehicles and Fuel Cells

Session Chair: Huei Peng

1B1 **An Efficient Scaling Methodology for Dynamic Models Using Dimensional and Activity Analyses**

Burit Kittirungsi, Hosam K Fathy, Jeffrey L. Stein, and Anna G. Stefanopoulou

This talk presents the development of a systematic methodology for scaling the outputs of a dynamic system to meet new desired specifications while maintaining the same system configuration. Scaling laws, which represent mathematical relationships between the design variables of the original and scaled models, are derived through dimensional analysis. Dynamic properties between the original and scaled models are similar if every scaling law can be achieved, but this is often too restrictive. An activity-based model reduction technique is then employed to attain more tractability in scaling by quantifying the importance of different scaling laws. The methodology is demonstrated using two examples. The first example, describing the scaling of a two-degree-of-freedom mass-spring-damper system, justifies the use of dimensional analysis in conjunction with activity. The second example shows that the developed methodology can be used to scale a fuel cell stack's air supply system design by evolving the existing optimal solution into a new solution that is very similar to the optimum of the scaled system.

1B2 **Control of Electric Architecture for Fuel Cell Electric Auxiliary Power Unit**

Kyung-Won Suh, Anna Stefanopoulou

Transient performance is a key characteristic of fuel cells (FC), that is sometimes more critical than efficiency, due to the importance of accepting unpredictable electric loads. To fulfill these transient requirements, a fuel cell stack is typically coupled with a battery through a DC/DC converter to form a hybrid power system. The purpose of this dissertation is to first define the dynamic limitations of power system with a FC as its sole power source. The coupled dynamics associated with the power sharing between the fuel cell and the battery is then investigated for various electric architectures. Analytic models are developed and optimal controllers are designed to regulate the power system voltage and prevent fuel cell reactant starvation. The control results provide insight into the fundamental system controllability, efficiency, component sizing, and ability to handle transient loading.

1B3 **Modeling and Validation of a Membrane Humidifier for Dynamic Fuel Cell Power and Fuel Processing**

Denise McKay, Anna Stefanopoulou

Water management is critical for optimizing both fuel cell and fuel processor efficiency, requiring accurate control of both gas humidity and temperature. A novel membrane-based humidifier system was designed and installed at the Fuel Cell Control Laboratory. This humidifier can be used to independently control temperature and humidity of a gas stream supplied to a fuel processor or fuel cell. We will summarize on-going efforts to develop a physically motivated, experimentally validated, humidifier model for control applications.

1C Human Centered Design

Session Chair: Matt Reed

1C1 **Fitting Biomechanical and Regression Models to Human-Vehicle Interaction Data: A Simulation Study and Initial Experiment**

Taeyoung Shin, Brent Gillespie

Our objective is to develop an empirically verified model of human manual performance onboard moving vehicles that incorporates both biomechanical and sensorimotor processes. The model will be used to evaluate the efficacy of various vehicle design modifications aimed at mitigating biodynamic feedthrough and similar factors that deteriorate manual control performance on-board moving vehicles. In previous work we have shown that a regression model of biodynamic feedthrough can be used in conjunction with a motorized manual control interface to suppress the effects of ride motion. Our recent work focuses on the construction of a biomechanical model parameterized by anthropometric measures in place of the regression models. The anthropometric biomechanical model can be easily extrapolated to evaluate various countermeasures, including new armrests, active or passive vibration isolation schemes, and active filters operating through motorized joysticks or steer-by-wire systems. In this presentation, the performance of a regression model and a structured state space model will be compared in a simulation study using goodness of fit, extrapolation, and interpolation performance measures. Fits to simulation and experimental data are performed using the prediction error method. Simulation study reveals that mechanical models benefit from the knowledge of system structure and provide more accurate parameter estimation due to the reduced number of estimated parameters.

1C2 **Simulating Reach Trajectories Perturbed by Vehicle Ride Motion**
Kevin Rider

The human-centered design of vehicle subsystems requires a thorough understanding of human capabilities and limitations. Within the vehicle cockpit, controls and displays are often designed that can require a high degree of manual dexterity to effectively operate, particularly when the vehicle is in motion. Ride motion perturbations cause human biodynamic responses that are posture- and frequency-dependent, and are associated with increased movement times and decreased endpoint accuracy of reaching and pointing tasks. This vibration feedthrough is being simulated by a human biodynamic response model to estimate the effects of ride motion on the speed and accuracy of in-vehicle reaching tasks. Predicting reach capabilities under ride motion will identify primary concerns with respect to the design and layout of vehicle controls and displays.

1C3 **Simulating Human Movement Coordination for Sequences of Tasks**
Matt Reed

The application of digital human models to the simulation of vehicle operators is hampered by a lack of valid models of movement coordination. In a multi-task environment, vehicle operators perform the physical activities associated with the primary vehicle operations (steering, shifting,operating the pedals, and looking at interior and exterior targets) in sequence with other tasks, such as operating in-vehicle communication and navigation systems. Most previous research on human movement coordination has focused on either discrete, usually ballistic tasks, such as reaches, or on cyclical activities such as gait. Current research in the Human Motion Simulation Laboratory at the University of Michigan is focused on the performance of sequences of goal-oriented tasks, such as interacting with in-vehicle controls and displays. In the current work, a resource-based model of motor component scheduling was developed. Under this paradigm, the vision system functions as a resource for the upper-extremity system in cases for which visual feedback is needed to complete an upper-extremity task. The torso functions as a resource serving both the gaze (head-eye) and upper-extremity systems. A demonstration implementation of this approach was developed in the Jack human modeling system and used to simulate reaches within a military truck. The system displays realistic coordination of the head, torso, and upper-extremities when performing sequences of visual, manual, and visuo-manual tasks.

1C4 **The Virtual Driver: Integrating Cognitive and Physical Models of Driver Performance**
Matt Reed, Omer Tsimhoni

The overall goal of this project is to integrate a physical architecture of human motion with a computational cognitive architecture to create a new, integrative approach to the analysis of human machine interaction. The first phase of this work will develop a proof-of-concept implementation to simulate the cognitive and physical aspects of driving a vehicle while using an in-vehicle navigation system. The Queuing Network — Model Human Processor (QN-MHP), a cognitive model developed at the University of Michigan, will be connected with the Human Motion Simulation (HUMOSIM) Ergonomics Framework, a suite of human motion simulation algorithms running in the Jack human modeling software environment. A network connection with a driving simulator at the University of Michigan Transportation Research Institute (UMTRI) will provide the road environment and vehicle dynamics. This presentation will focus on the architecture of the simulation system and preliminary results.

