ARC Conference 2001

Seventh Annual ARC Conference on Critical Technologies for Modeling and Simulation of Ground Vehicles

May 15-16, 2001

Ford Motor Company
Dearborn, MI
University of Michigan
College of Engineering
Ann Arbor, MI

Sponsored by:

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

CONFERENCE OBJECTIVES

INDUSTRY PARTICIPATION

DAY 1 - SCHEDULE

DAY 2 - SCHEDULE

SYMPOSIA MATRIX

SYMPOSIUM ABSTRACTS

ADDITIONAL INFORMATION

MAPS

ONLINE REGISTRATION

Conference Program

Tuesday, May 15, 2001

(Located at Ford Motor Company's World Headquarters)

7:30 - 8:30 am	**REGISTRATION AND CONTINENTAL BREAKFAST**
8:30 - 9:00	**WELCOME AND INTRODUCTIONS** Moderator: **Dennis Assanis,** Professor and ARC Director, University of Michigan Welcome: **Walter Bryzik**, Chief Scientist, U.S. Army TACOM-TARDEC **Dennis Wend,** Director, National Automotive Center, U.S. Army TACOM-TARDEC **Marvin Parnes**, Associate Vice-President for Research, University of Michigan
9:00 - 10:30	**VIEWPOINTS AND VISIONS FOR AN INDUSRTY-GOVERNMENT-UNIVERSITY COLLABORATIVE RESEARCH AGENDA ON VEHICLE DEVELOPMENT** Speakers: **Lt. General Paul J. Kern**, Military Deputy to the Assistant Secretary of the Army for Acquisition, Logistics, and Technology **Kenneth K. Kohrs**, Co-Director, Tauber Manufacturing Institute, University of Michigan; Vice-President (retired), Ford Motor Company **Robert N. Culver**, Executive Director, USCAR **Question and Answer Session**
10:30 - 11:00	**NETWORKING BREAK**
11:00-12:00pm	**ADVANCED HEAVY TACTICAL TRUCK: TARGET CASCADING CASE STUDY** Speakers: **Panos Papalambros,** Professor and ARC Executive Director **Nestor Michelena**, Research Scientist, University of Michigan **Loucas Louca**, Research Scientist, University of Michigan
12:00-12:45pm	**INSIDE TRACK** (Smart Truck and ARC) Speaker: **Dennis Wend,** Director, National Automotive Center, U.S. Army TACOM-TARDEC
1:00 - 2:00	**LUNCH** (Cafeteria)
2:00 - 2:45 pm	**CHALLENGES IN VEHICLE PRODUCT DEVELOPMENT** Speaker: **William W. Boddie**, Vice-President, Global Core Engineering, Ford Motor Company
2:45 - 3:45	**ADVANCED HYBRID PROPULSION SYSTEMS AND STRUCTURES FOR DUAL-PURPOSE TRUCKS** Speakers: **Dennis Assanis,** Professor and ARC Director, University of Michigan **Christophe Pierre,** Professor and ARC Thrust Leader, University of Michigan
3:45 - 4:15	**NETWORKING BREAK**
4:15 - 5:30	**HUMAN CENTERED VIRTUAL PROVING GROUND**

Speakers: **Edward Haug,** Professor and ARC Thrust Leader, University of Iowa
L.D. Chen, Professor and ARC Liaison, University of Iowa
Mongi Abidi, Professor and ARC Liaison, University of Tennessee
Don Chaffin, Professor and Interim ARC Thrust Leader, University of Michigan

5:15 - 5:30 **WRAP-UP AND Q & A**
Dennis Assanis, Professor and ARC Director, University of Michigan

5:30 **ADJOURN**

6:00 - 8:00 **RECEPTION** (Henry Ford Museum)

Concept vehicles will be on display the first day.

Conference Program

Wednesday, May 16, 2001

(Located at the University of Michigan North Campus)

7:30 - 8:30	**REGISTRATION AND CONTINENTAL BREAKFAST**
8:30 - 9:00	**WELCOME AND INTRODUCTION** (Auditorium)
9:00 - 4:30	**PARALLEL TECHNICAL SESSIONS**

The Balance of the day's activities will be divided into **four** Parallel Symposia:

Symposium I

1A Immersive Environments (Session Chair: Mongi Abidi)

9:00 - 9:25 1A-1 Curvature and Superquadrics Analysis for 3-D Object Segmentation and Representation of Automotive Parts
9:25 - 9:50 1A-2 Integration of multiple range, color and thermal images for the 3-D reconstruction of automotive components
9:50 - 10:15 1A-3 Building Photo-Realistic 3-D Terrain Models for Driving Simulators from Un-calibrated Video Sequences

1B Human Interactions (Session Chair: Don Chaffin)

10:45 - 11:10 1B-1 Shared Control Between Man and Machine
11:10 - 11:35 1B-2 Modeling Truck Driver Reach to Controls
11:35 - 12:00 1B-3 Shoulder Biomechanical Modeling During Arm Reaches In Workplace And Vehicle Simulation

1C Virtual Proving Grounds (Session Chair: LD Chen)

1:00 - 1:25 1C-1 Driver model for advanced collision warning and avoidance systems
1:25 - 1:50 1C-2 Statistical Road Characterization
1:50 - 2:15 1C-3 Real-time Modeling and Simulation Techniques for VPG Simulation
2:15 - 2:40 1C-4 Augmenting GPS Elevation Data For Producing Real-Time Simulation Synthetic Environments

1D Modeling and Control of Vehicle Systems (Session Chair: Loucas Louca)

3:10 - 3:35 1D-1 Proper Models for Design: Algorithms for Assessing Model Quality
3:35 - 4:00 1D-2 Output-Specific Reduction of a Truck Mobility Model for Design
4:00 - 4:25 1D-3 A Control Concept for Handling of Articulated Vehicle Guidance
4:25 - 4:50 1D-4 Cancellation of Vibration Feedthrough using a Force-Reflecting Joystick

Symposium II

2A Hybrid Electric Systems I (Session Chair: Brent Gillespie)

9:00 - 9:25 2A-1 Multivariable control of breathing systems in automotive powertrains: A case study on Fuel cells
9:25 - 9:50 2A-2 Hierarchical Modeling of Hybrid Electric Vehicle Systems
9:50 - 10:15 2A-3 Energy management strategy for a parallel hybrid electric vehicle

2B Hybrid Electric Systems II (Session Chair: Huei Peng)

10:45 - 11:10 2B-1 Nonlinear Modeling and Analysis of Power-Assist Steering Systems for Hybrid Vehicles
11:10 - 11:35 2B-2 Nonlinear Modeling and Control of a Continuously Variable Transmission (CVT) for Hybrid Vehicle Powertrains
11:35 - 12:00 2B-3 Hybrid Electric Vehicle Virtual Proving Grounds

2C Noise, Vibration and Harshness (Session Chair: Nick Vlahopoulos)

1:00 - 1:25 2C-1 Modeling Track/Terrain Interaction for Simulation of Tracked Vehicles
1:25 - 1:50 2C-2 Statistical Approximations of Mid-Frequency Vibration and Power Flow in Vehicle Structures
1:50 - 2:15 2C-3 Development of a Hybrid Finite Element Method for Mid-Frequency Computations
2:15 - 2:40 2C-4 A Sequential Adjoint Variable Method in Design Sensitivity Analysis of a NVH Problem

	2D Structures and Materials (Session Chair: KK Choi)
3:10 - 3:35	2D-1 Reliability-Based Design Optimization Using Moving Least Square Method
3:35 - 4:00	2D-2 Design of Heterogeneous Multi-Material Structures
4:00 - 4:25	2D-3 Optimum Design of Laminated Plates with Frequency Constraints
4:25 - 4:50	2D-4 A New Approach to the Identification of Eigen-Systems of Large-Scale Structures

Symposium III

	3A Diesel Combustion Processes (Session Chair: Naeim Henein)
9:00 - 9:25	3A-1 Welcome and introduction
9:25 - 9:50	3A-2 Multi-Zone DI Diesel Spray Combustion Model for Cycle Simulation Studies of Engine Performance and Emissions
9:50 - 10:15	3A-3 Phenomenological Soot Modeling
	3B Injection and Combustion Diagnostics (Session Chair: Dave Foster)
10:45 - 11:10	3B-1 Heavy-Duty Diesel Engine Diagnostics Using Videoscope Technology
11:10 - 11:35	3B-2 Actual versus Ideal Performance of a Common Rail Injection System in a Direct Injection Diesel Engine
11:35 - 12:00	3B-3 Visualization of Diesel Spray Combustion under Different EGR and Swirl Ratios
	3C Hybrid Propulsion Systems and Fuel Cells (Session Chair: Doug Goering)
1:00 - 1:25	3C-1 HEV PSAT and ADVISOR Platforms
1:25 - 1:50	3C-2 Advanced Hybrid Propulsion Systems Architectures for Future Light and Medium Trucks
1:50 - 2:15	3C-3 Development of a Forward-Looking Fuel Cell Vehicle Simulation
2:15 - 2:40	3C-4 Performance Of Hybrid And Fuel-Cell Vehicles At Low Temperatures
	3D Advanced Diesel Engine Systems (Session Chair: Zoran Filipi)
3:10 - 3:35	3D-1 The Reverse Engineering of a Turbocharged Diesel Engine through a Unified Systems Approach
3:35 - 4:00	3D-2 On Board Non-Intrusive Diagnostics System of Faulty Cylinder(s) in Multi-Cylinder Diesel Engines
4:00 - 4:25	3D-3 Environmental Effects on Engine Cold-Start - A Tribological Systems Approach
4:25 - 4:50	3D-4 Effect of EGR System on Autoignition, Combustion and Emissions in DI Diesel Engine

