ARC Conference 2002

Eighth Annual ARC Conference on Modeling and Simulation of Ground Vehicles

May 14-15, 2002

GM Tech Center
Warren, MI
University of Michigan
College of Engineering
Ann Arbor, MI

Sponsored by:

- ***Automotive Research Center***
- ***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

ONLINE REGISTRATION

DAY 1 - SCHEDULE

DAY 2 - SCHEDULE

SYMPOSIA MATRIX

SYMPOSIUM ABSTRACTS

ADDITIONAL INFORMATION

MAPS

The Conference will highlight advances in ground vehicle simulation. It will present the results of ARC research to university, industry, and government stakeholders and encourage collaboration between these sectors.

ARC Conference 2002 > Day 1 Schedule

Conference Program

Tuesday, May 14, 2002

(Located at General Motors Tech Center)

7:30 - 8:30 am	**REGISTRATION AND CONTINENTAL BREAKFAST** All photographic equipment (cameras, video cameras, etc.) MUST be pre-registered with GM Security. A form must be filled out for each camera ahead of time otherwise it will be confiscated. Contact: Dawn Ostaczewski, Security Chief, 586-986-7742.	
8:30 - 9:00	**WELCOME AND INTRODUCTIONS**	
		Dennis Assanis, Professor and ARC Director, University of Michigan
		Walter Bryzik, Chief Scientist, U.S. Army TACOM-TARDEC **Dennis Wend,** Director, National Automotive Center, U.S. Army TACOM-TARDEC
9:00 - 10:30	**VIEWPOINTS AND VISIONS FOR AN INDUSTRY-GOVERNMENT-UNIVERSITY COLLABORATIVE RESEARCH AGENDA ON VEHICLE DEVELOPMENT**	
	Moderator:	**Panos Papalambros**, Professor and ARC Executive Director, University of Michigan
	Speakers:	**General Paul J. Kern**, US Army Materiel Command **Major General N. Ross Thompson III**, US Army TACOM **Dr. Hazem Ezzat**, Co-Director, GM-UM Collaborative Research Laboratory **Dan Ustian**, President and Chief Operating Officer, Navistar International Corporation
	Question and Answer Session	
10:30 - 11:00	**NETWORKING BREAK**	
11:00-12:00pm	**HYBRID PROPULSION SYSTEMS FOR IMPROVED MOBILITY AND FUEL ECONOMY OF FUTURE MEDIUM TACTICAL TRUCKS**	
	Speakers:	**Dennis Assanis,** Professor and ARC Director, University of Michigan
		Zoran Filipi, Assoc. Research Scientist & Assistant ARC Director, University of Michigan **Loucas Louca**, Assistant Research Scientist, University of Michigan
12:00-12:30pm	**OVERVIEW OF NAC INITIATIVES**	
	Speaker:	**David Gorsich,** Senior Research Scientist , National Automotive Center, U.S. Army TACOM-TARDEC
12:30 - 1:45	**LUNCH** (Cafeteria)	
1:45 - 2:45 pm	**CHALLENGES IN VEHICLE PRODUCT DEVELOPMENT AND INNOVATION**	
	Speakers:	**Dr. Larry Burns**, Vice-President, Research, Development and Planning, General Motors Company
2:45 - 3:45	**PREDICTION AND DESIGN STRATEGIES TO ACHIEVE LIGHT WEIGHT, REDUCED NVH, AND IMPROVED DURABILITY FOR NEXT-GENERATION VEHICLES**	

Speakers: **Christophe Pierre,** Professor and ARC Thrust Leader, University of Michigan
K.K. Choi, Professor, University of Iowa

3:45 - 4:00 **NETWORKING BREAK**

4:00 - 4:45 **TARGET CASCADING FOR OPTIMAL CVT DESIGN**

Speakers: **George Fadel**, Professor, Clemson University
Vincent Blouin, Research Associate, Clemson University

4:45 - 5:00 **WRAP-UP AND Q & A**

Dennis Assanis, Professor and ARC Director, University of Michigan

5:15 **ADJOURN**

ARC Conference 2002 > Day 2 Schedule

Conference Program

Wednesday, May 15, 2002

(Located at the University of Michigan North Campus)

8:00 - 8:30	**REGISTRATION AND CONTINENTAL BREAKFAST**
8:30 - 9:00	**WELCOME AND INTRODUCTION** (Auditorium) **Dennis Assanis,** Professor and ARC Director, University of Michigan **David Gorsich**, Senior Research Scientist, National Automotive Center, U.S. Army TACOM-TARDEC
9:00 - 4:50	**PARALLEL SYMPOSIA I-IV**

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

Dynamics, Controls, and Structures
Human Centered Modeling and Simulation
Advanced Powertrain Systems
Integrated Product Design and iARC

The four symposia will run concurrent sessions concentrating on specific technical issues. A session matrix plan and abstracts of the technical presentations are included to allow conferees to select from the various topics presented to match their technical interests.