1C5 **Alteration of Movement Coordination Under Vehicle Vibration Exposure**
Bernard J. Martin, Jueun Lee

The understanding of movement coordination under whole-body vibration exposure is necessary to implement human motion simulation models in this particular environment. The specific aim of this work was to analyze the motion and coordination of upper body segments of operators performing reach tasks under whole-body vibration. The reach task consisted of pointing with the right hand index finger to targets placed in front of the subject in the right hemisphere of a mockup cabin of an HMMW vehicle placed on a ride motion simulator (RMS). Seven targets placed within reach distance in the following locations were used in this analysis: overhead, forward and upward (45° elevation), forward near and far (elbow level), lateral (in frontal plane) upward (45o elevation) near, lateral near and far (elbow level). The task was performed under stable condition (no vibration), sinusoidal vibration or vehicle ride simulated vibration. A motion capture system was used to record body link trajectories. Joint angles (torso, shoulder and elbow) were then computed using quaternions. Coordination between body links was quantified by a) a joint contribution vector and a joint change contribution vector, b) the joints angle-versus-angle relationships between the upper arm and lower arm, b) the joint motion onset relationships between torso, upper arm and lower arm in the time domain. Vehicle vibration affects reaching and pointing movement strategies. The effects are largely dependent on vibration frequency and direction as well as the relative direction of the movement. The major results indicate that 1) a more upright position of the torso is adopted before the initiation of the hand movement under vibration exposure, 2) the angle-angle relationships are generally linear under vertical vibration while they are rather non-linear under transverse vibration, 3) the timing of the onset of body segment motion is a function of motion direction and vibration expsoure and 4) 4Hz vibration seems to induce the strongest effects. These results indicate that some movement directions are more susceptible than others to the effects of vibration, which should be taken into account for the design of controls and their locations.

1D Terrain Modeling and Vehicle Analysis

Session Chair: Anna Stefanopoulou

1D1 **Large Scale 3D Terrain Modeling**
D. Page, S. Rangan, B. Grinstead, W. Hao, A. Koschan, M. Abidi

In this compilation, we present the capability of the Imaging, Robotics and Intelligent Systems Lab at the University of Tennessee, Knoxville to generate large scale terrain models of real world dynamic environments. Based on our previous experience with mobile scanning our proposed system for large scale terrain mapping leverages 3D laserrange sensors, video cameras, global positioning systems (GPS) and inertial measurement units (IMU) towards the generation of photo-realistic, geometrically accurate, georeferenced 3D models of terrain surfaces. The models that our mobile system delivers can serve as input to machine vision algorithms for surface defect and crack inspection, readily immersed into virtual environments for simulation and testing of ground vehicles to analyze vehicle/terrain interaction.

1D2 **Naturalistic Analysis of Drivers' Lateral Performance and Behavior Using the ACAS Database**
Jing Zhou, Huei Peng, Tim J. Gordon

Naturalistic driving data collected during a field operational test are used to characterize drivers' lateral control behaviour. Normative values of the standard deviation of lateral position and time-to-lane-crossing are first derived to describe driver population's lane-keeping performance statistically. Then a driver model is developed for the lane-keeping task on curved freeways. It is shown that the driver’s control characteristics can be represented by a quasi-linear system with look-ahead visual input with feedback and feedforward components. An optimization procedure is applied to obtain least-square-fit model parameters for each data segment separately. The pursuit and compensatory parts of drivers’ action are decoupled and parameter dependency on velocity is analyzed. The obtained model sets represent widely-varying driver behavior and can be used for the design and evaluation of vehicle active safety systems, driving simulator studies or microscopic traffic simulations.

1D3 **Initial Conditions of a Simple, Passive-Dynamic Walker**
Brooke Haueisen, Greg Hulbert, Greg Hudas, Kyle Nebel

Walking robots hold great potential for the future of military robotics. Their natural agility in rough, unstructured terrain make them ideal for military applications but their power requirements do not. Passive dynamic walkers offer a potentially low-power solution. This class of legged robots utilizes the natural inverted pendular dynamics that humans rely on to locomote. The most basic of these systems uses gravity as its power source and has no control system therefore its stability is heavily reliant on its initial conditions. The VICON Motion Capture System was used to record the motions of Coleman and Ruina’s1 TinkertoyWalker _c . The initial angles and angular velocities of the various trials were extracted from the motion capture data and used as inputs to a multi-body dynamics model of the walker. The model was created to provide insight into passive-dynamic walkers and the interactions between the walker and the ground surface. Several trials were performed to quantify the stability space of the experimental walker and improve the correlation of the dynamics model to the physical robot.

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Day 2, Wednesday , May 24, 2006
Symposium II Abstracts

2A Design and Control of Complex Systems

Session Chair: Michael Kokkolaras

2A1 **Analysis of Single-Level Formulations for Complex System Design Optimization**
James Allison

Design of modern engineering products requires complexity management. Several methodologies for complex system optimization have been developed in response. Single-level strategies centralize decision-making authority, while multi-level strategies distribute the decision-making process. This article studies fundamental differences between two single-level multidisciplinary design optimization formulations: multidisciplinary feasible (MDF) and individual disciplinary feasible (IDF). Results presented aim at aiding practitioners in selecting between formulations. Specifically, while IDF incurs some computational overhead, it may find superior optima that are hidden to MDF and is more efficient computationally for strongly coupled problems; further, MDF is sensitive to variations in coupling strength, while IDF is not. Conditions that lead to failure of MDF are clearly described. Two new reproducible design examples are used to illustrate these findings.

2A2 **Real-Time Optimization for Engine Calibration**
Andreas Malikopoulos

Engine technologies have been advancing rapidly during the last years, providing evermore available controllable engine variables that can be tuned during engine calibration to optimize fuel economy, emissions, torque, etc. As a result, engine calibration has become crucial. Conventional calibration methods rely on dynamometer mapping and transient vehicle testing to accomplish a satisfactory calibration. However, the state-of-art in engine calibration cannot guarantee optimal operation in the entire engine operating domain, especially for transient cases encountered in different driving cycles. We present a new approach for efficient optimal engine calibration for steady-state and transient cases that employs real-time optimization through learning. The engine is self-optimized during the driving cycle. The more often a particular engine operating point is visited the more the engine variables are optimized at this point. Consequently, as the engine operates according to a particular driving “style,” performance is optimized.

2A3 **Optimal Design of Fuel Cell Hybrid Vehicles**
Jeongwoo Han, Michael Kokkolaras and Panos Y. Papalambros

Fuel cells are being considered increasingly as a viable alternative energy source for automobiles because of their clean and efficient power generation. Numerous technological concepts have been developed and compared in terms of safety, robust operation, fuel economy, and vehicle performance. However, several issues still exist and must be addressed to improve the viability of this emerging technology. Despite the relatively large number of models and prototypes, a model-based vehicle design capability with sufficient fidelity and efficiency is not yet available in the literature. In this article we present an analysis and design optimization model for fuel cell vehicles that can be applied to both hybrid and non-hybrid vehicles by integrating a fuel cell vehicle simulator with a physics-based fuel cell model. The integration is achieved via quasi-steady fuel cell performance maps, and provides the ability to modify the characteristics of fuel cell systems with sufficient accuracy (less than 5% error) and efficiency (98% computational time reduction on average). Thus, a vehicle can be optimized subject to constraints that include various performance metrics and design specifications so that the overall efficiency of the hybrid fuel cell vehicle can be improved by 14% without violating any constraints. The obtained optimal fuel cell system is also compared to other, not vehicle-related, fuel cell systems optimized for maximum power density or maximum efficiency. A tradeoff between power density and efficiency can be observed depending on the size of compressors. Typically, a larger compressor results in higher fuel cell power density at the cost of fuel cell efficiency because it operates in a wider current region. When optimizing the fuel cell system for maximum power density, we observe that the optimal compressor operates efficiently. When optimizing the fuel cell system to be used as a power source in a vehicle, the optimal compressor is smaller and less efficient than the one of the fuel cell system optimized for maximum power density. In spite of this compressor inefficiency, the fuel cell system is 9% more efficient on average. In addition, vehicle performance can be improved significantly because the fuel cell system is designed both for maximum power density and efficiency. For a more comprehensive understanding of the overall design tradeoffs, several constraints dealing with cost, weight, and packaging issues must be considered.