Symposium IV

	4A Internet Initiatives (Session Chair: Greg Hulbert)
9:00 - 9:25	4A-1 The iARC Portal
9:25 - 9:50	4A-2 A Software Framework for Engineering System Design through Distributed Virtual Prototyping
9:50 - 10:15	4A-3 Collaborative Distributed Design
	4B Product Development and Design (Session Chair: Panos Papalambros)
10:45 - 11:10	4B-1 Organizational Design of a Product Development Process
11:10 - 11:35	4B-2 Enterprise-Wide Product Design
	4C Target Cascading (Session Chair: Nestor Michelena)
1:00 - 1:25	4C-1 Analytical Target Cascading in Product Development
1:25 - 1:50	4C-2 Target Cascading and Convergence Issues
1:50 - 2:15	4C-3 Product Platform Design
	4D Integrated Design and Simulation (Session Chair: Georges Fadel)
3:10 - 3:35	4D-1 Gluing Algorithms for Distributed Simulation
3:35 - 4:00	4D-2 Multi-Criteria, Multi-Scenario Optimization of the Dynamic, Performance of Vehicles
4:00 - 4:25	4D-3 Bi-Scenario Bi-Criteria Optimization in Vehicle Design
4:25-4:50	4D-4 Coupling in Design and Control System Optimization

12:00 - 1:00	**COOKOUT** (FXB Building)
4:30	**ADJOURN**

The second day will feature onsite simulation demonstrations. In addition a tour of the UM Lay Engine Research Laboratory will be conducted to interested parties. Individuals interested in the tour will need to sign up at the registration desk.

ARC Conference 2001: Symposia Matrix

Time	Symposium I		Symposium II		Symposium III		Symposium IV	
9:00 – 9:25	Immersive Environments	Curvature and Superquadrics Analysis for 3-D Object Segmentation and …	Hybrid Electric Systems I	Multivariable Control in Automotive Powertrains: A Case Study on Fuel Cells	Diesel Combustion Processes	Welcome and Introduction	Internet Initiatives	The iARC Portal
9:25 – 9:50		Integration of Multiple Range, Color and Thermal Images for the 3-D Reconstruction of …		Hierarchical Modeling of Hybrid Electric Vehicle Systems		Multi-Zone DI Diesel Spray Combustion Model for Cycle Simulation Studies of …		A Software Framework for Engineering System Design through Distributed Virtual Prototyping
9:50 – 10:15		Building Photo-Realistic 3-D Terrain Models for Driving Simulators from …		Energy Management Strategy for a Parallel Hybrid Electric Vehicle		Phenomenological Soot Modeling		Collaborative Distributed Design
10:15 – 10:45	**Break**							
10:45 – 11:10	Human Interactions	Shared Control Between Man and Machine	Hybrid Electric Systems II	Nonlinear Modeling and Analysis of Power-Assist Steering Systems for Hybrid Vehicles	Injection and Combustion Diagnostics	Heavy-Duty Diesel Engine Diagnostics Using Videoscope Technology	Product Development and Design	Organizational Design of a Product Development Process
11:10 – 11:35		Modeling Truck Driver Reach to Controls		Nonlinear Modeling and Control of a Continuously Variable Transmission (CVT) for Hybrid …		Actual versus Ideal Performance of a Common Rail Injection System in a Direct Injection Diesel Engine		Enterprise-Wide Product Design
11:35 – 12:00		Shoulder Biomechanical Modeling During Arm Reaches In Workplace and Vehicle Simulation		Hybrid Electric Vehicle Virtual Proving Grounds		Visualization of Diesel Spray Combustion under Different EGR and Swirl Ratios		
12:00 – 1:00	**Lunch**							
1:00 – 1:25	Virtual Proving Grounds	Driver Model for Advanced Collision Warning and Avoidance Systems	Noise, Vibration and Harshness	Modeling Track/Terrain Interaction for Simulation of Tracked Vehicles	Hybrid Propulsion Systems and Fuel Cells	HEV PSAT and ADVISOR Platforms	Target Cascading	Analytical Target Cascading in Product Development
1:25 – 1:50		Statistical Road Characterization		Statistical Approximations of Mid-Frequency Vibration and Power Flow in Vehicle Structures		Advanced Hybrid Propulsion Systems Architectures for Future Light and Medium Trucks		Target Cascading and Convergence Issues
1:50 – 2:15		Real-time Modeling and Simulation Techniques for VPG Simulation		Development of a Hybrid Finite Element Method for Mid-Frequency Computations		Development of a Forward-Looking Fuel Cell Vehicle Simulation		Product Platform Design
2:15 – 2:40		Augmenting GPS Elevation Data for Producing Real-Time Simulation Synthetic Environments		A Sequential Adjoint Variable Method in Design Sensitivity Analysis of a NVH Problem		Performance of Hybrid And Fuel-Cell Vehicles at Low Temperatures		
2:40 – 3:10	**Break**							
3:10 – 3:35	Modeling and Control of Vehicle Systems	Proper Models for Design: Algorithms for Assessing Model Quality	Structures and Materials	Reliability-Based Design Optimization Using Moving Least Square	Advanced Diesel Engine Systems	The Reverse Engineering of a Turbocharged Diesel Engine through a Unified	Integrated Design and Simulation	Gluing Algorithms for Distributed Simulation

				Method		Systems Approach		
3:35 – 4:00		Output-Specific Reduction of a Truck Mobility Model for Design		Design of Heterogeneous Multi-Material Structures		On Board Non-Intrusive Diagnostics System of Faulty Cylinder(s) in Multi-Cylinder Diesel Engines		Multi-Criteria, Multi-Scenario Optimization of the Dynamic, Performance of Vehicles
4:00 – 4:25		A Control Concept for Handling of Articulated Vehicle Guidance		Optimum Design of Laminated Plates with Frequency Constraints		Environmental Effects on Engine Cold-Start - A Tribological Systems Approach		Bi-Scenario Bi-Criteria Optimization in Vehicle Design
4:25 – 4:50		Cancellation of Vibration Feedthrough Using a Force-Reflecting Joystick		A New Approach to the Identification of Eigen-Systems of Large-Scale Structures		Effect of EGR System on Autoignition, Combustion and Emissions in DI Diesel Engine		Coupling in Design and Control System Optimization

Conference Program

Day 1

ADVANCED HEAVY TACTICAL TRUCK: A TARGET CASCADING CASE STUDY

Dennis Assanis, Zoran Filipi, Dohoy Jung, Michael Kokkolaras, Joe Lin, Loucas Louca, Nestor Michelena, Panos Papalambros, and Huei Peng The University of Michigan, Mark Feury Advanced Concepts - TACOM

Target cascading is a key challenge in early product development stages of complex artifacts: How to propagate desirable overall product targets to appropriate individual specifications for the various subsystems and components in a consistent and efficient manner. Consistency means that all parts of the designed system should end up working well together, while efficiency means that the process itself should avoid iterations at later stages, which are costly in time and resources.

In the present study, analytical target cascading is formalized in a process modeled as a multilevel optimal design problem. Design targets are cascaded down to lower levels using partitioning of the overall design problem into a hierarchical set of subproblems. For each design subproblem at a given level, a rigorous optimization problem is formulated to minimize deviations from the propagated targets and thus achieve intersystem compatibility. A coordination strategy links all subproblem decisions so that overall product performance targets are met.

The analytical target cascading methodology is applied to the design of an advanced heavy tactical truck. Novel technologies (e.g., series hybrid and electric propulsion systems, in-hub motors, and variable height suspension) are introduced with the intention of improving both commercial and military design attributes within the framework of a dual-use philosophy. Emphasis is given to fuel economy, and ride and mobility characteristics. A two-level target cascading hierarchy is defined and two optimization problems are formulated. At the top level, design targets for the vehicle are matched; at the bottom level, suspension characteristics, cascaded down from the top level, are matched using a detail-designed suspension system.

Necessary models were developed for simulating both a series hybrid and a series electric-driven truck, at the top level, and the variable height suspension, at the bottom level. Baseline designs are consistent with a concept vehicle of the U.S. Army initiative for Future Tactical Truck Systems. The targets have been defined to improve on the performance of existing designs (e.g., the HEMMT truck). Optimization studies are performed for both the series hybrid and series electric drive propulsion systems, and results are presented for a variety of vehicle specifications.

