Automotive Research Center

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

11th Annual ARC Conference May 24–25, 2005

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

Registration starts April 1st, 2005
Registration deadline May 16th, 2005

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Organized by the
Automotive Research Center

Sponsored by
U.S. Army Research, Development and Engineering Command (RDECOM)
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

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11TH ANNUAL ARC CONFERENCE
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Day 1 Schedule
Tuesday, May 24, 2005

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

8:30 - 9:00 **Welcome and Introductions**

Mary Sue Coleman
President, The University of Michigan

Dennis Assanis
Professor and ARC Director, The University of Michigan

Walter Bryzik
Chief Scientist, U.S. Army TARDEC

Senator Carl Levin
Senator for the State of Michigan

9:00 - 10:30 **Towards Future Vehicle Concepts And Designs – Efficient And Reliable Vehicle Solutions For An Uncertain World**

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

Speakers: **Dr. Alan Taub**
Executive Director, General Motors Corporation

Dr. Aly Badawy
Vice President Steering and Suspension Engineering, TRW Automotive

Raymond W. Corbin
President & CEO, AVL Powertrain Engineering, Inc.

Question and Answer Session

10:30 - 11:00 **Networking Break**

11:00 - 11:45 **National Automotive Center – Developing Modeling and Simulation Tools**

Speaker: **David Gorsich**
Associate Director, Modeling and Simulation, US-Army RDECOM-TARDEC

11:45 - 1:00 pm **Lunch**

1:00 - 1:45 **Engine-In-The-Loop Simulation: A Design and Evaluation Tool for Advanced Propulsion Systems**

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

Zoran Filipi
Associate Research Scientist and ARC Assistant Director, The University of Michigan

Hosam Fathy
Research Fellow, The University of Michigan

1:45 - 2:00 **Networking Break**

2:00 - 2:45 **Impact of Variability and Information Content on Vehicular Design**

Speakers: **Zissimos P. Mourelatos**
Associate Professor, Oakland University

Michael Kokkolaras
Assistant Research Scientist, The University of Michigan

Matthew Reed
Assistant Research Scientist, Transportation Research Institute, The University of Michigan

2:45 - 3:00 **Networking Break**

3:00 - 4:00 **Simulation and Design Optimization Tools for Improving Structural Reliability and Blast/Impact Protection** *(click here for abstract)*

Speakers: **Kyung K. Choi**
Professor, The University of Iowa

Tom Stadterman
US Army AMSAA

Nick Vlahopoulos
Professor, The University of Michigan

4:00 - 4:15 **Wrap-Up and Q & A**

Dennis Assanis
Professor and ARC Director, The University of Michigan

4:15 **Adjourn**

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Day 1, Tuesday, May 24, 2005
Keynote Speakers
Biographies

Dr. Alan Taub

Executive Director, Research and Development, General Motors Corporation

Alan Taub was named Executive Director, General Motors Research & Development, on April 1, 2004.

Taub is responsible for GM's seven science laboratories in Warren, Michigan, and Bangalore, India. These labs focus on a wide range of technology, including advanced powertrain systems; computer-based design and analysis systems for vehicle engineering; electronics and information-based vehicle systems; new materials and fabrication processes; new, more environmentally friendly fuels and lubricants, and more efficient emission control systems.

He also has responsibility for GM's advanced technical work activity, managing a portfolio of major innovation programs of strategic importance to the company. In addition, he oversees global technology collaboration, managed through technology offices around the world that coordinate government and industry partner projects and collaborative research at leading universities around the world. He also serves as the interface between R&D and the rest of GM on advanced technology development and implementation.

Taub joined General Motors Corp. on January 1, 2001 as Executive Director-Science Laboratories for GM Research and Development. He spent nearly 15 years in research and development with General Electric, where he earned 26 patents and authored more than 60 papers. For nine years, he conducted research on the mechanical and electrical properties of materials and later led a superconducting materials team that pioneered technology breakthroughs for commercial adoption by GE's medical group. He ultimately managed the GE materials properties and processes laboratory.

In 1993, Taub joined Ford Motor Company, managing the Materials Science Department where he was responsible for advanced automotive body, chassis and powertrain materials. Later, he was manager of North American vehicle crash safety. Prior to joining GM, he was in product development as manager of vehicle engineering for the Lincoln brand.

He received a bachelor's degree in materials engineering in 1976 from Brown University. He earned master's and Ph.D. degrees in applied physics from Harvard University in 1977 and 1979, respectively.

Taub was a member of the USCAR Automotive Composites Consortium from 1993 to 1997 and served with the PNGV Materials Tech Team from 1995 to 1997. He has been an active member of the Materials Research Society and serves on advisory boards of several institutions, including Harvard, Brown, Massachusetts Institute of Technology, Northwestern University, and the National Science Foundation.

He is married with three children and resides in West Bloomfield, Michigan.

Dr. Aly Badawy

Vice President Steering and Suspension Engineering, TRW Automotive

Aly Badawy is vice president of engineering for TRW Automotive's linkage, steering and suspension, and integrated vehicle control systems (IVCS) businesses. In this position, he holds responsibility for product engineering, including design, test, validation, and launch; and he oversees research and development on a global basis for these product lines.

Dr. Badawy joined TRW in July 1999 and has been leading the product development activities for linkage, steering and suspension, and IVCS.

Previously, he served Delphi and General Motors. From 1985 until 1999 he held engineering positions of increasing responsibility and was named director of engineering for General Motor's Electric Power Steering Systems in 1995.

Prior to General Motors, Dr. Badawy served as superintendent of manufac-turing engineering for New Departure Hyatt, a producer of wheel bearings, and he was a principal research scientist for Battelle Columbus Laboratories.

Dr. Badawy holds a Ph.D. and a master's degree in mechanical engineering from McMaster University and a bachelor's degree in marine engineering from Alexandria University in Egypt.

He is a member of the Society of Automotive Engineers and the Engineering Visiting Committee of the University of Michigan at Dearborn. Dr. Badawy also is a board member of Satyam Manufacturing Technology, Inc., a TRW joint venture partner.

Raymond W. Corbin

President & CEO, AVL Powertrain Engineering, Inc.

Raymond Corbin was named president of AVL Powertrain Engineering, Inc. in October 2003. AVL is the world's largest privately owned and independent company for the development of gasoline, diesel and alternative fuel powertrain systems, as well as fuel cell and hybrid technologies. The company offers combined solutions of powertrain engineering, simulation software and testing and instrumentation systems. Corbin is responsible for the company's powertrain engineering consultancy activities and growth of the company's North American simulation software sales.

Corbin adds more than 30 years of powertrain experience to AVL. Prior to this appointment he served as Chief Operating Officer of Quantum Technologies, a Tier 1 supplier of alternative fuel and fuel cell technologies. Before that he was Director of Engineering for Calsonic-Kansie, a Tier 1 supplier involved in exhaust and aftertreatment technology. Corbin also has experience as a General Motors development manager, responsible for engine controls, transmission and vehicle integration.

Corbin is an active member of the Society of Automotive Engineers (SAE) and the North American Defense Industry Association (NADIA).

Corbin holds a bachelor's degree from Kettering University (formerly General Motors Institute), Flint, Michigan, in mechanical engineering.

Corbin is married and lives in Troy, Michigan. The couple has two children.

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Day 2, Wednesday, May 25, 2005
Schedule

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

8:00 - 8:10am **Welcome**

Dennis Assanis
Professor and ARC Director, University of Michigan

Dennis J. Wend
Executive Director, National Automotive Center

8:10 - 8:50am **Keynote Speech**

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

9:00 - 9:30am **Symposia Introduction**
Each parallel symposium begins with an introduction by an invited speaker.

Symposium I
Danny Milot
Chief Engineer - Advanced Control Systems, New Products, N.A. TRW Automotive

Symposium II
Dr. Gary Strumolo
Manager Vehicle Design, Ford Research & Advanced Engineering

Symposium III
Dr. Ren-Jye Yang
Technical Leader, Optimization & Robustness Passive Safety Research and Advanced Engineering Department, Ford Research & Advanced Engineering

Symposium IV
Steve McKinley
Director - Development Passenger Car, Turbochargers - North America, BorgWarner

9:30am - 4:40pm **PARALLEL SYMPOSIA I, II, III, IV**
The balance of the day's activities is divided into **four** Parallel Symposia. They will run concurrent sessions concentrating on specific technical issues. Please refer to the symposia matrix plan and abstracts of the technical presentations to select from the various topics presented.

Click here for Symposia Matrix.
Links to presentation abstracts are located in the left navigation bar.

Symposium I

1A Vehicle Dynamics & Proper Modeling
Session Chair: Jeff Stein

1B Fuel Cell Modeling
Session Chair: Anna Stefanopoulou

1C Vehicle & Driver Modeling
Session Chair: Huei Peng

1D Component Shape Analysis & Modeling of Outdoor Scene
Session Chair: Andreas Koschan

Symposium II

2A Human Centered Design
Session Chair: Don Chaffin

2B System Optimization & Complex System Design
Session Chair: Panos Papalambros

2C Reliability & Robustness Optimization Methodologies
Session Chair: Zissimos Mourelatos

2D Distributed Simulation and Packaging Methodologies
Session Chair: Gregory Hulbert

Symposium III

3A Structural Analysis and Design under Uncertainty and Blast/Impact
Session Chair: Matt Castanier

3B Vehicle-Terrain Interaction Modeling
Session Chair: Zheng-Dong Ma

3C Reliability Based Design Optimization
Session Chair: K. K. Choi

3D Vehicle Component Structural Design Methodologies
Session Chair: Nick Vlahopoulos

Symposium IV

4A Advanced Diesel Engine Systems
Session Chair: Zoran Filipi

4B Diesel Injection & Combustion
Session Chair: Naeim E. Henein

4C Hybrid Vehicle Modeling
Session Chair: Doug Goering

4D Engine Friction & Vibration
Session Chair: Dinu Taraza

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Day 2, Wednesday, May 25, 2005
Keynote Speakers
Biographies

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 (MANPRINT) 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.