2B Design Under Uncertainty I

Session Chair: Panos Papalambros

2B1 **Optimal Design with Non-Normally Distributed Random Parameters, Conditional Probability, and Joint Constraint Reliabilities: A Case Study in Vehicle Emissions Regulations to Achieve Ambient Air Quality Standards**

Kuei-Yuan Chan, Steven J. Skerlos and Panos Y. Papalambros

Making appropriate environmental policy decisions requires considering various sources of uncertainty. An air pollution example is formulated as a design optimization problem with probabilistic constraints, also referred to as reliability-based design optimization (RBDO). Environmental applications with a large number of constraints and significant model complexity present special challenges. In this work an efficient active set strategy is integrated with a reliability contour surface approach to solve probabilistic problems with non-normal variable probability distributions. Discrete random parameters, which result in Bayesian probability, are also present and they are incorporated using delta function approximations. Joint constraint reliability that considers satisfying all regulatory constraints is also discussed. A demonstration example of setting the optimal vehicle speed limit while maintaining high reliability for CO and NOx standards of a residential area near two highway systems will be presented.

2B2 **Decision-Making for Complex Systems under Uncertainty and Risk: Application to an Engineering Selection Problem**

Tom Mitchell, Mo Salah, John R. Wagner, and Darren M. Dawson

The process of selecting design solutions, proposals, suppliers, materials, etc., belongs to the engineering selection problem and requires decision-making under uncertainty and risk. Decision-making for complex systems has typically been studied within mathematical programming, which may not offer effective solution techniques if systems are nonlinear or interactions between them are complex. As these characteristics are prevalent in complex engineering problems, we present a performance-based methodology for complex systems operating under uncertainty, which remains within the decision-making paradigm but goes beyond traditional mathematical programming. Stochastic analysis is used to model system performance and effectively account for the interactions. Computational models of subsystems and components use normal random fields defined over a space of uncertainties treated as parameters. System performance is measured by risk that is modeled as the variance of system performance and a function of the uncertainties. The approach employs multi-criteria decision making to screen feasible alternatives and identify an optimal, that is, minimum risk alternative.

2B3 **A Single-Loop Approach for System Reliability-Based Design Optimization**

Jinghong Liang, Zissimos P. Mourelatos

An efficient single-loop approach for series system reliability-based design optimization problems is presented. The approach enables the optimizer to apportion the system reliability among the failure modes in an optimal way. A previously reported methodology uses a sequential optimization and reliability approach. It also uses a linear extrapolation to determine the coordinates of the most probable points of the failure modes as the design changes. As a result, the approach can be slow and may not converge if the location of the most probable failure point changes significantly. This paper proposes an alternative system RBDO approach that overcomes the above difficulties by using a single-loop approach where the searches for the optimum design and for the most probable failure points proceed simultaneously. An easy to implement active set strategy is used. The maximum allowable failure probabilities of the failure modes are considered as design variables. The efficiency and robustness of the method is demonstrated using three design examples involving a beam, an internal combustion engine and a vehicle side impact. The results are compared with deterministic optimization and the conventional RBDO formulation.

2C Vehicle System Simulation

Session Chair: Gregory Hulbert

2C1 **Investigation of Rollover, Ride, and Obstacle Avoidance Maneuvers of Tactical Vehicles**
Joshua B. Stewart and E. H. Law

Current military operations in Iraq and Afghanistan are unique because the attlefield can be described as a non-linear, asymmetrical environment. Enemy ontact is no longer defined as a discernable forward line that can be physically dentified on a map, and secure areas or green zones no longer represent the entire area of operations to the front of enemy lines. Instead, units operate in zones that are susceptible to enemy contact from any direction at any time. This means that supply lines and logistical missions that were historically secure by virtue of the maneuver units which have “cleared” and established a perimeter now operate in potentially hostile areas and are always vulnerable to attack. The response to these issues has been the addition of add-on armor to HMMWV’s and other tactical vehicles. The retro-fitting of armor to these vehicles has resulted in many accidents due to rollover and instability. The goal of this project is to determine possible causes of the instability and rollover of up-armored tactical vehicles and to develop simulation tools that can analyze the transient dynamics and ride of the vehicle. This paper gives a brief review of progress to date. Models and simulations include a steady-state rollover scenario, analysis of understeer gradient, ride analysis and transient handling analysis. The transient handling simulation uses models of both a human driver and a vehicle to analyze how the vehicle responds to an obstacle avoidance maneuver. This type of maneuver was chosen because it represents a typical tactic, technique, and procedure (TTP) that units are employing in order to avoid improvised explosive devices (IEDs) and to avoid over-head attacks when traveling under over-passes.

2C2 **A Distributed Simulation Platform for HMMWV using the Gluing Algorithm**
Geunsoo Ryu, Zheng-Dong Ma, Gregory M. Hulbert

The use of distributed simulation technique can readily incorporate heterogeneous computing resources across the network (e.g., Internet and Intranet) and generate the computing power that is never existent before for simulating very complex physical systems. A simulation platform that can support multi-layered and multi-disciplinary design tasks and can protect the proprietary information of individual units involved in the product development process will also change both the information acquiring procedure and the way in which engineers share product models and associated information. This presentation demonstrates a distributed simulation platform developed for a military vehicle, HMMWV, for the purpose of proof of concept of the distributed simulation and design (DSD) system developed at the U of M. The new DSD system employs a T-T gluing algorithm, which can couple distributed subsystems’ simulation models, and can be used for the purpose of: 1) supporting the modularized vehicle design for the vehicle family in various applications, 2) developing new and innovative vehicle concepts, and 3) conducting fundamental researches across the thrust areas. A “System of Systems” approach is developed for the full vehicle assembly of HMMWV family, which leads to multi-layered substructuring across internet based on the XML model descriptions developed in this research. A data base of finite element models of HMMWV subsystems has been developed according to a multi-layered assembling tree, and is distributed into simulation servers for plug and play simulations. With the gluing algorithm developed, the subsystems models can be analyzed using their own independent solvers and on their own computer processing units. The developed Web interface enables researchers and engineers to search the model and execute the simulation in the distributed environment. It will be shown how to assemble different vehicle configurations and how to switch amount different subsystem designs/models under different design tasks. Multi-disciplinary simulation and design tasks, such as mobility, durability, NVH, crashworthiness, and blast protection, will been discussed including consideration of uncertainty. Future research includes: integration of subsystem models with various non-marching/separable interfaces, integration of multi-body system and finite element models, integration of vehicle and terrain interaction models, and dealing with other remaining challenging issues.