ADVANCED HYBRID PROPULSION SYSTEMS AND STRUCTURES FOR A DUAL-PURPOSE TRUCK

Assanis, D., M. Castanier, Filipi, Z., Lin, C.-C., Z.-D. Ma, C. Pierre, N. Vlahopoulos, Wu, B. The University of Michigan K. K. Choi, J. Dong, N. H. Kim The University of Iowa

Next-generation military vehicles suitable for Future Combat Systems need to be lighter, more agile, with better fuel economy and extended range. These goals are compatible with the objectives of the 21st Century Truck initiative, which calls for a dramatic increase in fuel economy of commercial trucks, as well as a significant reduction of exhaust emissions, a less detrimental effect on nation's roadways, and improved safety. Attainment of such goals will require new vehicle concepts and new approaches to vehicle design. Two areas that will likely see rapid advancements are propulsion system technologies and application of new materials and new structural designs for lighter weight and improved strength and performance under dynamic loads.

In the first part of this case study, an examination is made of hybrid powertrain architectures suitable for future medium- and light-duty trucks in both military and commercial applications. It is anticipated that a parallel configuration will be more attractive than a series configuration for this class of dual-purpose vehicles. However, the actual design will depend on the choice of components that provide additional power during acceleration as well as regeneration of braking energy. H-VESIM-the Automotive Research Center's flexible vehicle system simulation platform implemented in SIMULINK-is utilized to configure the 4x2 delivery truck based on two of the possible choices for auxiliary propulsion components, i.e., electric and hydraulic. The implications of using one versus the other, including highlights of power management strategies, are followed by a study of the fuel economy potential of each configuration. The study also addresses issues related to the effectiveness of the power regeneration process in the 4x2 truck configuration.

In the second part of this case study, the influence of the new hybrid components on the vehicle noise and vibration is considered. The dynamic response is predicted for both the traditional and hybrid powertrains using an integrated framework of vibration and acoustic analysis methods. It is found that the hydraulic components of the hybrid vehicle introduce structure-borne noise that leads to an increase in the sound pressure levels at the driver's ears. Using a design sensitivity analysis method recently developed in the Automotive Research Center, the relative influence of various parts of the structure on the interior noise is determined. Based on these calculations, modified structural designs are proposed and examined. In addition, a brief summary is presented of ongoing work in the Automotive Research Center for the development of efficient vibro-acoustic analysis methods and their implementation in distributed design.

HUMAN CENTERED VIRTUAL PROVING GROUND SIMULATION

Ed Haug, University of Iowa Mongi Abidi, University of Tennessee Don Chaffin, University of Michigan

The National Advanced Driving Simulator (NADS), a national shared-use advanced driving simulator constructed at the University of Iowa by the US Department of Transportation for highway safety research, and advanced off-road Army vehicle simulators are being extended under ARC research to serve as vehicle virtual proving grounds (VPG). Characteristics of the NADS simulator and its capabilities are summarized, together with simulation capabilities being created under ARC research to enable VPG applications at an engineering level of fidelity. The synthetic environments discussed provide detailed terrain and roadways, intelligent traffic, pedestrians, weather conditions, and other interactive features. The NADS is ready for researchers to conduct highway safety studies, with the goal of understanding driver-vehicle-environment interaction and finding effective ways to reduce the number of accidents on the nation's highways and secondary roads. ARC research that is underway to extend NADS capabilities and achieve a design-level of fidelity required for human-centered VPG applications is outlined.

ARC research and the University of Tennessee is creating fundamentally new capabilities for roadway and environment modeling, using experimental data and graphical reconstruction methods to rapidly create realistic databases required for VPG simulation. The focus of this research is outlined, including a summary of methods employed for data collection, analysis, and graphical reconstruction, which will create a much-needed capability for rapid environment modeling to support a broad range of virtual proving ground applications.

ARC research at the University of Michigan is developing human modeling techniques that will produce a new class of driver model for evaluating recent concepts in vehicle interface design, active safety, and shared control. Aspects of motor behavior, limb dynamics, haptic perception (including haptic scene analysis), cognition, and decision-making are accounted for. A driver model is being pursued that can predict the development of automaticity in populations of skilled and un-skilled drivers and account for the role of haptic feedback in skill acquisition. The presentation will identify specific questions and issues that are being studied, within the context of virtual human-vehicle simulation, including (1) simulation of driver/occupant reaching behaviors, (2) simulation of human dynamics when using controls and moving objects, (3) simulation of head motions to visually acquire a display or control, (4) simulation of perceptual and cognitive workload, and related issues.

Day 2

1 Symposium I

1A Immersive Environments (Session Chair: Mongi Abidi)

1A-1 Curvature and Superquadrics Analysis for 3-D Object Segmentation and Representation of Automotive Parts

D. Page, Y. Zhang, A. Koschan, and M. A. Abidi (The University of Tennessee)
Presenters: David Page and Yan Zhang

This presentation has two parts. In the first part, a new robust method for the estimation of surface curvature is presented for a polygonal mesh where this mesh is a discrete sampling of a piecewise smooth surface. The proposed method avoids the computationally expensive process of surface fitting and instead employs a non-iterative method called normal voting. The presentation shows results for an automotive reverse engineering application using synthetic and real data. In the second part, a superquadric representation is presented for representing part-based objects from range images. The algorithm is used to automatically recover both regular and globally deformable superquadric models from a single-view range image. The representation results consist of recovered superquadric models with parameters corresponding to each part-based object. Experimental results on real range images are shown to demonstrate the potential of this technique to represent and segment automotive parts.

1A-2 Integration of multiple range, color and thermal images for the 3-D reconstruction of automotive components

Yiyong Sun, J. K. Paik, and Mongi Abidi (University of Tennessee)
Presenter: Yiyong Sun

A framework of 3-D reconstruction from multiple range, color and thermal images is presented. At first the raw range images are smoothed by adaptive regularization using the concept of mean curvature flow. By minimizing the local area, the coarse surface mesh is deformed to a smooth one. The second step is the pose estimation of multiple range images by finding point correspondences using 3-D point's fingerprints that are the projected contours of the geodesic circles onto the tangent plane. Finally, the registered surfaces are integrated into a single 3-D model using a volumetric approach. Signed distance fields recording the distance between each voxel and the surface are fused, from which the integrated surface can be extracted. Color or thermal images captured along with the range data are incorporated as the textures to improve the appearance of the reconstructed model. Experimental results are shown for 3-D reconstruction of a vehicle and a tire.

1A-3 Building Photo-Realistic 3-D Terrain Models for Driving Simulators from Un-calibrated Video Sequences

Faysal Boughorbal, Andreas Koschan and Mongi Abidi (University of Tennessee)
Presenter: F. Boughorbal

A system for 3D modeling of large outdoor scenes from video sequences is being developed. The main application is building photo-realistic terrain models to be used in driving simulators. Current simulators use mainly hand built models, which are labor intensive and less convincing. The main approach is based on the recovery of scene structure from camera motion, similar techniques were widely studied in computer vision, and recently some significant progress was obtained. The techniques used in this system extend classic stereo approaches by using several views in the reconstruction process. Furthermore, camera calibration parameters will be recovered automatically from point correspondences over the views and selected constraints. Several fundamental computer vision and graphics problems will be addressed, including interest-points extraction and matching, motion estimation, dense depth recovery and polygon model building, and rendering. The research is emphasizing full automation of the modeling process. For this goal, robust algorithms are being developed and tested on actual image sequences.

1B Human Interactions (Session Chair: Don Chaffin)

1B-1 Shared Control Between Man and Machine

Mika Steel and Brent Gillespie (University of Michigan)

The field of automatic control has recently produced controllers that can steer vehicles among obstacles, perform parallel parking maneuvers (with and without trailers), and exhibit other advanced driving skills. With unmentioned exceptions, we now know how to automate the driver. But certainly we are not ready to take the driver out of the loop. This presentation details the investigation of the use of a force-reflecting steering wheel that place these automated steering controllers in the perceptual space of the driver. There, they can be used to assist drivers in navigation of land vehicles. Rather than take over control, our controllers appear to the driver through haptic display (a mechanism utilizing the human's sense of touch). This phenomenon manifests itself as externalized objects or agents such as virtual fixtures or the actions of a co-pilot. We present data and conclusions from a human subject experiment in which humans perform several time-sharing tasks, including navigation, with the aid of a haptic steering wheel.

1B-2 Modeling Truck Driver Reach to Controls

Matthew P. Reed, Matthew B. Parkinson and Don B. Chaffin (University of Michigan)

The design of vehicle interiors is facilitated by the use of digital human figure models to represent the driver. These models currently have sophisticated anthropometric scaling to represent occupants with a wide range of body sizes, but lack accurate movements. The Human Motion Simulation (HUMOSIM) laboratory is engaged in a multi-year program to develop an extensive database of human motions. The motions are analyzed using a range of new statistical techniques to create efficient models to drive the movements of human figure models. The current effort focuses on the movements of vehicle drivers reaching to controls within the cab. The research will combine kinematic analysis with modeling of reach difficulty. The resulting models will be useful in optimizing the layout of controls in the vehicle cab to improve the accommodation and performance of drivers of all body sizes.