Danny Milot

Chief Engineer - Advanced Control Systems, New Products, N.A. TRW Automotive

Not available.

Dr. Gary Strumolo

Manager Vehicle Design, Ford Research & Advanced Engineering

Gary Strumolo is the manager of the Vehicle Design department in the Research and Advanced Engineering laboratories of Ford Motor Company, where he has worked for the past 16 years. He has over 24 years of supervisory/managerial experience, leading groups in fluid mechanics, engineering mechanics, vehicle simulation, durability, CAE, NVH, CFD, aeroacoustics, and safety. He received his Doctorate in Applied Mathematics from the Courant Institute of Mathematical Sciences at NYU in 1979, and did postdoctoral research at the California Institute of Technology. His current responsibilities at Ford include the design and development of advanced products and engineering processes for future vehicle programs. He has written over 100 technical papers and reports, covering areas ranging from hydrodynamic instabilities, vehicle aerodynamics, aeroacoustics, multiphase flows, inverse design methods, and active safety systems. He holds 34 US patents and 3 European patents. He has also received two Henry Ford Technology Awards, the highest technical award given at Ford.

Dr. Ren-Jye Yang

Technical Leader, Optimization & Robustness Passive Safety Research and Advanced Engineering Department, Ford Research & Advanced Engineering

Dr. Ren-Jye Yang received his B.S. in Civil Engineering and M.S. degree in Engineering Mechanics from the National Taiwan University at Taipei, Taiwan. He received his Ph.D. degree in Civil Engineering from The University of Iowa at Iowa City in 1984. He is currently a Technical Leader in the Passive Safety Research and Advanced Engineering Department at Ford Research & Advanced Engineering, responsible for the development of safety optimization and robustness and high performance computing methodologies. Before he joined Ford in 1988, Dr. Yang was a Staff Research Engineer in the Engineering Mechanics Department at GM Research Laboratories. His research areas of interest include: Design Optimization, Reliability-Based Design Optimization, High Performance Computing, CAE, Mechanical Design, Probabilistic and Statistic Methods, Computational Mechanics, Robust Design, etc. Dr. Yang has received numerous awards, including the Henry Ford Technology Award, which is the highest award at Ford Motor Company. Dr. Yang has published 50 referred Journal papers. He is an ASME fellow and is a committee member of the ASME PTC 60 Verification and Validation in Computational Solid Mechanics. He is a Senior Advisor of the Structural and Multidisciplinary Optimization Journal and serves on the editorial board of the International Journal of Reliability and Safety. Dr. Yang has also served on the University/Industry Advisory Board for the University of Iowa, UCLA, and VPI. Recently, he was elected as an Industry Advisor for the ASME Design Automation Executive Committee.

Steve McKinley

Director - Development Passenger Car, Turbochargers - North America, BorgWarner

Not available .

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Day 2, Wednesday , May 25, 2005
Symposia Matrix

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Time	Symposium I	Symposium II	Symposium III	Symposium IV
	Introduction			
9.00 - 9.30	Danny Milot *Chief Engineer - Advanced Control Systems, New Products, N.A. TRW Automotive*	Gary Strumolo *Manager Vehicle Design, Ford Research & Advanced Development*	Dr. Ren-Jye Yang *Technical Leader, Optimization & Robustness Passive Safety Research and Advanced Engineering Department, Ford Research & Advanced Engineering*	Steve McKinley *Director - Development Passenger Car, Turbochargers - North America, BorgWarner*
	1A Vehicle Dynamics & Proper Modeling	**2A Human Centered Design**	**3A Structural Analysis and Design Under Uncertainty and Blast/Impact**	**4A Advanced Diesel Engine Systems**
9.30 - 9.50	Parameterization of Large Dynamic Models through the use of Model Reduction and Optimization Techniques	Modeling Truck Driver Reach	High Frequency Vibration of Light Weight Vehicles due to Loads from Blast/Impact	Dual Stage Turbocharging: Matching and Boost Control Options
9.50 - 10.10	Engine in the Loop Testing: Integration and Effects of Driveline Dynamics on Transients	Evaluating Reach Trajectories Perturbed by Ride Motion	A Sequential Most-Probable-Point Search Method and its Application to Probabilistic Vibration Analysis	Numerical Modeling of Cross Flow Compact Heat Exchanger with Louvered Fins using Thermal Resistance Concept
10.10 - 10.30	Analysis of HEV Propulsion with Power-Split Devices	Effects of Hand Force on Posture & Motion	A Magic Cubic Approach for Crashworthiness Design	Development of Simulink Based Cooling System Model
10.30 - 11.00	**Break**			
	1B Fuel Cell Modeling	**2B System Optimization & Complex System Design**	**3B Vehicle-Terrain Interaction Modeling**	**4B Diesel Injection and Combustion**
11.00 - 11.20	Scalable Modeling for Fuel Cell Stack Model: Selecting Pressure Operating Condition	Optimizing Truck Cab Layout	Transient Tire Models for Real-Time Vehicle Simulation	Using a Military Grade JP8 Fuel in the Heavy Duty Diesel Engine: Performance, Combustion and Emission Effects
11.20 - 11.40	Dynamics, Optimization and Control of a Natural Gas Reformer with a Fuel Cell for Combined Heat-Power Applications	Generalized Coupling Management in Complex Engineering Systems Optimization	Sinkage-Dependent Tire-Snow Modeling for Vehicle Mobility under Brake-and-Turn Maneuvers	Combustion and Emissions in a HSDI Diesel Engine from the Conventional to the Smokeless NOx-less Regimes
11.40 - 12.00	Development of a Fuel Cell Vehicle Simulation Model	On the Use of Analytical Target Cascading and Collaborative Optimization for Complex System Design	Finite Element Modeling of Tire-Snow Interaction: Present and Future	Dual-Use Engine Calibration: Leveraging Modern Technologies to Improve Performance-Emissions Tradeoff
12.00 - 1.30pm	**Lunch**			
	1C Vehicle & Driver Modeling	**2C Reliabilty & Robustness Optimization Methodologies**	**3C Reliability Based Design Optimization**	**4C Hybrid Vehicle Modeling**
1.30 - 1.50	Stochastic Reduction of a HMMWV Power Train Model	A Multi-Objective Optimization Approach to Reliability and Robustness	Integration of Reliability- And Possibility-Based Design Optimizations Using Performance Measure Approach	Engine-in-the-Loop Testing: Engine System Response and Transient Emissions
1.50 - 2.10	Driver Models for Reliability and Performance Analysis of Active Safety Systems	A Possibility-Based Design Optimization Method	Reliability-Based Robust Design Optimization Using The Performance Moment Integration Method and Case Study of Engine Gasket-Sealing Problem	Series Hydraulic Hybrid Propulsion System for the HMMWV
2.10 - 2.30	Biodynamic feedthrough cancellation for improved manual control within vehicles	Reliability Optimization Involving Mixed Continuous-Discrete Uncertainties	A New Fuzzy Analysis Method for Possibility-Based Design Optimization	Modeling of an Integrated Starter Alternator (ISA) System for the HMMWV

2.30 - 2.50	Modeling of a Rigid-Spine Robot	An Adaptive Sequential Linear Programming Algorithm for Optimal Design Problems with Probabilistic Constraints	A Univariate Method for Higher-Order Reliability Analysis	Sliding Mode Powertrain Control for a Military HEV
2.50 - 3.20	**Break**			
	1D Component Shape Analysis & Modeling of Outdoor Scenes	**2D Distributed Simulation and Packaging Methodologies**	**3D Vehicle Component Structural Design Methdolodogies**	**4D Engine Friction & Vibration**
3.20 - 3.40	Automotive Component Analysis using R-Functions and Supershapes	A New Methodology for Network-Distributed Simulation of Mechanical Systems	Component-Based and Parametric Reduced-Order Modeling Methods for Vibration Analysis of Vehicle Structures	Visualization and Simulations of Advanced IC Engine Spray and Combustions
3.40 - 4.00	3D Modeling of Outdoor Scenes and Automotive Components using the Gaussian Fields Framework	A New Genetic Algorithm for Packing Optimization	An Innovative Inflatable Morphing Body Structure for Crashworthiness of Military and Commercial Vehicles	Prediction of the Instantaneous Frictional Losses in ICE by Using a Modified (P-ω) Method
4.00 - 4.20	Shape Analysis and Multi-Sensor Fusion for 3D Reverse Engineering	Packing Optimization: Rubber-Band Analogy and Evolving Shape Objects	Stryker A-Arm Fatigue Analysis and Design Optimization	Integration of Engine Systems in a Simulation Model for Transient Operation
4.20 - 4.40	Statistical Modeling of Terrain Profiles	2D Decision-Making for Multicriteria Performance Navigation	Thermal Analysis of Composite Integral Armor	Lumped Transient Thermal Model of PEMFC with Cooling System Simulation

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Symposium I

1A Vehicle Dynamics & Proper Modeling

Session Chair: Jeff Stein

1A1 **Parameterization of Large Dynamic Models through the use of Model Reduction and Optimization Techniques**
Bryon Sohns, Hosam Fathy, and Jeffrey L. Stein
The parameterization of models of systems using experimental data is a common one within the engineering world. These problems are often solved using optimization and sensitivity methods. These methods can be computationally expensive for large nonlinear models, however. The goal of this work is to use information about model structure and energy flow from simulation data to control the dimensionality of the optimization problem. By dynamically updating the dimensionality of the design space using data that is readily available, we hope to increase the efficiency of parameterizing these models. In this presentation we will discuss the strategies being considered to solve this problem, and present some preliminary results involving a HMMWV model currently in use at TACOM.