2C3 **Underhood/Underbody Layout Design With Shape Morphing**
Hong Dong, Georges M. Fadel

This work focuses on incorporating component shape design into a vehicle underhood/underbody layout design process. A concurrent design process consisting of performing layout design and simultaneous shape morphing of some select components is adopted to replace the traditional sequential design approach. The objective is to improve design efficiency and reduce design cost. Two important issues in the packing optimization with shape morphing problem are identified and studied: the morphing and the optimization. A parameterizationbased morphing method and a mesh-based morphing method are implemented, and their advantages and disadvantages are discussed. To overcome the complexity of performing the placement simultaneously with the shape morphing, it is proposed to decompose the problem into a bi-level formulation: system level and component level. At the system level, the given functional objectives of the layout problem are optimized with respect to component positions and orientations. At the component level, the shape of select components is morphed to minimize the overlap with other objects and the enclosure. By iterating between these two levels, the original problem is solved.

2C4 **Performance Tradeoffs and System Sensitivity in Multicriteria Design Optimization**
Alexander Engau, Margaret M. Wiecek, and Georges M. Fadel
The large numbers of performance criteria and specifications in complex systems and design optimization problems lead to cumbersome and sometimes unachievable tradeoff analyses. To facilitate those analyses, the large-scale problem can frequently be divided into smaller-sized subproblems that, ideally, should be solved for only two criteria at a time. The subsequent integration of the obtained solutions into one overall design is achieved through a novel coordination mechanism. The approach uses the system sensitivities to provide the designer with knowledge and control on possible performance tradeoffs between the subproblems. Examples of applications in structural optimization and vehicle packaging are given.

2D Design Under Uncertainty II

Session Chair: Zissimos Mourelatos

2D1 **Interval Analysis in Multilevel System Design**
Michael Kokkolaras

The method for solving an optimal design problem under uncertainty depends on how the latter is quantified. When sufficient information is available the popular probabilistic approach can (and should) be adopted. In reality however, we often do not have sufficient data to infer appropriate probability distributions for the uncertain quantities modeled as random variables. The amount of available information about the uncertain quantities may be limited to ranges of values (intervals). In this case, the interval analysis approach can be employed to reformulate and solve the optimal design problem. We present an extension of the interval analysis approach to multilevel systems using an engine design example.

2D2 **A Bayesian Approach to Reliability-Based Optimization with Incomplete Information**
Subroto Gunawan

In engineering design, information regarding the uncertain variables or parameters is usually in the form of finite samples. Existing methods in optimal design under uncertainty cannot handle this form of incomplete information; they have to either discard some valuable information or postulate existence of additional information. In this work, we develop a reliability-based optimization method that is applicable when information of the uncertain variables or parameters is in the form of both finite samples and probability distributions. The method adopts a Bayesian Binomial inference technique to estimate reliability, and uses this estimate to maximize the confidence that the design will meet or exceed a target reliability. The method produces a set of Pareto trade-off designs instead of a single design, reflecting the levels of confidence about a design's reliability given certain incomplete information. As a demonstration, we apply the method to design an optimal piston-ring/cylinder-liner assembly under surface roughness uncertainty.

2D3 **A Sequential Algorithm for Possibility-Based Design Optimization**
Jun Zhou, Zissimos P. Mourelatos

Deterministic optimal designs that are obtained without taking into account uncertainty/variation are usually unreliable. Although reliability-based design optimization accounts for variation, it assumes that statistical information is available in the form of fully defined probabilistic distributions. For many engineering problems however, uncertainty is given in terms of interval ranges. In this case, interval analysis or possibility theory can be used instead of probability theory. This presentation describes a computationally efficient sequential optimization algorithm for possibility-based design. A double-loop, possibility-based design optimization algorithm is initially presented where all design constraints are expressed possibilistically. The algorithm handles problems with only uncertain or a combination of random and uncertain design variables and parameters. In order to reduce the high computational cost, a sequential algorithm for possibility-based design optimization is subsequently, presented. It consists of a sequence of cycles composed of a deterministic design optimization followed by a set of worst-case reliability evaluation loops. Two examples demonstrate the accuracy and efficiency of the proposed sequential algorithm.

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Day 2, Wednesday , May 24, 2006
Symposium III Abstracts

3A Structural Analysis and Design under Uncertainty

Session Chair: Matt Castanier

3A1 **Structural Reduced-Order Modeling Methods for Distributed Simulation, Uncertainty Analysis, and Design**
Keychun Park, Matt Castanier

In previous work by the authors, component-based reduced-order modeling methods were introduced for the efficient prediction of structural dynamic response in the low- to mid-frequency range. In this presentation, recent research progress in two main area will be covered: (1) developing more adaptive structural modeling methods that are suitable for implementation in distributed simulation environments, and (2) developing extremely fast simulation methods for predicting the response of structures subject to design changes and/or parameter uncertainties. Regarding this first topic, a key issue is to handle mismatched finite element meshes between connected component structures, which can occur if a component is re-designed or if different component-level models are used in a distributed simulation environment. Therefore, several approaches have been investigated for synthesizing component models with mismatched meshes, and the most promising methods will be presented. It will be shown that these techniques can eliminate the need to re-model the unchanged components, which directly supports both distributed simulation and design optimization. Regarding the second topic, a parametric reduced-order modeling method has been developed for quickly evaluating the effect of component-level parameter changes on the structural response. The application of this technique to uncertainty analysis and design optimization of vehicle structures will be demonstrated with numerical results. Future applications of this work to durability analysis and reliability-based design optimization will be discussed.

3A2 **Maximal Failure Search Method for Mixed Random and Fuzzy Variables Design Optimization**
Liu Du, K. K. Choi

Structural analysis and design optimization have recently been extended to consider various uncertainties. If the statistical data for the uncertainties are sufficient to construct the input distribution function, the uncertainties can be treated as random variables and RBDO is used; otherwise, the uncertainties can be treated as fuzzy variables and PBDO is used. However, many structural design problems include both uncertainties with sufficient data and uncertainties with insufficient data. For these problems, RBDO will yield an unreliable design since the distribution functions of uncertainties are not believable. On the other hand, treating the random variables as fuzzy variables and invoking PBDO may yield too conservative design with a higher optimum cost. This presentation proposes a new design formulation MVDO (Design Optimization with Mixed input random and fuzzy Variables) using the performance measure approach (PMA). For the inverse analysis of MVDO, a new most probable/possible point (MPPP) search method called maximal failure search (MFS) is proposed, which is an integration of the enhanced hybrid mean value method (HMV+) and maximal possibility search (MPS) method. Some mathematical and physical examples are used to demonstrate the proposed inverse analysis method and design formulation.

3A3 **Dynamic Tire Model: Parameter Identification Via Virtual Tests And Validation In Real And Virtual Environments**
Weidong Pan
This paper presents recent development of a dynamic tire model that is suitable for real-time human-in-the-loop driving simulation of off-road vehicles. Emphasis is on the process to validate the tire model by comparing to results of various field tests that are designed to excite the dynamic aspects of interest. Subjective evaluation of the tire model in a driver-in-the-loop virtual environment is also described in detail. The paper concludes that the dynamic tire model is accurate and useful for

real-time human-in-the-loop driving simulation in a high fidelity simulator such as the National Advanced Driving Simulator.