1B-3 Shoulder Biomechanical Modeling During Arm Reaches In Workplace And Vehicle Simulation

Clark Dickerson and Don Chaffin (University of Michigan)

The Laboratory for Human Motion Simulation is dedicated to the design of mathematical motion models for the description of human movement, which are combined with human visualization software to enhance product and workplace design. This purpose is predicated on the reality that accurate human motion data is essential to the design of ergonomically friendly, safe work environments. In order to supply this data effectively, mathematical physical models are combined with observed human motion data to produce a robust interpretation of human movement. Within the realm of human motion, the joint that elicits the most attention for seated workplace tasks is the shoulder.

The shoulder joint is widely accepted as the most mobile joint in the human body. The range of motion and associated musculature are far more complex than the joints of the lower extremities. Further, the numerous bone interactions seen in the shoulder joint are without peer in the body. The motivating force behind study of the shoulder in seated applications, or any task that requires fine muscle control, including many operations associated with vehicular use, is its intrinsic necessity to all hand positioning tasks. The shoulder is the beginning of the upper limb kinematic chain. To effectively evaluate the displacements of the upper arm, forearm, wrist and hand, we must first necessarily comprehend the activity in the shoulder.

Motions necessary to operate a vehicle and associated tasks are dynamic exertions. One limitation of the current state of shoulder research is that a majority of the research that has been conducted focuses on passive movement of the shoulder, and thus limits the effects of physical voluntary motion. A variety of static shoulder models have been created to represent the forces and moments that act on the joint, but these models fail to take into consideration the changing magnitudes and nature of forces that are extent in actual exertions. This current state of model development must necessarily be enhanced in order to produce a model that effectively and accurately describes motion of the shoulder while performing specific, industrially significant exertions, such as those involved in the driving of a motor vehicle. The current models are believed to be unsuited to describe the complex dynamic reality that exists in human motion, and as a result, beg improvement. This formal investigation has focused initially on delineating the differences between the outputs of dynamic and static model evaluation of several work tasks.

1C Virtual Proving Grounds (Session Chair: LD Chen)

1C-1 Driver model for advanced collision warning and avoidance systems

Wayne Lee and Huei Peng (University of Michigan)

Roughly 30% of all traffic accidents occurred in the US are rear-end collisions. Although this type of crashes is, on average, less fatal compared with the other two major crash types (lane departure and intersection crashes), it is targeted by many automotive companies due to the fact most of the rear-end crashes are preventable. With the growing popularity of Adaptive Cruise Control (ACC) and ABS, more ground vehicles will be equipped with all the necessary sensors and actuators to implement an effective collision warning and collision avoidance system. One of the major technical obstacles for their implementation is an algorithm that is both robust and driver-compatible. For robust we mean that the algorithm needs to ensure highest possible safety under all possible scenarios, while driver-compatible implies that the warning and control algorithms need to be intelligent enough to learn from observing the driver's action to generate non-intrusive actions. We have studied two databases and extract proper information to develop accurate longitudinal driver models. These two databases are the ACC-FOT database and the SAVME database. Existing driver models were reviewed and a new driver model is suggested.

1C-2 Statistical Road Characterization

David Gorsich, Milton Chaika (U.S. Army Tank Automotive Research, Development and Engineering Center) and T.C. Sun (Wayne State University)

Properly characterizing terrain roughness is a critical problem for the United States Army. In the procurement of new vehicles, the Army specifies the roughness of the test course by a RMS of elevation number. Using this number assumes stationarity of the spatial field. Without stationarity and other assumptions, the RMS number is meaningless. Several ways to handle and represent the roughness of a test course without violating key assumptions will be discussed, primarily the universal kriging technique. If the Army uses a new standard in its description of the roughness of roads and terrain, it will be able to improve its prediction of the fatigue life, reliability and mobility of its vehicle systems.

1C-3 Real-time Modeling and Simulation Techniques for VPG Simulation

Dario Solis (University of Iowa)

This presentation will include an update on the technology development activities in numerical methods, parallel processing, tire-soil interaction and real-time vehicle modeling and simulation technologies in support of Virtual Proving Ground simulation environments at NADS and TACOM simulator facilities.

1C-4 Augmenting GPS Elevation Data For Producing Real-Time Simulation Synthetic Environments

Yiannis Papelis (University of Iowa)

Prior work in utilizing high accuracy vehicle-mounted GPS units for sampling roadways yielded encouraging results as far as the re-construction of road geometry. However, in addition to road geometry, synthetic environments meant to be used in high fidelity simulation require additional features including textures, surrounding terrain and features. This presentation outlines some early work in augmenting the road geometry obtained through the use of GPS with synthetic road textures and integration of the road network into a geo-specific elevation grid.

1D Modeling and Control of Vehicle Systems (Session Chair: Loucas Louca)

1D-1 Proper Models for Design: Algorithms for Assessing Model Quality

Polat Sendur and Jeff Stein (University of Michigan)

Dynamic system models with known "quality" have become increasingly important, because the design, control and even procurement decisions are based on computer simulations of these models. Over the years, algorithms have been developed to help formulate and integrate the dynamic equations. More recently algorithms have been develop to create procedures and algorithms that use modeling metrics for generating minimum complexity dynamic system models with physically meaningful parameters (proper models). Missing from the literature, however, are algorithms to assess the quality of dynamic system models. The objective of this research is to develop a methodology to quantify the accuracy of the predicted system variables and to determine the validity of reduced order models with respect to a set of criteria derived from engineering design specifications or measurement noise.

The Model Validation Procedure is a time-based perspective comparing the model's time based output trajectories to targets at specific time points and targets related to the response over the total simulation time. The tolerances on the specific time point and overall response are determined by the user's domain knowledge (engineering specifications). The quality of a model performance is determined from its ability to match target points and overall response. The performance is formulated as a performance index that is determined from measures such as Relative error, Residuals Sum, etc.) to quantify the accuracy with respect to target points and overall response magnitude.. The validity of the model is then determined by comparing the performance indices of the model to performance indices of a "threshold model" derived from the engineering targets or measurement noise on a data set.

A full system model for an International Class VI Truck is created as an illustrative example. Model Order Reduction Algorithm (MORA) (Louca et al.) is applied to obtain different complexity models under full throttle and braking inputs to study vehicle mobility. The performance evaluation of the reduced models is carried out using the Model Validity Procedure. Performance Index versus model complexity is presented along with the "computational efficiency". Results show that accuracy and validity of reduced models can be systematically assessed.

1D-2 Output-Specific Reduction of a Truck Mobility Model for Design

Geoff Rideout and Jeff Stein (University of Michigan)

The efficacy of the Target Cascading design process is increased when models of appropriate complexity are used at each level of the hierarchy. There thus exists a need to combine Proper Modeling and Target Cascading. A first step towards determining Target Cascading models systematically, rather than intuitively, is to extend existing proper modeling techniques to generate output-specific reduced models.

A mobility model of a Class VI truck (with integrated engine, drivetrain, and vehicle dynamics models) shows that the relative importance of pitch dynamics to the vehicle response dramatically depends on the road course and throttle conditions. Conventional model reduction techniques do not systematically determine which dynamics are important to a specific output of interest such as pitch angle or longitudinal velocity.

This study shows that MORA (a Model Order Reduction Algorithm previously developed in the ARC) can be extended to determine the conditions under which certain dynamics are important, and to identify elements affecting dynamics of interest. The case study uses the extended technique to generate a reduced version of the above mentioned mobility model that predicts longitudinal velocity as well as pitch angle. The reduced model's utility for design studies is assured by the fact that parameters remain physically meaningful.

1D-3 A Control Concept for Handling of Articulated Vehicle Guidance

Frank Schaefer (Clemson University)

In this presentation a control structure is presented that separates the information processing of the human operator into two basic steps: (1) the planning of a desired motion, called 'gd-planning'; (2) the computation of appropriate control parameters so that the plant performs the desired motion, called 'plan-to-action mapping'. The construction of a desired motion basically deals with the mathematical problems of geometric dynamic short term planning. The result of gd-plan construction is a set of parameters, a gd-plan, that describes a desired motion of the vehicle for the next control interval. Plan-to-action mapping approximates the inverse system function in order to make the vehicle move as specified by the gd-plan. This presentation gives a brief overview over gd-plan construction and plan-to-action mapping for the control of an articulated vehicle. Finally, some results show the potential of the driver model.

1D-4 Cancellation of Vibration Feedthrough using a Force-Reflecting Joystick

Steve Lee and Brent Gillespie (University of Michigan)

This presentation examines the control and dynamics of joystick-controlled vehicles and attempts to improve performance through the cancellation of feedthrough vibration using a force-reflecting joystick. Feedthrough vibration refers to non-voluntary joystick control inputs that arise from the action of inertia forces on the operator's body and arm. This effect occurs in all manner of joystick-controlled vehicles from fly-by-wire jets, where the phenomenon is known as roll ratcheting, to wheelchairs, where the phenomenon is called bucking. To eliminate feedthrough vibrations, a canceling force is produced on the force-reflecting joystick using a model of the pilot dynamics and the known vehicle accelerations. Parameter values for the pilot model are estimated by observing the response of the operator's body to known accelerations. A set of experiments was performed utilizing the U.S. Army's Ride Motion Simulator, a motion platform, in conjunction with TACOM's Motion Base Technologies Team.