1A2 **Engine in the Loop Testing: Integration and Effects of Driveline Dynamics on Transients**
Rahul Ahlawat, Hosam K. Fathy, and Jeffrey L. Stein
Previous projects of the ARC produced an integrated simulation environment of a vehicle - VESIM (Vehicle Engine Simulation) which is a physics based library of powertrain models that can be utilized by engineers for optimization and real time hardware in the loop validation of both conventional and hybrid powertrains. In an extension of this work, a V8 6L diesel engine is used as a hardware in the loop for the simulation of a HMMWV vehicle to study the effect of powertrain dynamics on transient emissions. The experiments were conducted for the conventional powertrain as well as various hybrid configurations. These results are applied to study the formation of transient emissions and subsequently develop hybrid vehicles tuned for minimum emissions, maximum performance or maximum fuel economy.

1A3 **Analysis of HEV Propulsion with Power-Split Devices**
Jinming Liu, Prof. Huei Peng, Dr. Zoran S. Filipi
Toyota Hybrid System (THS) is used in the current best-selling hybrid vehicle on the market—the Toyota Prius. It uses a split-type hybrid configuration which contains both a parallel power path and a serial power path to achieve the benefits of both. The design of the hybrid vehicle control algorithm is not straightforward because of the complexity of the vehicle power train. The main purpose of this presentation is to introduce a detailed dynamic model which is used to investigate the unique design of THS, analyze the control strategy, and explore the potential of further improvement of this unique design. A Matlab/Simulink model for the THS power train system is developed and a control algorithm is derived. Simulation results over standard driving cycles are presented. The overall behavior of the model seems to agree with the actual Prius vehicle satisfactorily.

1B Fuel Cell Modeling

Session Chair: Anna Stefanopoulou

1B1 **Scalable Modeling for Fuel Cell Stack Model: Selecting Pressure Operating Condition**
Burit Kittirungsi, Anna G. Stefanopoulou, Hosam K. Fathy, and Jeffrey L. Stein
A methodology for developing a scalable fuel cell stack model is presented. This work is motivated by the need to have an ability to systematically scale the existing hi-pressure 75 KW fuel cell stack model

developed in previous ARC research so that it can efficiently be operated under a different power requirement. First, we investigate benefits that arise when the fuel cell system is operated at low-pressure. We show that there exist trade-offs in efficiency and maximum power output between the low-pressure and hi-pressure operating conditions. Then, we propose a scalable modeling approach that can be utilized to scale components in the fuel cell system accordingly.

1B2 **Dynamics, Optimization and Control of a Natural Gas Reformer with a Fuel Cell for Combined Heat-Power Applications**
Vasilis Tsourapas
In this work, a natural gas fuel processor system (FPS), a proton exchange membrane fuel cell (PEM-FC) and a catalytic burner (CB) are integrated in a combined heat power (CHP) generation plant.The FC provides the power based on electrochemical reaction of hydrogen. The FPS generates the hydrogen from natural gas and the CB provides the energy for preheating the FPS inlet flows by burning any excess hydrogen from the FC exhaust. The coupling of these three systems is necessary for high efficiency and autonomy but poses a challenging optimization and control problem. We show in simulations that an observer based feedback controller, which relies on temperature measurements of two reactors, speeds up the hydrogen generation by a fivefold, as compared to the baseline system when only look-up tables are employed.

1B3 **Development of a Fuel Cell Vehicle Simulation Model**
Min Joong Kim, Huei Peng
A comprehensive procedure for testing, modeling, and control design of a fuel cell hybrid vehicle (FCHV) will be described. A dynamic fuel cell vehicle model is developed through collaboration between DaimlerChrysler and the University of Michigan. The model is developed based on test results obtained on Natrium prototype vehicle and a test rig. The subsystems are first modeled by examining input/output data from carefully designed tests. FC-VESIM (fuel cell hybrid vehicle simulation) model is then constructed by following the configuration used in Natrium. Model validation results confirm that the forward-looking simulation model predicts vehicle performance accurately. The stochastic dynamic programming methodology was introduced to obtain a power management algorithm to optimize vehicle fuel economy while ensuring drivability. The fuel cell vehicle achieves a fuel economy favorably compared against its gasoline counterpart. These preliminary results lay a good foundation for future model-based fuel cell vehicle development process, currently being developed by DaimlerChrysler and the University of Michigan.

1C Vehicle & Driver Modeling

Session Chair: Huei Peng

1C1 **Stochastic Reduction of a HMMWV Power Train Model**
Hosam K. Fathy, Yuan Wang, and Jeffrey L. Stein
Previous ARC research developed MORA, a Model Order Reduction Algorithm capable of improving a dynamic model's simulation speed significantly with minimal loss of fidelity. MORA is equally suited to linear and nonlinear models, but a limitation is its input dependence. Applying MORA to a model of a conventional HMMWV power train, for instance, gives different reduced models for different drive cycles. Combining MORA with Monte Carlo simulation alleviates this input dependence at a large computational expense. This presentation proposes a novel method for applying MORA to models with stochastic inputs. The approach involves constructing, from the stochastic inputs, a single input profile with sufficient richness to excite the wide spectrum of modes excited by the individual stochastic inputs. Applying MORA just once using this rich input furnishes a reduced model that accounts for the stochasticity in the original model's inputs. This stochastic model order reduction algorithm is developed for linear systems, but can be applied to nonlinear systems as well. Its application to the HMMWV power train model produces a reduced model similar to that produced by combined MORA/Monte Carlo reduction, in a fraction of the time required by the latter.

1C2 **Driver Models for Reliability and Performance Analysis of Active Safety Systems**
Jing Zhou, Huei Peng
Human error is ubiquitous and inevitable. Driver constitutes the weakest link in the human-vehicle-environment interactions, not only due to its vulnerability to internal inattention and fatigue, but also the external distractions arising from increasing secondary in-vehicle tasks. Although driver models for regular performance have seen tremendous progress in engineering field and cognitive science, deviant driver behaviors are not adequately accounted for. The recently finished field operational test of the Automotive Collision Avoidance System (ACAS) Project provides extensive naturalistic driving records, which contains massive normal driving data as well as representative emergent behaviors. In this study, preliminary effort is undertaken to modify a computational cognitive model "Queueing

Network-Model Human Processor" to statistically predict the occurrence of driver errors. Risky scenarios queried from ACAS FOT database will be used for training and validation. It is believed that an errable driver model will have long-term impact on the design of vehicle active safety system.

1C3 **Biodynamic feedthrough cancellation for improved manual control within vehicles**
Szabolcs Sovenyi, Prof. R. Brent Gillespie
Manual control performance on-board a moving vehicle is often impeded by biodynamic feedthrough, which describes the effects of vehicle motion feeding through the operator's body to produce unintended forces on the control interface. We investigated vibration feedthrough for two scenarios. The first we call open loop or targeting, involving the control of a machine other than the vehicle itself by the operator. Vehicle ride motion is known to deteriorate tracking performance under such conditions. The second scenario we call closed loop or driving, involving the control of the vehicle itself. In that case, in addition to tracking performance degradation, vibration feedthrough may also lead to oscillatory response. We propose to mitigate feedthrough effects using a model of the biodynamic system. We create a linear, time-invariant model using a novel system identification test protocol. In operation, the model estimates the unintended force the operator imposes on the joystick using the biodynamic model and measured vehicle accelerations. The computed force is imposed on the joystick with a DC motor, where it cancels biodynamic feedthrough effects. The cancellation controller was tested both for open loop and closed loop cases. In open loop tests, the harmful effect of vehicle ride motion on tracking performance was demonstrated along with the effectiveness of the cancellation controller in restoring tracking. In closed loop tests the human-machine system witnessed oscillatory response and poor tracking performance without the cancellation controller. The controller suppressed oscillations and significantly restored tracking.

1C4 **Modeling of a Rigid-Spine Robot**
Brooke M Haueisen, Gregory M. Hulbert
Biomechanically speaking the spine serves many functions. A good description is provided by Boszczyk et al. (2001). "As an essential organ of both weight bearing and locomotion, the spine is subject to the conflict of providing maximal stability while maintaining crucial mobility" A contractor for the Army is currently working on a dual virtual-wheeled robot for material and supply transport. The vehicle is encountering difficulties maintaining stability over small ground perturbations. To enhance the stability and increase mobility of this robot, it is proposed to incorporate an articulated spine, utilizing the distributed flexibility of a snake-like mechanism. Current results from the modeling of the rigid-spine robot will be presented as a baseline for the future flexible model.

1D Component Shape Analysis & Modeling of Outdoor Scenes

Session Chair: Andreas Koschan

1D1 **Automotive Component Analysis using R-Functions and Supershapes**
Andrei Gribok, Yohan Fougerolle, Mongi Abidi
Many problems in automotive modeling require efficient representation of complex shapes. For example, such problems as automotive component analysis and automotive simulations benefit enormously from efficient shape representation and visualization. We present a new and efficient algorithm to compute multiple Boolean operations with globally deformed primitives to represent arbitrary shapes. Our algorithm is generic in the sense that it can be applied to objects with both an implicit and a parametric representation, such as superquadrics, supershapes, and Dupin cyclides. The input is a Constructive Solid Geometry tree (CSG tree) that contains the Boolean operations, the parameters of the primitives, and the global deformations. The output is both an implicit equation and a mesh representing its solution. For the resulting object, an implicit equation with guaranteed differential properties is obtained by simple combinations of the primitives' implicit equations using R-functions. Depending on the chosen R-function, this equation is continuous and can be differentiable everywhere. The primitives' parametric representations are used to directly polygonize the resulting surface by generating vertices that belong exactly to the zero-set of the resulting implicit equation. The proposed approach has many potential applications ranging from mechanical engineering to shape recognition and data compression. Examples of complex objects are presented and commented to show the potential of our approach for shape modeling.