3B Reliability Based Design Optimization

Session Chair: K.K. Choi

3B1 **Dimension Reduction Method for Reliability-Based Robust Design Optimization**
Ikjin Lee, K. K. Choi

The objective of reliability-based robust design optimization (RBRDO) is to minimize the product quality loss function subject to probabilistic constraints. Since the quality loss function is usually expressed in terms of the first two statistical moments, mean and variance, many methods have been proposed to accurately and efficiently estimate the moments. Among the methods, univariate dimension reduction method (DRM), performance moment integration (PMI), and percentile difference method (PDM) are recently proposed methods. In this presentation, estimation of statistical moments and their sensitivities are carried out using DRM and compared with results obtained using PMI and PDM. In addition, PMI and DRM are also compared in terms of how accurately and efficiently they estimate the statistical moments and their sensitivities of a performance function. In this comparison, PDM is excluded since PDM could not even accurately estimate the statistical moments of the performance function. Also, robust design optimization using DRM is developed and then compared with the results of RBRDO using PMI and PDM. Several numerical examples are used for the two comparisons. The comparisons show that DRM is efficient when the number of design variables is small and PMI is efficient when the number of design variables is relatively large. For the inverse reliability analysis of reliability-based design, the enriched performance measure approach (PMA+) is used.

3B2 **Reliability-Based Design Optimization of Problems with Correlated Input Parameters**
Yoojeong Noh, K. K. Choi

The reliability-based design optimization (RBDO) process requires two optimization procedures: design optimization in the design space and inverse reliability analysis in the standard normal space. Thus, transformations between the input random variables and the standard normal random variables are necessary for the inverse reliability analysis in RBDO. Rosenblatt and Nataf transformations are the most representative transformation methods and have been widely used in the reliability analysis. In many RBDO problems, the input random variables are correlated. However, often in applications, only limited information such as the marginal distribution and covariance could be practically obtained, whereas the input joint probability distribution functions (PDF) could be very difficult to obtain. Thus, in literature, most RBDO studies assume all input random variables are independent. However, in this study, it is found that the RBDO results can be significantly affected by the correlation of input variables. Thus, various transformation methods are investigated for possible application to the RBDO of problems with correlated input variables. It is found that Rosenblatt transformation is impractical for problems with correlated input variables due to difficulty of constructing a joint PDF from the marginal distributions and covariance. On the other hand, Nataf transformation, which belongs to the copula family, can construct the joint PDF using marginal distributions and covariance, and thus applicable to problems with correlated input parameters. In this presentation, Nataf transformation is used to develop a RBDO method for design problems with correlated random input variables. Numerical examples are used to demonstrate the proposed method. Also, it is shown that the correlated random input variables significantly affect the RBDO result using numerical examples.

3B3 **Weight Minimization of Stryker A-Arm and Morpher-Based RBDO of M1A1 Roadarm for Durability**
Ed Hardee, K. K. Choi

Shape and sizing design optimization was carried out for the Stryker A-Arm to minimize weight and improve fatigue life. For shape design paramterization, PATRAN is used, where all geometric entities are represented using parametric cubic lines, patches, and hyperpatches, which are then glued together as one geometric feature. The result was a deterministically optimized design with significant weight savings and an increase of almost five times in fatigue life. To understand effects of the input uncertainties, inverse reliability, possibility, and mixed variable analyses are carried out for the deterministically optimized design in which the geometric design parameters and selected material properties are considered to be random and/or fuzzy variables. To improve the ease of use of shape design sensitivity analysis technology, shape design parameterization based on LMS's VirtualLab Morpher was investigated. The Morpher-based model provides shape design velocity fields that satisfy theoretical and practical requirements, such as linear dependency and preserving topology, identified in the literature. Reliability-based design optimization (RBDO) was carried out for a design model of the M1A1 tank roadarm, using Morpher-based design parameterization. The design parameterization process based on the Morpher will be compared with a PATRAN geometry-based process for the Stryker A-Arm, which has relatively complicated geometry, to demonstrate effectiveness of Morpher-based shape design parameterization, sensitivity analysis, and optimization. It is shown that the Morpher-based shape design parameterization is the best alternative to either CAD-based or PATRAN/HyperMesh-based shape design parameterizations.

3C Blast Protection and Crashworthiness Analysis

Session Chair: Nick Vlahopoulos

3C1 **EFEA Developments for High Frequency Shock Analysis of Composite Structures Subjected to Blast Loads**

Xiayan Yan Nick Vlahopoulos

Enabling better transportability and improving the fuel efficiency are driving factors for making new Army vehicles light weight. Composite materials are considered for their construction for achieving the desired weight reduction. However, at the same time their vulnerability to shock effects from conventional weapons is increasing. The high frequency content of the shock load generated from a blast or impact is responsible for transferring power from the location of impact to critical locations where sensitive electronic equipment is mounted. Due to the short duration of the load the high frequency content becomes critical in assessing the response of the vehicle. In order to access the vehicle's damage it is necessary to compute accurately the transfer function between the location of impact and the locations where the equipment is mounted. Using conventional simulation tools such FEA for high frequency shock assessment is impractical due to the computational resources required for capturing the response of the vehicle at high frequencies. Recently, a new finite element approach has been developed and validated for efficient high frequency dynamic analysis of structures made out of isotropic materials. The governing differential equations of this new Energy Finite Element Analysis (EFEA) formulation are developed for the energy density. A small number of elements are required for capturing the high frequency vibration in EFEA, and models are developed directly from CAD data. In this research EFEA developments are pursued for modeling composite materials in order for the EFEA to be used in shock analysis of composite Army vehicles. New governing differential equations are formulated based on the properties of the composite materials and the fundamental displacement solutions for vibration of composites. A finite element numerical solution is developed for solving the new differential equations. An initial validation is presented by comparing results from very dense conventional finite element models to the results of the new EFEA formulation for composites.

3C2 **An Innovative Inflatable Morphing Body Structure for Crashworthiness of Military and Commercial Vehicles Byeng**

Dong Wook Lee, Zheng-Dong Ma, Noboru Kikuchi

Automotive industry is facing greatest demand from customers, regulators, and the media to provide safer vehicles with lighter weight, especially, for improving transportability and fuel efficiency of the vehicles. The conventional design order, Durability _ NVH _ Crashworthiness, has been reversed as Crashworthiness _ NVH _ Durability. Thus crashworthiness becomes a most important task in the vehicle design process. On the other hand, safety is always a central concern in developing military vehicles for the purpose of fighting effectiveness and survivability. Conventional safety equipments, such as air bags, seat belts, and various crash avoidance devices have been developed as standard in many commercial and military vehicles. However, breaking-through is still a key requirement for meeting future demands of the vehicle design. In this presentation, we introduce an "inflatable morphing body" concept as an example of innovative body designs for crashworthiness and improved safety of military and commercial vehicles. The proposed inflatable body has several components, including an active bumper, two airbags, two springs, and an energy absorbing truss structure, which are attached to the main body of a vehicle. A simple dummy model of LSTC is also implemented in the vehicle model for evaluating HIC (Head Injury Criterion) of the occupant during the crash process. Extensive model validations have been conducted in the past period for crash simulation models of the truck and dummy to ensure their suitability for using in the current design study. Example simulation results will be given to demonstrate effectiveness and potential energy absorption capability of the active crash-protective device proposed. Major design variables and design guidelines/procedures will also be introduced. In the next step, an analytical design model will be developed based on the finite element truck model along with a newly developed airbag model for optimizing the inflatable body design for significantly improved crashworthiness of vehicle system. The advanced design methodologies developed in this research can be used for developing innovative structural concepts of manned, unmanned, and alternative vehicles in military and civilian applications.