2 Symposium II

2A Hybrid Electric Systems I (Session Chair: Brent Gillespie)

2A-1 Multivariable control of breathing systems in automotive powertrains: A case study on Fuel cells

Anna Stefanopoulou (University of Michigan)

In this talk we will review research in control of systems with multi-loop conflicts and subsystem interactions with emphasis on IC engine breathing systems. We will then motivate a new ARC project that addresses the coordination of hydrogen and air subsystems for transient fuel cell loading control. The breathing process of a proton exchange membrane fuel cell (PEMFC) is a multi-input multi-output system with transient performance requirements, bandwidth limitations, nonlinear internal feedback loops between flow and pressure regulation. Currently these issues are not addressed in a comprehensive way and the main emphasis is in the system integration for nominal operating conditions. Classical single-input single-output controllers are employed for each loop and tuned or detuned based on subsequent loop interaction. This typically leads to complex calibration procedures and sub-optimal performance.

2A-2 Hierarchical Modeling of Hybrid Electric Vehicle Systems

Loucas Louca and Umut Yildir (University of Michigan)

A model for the simulation of hybrid trucks mobility has been developed using the 20-SIM modeling and simulation computer environment. Our current focus is on a series configuration that has apparent advantages for truck designs with high ground clearance. SH-VESIM (Series Hybrid-Vehicle Engine SIMulation), our current mobility simulation package is upgraded to include models of hybrid powertrains, hybrid power plant controllers and enhanced vehicle dynamics reflecting the characteristics of future hybrid trucks. The necessary complexity of the different component models is determined using MORA, a previously developed energy-based model selection procedure. This approach provides the flexibility to easily modify the system model structure, and complexity of individual components in order to generate a system model that is able to accurately predict the system behavior. A library of component models is built to allow recycling of these components in system models of new vehicle designs. Furthermore, the 20-SIM environment allows the transfer of individual components or the overall system model to other simulation environments, e.g., MATLAB Simulink, through standard C code modules. SH-VESIM is used within other ARC projects for designing the power controller and design studies using the target cascading framework.

2A-3 Energy management strategy for a parallel hybrid electric vehicle

Joe Lin and Huei Peng (University of Michigan)

Due to the complex nature of hybrid electric vehicles, control strategies based on engineering intuition frequently fail to achieve satisfactory overall system efficiency. This study presents a procedure for improving the energy management strategy for a parallel hybrid electric truck on the basis of dynamic optimization over a given driving cycle. Dynamic Programming techniques are utilized to determine the optimal control actions for a hybrid powertrain in order to minimize fuel consumption. By carefully analyzing the resulting optimal policy, new rules can be ascertained to improve the basic control strategy. The resulting new control strategy is shown to achieve better fuel economy through simulations on a detailed vehicle model.

2B Hybrid Electric Systems II (Session Chair: Huei Peng)

2B-1 Nonlinear Modeling and Analysis of Power-Assist Steering Systems for Hybrid Vehicles

V. Mills, D. Dawson, I, Haque, J. Wagner (Clemson University)

Hybrid vehicles integrate an internal combustion engine, electric motor with accompanying battery pack and generator, and potentially fuel cells to realize greater fuel economy and reduced emission levels. An attractive advantage of multiple energy sources is the increased travel range, reduced stationary recharging times, and availability of greater power for acceleration and payloads. A variety of operating scenarios exist for hybrid vehicle powertrains including engine (and belt driven generator), electric motor using battery back and/or fuel cell, and finally, engine and electric motor. Therefore, automotive subsystems such as hydraulic power steering cannot be consistently powered by a conventional belt driven hydraulic pump since the engine may be frequently turned-off to conserve energy. A need exists to investigate the dynamic behavior of power-assisted steering systems for hybrid vehicles in terms of platform steering characteristics, power consumption, control, and identification of performance requirements for a servo-motor steering system. In this paper, an empirical and analytical mathematical model will be presented for a power rack and pinion steering unit. The influence of vehicle and steering system nonlinearities will be introduced for greater accuracy in predicting the vehicle's transient response. Representative results will be presented and discussed to investigate the response of a vehicle to different driver inputs as the steering system parameters are adjusted. An analysis of the numerical results will allow the prediction of vehicle trajectory and feedback torque during the driving maneuvers.

2B-2 Nonlinear Modeling and Control of a Continuously Variable Transmission (CVT) for Hybrid Vehicle Powertrains

P. Setlur, B. Samuels, D. M. Dawson, and J. R. Wagner (Clemson University)

Automotive engineers are continuously exploring various engine, transmission, and chassis technologies to increase overall vehicle performance, fuel economy, and safety. One promising powertrain concept is the continuously variable transmission (CVT) which offers a continuum of infinitely variable gear ratios between established minimum and maximum limits. This continuous gear ratio spectrum can increase the overall powertrain efficiency and eliminate the unwanted jerks associated with manual and automatic transmissions. Although basic CVT designs may have difficulty with high torque/low speed requirements, a hybrid power split continuously variable transmission configuration offers both fixed gearing and adjustable pulleys to satisfy driving demands. The effective control of the variable radius pulleys allows the designation of engine torque/speed to optimize overall system performance for the given operating condition. In this paper, the fundamental components, configuration, and kinematics of a power split CVT will be discussed. A suite of mathematical models will be presented which includes the internal combustion spark ignition engine, clutch, transmission differential, and chassis dynamics. The problem of wheel speed (i.e., cruise) control of a CVT equipped vehicle will be considered. An innovative adaptive nonlinear controller will be designed to ensure global asymptotic tracking of the desired wheel speed with consideration of engine speed. Representative numerical results are presented and discussed to demonstrate the ability of the integrated CVT and engine controller in tracking the prescribed wheel and engine speeds.

2B-3 Hybrid Electric Vehicle Virtual Proving Grounds

Chris Schwarz (University of Iowa)

A Virtual Proving Ground environment for a real-time hybrid-electric vehicle system using the NADS instrument will be presented. Details on the powertrain modeling and real-time implementation issues will be given with a number of accompanying technologies and tools that will help to carry out driver in the loop studies for HEV systems.

2C Noise, Vibration and Harshness (Session Chair: Nick Vlahopoulos)

2C-1 Modeling Track/Terrain Interaction for Simulation of Tracked Vehicles

Zheng-Dong Ma, Jae-Hong Lee and Noel Perkins (University of Michigan)

This presentation will summarize our research in simulating tracked vehicle dynamics with a focus on modeling the interaction of the track with the terrain. The track/terrain interface model is the critical issue for accurately simulating the dynamic response of tracked vehicles. The challenges in modeling this interface result from difficulties in characterizing the mechanics of the terrain, the nonlinear mechanics of the track, and then coupling the interface models to the remainder of the vehicle. To address these challenges, we will review a novel formulation of the track/terrain interface that represents the track as a continuum. Finite element discretization of the track continuum model leads to a nonlinear boundary-value problem that is solved at each time step during a simulation. Computed solutions will illustrate how the track deforms under the action of sinkage and bridging on rough terrain. In addition, results will also illustrate the seismic loading produced by the tracked vehicle. The extensive numerical effort in obtaining solutions by finite element discretization has motivated us to develop simple analytic approximations. Several approximations will be reviewed with a view towards their future use for real-time simulation of tracked-vehicle dynamics.

2C-2 Statistical Approximations of Mid-Frequency Vibration and Power Flow in Vehicle Structures

Yung-Chang Tan, Matt Castanier and Christophe Pierre (University of Michigan)

A technique is presented for generating low order models of vibration and power flow from a finite element model of arbitrary size and complexity. This method is based on component mode synthesis, but in addition to the classical component modes, an additional set of modes corresponding to interface motion is obtained. These interface modes are called the characteristic constraint (CC) modes. By truncating the set of CC modes, highly efficient yet accurate models of vibration and power flow can be generated for a selected frequency band, including the mid-frequency range. This allows the analysis of global modes and vibration response for an entire vehicle structure. Furthermore, it is shown that the technique can be extended to determine the effect of parameter uncertainties (e.g., manufacturing tolerances) on the vibration transmitted through the structure. Computational results are shown for a military vehicle and for a pick-up truck.

2C-3 Development of a Hybrid Finite Element Method for Mid-Frequency Computations

Nick Vlahopoulos, Sang-Bum Hong (University of Michigan) and Jenny X. Zhao (General Motors)

A hybrid finite element method is being developed for mid-frequency NVH computations. The mid-frequency region in automotive NVH applications (100Hz-600Hz) is defined as the frequency range where some components of a vehicle system demonstrate low modal overlap, resonant behavior, and contain a small number of wavelengths within their dimension (stiff members). The remaining components demonstrate high modal overlap, incoherent behavior, and contain a large number of wavelengths within their dimension (flexible members). In a vehicle body, the members that provide structural integrity constitute the stiff members, while the panels constitute the flexible members. The acoustic space of the vehicle interior also behaves as a “stiff” member with low modal overlap due to the long acoustic wavelengths exhibited at frequencies below 600Hz. The differences in the dynamic behavior between the stiff and the flexible members are amplified in hybrid vehicles where the body structures are made by lightweight materials. In the hybrid finite element method being developed, the behavior of the flexible members is modeled by energy-based variables, while conventional displacement-based variables are employed for modeling the stiff members. In addition, manufacturing tolerances introduce significant variations in the NVH characteristics of vehicles in the mid-frequency range. Thus, fast probability integration algorithms are combined with conventional computational methods in order to simulate manufacturing variability in the NVH performance of a vehicle.