Symposium I

1A Fuel Cell Power

9:00 - 9:25 1A-1 Control-Oriented Modeling of Automotive Fuel Cell Stack System
9:25 - 9:50 1A-2 Experiments on a PEM Fuel Cell During Transient Load Conditions
9:50 - 10:15 1A-3 Control of Fuel Cell Stack Air Supply System and DC/DC Converter

1B Hybrid Component Modeling

10:45 - 11:10 1B-1 Modeling of Integrated Hybrid Vehicle Systems
11:10 - 11:35 1B-2 Modeling and Control of an Alternative Steering System for Hybrid Vehicles
11:35 - 12:00 1B-3 Performance of a Continuously Variable Transmission in a Medium Duty Vehicle - A Case Study

12:00 - 1:00 **LUNCH** (FXB Building)

1C Efficient NVH Analysis and Optimization of Veh. Structures

1:00 - 1:25 1C-1 Energy Boundary Element and Hybrid Finite Element Developments
1:25 - 1:50 1C-2 Component-Based Analysis of Vibration and Power Flow in Vehicle Structures
1:50 - 2:15 1C-3 Design Sensitivity Analysis and Optimization of Complex Vehicle Structures for Minimum Weight
2:15 - 2:40 1C-4 Identification of Lowest Eigen-Systems of Large-Scale Structures

1D Modeling, Simulation and Design of Veh. Structures and Systems

3:10 - 3:35 1D-1 Simulation of Tracked Vehicles: Developments for Robotic Vehicles and for Real-time Simulation
3:35 - 4:00 1D-2 Tire-Soil Modeling and Simulation Methods for VPG Applications
4:00 - 4:25 1D-3 GA-Based Multi-Material Structural Optimization Using Stepwise Mesh Refinement
4:25 - 4:50 1D-4 Adaptive Probability Analysis by Using Performance Measure Approach

Symposium II

2A Human Centered Design I

9:00 - 9:25 2A-1 Overview of Human Centered Design Simulation - Progress and Challenges

9:25 - 9:50	2A-2 Biomechanical Modeling of Shoulder Loading and Perceived Effort during Reaching Task Performance
9:50 - 10:15	2A-3 Modeling the Difficulty of Seated Reaches

2B Human Centered Design II

10:45 - 11:10	2B-1 Task Based Posture Prediction
11:10 - 11:35	2B-2 Surface Reconstruction from Multiple View Range and Color Images for Automotive Parts Reverse Engineering and 3D Scene Building
11:35 - 12:00	2B-3 Analysis and Cancellation of Vibration Feedthrough in Manual Control of Ground Vehicles
12:00 - 1:00	**LUNCH** (FXB Building)

2C Driver Models and Simulation Environments

1:00 - 1:25	2C-1 Further Progress in Development of a Driver Model for Heavy Vehicle Applications
1:25 - 1:50	2C-2 Longitudinal Human Driving Model for Advanced Vehicle Safety Systems
1:50 - 2:15	2C-3 Off-road Real-time Vehicle Simulation Environments
2:15 - 2:40	2C-4 Smoothing and Simplification of Reconstructed Triangle Meshes of As-Built Automotive Parts and Realistic Driving Scenes

2D Modeling and Control of Vehicle Systems

3:10 - 3:35	2D-1 A Systematic Approach to Model Quality Assessment
3:35 - 4:00	2D-2 Enhanced Mobility through Cooperation
4:00 - 4:25	2D-3 Proper Models for Durability Assessment
4:25 - 4:50	2D-4 Numerical Techniques for Real-time Multi-body Dynamics Simulation

Symposium III

3A Diesel Combustion Process

9:00 - 9:25	3A-1 Introduction and Future Directions
9:25 - 9:50	3A-2 Correlating Nozzle Design to the Spray Performance in DI Injectors
9:50 - 10:15	3A-3Refined Model for Combustion and Emissions Predictions in a Heavy-Duty Diesel Engine

3B Control of In-Cylinder Processes

10:45 - 11:10	3B-1 Optimization of Parameters in a HSDI Engine for Minimum Engine-Out Emissions
11:10 - 11:35	3B-2 Experimental Analysis of Exhaust Gas Recirculation Effects on Diesel Engine Combustion
11:35 - 12:00	3B-3 Development and Validation of Unsteady Heat Transfer Model
12:00 - 1:00	**LUNCH** (FXB Building)