3C3 **HMMWV Rollover Case Study Simulation**
Youngwon Hahn, Zheng-Dong Ma, Gregory M. Hulbert, Noboru Kikuchi

In this research, an ADAMS model of the HMMWV was constructed and several dynamic rollover test procedures were performed using ADAMS. The presentation is divided into several parts. First, the general vehicle information and ADAMS model of HMMWV will be described. Second, results will be presented from Fishhook and J-turn maneuvers with the variation of vehicle speed, following the NHTSA vehicle dynamic rollover propensity report. Third, rollover phenomena will be assessed by changing several design variables. Two design variables were selected for the case study and two objective functions were selected in order to assess vehicle rollover. Results from sensitivity analyses will be also shown.

3C4 **A Magic Cube Approach for Crashworthiness Design**
Chang Qi, Zheng-Dong Ma, Noboru Kikuchi and Christophe Pierre

Vehicle structure crashworthiness design is one of the most challenging problems in product development and it has been studied for decades. Challenges still remain, which include developing a reliable and systematic approach for general crashworthiness design problems, which can be used to design an optimum vehicle structure in terms of topology, shape, and size, and for both structural layout and material layout. In this paper, an advanced and systematic approach is presented, which is called Magic Cube (MQ) approach for crashworthiness design. The proposed MQ Approach consists of three major dimensions: Approach, Methodology, and General Considerations. The Approach dimension is related to the major approaches developed for the crashworthiness design problem, which has three layers: Time (Process) Decomposition, Space Decomposition, and Scale Decomposition. Time decomposition is to decompose the whole crash process into a sequence of sub-crash processes based on the major scenarios in the crash process; Space decomposition is to decouple the overall vehicle crashworthiness design problem into parallel subsystem design problems, where each subsystem design problem can be solved easily; Scale decomposition is to decouple the design process into those at the structural level and at the material level, so that both the structure and material can be optimized. The Methodology dimension is related to the techniques applied to the crashworthiness design, three layers in this dimension are: Target Cascading, Failure Mechanism Analysis, and Optimization Method. The three decomposition methods can be employed through a target cascading process; while failure mechanism analysis aims to provide design criteria for more energy absorption during crash. Optimization methods can include size, shape, and topology optimization techniques. The General Considerations dimension has three layers, which are: Multidisciplinary Objectives, Loading Conditions, and Uncertainty Effects. For the crashworthiness design, multidisciplinary objectives include both structural objectives and passenger injury criteria objectives; loading conditions include different crash scenarios such as frontal, side or rear impact, and for armored military vehicles, landmine explosion is another important loading condition need to be considered; Uncertainty effects include modeling uncertainties, parameter uncertainties, uncertainties in loading and boundary conditions. Uncertainty effects will have significant effects on crashworthiness design, as will be shown by examples. All these layers are coupled with each other to form a 27-element magic cube. A crashworthiness design problem can be then solved by employing the elements in the magic cube. Examples will be given to demonstrate the proposed approach and its successful application in real vehicle crashworthiness design problems.

3D Vehicle-Terrain Interaction Modeling

Session Chair: Jonah Lee

3D1 **Current Developments in Tire-Snow Interfacial Forces: Effects of Density with Uncertainty and Depth, Validation and Terrain Characterization**
Jonah Lee and Qing Liu, University of Alaska Fairbanks, Zissimos Mourelatos, Oakland University

In order to accurately predict vehicle-terrain interaction, many important building blocks must be in place that include: 1) characterization of the geometric and material properties of terrain, 2) proper representation of tire for wheeled vehicles, 3) relationship between the terrain properties and vehicle-terrain interfacial forces, 4) the effect of vehicle-terrain interfacial forces on vehicle dynamics, 5) development of modeling tools and lab facilities, 6) validation. In this presentation, we summarize work accomplished in the effects of density with uncertainy and depth on tire-snow interfacial forces. We also discuss on-going work and plans in the modeling of polycrystalline ice as the matrix material of the (porous) snow, characterization of the density, depth and hardness of snow using ground penetrating radar, as well as validation of vehicle-snow interaction. Uncertainties of snow material properties and effects of snow depth on traction forces are analyzed through finite element simulation, optimization and numerical evaluations. In the field, density of snow cover can vary between that of fresh snow to heavily compacted snow that is similar to porous ice. Even for fresh snow, as a vehicle moves forward, the rear wheels experience higher snow densities than the front wheels. The physical properties of natural snow vary significantly even for the same density. Here, snow is considered as a pressure-sensitive Drucker-Prager material. The uncertainties of snow properties are characterized using the principles of interval analysis. The bounds of snow sinkage, motion resistances and shear forces under combined slip conditions are achieved through constrained optimization. Snow sinkages and interaction forces under different snow depths are analytically calculated and agree reasonably well with finite element simulation results. The depth-dependent results also show that lateral shear force has a non-monotonic relationship with snow depth although it increases monotonically as slip angle increases.

3D2 **Time-Varying Off-Terrain Traction Forces Modeling Methodology and Frequency Response within Tire and Snow-Covered Ground Interface**

Qing Liu and Jonah Lee, University of Alaska Fairbanks

Time-Varying analytical tire-snow interaction modeling methodology is developed for quasi-real vehicle dynamics simulation on deformable terrains, especially under time-dependent operation conditions, such as urgent turning, rapid acceleration or deceleration, shimmy, slalom, obstacle avoidance, sudden crosswind response, etc. Two representative theoretical transfer functions (forces versus slips) are employed to consistently derive the first-order lag filter equation for lateral slip conditions through Taylor series simplification. The lag equations for combined longitudinal and lateral slips are then obtained based upon the collinear relationships between two dimensional normalized slips. Non-steady state tire stiffness concept is introduced to analyze tire relaxation characteristics. The effects of normal load, slips and depth on generalized relaxation length are discussed. The computation scheme for real-time gross/net traction forces, in both time domain and frequency domain, is briefly described. The frequency response results with successive step changes in 2D slips as inputs are presented from self-delayed and superposition processed time-history forces and slips. The modeling methodology can be further applied to off-terrain vehicle modeling and simulation of other deformable terrains, such as sands, soils, etc.

3D3 **Two Examples of Statistical Modeling of Terrain Profiles**

T. C. Sun

We shall demonstrate here, in two examples, how statistical modeling of terrain profiles is done with step by step details. In the first example we use data from the Belgian Block Track and we show that a uniform modulated process can be used to model the data. In the second example we use the data from the Perryman3 track and we apply the empirical mode decomposition method to decompose the data into intrinsic mode functions, and we show that each of these intrinsic mode functions can be modeled by a uniform modulated process. The goodness of fit for both examples are shown by the results that the residues are indeed white noises.