2C-4 A Sequential Adjoint Variable Method in Design Sensitivity Analysis of a NVH Problem

Nam Ho Kim, Jun Dong, KK Choi (University of Iowa), Zheng-Dong Ma and Nick Vlahopoulos (University of Michigan)

A design sensitivity analysis of a sequential structural-acoustic problem is presented in which the structural and the acoustic behaviors are de-coupled. Frequency response is used to analyze the dynamic behavior of an automotive structure, while the boundary element method is used to solve the pressure response of an interior, acoustic domain. For the purposes of design sensitivity analysis, a direct differentiation method and an adjoint variable method are presented. In the adjoint variable method, an adjoint load is obtained from the acoustic boundary element re-analysis, and the adjoint solution is calculated from the structural dynamic re-analysis. The evaluation of pressure sensitivity only involves the numerical integration of the structural part.

2D Structures and Materials (Session Chair: KK Choi)

2D-1 Reliability-Based Design Optimization Using Moving Least Square Method

KK Choi, Byung-Dong Youn (University of Iowa) and Ren-Jye Yang (Ford Motor Company)

The conventional Reliability-Based Design Optimization (RBDO) method involves evaluation of probabilistic constraints by using the first-order reliability method (FORM) to obtain the reliability index for each constraint. This is called the reliability index approach (RIA). However, it has been noted that RIA behaves slow convergence or even divergence for some problems. To alleviate this problem, a performance measure approach (PMA) is proposed for robust and efficient reliability analysis. For the numerical solution of PMA, the Advanced Mean Value (AMV) method can be used. However, it is found that AMV diverges for concave constraint functions, although it is effective for convex constraint functions. To overcome difficulties of the AMV method, the conjugate mean value (CMV) method is proposed for the concave constraint function in PMA. By combining CMV and AMV, a hybrid mean value (HMV) is developed, where CMV is used for the concave constraint functions and AMV is used for the convex constraint functions. Even with the efficient HMV method in PMA, the RBDO process is very expensive for large-scale applications. Thus, a response surface method (RSM) is proposed to obtain reliability-based optimum designs at affordable computational cost. The proposed RSM employs a moving lease square (MLS) method and a new design of experiment (DOE) to better approximate the implicit response by imposing a variable weight over a compact support.

2D-2 Design of Heterogeneous Multi-Material Structures

Y. Hu, J. Neal, V. Blouin and G. Fadel (Clemson University)

Rapid Prototyping has made the use of heterogeneous materials possible to create high performance components. Several optimization techniques are investigated for various applications. In multi-material flywheel optimization, a parametric representation method is used to model the material distribution, a cell based inclusion method calculates the effective material properties, and Bezier curves are used to control the flywheel profile. Multi-objective optimization techniques are used to reach the best solution for maximum stored energy and minimum stress. Topology and material optimizations can be accomplished simultaneously in structural problems using genetic algorithms. Fitness values for the material arrangements are calculated using standard finite element method. The optimization objectives are to minimize weight while maintaining structural integrity sufficient to support the applied loads without exceeding the maximum allowable stresses. This research demonstrates that these methods can be successfully utilized to accomplish multi-material optimization of high performance vehicle components.

2D-3 Optimum Design of Laminated Plates with Frequency Constraints

Noboru Kikuchi and Hong Li (University of Michigan)

This paper integrates the homogenization method and the two-point approximation method to obtain the optimum design of composite laminates with frequency constraints. The homogenization method bridges the micro-scale properties and the macro-scale ones. The two-point approximation method recasts the highly nonlinear eigen-frequency problem as an approximate eigen-frequency problem with moving limits, which is computationally inexpensive. Several design examples are given, among which are special cases such as the static design of the simply supported homogenous plate. These examples demonstrate the efficiency of this integrated approach. This research may be expanded to include the optimum design with mode shape and energy constraints. Future work will also consider the cost of fabricating the composite materials and statistical optimum design, etc.

2D-4 A New Approach to the Identification of Eigen-Systems of Large-Scale Structures

Noboru Kikuchi and Hong Li (University of Michigan)

This research aims at reducing the computing time without losing accuracy in the identification of the eigen-systems of large-scale structures. The voxel-based finite element scheme is employed to save human resources to build the FEM models. The direct time integration is carried out to obtain the transient response to excitation forces. Either the time domain response or its counterpart in the frequency domain will be studied to identify the eigen-systems. To investigate the numerical properties of the proposed approach, several computing examples will be provided. Tentative suggestions will be given regarding the use of this approach.

3 Symposium III

3A Diesel Combustion Processes (Session Chair: Naeim Henein)

3A-1 Welcome and introduction

Session Opening Remarks, Naeim Henein, (Wayne State University)

FCS: Future Combat Systems, Walter Bryzik (TARDEC)

3A-2 Multi-Zone DI Diesel Spray Combustion Model for Cycle Simulation Studies of Engine Performance and Emissions

Dohoy Jung and Dennis Assanis (University of Michigan)

A quasi-dimensional, multi-zone, direct injection (DI) diesel combustion model has been developed and implemented in a full cycle simulation of a turbocharged engine. The combustion model accounts for transient fuel spray evolution, fuel-air mixing, ignition, combustion and NO and soot pollutant formation. In the model, the fuel spray is divided into a number of zones, which are treated as open systems. While mass and energy equations are solved for each zone, a simplified momentum conservation equation is used to calculate the amount of air entrained into each zone. Details of the DI spray, combustion model and its implementation into the cycle simulation of Assanis and Heywood [1] are described in this paper. The model is validated with experimental data obtained in a constant volume chamber and engines. First, predictions of spray penetration and spray angle are validated against measurements in a pressurized constant volume chamber. Subsequently, predictions of heat release rate, as well as NO and soot emissions are compared with experimental data obtained from representative heavy-duty, turbocharged diesel engines. It is demonstrated that the model can predict the rate of heat release and engine performance with high fidelity. However, additional effort is required to enhance the fidelity of NO and soot predictions across a wide range of operating conditions.

3A-3 Phenomenological Soot Modeling

Dave Foster (University of Wisconsin)

Future Combat Systems for the military need to employ efficient, high power density energy converters for their mobility units. The diesel engine is a candidate powerplant for this application, however its power density is limited by the air – fuel mixing processes in the engine cylinder. It is easy to identify the point at which the air-fuel mixing limit has been exceeded; black smoke – particulate matter, soot – is emitted from the engine. The emission of significant quantities of particulate matter, soot, indicate the operating point at which increases in power are being obtained at significant cost in increased fuel consumption. If one wants to explore the potential development of FCS powertrain though simulation efforts, and if the powertrains being considered include diesel engines, then a model for predicting the soot emission needs to be included. The objective of the ARC supported research being conducted at the Engine Research Center (ERC) in Madison is to develop a soot sub-model for inclusion into the ARC modular powertrain engine model. The models being used for the ARC simulation effort do not included spatially resolved calculations. Therefore the soot model must be able to predict spatially dependant phenomena using only time dependant variables. This presentation will give an overview of our approach to incorporating spatially dependent information into a zero-dimensional model. We will present our ideas on incorporating spatial information for such parameters as air - fuel ratio, fuel spray geometry, temperature and pressure as well as their rates of change into a multi-zonal spatially independent model. How the sub-model being developed integrates into the overall powertrain simulation will also be presented.

3B Injection and Combustion Diagnostics (Session Chair: Dave Foster)

3B-1 Heavy-Duty Diesel Engine Diagnostics Using Videoscope Technology

Tim Jacobs, Zoran Filipi and Dennis Assanis (University of Michigan)

The use of a high-speed color camera for visualizing Diesel injection spray and combustion provides meaningful qualitative and quantitative analysis. The new insight into injection and combustion processes under realistic in-cylinder conditions is an important component of research leading towards increased power density and efficiency of diesels for Future Combat Systems. This videoscope technology has been implemented for visualizing in-cylinder physical phenomena and thus supporting diesel engine modeling work within the Advanced Propulsion Systems area. Experimental insight Multizonal spray and combustion can now be validated with true experimental visualization. This presentation highlights the design and implementation of the AVL 513D Videoscope, and analyzes the visual inspection of start of injection and combustion features in the heavy-duty diesel.

3B-2 Actual versus Ideal Performance of a Common Rail Injection System in a Direct Injection Diesel Engine

Inderpal Singh, Joong-Sub Han, Lourun Zhong, Ming-Chia Lai and Naeim A. Henein (Wayne State University)

Diesel Common Rail Systems (CRS) are expected to be applied in heavy duty diesel engines for dual use as well as military Future Combat Systems. One of the important features of the CRS is its ability to control of the fuel delivery in the pilot, main and post injection modes independently of engine speed. This is achieved by precisely controlling the timing and period of injection in each of these modes, on the assumption that the pressure in the common rail is constant during the whole injection process. This paper examines the interactions between the common rail and injector under actual engine running conditions. Experiments covered a broad range of pilot and post injection timings and rates. The effects on different engine performance and emissions parameters and the trade-off between the NOx and particulate matter are presented.