1D2 **3D Modeling of Outdoor Scenes and Automotive Components using the Gaussian Fields Framework**
Andreas Koschan, Faysal Boughorbel, Mongi Abidi
The focus of this research is on the reconstruction of 3D representations of real world outdoor scenes and automotive components using multiple sensors. The sensors considered are primarily range acquisition devices that allow the recovery of 3D geometry, and multi-spectral image sequences

including video and thermal IR images that provide additional scene characteristics. One of the most important technical challenges that we are addressing is the registration task in both its multi-modal and single modality aspects. Our work is based on a unified approach that formulates the correspondence problem as an optimization task. In this context we developed a criterion that can be used for 3D free-form shape registration as well as for multimodal image alignment. The new criterion is derived from simple combinatorial matching principles by approximation and relaxation. Technically, one of the main advantages of the proposed approach is convexity in the neighborhood of the alignment parameters and continuous differentiability, allowing for the use of standard gradient-based optimization techniques. The proposed algorithm allows also for a significant automation of the scene modeling task by reducing the intervention of human operators in the tedious image registration task. Furthermore we show that the criterion can be computed in linear time complexity which permits the fast implementation critical in many applications of autonomous mobile platforms.

1D3 **Shape Analysis and Multi-Sensor Fusion for 3D Reverse Engineering**

David Page, Sreenivas Rangan, Sophie Voisin, Ngozi Ali, Mongi Abidi

Reverse engineering of an automotive component involves duplicating the components geometry and its functionality. With focus on recovering geometry, we provide the methodology to scan as-built automotive components and create CAD-like models. We leverage active range sensing techniques for high fidelity shape reconstruction and generate water-tight 3D models by integrating multiple view scans after noise smoothing and view registration. Our laser imaging system guarantees high level of accuracy (less than a millimeter) suitable for wear–tear analysis and thermal simulations. We are able to automatically decompose the 3D model into simpler surface patches and characterize the surfaces using a novel curvature variation measure (CVM). The CVM is an information-theoretic curvature-based measure that aims to quantify the surface complexity and feature detail in a given surface. We leverage the definition of the CVM as a 3D surface feature to output the scanned 3D models as a graph network of smooth surface patches to aid rapid prototyping and manufacturing on demand. We demonstrate results on components (such as mufflers) dismounted from automobiles.

1D4 **Statistical Modeling of Terrain Profiles**

T.C Sun, Milt Chaika

We will summarise our past research that tested the assumptions on which the current Army models of terrain profiles are based.These assumptions were that the digitized terrain profiles were stationary, normal (Gaussian), and linear. In our research, we showed, using statistical tests ,that Belgian Block was tame enough to be modeled as a uniformly modulated process.This generalisation of stationarity is due to Priestley and has a simple formula which will be discussed.The statistical tests showed that the profile of Perryman3 is much too irregular for any standard model .We show how the recent method of intrinsic functions can be used in modeling this difficult terrain. We will present some heuristics of the method of intrinsic functions and present a data based adaptive algorithm that generates the intrinsic functions. Then we will test statistially and the tests will show that some of the functions are also uniformly modulated showing a simple representation.

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Symposium II

2A Human Centered Design

Session Chair: Don Chaffin

2A1 **Modeling Truck Driver Reach**
Matt Reed, Josh Danker
The use of Digital Human Models (DHM) is steadily gaining acceptance as an ergonomic design and analysis technique in industry. Ergonomic analysis capabilities of DHM's would be significantly improved by the addition of a model of coordinated upper body motions during asynchronous, visually guided manual tasks. Previous HUMOSIM work on upper extremity reaches has focused primarily on one-handed reaches; how they are performed and how they affect torso and head motion as well as balance. Investigations of two-handed work were restricted to coupled tasks, such as lifting a box, when the left and right hands moved together. The work into asynchronous manual tasks will investigate how the torso manages the simultaneous requirements of the upper extremities and the head while maintaining balance, and will take a modular approach. a modular approach. A hierarchical coordination module will manage submodules, including a gaze-based head-motion module. New routines have been developed for upper-extremity inverse kinematics that incorporate a data-based model of clavicle rhythm.

2A2 **Evaluating Reach Trajectories Perturbed by Ride Motion**
Bernard Martin, Kevin Rider
Terrain-induced ride motion produces biodynamic responses in vehicle operators that inhibit their ability to perform in-vehicle reaching and pointing tasks. Vibration transmitted through the spinal column and the extended arm of seated occupants disrupts intended arm movements, resulting in slower and less accurate movements. Specific frequency bandwidths of ride motion have been shown to severely affect the stability of operators' manual control. The understanding of this degradation is essential for the human-centered design of several vehicle subsystems, including the suspension, seating, controls, and displays. The operators' performance was specifically quantified for stationary and moving vehicles with respect to the variability in fingertip trajectories and endpoint locations. Systematic increases were observed in endpoint variability due to ride motion, principally in the on-axis direction of movement. Analysis of fingertip trajectories under ride motion provided additional insight into the neuromuscular and physiological capabilities of performing pointing tasks. Visually-guided reaches were compared with visually-occluded reaches to investigate movement control strategies used with available sensory feedbacks. The understanding of how sensory feedback is utilized can assist the development of more effective and efficient ways to monitor and control in-vehicle systems.

2A3 **Effects of Hand Force on Posture & Motion**
Suzanne G. Hoffman, Chaffin, D.B., & Reed, M.P.
Knowledge of how workers alter their torso and upper extremity postures in response to changing job strength requirements is required for accurate job assessment. It has been shown that a 10 degree error in the limiting joint angle can result in +/- 30% variations in percent capable strength predictions (Chaffin & Erig, 1991). Accurate job assessment is critical since the risk of injury is greatly increased when job strength requirements exceed worker capabilities. The objective of this work is to predict how torso and upper extremity postures and motions change in response to changes in the location of a force handle and the magnitude and direction of the external force exertion required at the hand. A pilot study was conducted to observe how task postures and motions change with alterations in task parameters. Two male subjects (~50%tile anthropometry) participated in the study which consisted of a series of high and low force seated push/pull exertions. Task parameters included horizontal handle

location, azimuth, handle height, hand force direction and magnitude. Video of each trial was collected and revealed several behaviors which were consistent across all trials. It was revealed that all exertions were performed with a 'locked' elbow, and in a posture which allowed the push or pull force vector to be directed through the shoulder joint. A tendency to rotate the shoulders towards the handle was also observed. These strategies were believed to minimize the amount of elbow and shoulder strength required to perform the task. Preliminary results indicate that postural changes are small and restricted to the torso when the hand force vector passes through the shoulder joint. These findings suggest the need for additional research and biomechanical modeling to examine seated push/pull exertions with a variety of force handle locations and loading conditions.

2B System Optimization & Complex System Design

Session Chair: Panos Papalambros

2B1 **Optimizing Truck Cab Layout**
Matthew Parkinson, Panos Papalambros, Matt Reed, Don Chaffin
One important source of variance in the performance and success of products designed for use by people is the people themselves. In many cases, the acceptability of the design is affected more by the variance in the human users than by the variance attributable to the hardware from which the product is constructed. Consequently, optimization of products used by people may benefit from consideration of human variance through robust design methodologies. A case study involving the layout of the interior of a heavy truck cab is presented, focusing on simultaneous placement of the seat and steering wheel adjustment ranges. Tradeoffs between adjustability/cost, driver accommodation, and safety are explored under this paradigm.

2B2 **Generalized Coupling Management in Complex Engineering Systems Optimization**
Sulaiman Alyaqout, Panos Papalambros
Decomposition-based design optimization approaches are used to solve large, complex engineering system problems that might be otherwise unsolvable. Yet, the associated computational cost can be prohibitively high due to large number of iterations needed for coordination of subproblem solutions. To reduce this cost, one may exploit the fact that some systems are weakly coupled and their interactions can be temporarily suspended with little loss in accuracy. In practice, such interaction suspension is based on the analyst's experience or experimental observation. In this article, an optimization coupling function is introduced to measure the level of interaction or coupling strength among interconnected subproblems in the decomposed system. A hierarchical coupling suspension strategy is constructed to improve system solution with a model coordination method by intelligently suspending some of the system interactions. Results from case studies show that this strategy can decrease significantly the number of iterations required for the model coordination method. A systematic approach to calculate the coupling strength is also presented along with numerical examples.

2B3 **On the Use of Analytical Target Cascading and Collaborative Optimization for Complex System Design**
James Allison, Michael Kokkolaras, Panos Papalambros
The methods of analytical target cascading (ATC) and collaborative optimization (CO) are studied with respect to their intended use and applicability. ATC was initially developed as a product development tool, while CO evolved from efforts to coordinate multidisciplinary analyses using a multidisciplinary design optimization (MDO) formulation. ATC and CO are used typically to solve object-based and aspect (discipline)-based decomposed system problems, respectively. Their mathematical formulations appear to be similar although they were developed with different motivations. The article defines and compares terminologies for each approach and shows that each has unique applicability and solution process. Two new analytical example problems are employed to illustrate the distinctions between ATC and CO. The first example elucidates how each method can be used to solve the same design problem. The second example uses a new optimization formulation, nested ATC-MDO, to illustrate their complementary nature. In this formulation a system is partitioned by object, and objects are partitioned by discipline. ATC coordinates the design of system elements and an MDO method, such as interdisciplinary feasible (IDF) or CO, coordinates the multidisciplinary design of an element. The formulation maps well to organizational matrix structures. The overall study demonstrates the benefits of using complementary solution strategies in solving complex system optimization problems.