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Day 2, Wednesday , May 24, 2006
Symposium IV Abstracts

4A Advanced Diesel Engine Systems

Session Chair: Naeim E. Henein

4A1 **Analysis of the Series Hydraulic Hybrid Propulsion for the HMMWV Using Simulation and Engine-in-the-Loop Testing**
Youngjae Kim, Jonathan Hagena, Zoran Filipi

The changing role of the High Mobility Multipurpose Wheeled Vehicle (HMMWV) leads to increased numbers of up-armored, heavier models and emphasizes the relevance of high-mobility. Novel approaches are needed to provide propulsion options capable of simultaneously improving performance, fuel economy and emission of the vehicle. Given that some of the goals are conflicting, as well as the fact that vehicle weight or aerodynamics can not be significantly altered in near-term, powertrain hybridization is the most promising approach to achieving such ambitious goals. In particular, the series configuration removes the mechanical connection between the engine and the wheels and allows full flexibility in controlling the engine operation for improved fuel economy and vehicle performance. In this study, a series hydraulic hybrid (SHH) vehicle system is configured for the HMMWV and modeled in MATLAB/SIMULINK. The complete vehicle simulation is utilized to explore vehicle design options, e.g. number, size and modes of operation of propulsion motors, accumulator size etc. Alternative approaches for power management of the system are also explored. The combined design/power management analysis enables quantitative assessment of the SHH fuel economy potential. Subsequently, validation of predictions and evaluation of transient exhaust emissions is carried out with a real engine in an Engine-in-the-Loop setup. The results demonstrate a great improvement in fuel economy while meeting aggressive performance targets, and offer clear guidance for selecting a “clean” power management strategy for reduced visual signature.

4A2 **Simulation Study of the Power Split Hydraulic Hybrid Propulsion System**
Youngjae Kim, Jinming Liu, Zoran Filipi

The power split approach to hybridization combines advantages of both the series and parallel hybrid vehicle configurations. The system introduced by Toyota on a Prius vehicle uses two motor/generators and a planetary power split device to operate the engine in the most efficient region as in a series configuration or a direct connection between the engine and the wheels when benefits of the efficient mechanical connection outweigh other considerations. The latter mode obviously resembles classic parallel arrangement. This system has previously been demonstrated only in conjunction with electric motors and a battery. In this study however, the potential of a hydraulic power-split hybrid configuration is evaluated. The system promises unique advantages, stemming from high power density and efficiency of hydraulic components, as well as challenges related to relatively low energy density of the accumulator. Decisions about operating modes are made according to the power management scheme contained in the vehicle control module. With simplified rule-based control strategy, design optimization of hydraulic component sizes and vehicle parameters is carried out. Finally, the fuel economy and vehicle performance are compared with those of an electric hybrid version of a power split system.

4A3 **Control Analysis of a Hybrid Electric HMMWV**
Jinming Liu, Prof. Huei Peng, Zoran S. Filipi

The study of new fuel efficient technology has been popular in the recent years due to the depleting global crude oil supply and growing environmental concerns. Among many contenders, hybrid electric powertrain seems to be one of the most promising technologies under development. This presentation will introduce two different hybrid electric configurations. Both are designed for HMMWV vehicles. The first one is a parallel electric powertrain which shows a continuous development from last year's case study and concludes an optimized performance with the Engine-in-the-loop experiment. The second one is a power split (series/parallel) powertrain based on the design of Allison Hybrid System (AHS II). The AHS II is the underlying technology for GM's hybrid SUV and full-size pickups that are being developed for several MY2007-2008 products. Matlab/Simulink models for both powertrain systems are developed and control algorithms are analyzed.

4B Diesel Injection & Combustion

Session Chair: Dohoy Jung

4B1 **Spray Dynamics and Breakup Mechanisms for Transient and Short Pilot Injections**
Ming-Chia Lai

Pilot injection are routinely used more frequently for various combustion and emission control in DI diesel engines. For diesel injection systems, the injector nozzle geometry has a significant effect on fuel atomization. A combination of experimental and numerical analyses were carried out to investigate the dynamics of flow structure of short pilot injection on the order of millisecond or less. Time-dependant CFD simulation with cavitation models were used to correlate the internal flow structure to the external spray visualized by high-speed microscopic visualization of single-hole and multi-hole nozzles. The effects of nozzle geometry, hydro-grinding and injection pressure and injection duration are characterized. In addition time-resolved x-radiography was employed to measure fuel mass distributions in the near-nozzle region of sprays from two single-hole mini-sac nozzles. The result has demonstrated that liquid-fuel breakup is extremely sensitive to nozzle internal geometry, especially at a quasi-steady condition when the injector pintle is fully opened. Under these testing conditions, we can attribute the different spray cone angles to the internal-turbulence and cavitation-induced jet breakups.

4B2 **A Simulation-Based Cold-Start Control-Strategy for a Common Rail Diesel Engine at different Ambient Temperatures**
N. A. Henein, L. Zhong and W. Bryzik

Advanced diesel injection systems are capable of delivering the fuel in multiple events with accurate injecting timing, duration and the dwell time between the events. The new strategy utilizes this capability to arrive at the proper injection system parameters that would improve the cold startability of the diesel engine over a wide range of ambient temperatures. The concept behind the strategy is based on the fact that the best combination of the fuel injection parameters would produce the highest IMEP (Indicated Mean Effective Pressure) and efficiency in the first firing cycle after cranking. This investigation is limited to two injection events, which can be tested on the experimental engine. The effects of several combinations of the split injection parameters on the IMEP have been theoretically investigated by using a diesel cycle multi-zone simulation model for the fuel spray development, evaporation, autoignition and combustion. Maps are developed for the dwell time versus split injection fraction at different injection timings and ambient temperatures, showing constant IMEP contours. The zone that gives the highest IMEP is identified from which the split injection fraction and the dwell period are determined. The strategies have been validated experimentally on a 1.2L, 4-cylinder turbocharged diesel engine fitted with a common rail injection system. Cold-start tests are conducted in a cold room at ambient temperatures varying from normal room temperature to -20°C, after the engine and fuel tank are soaked for 8 hours. The new strategies proved to be effective in shortening the cranking period, and at the same time, reducing the fuel injection rate during cranking by about 50%.

4B3 **Impact of Transient Diesel Engine Operation on Visual Signature**
Jonathan Hagena, Zoran Filipi

This study investigates the impact of transient engine operation on the emissions formed during a tip-in procedure. A medium-duty production V-8 diesel engine is used to conduct experiments in which the rate of pedal position change is varied. Highly-dynamic emissions instrumentation is implemented to provide real-time measurement of NOX and particulate. Engine subsystems are analyzed to understand their role in emissions formation. As the rate of pedal position change increases, the emissions of NOX and particulates are affected dramatically. An instantaneous load increase was found to produce peak NOX values 1.8 times higher and peak particulate concentrations an order of magnitude above levels corresponding to a five-second ramp-up. The results provide insight into relationship between driver aggressiveness and diesel emissions applicable to development of drive-by-wire systems. In addition, they provide direct guidance for devising low-emission strategies for hybrid vehicles. Hybrids offer more flexibility in controlling the engine, but optimizing their supervisory control for fuel economy can lead to frequent and sharp load increases that can contribute greatly to higher overall emissions levels. The characterization of transient effects on emissions can be applied towards shaping of tip-in functions for optimal economy–emissions tradeoff in hybrids.