3B-3 Visualization of Diesel Spray Combustion under Different EGR and Swirl Ratios

Pai-Hsiu Lu, Joong-Sub Han, Xingbin Xie, Ming-Chia Lai and Naeim A. Henein (Wayne State University)

An experimental study to characterize simulated combustion processes in high-speed small bore direct injection diesel engines, potentially used for Future Combat System (FCS), is described. The dynamics of sprays from various new designs of the mini-sac and valve-covered-orifice nozzles, using high-pressure diesel common-rail system, were characterized. High-speed movies up to 35,000 frame-per-second are taken using a framing drum camera to record the combustion events. Typical combustion visualization results of diesel spray tip penetration, spray/wall/swirl interactions, ignition and combustion under different EGR, swirl, injection pressure and nozzle conditions are presented. The results show that liquid spray could be influenced by the nozzle shape design including hydro-erosion or K-factor. The results confirm earlier engine combustion results, which show that EGR decreases the heat-release rate and increases the soot luminous radiation. Higher injection pressures do not always provide better soot emission results at high EGR conditions, due to wall interactions. Therefore, the trade-off between soot-NOx should be optimized with injection pressure and swirl ratio in small-bore high-speed diesel engines.

3C Hybrid Propulsion Systems and Fuel Cells (Session Chair: Doug Goering)

3C-1 HEV PSAT and ADVISOR Platforms

Nabil Chalhoub and Bogdan Nitu (Wayne State University)

This work performs a comparative analysis between two commonly used vehicle simulation platforms namely ADVISOR and PSAT. The scope of this study will be on the HEV powertrain configuration. The emphasis will be on the platform accuracy, speed of execution and the ability to predict transient behavior of the engine under the HEV configuration.

3C-2 Advanced Hybrid Propulsion Systems Architectures for Future Light and Medium Trucks

Zoran Filipi, Bin Wu, Chan-Chiao (Joe) Lin and Dennis Assanis (University of Michigan)

The new generation of agile, fuel-efficient military vehicles suitable for Future Combat Systems requires advanced powertrain architectures with high power density and regenerative capability. It is anticipated that the parallel configuration will be more attractive than series for dual use vehicles, i.e. trucks that can be used for either military or commercial purposes. This simulation study compares hybrid propulsion system concepts based on coupling of the diesel engine with electric or hydraulic motors and generators/pumps. The discussion of the merits of each of the concepts is followed by the simulation study of their potential for improvement of vehicle fuel economy.

3C-3 Development of a Forward-Looking Fuel Cell Vehicle Simulation

Selim Buyuktur, Margaret Wooldridge and Dennis Assanis (University of Michigan)

A fuel cell vehicle simulation tool (FC-VESIM) has been developed at the Automotive Research Center (ARC) of the University of Michigan to study the different aspects of the newly developing fuel cell technology in automotive applications. In this paper, the integration of a feed-forward fuel cell vehicle system into SIMULINK is described, together with basic features of fuel cells and the subsystem modules. The 0 to 60 mph acceleration performance and fuel economy results over the urban driving cycle are also presented.

3C-4 Performance Of Hybrid And Fuel-Cell Vehicles At Low Temperatures

Jonah Lee, Doug Goering, Beiqing Huang, Jingbo Li, Tom Johnson, Ron Johnson and Jack Schmidt (University of Alaska Fairbanks)

Laboratory and modeling studies aimed at improved model simulations for hybrid and fuel cell powered vehicles are being conducted. Fuel cell data collected in the laboratory is being incorporated into appropriate modules in the Advisor and PSAT simulation codes in order to improve predictive capability. Measured data includes the impact of parasitic loads caused by gas and liquid handling systems. Battery systems are also being evaluated at the extreme temperatures typical of Alaska's arctic climate. NiMH battery technology, typical of current EV and HEV systems, are being tested at low temperatures and at the high charge/discharge rates typical of HEV applications. The data is being used to extend and improve HEV simulation modules contained within Advisor and PSAT.

3D Advanced Diesel Engine Systems (Session Chair: Zoran Filipi)

3D-1 The Reverse Engineering of a Turbocharged Diesel Engine through a Unified Systems Approach

George Delagrammatikas and Dennis Assanis (University of Michigan)

The need for a rigorous systems engineering approach to automotive powertrains has been addressed in this work from the perspective of the diesel engine. A high-fidelity engine simulation has been integrated with a total vehicle model for the purpose of reverse engineering the optimal powerplant for a given vehicle mission. Engine parameters have been coordinated between the simulations to develop a framework for total vehicle design. These design strategies allow engine researchers to set targets for individual system components and to analyze the tradeoffs associated with different vehicle mission objectives. A detailed case study employing these techniques is presented for a conventional vehicle where the most fuel-efficient engine is found that simultaneously conforms to the desired performance criteria.

3D-2 On Board Non-Intrusive Diagnostics System of Faulty Cylinder(s) in Multi-Cylinder Diesel Engines

Dinu Taraza, Naeim A. Henein and Walter Bryzik (Wayne State University)

The variation of the angular velocity of the crankshaft is determined by the gas-pressure torque and the reciprocating inertia torque of individual cylinders and is highly influenced by the elasticity of the crankshaft and its torsional vibrations. In order to avoid the influence of vibrations and extract the information regarding the gas-pressure torque of individual cylinders, only the lowest harmonic order of the measured crankshaft's speed is determined by Discrete Fourier Transform. The amplitude and phase of this harmonic component are used to determine if all cylinders are uniformly contributing to the total engine output and, if a cylinder is deficient to be identified. The technique developed in this investigation can be used for on board non-intrusive diagnostics of faulty cylinders and implementation in engine electronic controls**.**

3D-3 Environmental Effects on Engine Cold-Start - A Tribological Systems Approach

Guizhen Helen Xu, Stephen Meurer, Mathea E. Rasmussen, Frank Toth, Hong Liang, Jonah Lee and Doug Goering (University of Alaska Fairbanks)

Alaska's arctic climate offers a unique environment for engine studies. Low temperatures, in particular, challenge engine performance, efficiency, corrosion resistance, and service life. At the beginning of a long-term investigation, we discovered that one of the key factors affecting engine cold-start is the presence of condensed water that accumulates on critical engine surfaces. In this presentation we illustrate a test system that we assembled in order to investigate the effect of condensed water. We discuss initial findings regarding the friction, wear, and oxidation behavior of an engine influenced by condensed water due to low ambient temperature.

3D-4 Effect of EGR System on Autoignition, Combustion and Emissions in DI Diesel Engine

Bogdan Nitu, Inderpal Singh, Lourun Zhong, Kamal Badresheni, Walter Bryzik and Naeim Henein

An experimental investigation was conducted to determine the effect of EGR on the autoignition, combustion and emissions in diesel engines. The experiments, conducted on two different engines, covered a wide range of EGR ratios, injection pressures, supercharging pressures and temperatures, speeds and loads. One engine had the pump-line-injector fuel system, and the other had a common rail injection system. EGR was found to increase the ignition delay, and thus affect the premixed combustion and most of the emissions. A detailed analysis showed that EGR had no effect on the global activation energy of the autoignition reactions. Accordingly, a new formulation was developed for the ignition delay to account for the change in oxygen concentration with EGR. The emissions measured include NO_X, Bosch Smoke Unit, HC, CO and aldehydes. The analysis indicated that the major effect of EGR on combustion and emissions is related to its effect on oxygen concentration.

4 Parallel Session IV

4A Internet Initiatives (Session Chair: Greg Hulbert)

4A-1 The iARC Portal

Matt Parkinson and Panos Papalambros (University of Michigan)

The Hyperwave-based iARC portal was rolled-out several months ago. This presentation discusses how the portal can be used to improve collaborative efforts within research groups and across the ARC collaborative partners. Activities such as online discussions and the archiving of project information will be covered.

4A-2 A Software Framework for Engineering System Design through Distributed Virtual Prototyping

Sharat Shroff, Ed Kokko, Matt Parkinson, Hyung-Min Kim, Zheng-Dong Ma, Nestor Michelena, Michael Kokkolaras, Dohoy Jung, Greg Hulbert, H.V. Jagadish, Kazuhiro Saitou and Panos Papalambros (University of Michigan)

We propose to create the fundamental software technology enabling an online “marketplace” for simulation-based, development of large-scale engineering products via distributed virtual prototyping. We predict that such a marketplace will be the dominant mechanism large companies will use to bring new products to market, quickly and successfully. In this marketplace, analysts and designers from product assemblers and suppliers will participate by registering and searching for the proper analysis and design models required for building the product's virtual prototype. Having found the desired models, the models can then be glued together to perform the required analysis and/or design tasks.