2C Reliabilty & Robustness Optimization Methodologies

Session Chair: Zissimos Mourelatos

2C1 **A Multi-Objective Optimization Approach to Reliability and Robustness**
Zissimos P. Mourelatos and Jinghong Liang
Mathematical optimization plays an important role in engineering design, leading to greatly improved performance. Deterministic optimization however, may result in undesired choices because it neglects uncertainty. Reliability-based design optimization (RBDO) and robust design can improve optimization by considering uncertainty. An efficient design optimization method under uncertainty is proposed here, which simultaneously considers reliability and robustness. A mean performance is traded-off against robustness for a given reliability level of all performance targets. This results in a probabilistic multi-objective optimization problem. Variation is expressed in terms of a percentile difference, which is efficiently computed using the Advanced Mean Value (AMV) method. A preference aggregation method converts the multi-objective problem to a single-objective problem, which is then solved using an RBDO approach. Indifference points are used to select the best solution without calculating the entire Pareto frontier. Examples illustrate the concepts and demonstrate their applicability.

2C2 **A Possibility-Based Design Optimization Method**
Zissimos P. Mourelatos and Jun Zhou
Early in the engineering design cycle, it is difficult to quantify product reliability or compliance to performance targets due to insufficient data or information for modeling the uncertainties. Design decisions are therefore, based on fuzzy information that is vague, imprecise qualitative, linguistic or incomplete. The uncertain information is usually available as intervals with lower and upper limits. In this work, the possibility theory is used to assess design reliability with incomplete information. The possibility theory can be viewed as a variant of fuzzy set theory. A possibility-based design optimization method is proposed where all design constraints are expressed possibilistically. It is shown that the method gives a conservative solution compared with all conventional reliability-based designs obtained with different probability distributions. A general possibility-based design optimization method is also presented which handles a combination of random and possibilistic design variables. Numerical examples demonstrate the application of possibility theory in design.

2C3 **Reliability Optimization Involving Mixed Continuous-Discrete Uncertainties**
Subroto Gunawan
Engineering design problems frequently involve a mix of both continuous and discrete uncertainties. However, most methods in the literature deal with either continuous or discrete uncertainties, but not both. In particular, no method has yet addressed uncertainty for categorically discrete variables or parameters. This article develops an efficient optimization method for problems involving mixed continuous-discrete uncertainties. The method reduces the number of function evaluations performed by systematically selecting the discrete factorials for reliability analysis based on their importance. The importance of a discrete factorial is assessed based on the spatial distance from the feasible boundary and on the probability of the discrete components. A demonstration is given for a numerical and an engineering example. Results show that the method is very efficient with only small errors

2C4 **An Adaptive Sequential Linear Programming Algorithm for Optimal Design Problems with Probabilistic Constraints**
Kuei-Yuan Chan
Optimal design problems with probabilistic constraints, often referred to as Reliability-Based Design Optimization (RBDO) problems, have been the subject of extensive recent studies. Solution methods to date have focused more on improving efficiency rather than accuracy and the global convergence behavior of the solution. A new strategy utilizing an adaptive sequential linear programming (SLP) algorithm is proposed as a promising approach to balance accuracy, efficiency, and convergence. The strategy transforms the nonlinear probabilistic constraints into equivalent deterministic ones using both first order and second order approximations, and applies a filter-based SLP algorithm to reach the optimum. Simple numerical examples show promise for increased accuracy without sacrificing efficiency.

2D Distributed Simulation and Packaging Methodologies

Session Chair: Gregory Hulbert

2D1 **A New Methodology for Network-Distributed Simulation of Mechanical Systems**
Jinzhong Wang, Zheng-Dong Ma, Gregory M. Hulbert
The multi-layered supply chains operation and modularized design in automotive industry result in that the component and subsystem models are distributed in different companies and locations. This research, taking the vehicle system simulation as an example, developed a new methodology for distributed simulation of mechanical systems, which is essential to support the collaborative design and meet the time stringent requirement in the CAE engineering. Three key ingredients comprise the

foundation of a distributed simulation platform for design and virtual prototyping of general mechanical systems that have their subsystems distributed amongst dispersed development units. First, a general and efficient model description for simulation is defined using XML. Each model is described with an XML file and stored in model database. A complete model can be then assembled based on these model descriptions. Simulation of a model is started simply by sending the model description to a simulation server and running it through a web-based graphics user interface. Second, a new gluing algorithm, denoted as the T-T method, is developed, which enables distributed simulations (both the component models and simulation of the components) to be coupled while maintaining the independence of the separate component simulations. Third, a logical distributed simulation architecture is laid out that can be implemented with one of the existing technologies for distributed computing. Interfaces between different network components have been standardized to enable extensibility of the architecture. These concepts have been incorporated into a prototype web-based distributed simulation system that demonstrates the potential of the new techniques for solving real engineering design problems. This presentation will summarize the work that has been reported in previous ARC conferences and present the new development in non-matching interface treatment. By laying out the whole picture of the methodology, the possible applications are presented to draw more attention to the potential of this methodology.

2D2 **A New Genetic Algorithm for Packing Optimization**

Y. Miao, G.M. Fadel

The packing problem is an optimization process consisting of searching for the optimal locations of a group of objects while satisfying certain design constraints and meeting or exceeding performance objectives. Packing problems have found wide applications in different industrial areas, such as truck loading, circuit board layout, and vehicle configuration design. This presentation gives out a Genetic Algorithm specially adapted to the requirements of the packing problem. The new designed GA, called the Packing GA totally revises the encoding and GA operators under the guidance of the Schema Theorem. Based on test cases, the performance of the Packing GA dramatically outperforms the traditional GA. The Packing GA is then applied to the vehicle configuration design, whose goal is to optimize the performance of the vehicle by relocating its components.

2D3 **Packing Optimization: Rubber-Band Analogy and Evolving Shape Objects**

H. Dong, G.M. Fadel, V.Y. Blouin

New developments to the packing optimization method based on the rubber band analogy are presented. This method solves packing problems by simulating the physical movements of a set of objects wrapped by a rubber band in the case of two-dimensional problems or by a rubber balloon in the case of three-dimensional problems. The objects are subjected to elastic forces applied by the rubber band to their vertices as well as reaction forces when contacts between objects occur. Based on these forces, all objects translate or rotate until maximum compactness is reached. To improve the compactness further, the method is enhanced by adding two new operators: volume relaxation and temporary retraction. These two operators allow temporary volume (elastic energy) increase to get potentially better packing results. The method is implemented and applied for three dimensional arbitrary shape objects.

2D4 **2D Decision-Making for Multicriteria Performance Navigation**

A. Engau and M.M. Wiecek

The high dimensionality of systems due to a large number of relevant criteria necessitates the development of performance-based decomposition. Choosing a Pareto optimal decision for a large-scale problem is accomplished through the consideration of a collection of bicriteria problems. The approach allows to explore the complete performance space based on decision-making in merely two dimensions and effectively uses computer graphics and distributed computation to identify solutions for the large-scale problem. The navigation between these solutions is controlled through appropriate integration of tradeoff decisions made on a chosen reference problem in the collection. A main benefit of the approach is that all solutions found for the bicriteria problems are also (weak) Pareto optimal for the original problem, and that the method is capable of capturing all Pareto optimal solutions for the original problem. Supporting theoretical results are established, an algorithm is proposed and the method is illustrated on an example.

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Symposium III

3A Structural Analysis and Design under Uncertainty and Blast/Impact

Session Chair: Matt Castanier

3A1 **High Frequency Vibration of Light Weight Vehicles due to Loads from Blast/Impact**
Nick Vlahopoulos
An overview is presented of an important new ARC initiative for developing simulation methods for vehicles subject to blast/impact. This work includes both prediction of high-frequency response to blast and shock environments and assessment of vehicle damage due to blast loads. For an example case of a structure subject to a mine blast, comparisons are shown between predictions and test data.

3A2 **A Sequential Most-Probable-Point Search Method and its Application to Probabilistic Vibration Analysis**
Soo-Yeol Lee, Matthew P. Castanier, and Christophe Pierre
In this work, a new method is presented for probabilistic vibration and power flow analysis of complex structures with parameter uncertainties. One efficient probabilistic approach is to utilize a most probable point (MPP)-based method, such as the first-order reliability method (FORM), the second-order reliability method (SORM), or the advanced mean value (AMV+) method. However, the accuracy or convergence of this type of method breaks down if the vibration response is non-monotonic with respect to the parameter space. To overcome this difficulty, a new MPP-based method is proposed, in which the MPPs are successively approximated by the gradient of the response function and a specific step-size at each step. Thus, while a random variable space is scanned at each step, the MPPs and the corresponding responses are obtained, which enables prediction of the probabilistic vibration response.

3A3 **A Magic Cubic Approach for Crashworthiness Design**
Chang Qi, Zheng-Dong Ma, and Noboru Kikuchi
In the automotive industry, crashworthiness stands for a measure of the vehicle's structural ability to plastically deform and yet maintain a sufficient survival space for its occupants in crashes involving reasonable deceleration loads. Vehicle structure crashworthiness design is one of the most challenging problems in product development and has been studied for decades. In the methodology development, challenges still remain, which include to develop a reliable and systematic approach for general crashworthiness design problems, from structural topology, to shape, and to size, and for both structural layout and material layout. In this presentation, an advanced and systematic approach is presented, which is called *Magic Cubic* (MQ) approach for crashworthiness design. The proposed MQ Approach consists 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: *Space Decomposition*, *Time (Process) Decomposition*, and *Scale Decomposition*. The *Methodology* dimension is related to the techniques applied to the crashworthiness design, three layers in this dimension are: *Target Cascading*, *Failure Mechanism*, and *Optimization Method*. The *General Considerations* dimension has three layers, which are: *Uncertainty Effects*, *Multidisciplinary Objectives* and *Loading Conditions*. All these lays 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 with preliminary results to illustrate the effectiveness of the new approach with uncertainties in the crashworthiness design problems..