4C Hybrid Vehicle Modeling

Session Chair: Zoran Filipi

4C1 **Transient Engine System Simulation using a Quasi-Dimensional Diesel Spray Combustion Model.**
Dohoy Jung, Dennis Assanis

Zero-dimensional diesel engine cycle module based on empirical combustion correlations implemented in VESIM (Vehicle Engine SIMulation) has been successfully used for vehicle performance predictions during transient driving conditions. However, a physics-based engine cycle simulation is required to predict the effect of engine control strategies on the combustion process and the black smoke. In order to improve the predictive capability of the engine cycle simulation, the zero-dimensional engine cycle module has been replaced with a multi-zone engine cycle module. A new integration method was employed to integrate the high-fidelity engine cycle model with acceptable computational time. Independent solver for the engine cycle module with a time step in crank angle resolution was used to improve the computational accuracy. To improve the computational efficiency, quasi-steady assumption for the engine cycle calculation was used and multi-cylinder modules (Zero-dimensional model) were replaced with a single master module with a multi-zone spray model. For the demonstration of the predictive capability of the model, transient load tip-in was simulated and presented in this study.

4C2 **Simulation-based Analysis of Two-Stage Hybrid Turbocharging Systems**
Byungchan Lee, Zoran Filipi

A two-stage "hybrid" turbocharging system consists of a turbocharger and other types of air charging devices such as mechanically driven supercharger or electrically driven compressor connected in series. In this study, several different arrangements of such turbocharging systems are analyzed and compared with the conventional two-stage turbocharging system.

4C3 **High Power Density Diesel Engine Dynamics and Cycle Simulation**
Bogdan Bitu, Nabil G. Chalhoub, Naeim, A Henein and Walter Bryzik

A multi-zone model has been developed to predict the behavior of a four-stroke, direct injection, supercharged, single cylinder diesel engine under both transient and steady-state modes of operation. The model accounts for the engine thermodynamics, chemical kinetics and dynamics of the reciprocating engine components. It preserves the relationships with which these various components would interact. In addition, the mixture composition in all engine components considered in the model are accounted for. The formulation of the multi-zone model reflects the spray evolution along with the processes dealing with atomization, droplet evaporation, air entrainment and fuel burning. This has led each zone, defined in the spray model, to have its own ignition delay, time history of temperature, volume, burning rate and mixture composition. An empirical soot model along with the extended Zeldovich mechanism has been used to complement the chemical kinetic model in order to predict engine-out soot and NOx emissions. Moreover, the engine dynamics are formulated based on a multi-body dynamic model, which determines the rigid body motion of the crankshaft/connecting-rod/piston mechanism. The model predictions of the engine-out soot and NOx emissions compared fairly well with data obtained experimentally.

4C4 **Engine Friction Model for Transient Operation of Turbocharged, Common Rail Diesel Engines**
Dinu Taraza, Naeim A. Henein, Radu Ceausu

Engine friction plays a significant role during the transients of an automotive engine. A correct estimation of the engine friction and its variation with speed and load would allow a better prediction of engine acceleration under heavy load. A simulation model is developed in the Simulink environment for a multi-cylinder, common rail and turbocharged diesel engine. The friction model consists of sub-models for the piston – ring assembly, engine bearings and valve train. The other mechanical losses of the engine are simulated by separate models of the high pressure fuel pump, the water pump and the oil pump. The model validation is achieved on a 2.5 liter common rail turbocharged diesel engine connected to an AC dynamometer capable to operate controlled transients. The experimental engine is heavily instrumented to allow comparisons between many operating and simulated parameters. Comparisons between simulated and actual engine transients show a fairly good agreement.

4D Engine Friction & Vibration

Session Chair: Dinu Taraza

4D1 **Advanced Thermal Management for Internal Combustion Engines**
Tom Mitchell, Mohammad Salah, Dr. John Wagner, and Dr. Darren Dawson

Advanced thermal management systems for spark/compression ignition engines improve both the fuel economy and the emissions reductions by better regulating the combustion process with multiple electro-mechanical components. The traditional thermostat valve, coolant pump and clutch-driven radiator fan are upgraded with servomotor actuators. When the system components function harmoniously, desired thermal conditions can be accomplished in a power efficient manner. In this presentation, a comprehensive nonlinear control architecture is proposed for transient temperature tracking and power minimization. An experimental system has been fabricated and assembled which features a variable position smart thermostat valve, variable speed electric water pump, variable speed electric radiator fan, engine block, and various sensors. In the configured system, a steam-based heat exchanger emulates the heat generated by the engine's combustion process within a repeatable laboratory environment. Representative numerical and experimental results will be discussed to demonstrate the functionality of the thermal management system in tracking prescribed temperature profiles.

4D2 **Airflow Management for the Cooling System Performance**
Hoon Cho, Dohoy Jung, Zoran Filipi, and Dennis Assanis

Simulink based cooling system model was developed in order to provide the fully integrated high-fidelity simulation capability for the studies of the vehicle cooling system. This cooling system consists of various module based cooling component models, such as coolant pump, thermostat, and cooling fan, and it also has the high fidelity radiator model which has the capability to estimate the effect of radiator design variables on the radiator performance. The ram air flow model based on system resistance concept was incorporated into the cooling system model in order to enhance the accuracy of the model by including the effects of fan configurations on the air-side mal-distribution as well as the cooling performance. In this work, the vehicle system resistance combined with fan performance curves was used to determine the cooling air flow rate with respect to vehicle and fan speeds, and then the heat rejection rate to cooling air flow in the radiator was calculated to estimate the effect of two different types of fan configurations (full and partial shrouds) on the cooling performance. It was also demonstrated that the effect of the coolant flow direction in the radiator on the cooling performance at each fan configuration.

4D3 **A Systematic Analysis of the Performance of the Large Active Area PEMFC Stack with Water Cooling System**
Sangseok Yu, Dohoy Jung, and Dennis N. Assanis

A systematic analysis of the performance of the large active area PEMFC stack with a water cooling system has been conducted. In this study, fuel cell operating temperature has been set at 348.15 K considering the durability and transient safety margin. The analysis has employed two simulation models in order to improve the computational efficiency with proper accuracy; a comprehensive multi-dimensional thermal model of PEMFC and a transient PEMFC system model. The comprehensive multi-dimensional thermal model is used for determining the thermal management criteria which are aimed at the operating conditions of maximum power with minimum parasitic loss. At the system level, it is necessary to determine the control algorithm for the thermal management criteria. Accordingly, the transient PEMFC system model is used for the evaluation of feedback control algorithm and conventional PWM (pulse width modulation) algorithm of water cooling system. As a result, when the cooling system is managed by a feedback control algorithm, the parasitic power consumption is decreased by 60.4% of conventionally controlled cooling system and net energy is 1.2% higher at given current density conditions.

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