In this talk we will describe the results of our research during the past year towards building this fundamental software framework. We will present our prototype that we have come up, in the form a document type descriptor (DTD) for a model description. This descriptor is based primarily on the set of inputs and outputs of the model, and on characteristics of each of these inputs and outputs, as well as of the model itself. The range of characteristics considered is quite broad: ranging, for example, from whether the model is static or dynamic (time-varying), and the operating system it runs on, to what its typical running time is given a certain set of input parameter values and a certain machine configuration. Examples of models implemented into our model database will be highlighted.

4A-3 Collaborative Distributed Design

Georges Fadel (Clemson University)

As companies are becoming more global, and products more complex, the need to have distributed teams design is becoming critical. This presentation summarizes the approach taken by three universities, the Technische Universitat Darmstadt, Technische Universitat Munich and Clemson University to design collaboratively a thermodynamic test engine for BMW. The issues of distributed teaming, of data sharing and exchange as well as the logistics of managing and executing such a project along with the lessons learned and achievements will be presented.

4B Product Development and Design (Session Chair: Panos Papalambros)

4B-1 Organizational Design of a Product Development Process

Adam Cooper, Panayiotis Georgiopoulos, Nestor Michelena, Panos Papalambros and Wayne Baker (University of Michigan)

For a product development process to succeed, there are countless interactions between engineers to not only finalize an idea, but to complete the project in an efficient manner. The organization structure, which determines how these engineers interact, is thus a very important aspect of the product development process. This research proposes a method to determine the alignment of an organizational structure based on its product development process. The focus is to correlate the social interaction with the engineering procedures. The Automotive Research Center (ARC) is an ideal paradigm to this research because of its engineering abilities. An online questionnaire was developed to collect data for this research. The questionnaire examines the ARC members' involvement with the engineering models they use to investigate Army vehicle's performance and also the interaction among one another. This maps the engineering interactions of the information flow and the social network created by the organization. The data will be used to determine if a more efficient configuration exists between the product development process and organization structure.

4B-2 Enterprise-Wide Product Design

Olena Sinkevich, Panayiotis Georgiopoulos, Ryan Fellini, Eric Rask, Richard Gonzalez and Panos Papalambros (University of Michigan)

In a traditional math-based design process we start with analysis models based on principles of engineering science. The decision process is to select a design in the feasible space that minimizes the objective function. Such models tend to include only engineering decisions since their functions are based on the physical sciences. A first step in aligning engineering with enterprise-wide decision-making is to identify a consistent and formal way to include customer preferences in the design decision model. A manager's "big picture" decision must account for additional requirements based on existing market conditions to select one or more of the feasible designs for market launch. A formal, flexible and easy to modify approach that links engineering to business decisions will be presented. The product platform design approach previously applied to a family of advanced automotive powertrains will be used to illustrate the framework.

Another important question in the design of the product is the interaction between engineers and designers/artists. The success of the product on the market depends on the success of such collaboration. We have designed and conducted the study that is aimed at providing more understanding about the values that engineers and designers/artists hold and about their similarities and differences. We will discuss the study and its results.

4C Target Cascading (Session Chair: Nestor Michelena)

4C-1 Analytical Target Cascading in Product Development

George Delagrammatikas, Hyung Min Kim, Michael Kokkolaras, Loucas Louca, Umut Yildir, Dennis Assanis, Zoran Filipi, Nestor Michelena and Panos Papalambros (University of Michigan)

Target cascading in product development is a systematic effort to propagate the desired top-level system design targets to appropriate specifications for subsystems and components in a consistent and efficient manner. If analysis models are available to represent the relevant design decisions, analytical target cascading can be formalized as a hierarchical multilevel optimization problem. In this presentation, target cascading is demonstrated for the conventional class VI vehicle design for fuel economy and ride quality targets. VESIM vehicle analysis model is developed at the system level and the suspension, engine, and transmission models are integrated at the subsystem level. SQP and DIRECT are applied to obtain consistent subsystem targets and optimal designs.

4C-2 Target Cascading and Convergence Issues

H. Alan Park (Oakland University), Nestor Michelena, and Panos Papalambros (University of Michigan)

Target Cascading is a method of coordinating many subsystem designs to achieve a near-optimal system design. However it is not known when this coordination method produces an optimal system-wide design. In this talk, we reformulate Target Cascading in the framework of hierarchical overlapping coordination (HOC). In the case of linear constraints, Lagrange Multiplier Theorem can be applied to the resulting HOC problem.

This produces some conditions under which the original Target Cascading problem should converge to an optimal solution. Any Target Cascading problem with linear constraints can be shown to satisfy these convergence conditions, and therefore convergence is guaranteed. An extension to the case of nonlinear constraints will also be outlined.

4C-3 Product Platform Design

Ryan Fellini, Panayiotis Georgiopoulos, Hyung-Min Kim, Michael Kokkolaras, Nestor Michelena, Panos Papalambros, Mike Sasena, and Olena Sinkevich (University of Michigan)

Product platforms (defined in the literature as the set of subsystems, interfaces, and manufacturing processes that are shared among a set of products) allow the development of product families and enable rapid enrichment of a product portfolio to meet changing market needs while keeping design and manufacturing cycle times and costs low. Product variants within a family are typically characterized by conflicting performance criteria. In this regard, the product platform architecture is determined through the solution of multi-objective optimization problems. The associated trade-offs are evaluated using, for example, Pareto theory, and design decisions are made based on engineering, manufacturing, formalized customer preferences, and business related criteria. Analytical target cascading (a novel methodology for the design of large engineering systems at the early product development stages) is extended for optimal product platform design with a fixed commonality architecture.

The single-product formulation is modified to accommodate the presence of shared systems, subsystems, and/or components. Surrogate modeling enables the efficient solution of the high level, low fidelity subproblems, while the solution of the overall design problem is coordinated so that the shared elements are consistent with the performance and behavior of the product variants. An automotive design example is demonstrated.

4D Integrated Design and Simulation (Session Chair: Georges Fadel)

4D-1 Gluing Algorithms for Distributed Simulation

Ed Kokko, Zheng-Dong Ma and Greg Hulbert (University of Michigan)

To realize the goal of complete vehicle simulation and design, methodologies are needed to combine different simulation programs together without requiring code developers to rewrite their programs or for modelers to rebuild their models into all-in-one programs. The purpose of a gluing algorithm is to integrate these different simulation modules together in the least intrusive manner possible.

As part of earlier ARC research, we developed two different types of gluing algorithms. In this presentation, we will discuss one implementation of the Manifold Orthogonal Projection (MOP) Method. In particular, we will highlight some of the fundamental challenges that remain to achieve accurate coupled simulation using the MOP scheme.

4D-2 Multi-Criteria, Multi-Scenario Optimization of the Dynamic, Performance of Vehicles

Imtiaz Haque (Clemson University)

The paper presents a Monte-Carlo approach to simulation-based vehicle design with multiple objectives and multiple scenarios. In the current study, an 8 Degree-of-Freedom vehicle model representing the lateral dynamics of an automobile is used to generate the results. The model is used to simulate a number of ISO maneuvers and improve vehicle handling across all the maneuvers. A relatively large number of design variables have been considered. ISO-standard Performance Indices are calculated for each individual maneuver considered. Vehicle performance is judged based on improvements in these indicators.

Correlations between performance indices are developed in the course of the research as are response surfaces that relate each performance index to the design variables. This information can be utilized in deterministic optimization methods for finding optimum designs.

Results of this approach show good improvements in vehicle performance for the dynamic indicators and maneuvers considered. Extensions of this approach are currently being explored for heavy vehicles.

4D-3 Bi-Scenario Bi-Criteria Optimization in Vehicle Design

Margaret M. Wiecek, Brian Hunt and Vijay Singh (Clemson University)

A vehicle needs to be designed to perform acceptably with respect to a set of performance criteria used to evaluate the vehicle. The vehicle may also be expected to meet certain performance requirements over a set of different driving scenarios that may be encountered. In a particular driving scenario, the designer may consider specific performance criteria and ignore some others, or may consider some criterion more important relative to the other criterion. The former leads the designer to deal with a collection of optimization problems over the common design space. The latter may lead the designer to allow the "more important" criterion to improve while allowing the other criterion to decay within a set of tolerable limits. An improvement in one criterion at the expense of the other criterion is called a tradeoff. The performance criteria or the relative importance of the criteria and the allowable tradeoffs between criteria may change from one scenario to another. The objective of our work is to incorporate scenario-dependent criteria and/or tradeoff allowances into the development of a bi-scenario bi-criteria optimization approach to assist in the design of a vehicle that will meet performance requirements in two driving scenarios. Preliminary structural examples are included.

4D-4 Coupling in Design and Control System Optimization

Julie Ryer and Panos Papalambros

Many engineering systems, such as hybrid electric vehilces, involve a physical object (its embodiment) and its desired dynamic response (its control.) These properties are inherently coupled, though they are typically considered separately. Separate treatments limit the ability to exploit the coupling in the system. Furthermore, separate optimizations do not allow for explorations of the tradeoffs between improving the embodiment or improving the control. In the literature these systems are often optimized using problem specific, ad hoc strategies. The issue is whether the ad hoc strategies are capable of finding the true optimum of the system. If not, can we develop a strategy that will find the system optimum? In this talk we will consider how these strategies can be applied to complex systems, such as automotive applications.