3B Vehicle-Terrain Interaction Modeling

Session Chair: Zheng-Dong Ma

3B1 **Transient Tire Models for Real-Time Vehicle Simulation**

Weidong Pan

This paper is concerned with modeling tire transient response in real-time vehicle dynamics simulation. Tire transient behavior is important when tire size is big and/or in situation like fast steering, hard-braking, and rough terrain. This paper first reviews transient tire models in the literature. A new model and its implementation in multi-body vehicle dynamics software are then presented.

3B2 **Sinkage-Dependent Tire-Snow Modeling for Vehicle Mobility under Brake-and-Turn Maneuvers**

J. H. Lee, T. Zhang and Q. Liu

Snow-covered ground severely affects vehicle mobility in cold regions due to low friction coefficients and snow sinkage. Simulation and evaluation of vehicle mobility in cold regions require real-time friendly tire-snow interaction models that are applicable for quasi-real driving environments. Vehicle mobility under brake-and-turn maneuvers represents general combined longitudinal and lateral slip operation conditions. One of the major differences between tire-snow and tire-soil interactions is that the former is typically depth-dependent, especially for shallow snow. An analytical indentation model to describe the relationships of pressure and snow depth is established, using the upper bound theory, as an extension of the work of Johnson and Mellor for pressure-independent von Mises materials. Snow is considered as a pressure-sensitive Drucker-Prager material. Snow sinkages under different snow depths and arbitrary normal loads are numerically solved through incorporating the model into Wong's pressure-sinkage equation. A theoretical analysis regarding slip shift due to snow sinkage is obtained based on shear stress expression. In-plane and out-of-plan motion resistances and traction forces (gross traction and net traction) are analytically derived for combined slip conditions. The results of sinkages, captured stiffness and friction show reasonable agreement with those from tire-snow finite element simulations by using the measured snow material constants from the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). The computation results of shear forces under combined longitudinal and lateral slips are presented.

3B3 **Finite Element Modeling of Tire-Snow Interaction: Present and Future**

J. H. Lee, T. Zhang and Q. Liu

To gain understanding of the complex interaction between a pneumatic tire and snow cover and to reduce the heavy dependency of tire-snow research on the need to collect a tremendous amount of experimental data, we have been developing three-dimensional finite element (FE) models for dry and fresh snow for a couple of years. The general-purpose finite element program ABAQUS was used to conduct the simulation and to calculate tire forces and moments as a function of the longitudinal slip, slip angle and vertical wheel loads. FE simulation also provides an applicable platform for a broad range of virtual tests of tire-snow interaction that is highly non-linear and with a high level of uncertainty. Recently, we have successfully extracted traction, motion resistance and drawbar pull for combined slips from the reaction forces at the center of the wheel as well as from the contact surfaces, a first of its kind for tire-snow interaction simulation. In addition, we have examined the effect of the size of the snow cover to the trend and accuracy of the results of simulations. The finite element results have been used to construct semi-analytical equations of tire-snow interaction, which could be used in vehicle dynamics to assess the performance of vehicles. In the absence of test data, FE simulation results are adopted to calibrate the required analytical model parameters. Areas and strategies of improvement of the current models are also discussed in this presentation.

3C Reliability Based Design Optimization

Session Chair: K. K. Choi

3C1 **Integration of Reliability- And Possibility-Based Design Optimizations Using Performance Measure Approach**

KK. Choi (presenter), Liu Du, and Byeng D. Youn, David Gorsich

The reliability-based design optimization (RBDO) method is prevailing in stochastic structural design optimization by assuming the amount of input data is sufficient enough to create accurate statistical distribution. When sufficient information of input data cannot be obtained due to restrictions of budgets, facilities, human, time, etc., the input statistical distribution is not believable (i.e., epistemic uncertainties). In this case, the probability method cannot be used for reliability analysis and design optimization. To deal with the situation that input uncertainties have insufficient information, a possibility (or fuzzy set) method should be used for structural analysis and thus design optimization. For RBDO, the performance measure approach (PMA) is well established and accepted by many investigators. It is found that the same PMA is quite applicable to the possibility-based design optimization (PBDO) formulation. In general, it is known that PBDO provides more conservative optimum designs than RBDO, assuming the same random input distribution is used and the possibility-probability consistency theory is used to generate the membership function. In many industry design problems, we may have to deal with the statistical random and fuzzy variables simultaneously. For the design problem with both statistical random variable and fuzzy variable, it is not desirable to use RBDO since it could lead to an unreliable optimum design. This presentation proposes to use PBDO for design optimization. For fuzzy variables, the proposed membership function generation methods will be used. For statistical random variable, the membership function that yields least conservative optimum design will be selected by using the possibility-probability consistency theory and the least conservative condition. Numerical examples are used to demonstrate the proposed approach for mixed input variables.

3C2 **Reliability-Based Robust Design Optimization Using The Performance Moment Integration Method and Case Study of Engine Gasket-Sealing Problem**

Byeng D. Youn (presenter), KK Choi, and Kiyoung Yi

Due to competitive market, industries are trying to improve the reliability and quality of their product designs. Thus, incorporating various uncertainties in developing a product design has become increasingly important to produce reliable and robust product design. Reliability-based robust design optimization deals with two objectives of structural design methodologies subject to various uncertainties: reliability-based design and robust design. A reliability-based design optimization deals with the probability of failure, while a robust design optimization minimizes the product quality loss. In general, the product quality loss is described by using the first two statistical moments: mean and standard deviation. In this presentation, the performance moment integration (PMI) method is proposed by using numerical integration scheme for output response to estimate the product quality loss. For the reliability part of the reliability-based robust design optimization, the performance measure approach (PMA+) and its numerical method, hybrid-mean value (HMV+) method, are used. New formulations of reliability-based robust design optimization are presented for three different types of robust objectives, such as smaller-the-better, larger-the-better, and nominal-the-better types. Examples are used to demonstrate the effectiveness of reliability-based robust design optimization using the proposed PMI method for different types of robust objective.

3C3 **A New Fuzzy Analysis Method for Possibility-Based Design Optimization**

Liu Du (presenter), KK Choi, and Byeng D. Youn

Structural analysis and design optimization have recently been extended to stochastic approach to take various uncertainties into account. However in areas where it is not possible to produce accurate statistical information, the probabilistic method is not appropriate for stochastic structural analysis and design optimization, since improper modeling of uncertainty could cause greater degree of statistical uncertainty than those of physical uncertainty. For uncertainty with insufficient information, possibility-based (or fuzzy set) methods have recently been introduced in stochastic structural analysis and design optimization. The main advantage of the fuzzy analysis is that it preserves the intrinsic random nature of physical variables through their membership functions and, when used for evaluation of designs, yields more conservative design than those from the probabilistic methods. This presentation suggests several ways to model the uncertainties with different level of insufficient data such that possibility theory can be used. It is proposed a new formulation of PBDO using performance measure approach (PMA) for the inverse fuzzy analysis, since PMA is more appropriate than other approaches, such as a possibility index approach. It is also found that PBDO is more desirable than RBDO, since PBDO can inherently handle a system level possibility unlike RBDO. For the inverse fuzzy analysis, the maximal possibility search (MPS) method is proposed to improve numerical efficiency and accuracy comparing with the vertex method and the multilevel-cut method. Two mathematical examples including a non-monotonic response and a physical example of vehicle side impact are used to demonstrate the proposed MPS method and PBDO.

3C4 **A Univariate Method for Higher-Order Reliability Analysis**

Sharif Rahman and Dong Wei

A new univariate method is developed by employing the most probable point as the reference point for predicting failure probability of structural and mechanical systems subject to random loads, material properties, and geometry. The method involves a novel decomposition at most probable point that facilitates a univariate approximation of a general multivariate function, response surface generation of the univariate function, and Monte Carlo simulation. In addition to the effort of identifying the most probable point, the method requires a small number of exact or numerical evaluations of the performance function at selected input. The proposed method, which entails higher-order approximation of a performance function, is theoretically more accurate than commonly used first-and second-order reliability methods (FORM/SORM). Indeed, numerical results confirm the accuracy of the univariate method when several examples involving mathematical functions and solid-mechanics problems are solved. The computational effort by the univariate method is slightly larger than that by FORM, but significantly less than that by SORM. Finally, the fatigue failure of lever arm in a wheel loader has been evaluated, demonstrating the ability of the method developed in solving large-scale fatigue reliability problems.

3D Vehicle Component Structural Design Methodologies

Session Chair: Nick Vlahopoulos

3D1 **Component-Based and Parametric Reduced-Order Modeling Methods for Vibration Analysis of Vehicle Structures**

Geng Zhang, Keychun Park, Matthew P. Castanier, and Christophe Pierre

Several advances have been made in previous work by the authors to enhance traditional component mode synthesis, in order to achieve better efficiency of the reduced-order modeling process and to generate more compact vibration models. In this work, these improvements are integrated with a parametric approach recently introduced in the literature to obtain a component-based parametric reduced-order modeling method. This new method can be used to efficiently handle both probabilistic vibration analysis and design of complex structures, including structures that are initially represented by very-large-scale finite element models. The method is applied to an example case of a vehicle model, and the numerical results demonstrate the accuracy and efficiency of the proposed method.

3D2 **An Innovative Inflatable Morphing Body Structure for Crashworthiness of Military and Commercial Vehicles**

Dong Wook Lee, Zheng-Dong Ma, and Noboru Kikuchi

In recent years, the automotive industry has experienced the greatest demand from customers, regulators, and the media to provide safer vehicles with significantly lighter body structures for increased fuel efficiency and transportability. Crashworthiness thus has become an increasingly important topic in the automotive industry. On the other hand, advanced usages of military vehicles, i.e. reconnaissance missions, search and recovery operations, and anti-terrorism applications, have revolutionized the design concepts of the modern military vehicles, in which safety always a centered concern. Conventional energy absorbing front and side structures, air bags, seats with integrated seat belts, and various crash avoidance devices have been developed as standard equipment on many vehicles. However, breaking-through and innovation are still a key requirement for meeting the future demands of the vehicle design. In this presentation, we introduce an “innovative inflatable morphing body structure” as an example for crashworthiness or safety design of military and commercial vehicles. An innovative structure using the “inflatable body” is proposed with a preliminary proof-of-concept through prototyping and numerical simulation. The advanced body design methodologies developed can be used for innovative structural concepts of manned, unmanned, and alternative vehicles, including vehicle configuration, body shape, and morphing structure. The innovative structure concepts developed can be used for designing better and safer vehicles for improving crashworthiness of military and civilian vehicles.

3D3 **Stryker A-Arm Fatigue Analysis and Design Optimization**

Ed Hardee (presenter), Jun Tang, and KK Choi

In the Army mechanical fatigue subject to external and inertia transient loads in the service life of mechanical systems often leads to a structural failure due to accumulated damage. Structural durability analysis that predicts the fatigue life of mechanical components subject to dynamic stresses and strains is a compute intensive multidisciplinary simulation process, since it requires the integration of several computer-aided engineering tools and considerable data communication and computation. Uncertainties in geometric dimensions due to manufacturing tolerances cause the indeterministic nature of the fatigue life of a mechanical component. Due to the fact that uncertainty propagation to structural fatigue under transient dynamic loading is not only numerically complicated but also extremely computationally expensive, it is a challenging task to develop a structural durability-based design optimization process and reliability analysis to ascertain whether the optimal design is reliable. This presentation discusses the demonstration of an integrated CAD-based computer-aided engineering process to effectively carry out design parameterization, design sensitivity analysis (DSA), and design optimization for minimum weight and structural durability. The preliminary results of minimum weight durability design optimization for the Army Stryker A-Arm will be shown. The efforts to match strain and fatigue life predicted by CAE tools with that measured field data will be discussed. The definition of the fatigue-life design optimization problem and the CAE environment used to solve it will be explained. Finally the reliability analysis of the optimal design will be described.

3D4 **Thermal Analysis of Composite Integral Armor**

V.Y. Yu and C.T. Jagmin

The Army's Future Combat System (FCS) is the United States' vision on transforming its armed forces to gain a technological edge on today's modern battlefield. Though the FCS consists of numerous components which forms an integrated and networked system, this paper focuses on the composite armor which will outfit the land systems, or armored vehicles of the FCS. In order to field the innovative concept of composite armor, extensive testing of ballistics, survivability, and structural integrity must be performed. Nested within structural integrity analysis, the thermal properties of armor must be investigated to ensure the equipment is capable of operation in extreme climates. In this paper, a thermal analysis of proposed FCS armor specimens was conducted to compare the thermal strains in several composite material recipes. Titanium, aluminum, and an S2-glass blend were each used for the armor backplate. These backplate materials were bonded to an exterior ceramic tile of silicon carbide to form the composite armor. In order to reduce the thermal stresses of the composite material, an intermediate rubber layer was bonded between the backplate and ceramic tile. The purpose of the rubber layer was to reduce the thermal strain mismatch near the interface due to the dissimilar coefficients of thermal expansion. The rubber layer would theoretically provide a more compliant layer between the top and bottom plates. Experiments were conducted on several configurations of composite armor specimens exposing them to temperature ranges from -51.1 ºC (-60 ºF) to 82.2 ºC (180 ºF). Strain gages were attached to the composite materials to determine thermal deformations and strains. In addition, finite element analysie were conducted using ANSYS 8.1 which modeled the laminar composite material. Furthermore, a theoretical model using Composite Materials Analysis of Plates (CMAP) was used to determine strains using classical laminar plate theory. Strains calculated from the finite element model and CMAP were compared to the strains from the experiment. The results served to verify the current thermal properties of the composite armor recipes, helping to integrate thermal effects into ballistic and other structural testing for FCS armor research.

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Automotive Research Center

A U.S. Army RDECOM Center of Excellence for Modeling and Simulation of Ground Vehicles at the University of Michigan

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Symposium IV

4A Advanced Diesel Engine Systems

Session Chair: Zoran Filipi

4A1 **Dual Stage Turbocharging: Matching and Boost Control Options**
Byungchan Lee, Zoran Filipi
A need for increased power density of military and commercial vehicles stimulates development of advanced air-charging devices. An attractive option for providing a high-boost system is the use of dual-stage turbocharging. However, this increases the complexity of the system and requires simulation-based methodologies for matching of two turbochargers to the given engine. In addition, a favorable engine-in-vehicle response depends on achieving the high boost pressure even at low engine speed and prevention of overboosting at high speeds. This work proposes a method for dual stage turbocharger matching, through an iterative procedure predicting optimal configurations of compressors and turbines for given operating conditions. The final system configuration is selected based on engine and vehicle design constraints and torque characteristics. The system is configured for an advanced V6 engine installed in the HMMWV. In addition, two locations of the exhaust by-pass valve are compared regarding their ability to improve the engine torque characteristics and transient response during vehicle acceleration.

4A2 **Numerical Modeling of Cross Flow Compact Heat Exchanger with Louvered Fins using Thermal Resistance Concept**
Dohoy Jung
Compact heat exchanger has been widely used in various applications including automotive area. Radiator for vehicle cooling, evaporator and condenser for HVAC system, oil cooler and intercooler are typical examples of compact heat exchangers that can be found in ground vehicles. Among the different type of heat exchangers cross flow compact heat exchanger with louvered fins is of special interest in automotive applications because of its higher heat rejection capability with lower flow resistance. In this study, numerical model for cross flow type heat exchanger with louvered fin has been developed based on thermal resistance concept and finite difference method. The model was also validated with the experimental data. As a case study, the effect of geometric changes of heat exchanger on heat rejection performance was investigated with the model. It was concluded that high fidelity heat exchanger model is advised for the investigation of the effect of any geometric changes due to the non-linear characteristics of heat exchanger performance and geometric change. .

4A3 **Development of Simulink Based Cooling System Model**
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 with Vehicle and Engine SIMulation (VESIM). This cooling system consists of various module based cooling component models, such as coolant pump, radiator, thermostat, and cooling fan, and the simple ram air flow model was incorporated into the cooling system model in order to enhance the accuracy of the model by including the effect of cooling air flow on the cooling performance. In this work, prior to the integration of the VESIM and the cooling system model, one-dimension heat transfer model for engine and engine block was added to the cooling system model in order to calculate the heat rejection rate to coolant. The coolant temperature was calculated to estimate the capacity of the conventional cooling system, and the conventional coolant pump sub-model was replaced with electric pump sub-model in order to investigate the possibility of radiator down-sizing. It was also demonstrated that the aspect ratio effect of down-sized radiator on cooling performance using the high fidelity radiator model.

4B Diesel Injection & Combustion

Session Chair: Naeim E. Henein

4B1 **Using a Military Grade JP8 Fuel in the Heavy Duty Diesel Engine: Performance, Combustion and Emission Effects**

Gerald Fernandes, Jerry Fuschetto, Zoran Filipi and Dennis Assanis

The US Army Single Fuel Forward Policy mandates that deployed vehicles must refuel with aviation fuel JP-8, and when not available, are permitted to use diesel. The US Army is expected to use JP-8 till year 2025 and few experimental studies suggest that kerosene-based fuels such as JP-8 are likely to produce lower diesel exhaust emissions (especially particulate matter) than typical distillate fuels such as diesel, even with higher sulfur content. However, a torque and fuel economy penalty is expected when running with JP-8 due to its lower density and viscosity. The main objectives of this study are to fully understand the reasons behind the observed differences in combustion and performance when operating with JP8 rather than diesel fuel, and to subsequently propose a new engine calibration capable of compensating for the JP8 effects..

4B2 **Combustion and Emissions in a HSDI Diesel Engine from the Conventional to the Smokeless NOxless Regimes**

N.A. Henein, A. Bhattacharyya, J. Schipper, W. Bryzik

The combustion and emission characteristics of a small-bore, high speed direct injection (HSDI) diesel engine are investigated showing the differences from the large bore heavy duty quiescent combustion engine and the effects of wall impingement and the swirl and squish components on spray behavior and engine-out emissions. The engine used in the investigation is equipped with a common-rail injection system and is supercharged to simulate the conditions of a turbocharged engine. The investigation covers a wide range of injection pressures, EGR rates, injection timings and swirl ratios. 2-D maps are developed for the trade-off between indicated specific NOx and smoke intensity in Bosch Smoke Units (BSU). The maps show the iso-bar, iso-EGR and iso-swirl lines. In addition 3-D trade-off maps are developed to show the iso-EGR surfaces at different operating parameters. The study covers the behavior of the spray from the conventional diesel combustion to the low temperature combustion regime with smokeless and close to NOxless engine-out emissions. The different approaches to reach the low temperature combustion regime are investigated, with their effect on engine performance, fuel economy and the HC and CO emissions.

4B3 **Dual-Use Engine Calibration: Leveraging Modern Technologies to Improve Performance-Emissions Tradeoff**

Alex Knafl, Jonathan Hagena, Zoran Filipi, Dennis Assanis

Modern diesel engines manufactured for commercial vehicles are calibrated to meet EPA emissions regulations. Many of the technologies and strategies typically incorporated to meet emissions targets compromise engine performance and efficiency. When used in military applications, however, engine performance and efficiency are of utmost importance in combat conditions or in remote locations where fuel supplies are scarce. This motivates the study of the potential to utilize the flexibility of emissions-reduction technologies toward optimizing engine performance while still keeping the emissions within tolerable limits. The study was conducted on a modern medium-duty International V-8 diesel engine with variable geometry turbocharger (VGT) and exhaust gas recirculation (EGR). The performance-emissions tradeoffs were explored using design of experiments and response surface methodology. Then the newly acquired insight is utilized to demonstrate the benefit of dual use strategies that incorporate optimal use of injection timing, injection pressure, VGT setting, and pilot injection. The methodology enables optimizing the engine operation for different objectives, such as minimum emissions or maximum efficiency, and subsequent development of a “best compromise” that improves the fuel efficiency while maintaining emissions within the regulation constraints, but without the use of EGR. Potential elimination of cooled EGR is very significant in dual-use applications, as it reduces the total heat rejection and alleviates packaging difficulties. .

4C Hybrid Vehicle Modeling

Session Chair: Doug Goering

4C1 **Engine-in-the-Loop Testing: Engine System Response and Transient Emissions**

Jonathan Hagena, Alex Knafl, Hosam Fahty, Zoran Filipi, Huei Peng, Dennis Assanis

Most of the real-life problems related to response of sub-systems, driveability, performance, and emissions stem from vehicle transients. If the engine is mated to hybrid propulsion system instead of conventional driveline, the interactions in the system and engine transients will be altered significantly. While the ability of modeling and simulation to provide powerful tools for evaluating new propulsion system concepts has been shown in the past, accounting for the response of real actuators and transient emissions are still a challenge. This motivates development of the engine-in-the-loop testing capability, as the means for providing detailed insight into the response of the real engine system coupled to any driveline/vehicle. The interfacing of the real engine, highly dynamic dynamometer and the virtual driveline/vehicle is discussed briefly, followed by the description of the V8 diesel engine coupled to the virtual HMMWV vehicle. The results characterize real engine transients and highlight critical conditions. Finally, the conventional driveline is replaced by the selected hybrid electric model, and details of component interactions and engine emissions are contrasted to the conventional case.

4C2 **Series Hydraulic Hybrid Propulsion System for the HMMWV**

Youngjae Kim and Zoran Filipi

In this study, an integrated simulation of a series hydraulic hybrid vehicle simulation was developed for the propulsion system of the HMMWV in MATLAB/SIMULINK environment. This configuration removes the mechanical connection between the engine and the driveline and allows full flexibility in controlling the engine operation. The propulsion and energy storage are sized based on critical vehicle performance requirements. Subsequently, systematic simulation studies allowed development of an improved power management strategy, capable of maximizing the fuel economy improvement. In addition, 4x4 drivelines with one traction motor and two traction motors (one per axle) are compared. The results demonstrate a great improvement in fuel economy, while enhancing acceleration performance and gradeability compared to the baseline conventional HMMWV.

4C3 **Modeling of an Integrated Starter Alternator (ISA) System for the HMMWV**

Andreas Malikopoulos, Zoran Filipi, Dennis Assanis

In this study the use of an Integrated Starter Alternator (ISA) in a HMMWV vehicle is employed. The 10kW ISA is mechanically coupled in series with the engine. While the primary purpose is to provide electric power for additional accessories, it can also be utilized for mild hybridization of the powertrain. This simulation study explores the potential for improving the fuel economy of such configuration. An ISA model capable of both producing and absorbing mechanical power is developed in Simulink. A rule based power management control algorithm is developed that engages the suitable modes of the ISA during driving. Namely, based on driver's power request and the state of charge of the battery (SOC) decision is made on whether the ISA should contribute power to or absorb power from the crankshaft. The ISA model and the rule based control algorithm are integrated in the Hybrid Vehicle-Engine SIMulation (HE-VESIM). Comparison between the powertrain configuration with ISA and the conventional one is presented.

4C4 **Sliding Mode Powertrain Control for a Military HEV**

M. Gokasan, S. Bogosyan, D. Goering, and H. Bargar

In this work the use of sliding mode control is investigated to improve the overall efficiency of a series hybrid-electric HMMWV. A control strategy based on two chattering free sliding mode controllers (SMC's) is used to restrict the engine operation to it's high efficiency region. One of the SMC's performs engine speed control, while the other controls the engine/generator torque, together achieving the desired operational characteristics. The SMC's require only basic models of the engine and generator and provide robustness to parameter and model variations and/or uncertainties. The system is simulated using a Matlab based model and the performance of new control strategy is compared with a baseline hybrid-electric HMMWV model. Improved performance is obtained with the new approach in terms of overall and average engine efficiency and fuel utilization, while maintaining a higher average battery state-of-charge.

4D Engine Friction & Vibration

Session Chair: Dinu Taraza

4D1 **Visualization and Simulations of Advanced IC Engine Spray and Combustions**

Ming-Chia Lai, Xingbin Xie, Pai-Hsiu Lu, Ming Li, Naeim Henein, and Walter Bryzik

Late-injection low-temperature diesel combustion has been shown to reduce NOx and soot simultaneously. The combustion phenomena and detail chemical kinetics are studied with high speed spray/combustion images and time-resolved spectroscopy analysis in a rapid compression machine (RCM) with a small bowl combustion chamber. High swirl and high EGR condition can be achieved in the RCM; variable injection pressure and injection timing is supplied by the high-pressure common-rail fuel injection system. Effects of addition of hydrogen in the charge air and bio-diesel additives in the fuel are also studied. High speed color images of spray and combustion show not only the high sooting diesel spray impinging on the chamber wall and interacting with very strong swirling air, but also the color temperature and volume fraction of soot. Hydrogen addition of 10% of energy released for low temperature combustion is shown to further reduced soot concentration, but hydrogen at 15% shows higher soot temperature and concentration. Small amount of hydrogen does not results in increasing peak pressure and fast burning rate because of higher EGR up to 50%. Bio-diesel addition results in reduction of in-cylinder soot reductions. 3-D CFD simulation of diesel sprays and combustion for Mixing-Controlled Diesel Combustion and Low-Temperature combustion was carried out. Different spray and combustion models were compared and validated with experimental data. Parametric study of different engine parameters with NOx and soot emission results can contribute to model development and engine design.

4D2 **Prediction of the Instantaneous Frictional Losses in ICE by Using a Modified (P-ω) Method**

G.A. Kfoury, N.G. Chalhoub and N.A. Henein

The (P-ω) method is a model-based approach developed for determining the instantaneous friction torque in internal combustion engines. The original formulation of this method is limited to the rigid body motion of the crank-slider mechanism. It requires measurements of the cylinder gas pressure, the engine load torque, the crankshaft angular displacement and its time derivatives for the computation of the engine friction torque. However, the effects of the higher order dynamics of the crank-slider mechanism on the measured angular motion of the crankshaft, and the exclusion of the structural deformations from the formulation of the (P-ω) method, have caused this approach to yield erroneous results, especially, at high engine speeds. To alleviate these problems, a nonlinear sliding mode observer has been developed herein to accurately estimate the rigid and flexible motions of the piston-assembly/connecting-rod/crankshaft mechanism of a single cylinder engine. The observer has been designed to yield a robust performance in the presence of disturbances and modeling imprecision. Furthermore, the formulation of the (P-ω) method has been expanded to account for the first two elastic modes of the torsional and out-of-plane transverse deformations of the crankshaft. The digital simulation results, generated under transient engine operating conditions, have illustrated that the modified version of the (P-ω) method is far more superior in predicting the engine friction torque at high engine speeds than the original version.

4D3 **Integration of Engine Systems in a Simulation Model for Transient Operation**

Dinu Taraza, Naeim A. Henein, Radu Ceausu

The Internal Combustion Engine is a fairly complex system consisting of components that are interconnected by thermodynamic and fluid flow processes and components that are connected by mechanical processes. In order to determine the best choice of the characteristic parameters of each component it is necessary to integrate them in a comprehensive simulation model. The paper presents the integration of generic models of the components of a turbocharged, common rail diesel engine developed on a SIMULINK platform. The main goal is to predict transient behavior of the turbocharged engine, especially acceleration under load and, in order to reduce computer time, the model is zero – dimensional as far as combustion is concerned. Multiple injections are considered to simulate the main characteristic of modern common rail diesel engines. A generic model of the turbocharger is also developed such as to determine the effects of different design parameters on the acceleration of the engine. The validation is achieved by comparing simulated results with measurements mad on a 2.2 liter Common rail direct injection diesel engine

4D4 **Lumped Transient Thermal Model of PEMFC with Cooling System Simulation**

Sangseok Yu, Dohoy Jung

A numerical model of PEMFC (proton exchange membrane fuel cells) stack was developed to investigate the performance of PEMFC stack on various operating conditions. The model includes a water transport and electric conductivity in the membrane electrolyte, an electrochemical reaction at the cathode catalyst layer, and heat generation/heat rejection. An electrochemical reaction model at the catalyst layer enables PEMFC stack model to predict mass transport limitation at high current density. In this study, a lumped transient heat transfer between coolant and stack is employed. Since operating temperature of PEMFC stack is lower than that of conventional engines, a cooling capacity of conventional engines is not enough to satisfy that of PEMFC stack. Therefore, high fidelity cooling system model is required to investigate proper design of cooling components.

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