3C Hybrid Propulsion Systems

1:00 - 1:25	3C-1 Modeling of a Military Hybrid Vehicle
1:25 - 1:50	3C-2 Analysis of Hybrid Electric and Hydraulic Hybrid Propulsion Systems for Medium Tactical Trucks
1:50 - 2:15	3C-3 MATLAB-Based HD Engine Model Compatible with PSAT Platform for HEV Simulation
2:15 - 2:40	3C-4 Hybrid Electric Vehicle Control for Improved Fuel Economy and Emissions

3D Engine Systems Simulation and Diagnostics

3:10 - 3:35	3D-1 Simulation and Validation of Cold-Start Cranking and Transients
3:35 - 4:00	3D-2 Low Temperature Tribological Behavior of a Solid Lubricating Film
4:00 - 4:25	3D-3 Fast Detection Algorithm for the Identification of Faulty Cylinders in a Multi-Cylinder Diesel Engine
4:25 - 4:50	3D-4 Driving Cycle Assessments of Advanced Diesel Engine Designs using Neural Network Models and Optimization Techniques

Symposium IV

4A Analytical Target Cascading

9:00 - 9:25	4A-1 Analytical Target Cascading for the Design of an Advanced Technology Heavy Truck
9:25 - 9:50	4A-2 Convergence Properties of the Analytical Target Cascading Process
9:50 - 10:15	4A-3 A Duality Perspective on Analytical Target Cascading

4B Distributed Computer-Aided Engineering

10:45 - 11:10	4B-1 Volumetric Part Decomposition of 3-D Triangulated Complex Models for Inspection and Reverse-Engineering of Automotive Parts
11:10 - 11:35	4B-2 Integration of ARC-developed powertrains models into TACOM/TARDEC RTS Environment
11:35 - 12:00	4B-3 Development of Network-Distributed Simulation Toolkit
12:00 - 1:00	**LUNCH** (FXB Building)

	4C Automotive Product Development I
1:00 - 1:25	4C-1 Optimal Design Decisions in Product Valuation Including CAF� Considerations
1:25 - 1:50	4C-2 Commonality Decisions in Product Platform Design: Theory
1:50 - 2:15	4C-3 Commonality Decisions in Product Platform Design: Applications
2:15 - 2:40	4C-4 A Kriging Metamodeling Algorithm for Efficient Simulation-Based Design Optimization
	4D Automotive Product Development II
3:10 - 3:35	4D-1 Multicriteria Multiscenario Design of Vehicles
3:35 - 4:00	4D-2 Combined optimal design and control: theory and application to suspension design
4:00 - 4:25	4D-3 Contingent Weighting of Product Attributes in Interactive Decision-Making
4:25-4:50	4D-4 Extending Energy-based Proper Modeling for Design: Beyond Energetic Elements
4:50	**ADJOURN**

Exhibits and Tour

Concept vehicles will be on display the first day. The second day will feature onsite simulation demonstrations. In addition a tour of the UM Walter E. Lay Automotive Research Laboratory will be given to interested parties. Individuals interested in the tour will need to sign up at the registration desk by noon on the second day.

Time	Symposium I		Symposium II		Symposium III		Symposium IV	
9:00 – 9:25	**Fuel Cell Power**	Control-Oriented Modeling of Automotive Fuel Cell Stack System	Human Centered Design I	Overview of Human Centered Design Simulation - Progress and Challenges	Diesel Combustion Process	Introduction and Future Directions	Analytical Target Cascading	Analytical Target Cascading for the Design of an Advanced Technology Heavy Truck
9:25 – 9:50		Experiments on a PEM Fuel Cell During Transient Load Conditions		Biomechanical Modeling of Shoulder Loading and Perceived Effort during Reaching Task Performance		Correlating Nozzle Design to the Spray Performance in DI Injectors		Convergence Properties of the Analytical Target Cascading Process
9:50 – 10:15		Control of Fuel Cell Stack Air Supply System and DC/DC Converter		Modeling the Difficulty of Seated Reaches		Refined Model for Combustion and Emissions Predictions in a Heavy-Duty Diesel Engine		A Duality Perspective on Analytical Target Cascading
10:15 – 10:45	**Break**							
10:45 – 11:10	Hybrid Component Modeling	Modeling of Integrated Hybrid Vehicle Systems	Human Centered Design II	Task Based Posture Prediction	Control of In-Cylinder Processes	Optimization of Parameters in a HSDI Engine for Minimum Engine-Out Emissions	Distributed Computer-Aided Engineering	Volumetric Part Decomposition of 3-D Triangulated Complex Models for Inspection and Reverse-Engineering of Automotive Parts
11:10 – 11:35		Modeling and Control of an Alternative Steering System for Hybrid Vehicles		Surface Reconstruction from Multiple View Range and Color Images for Automotive Parts Reverse Engineering and 3D Scene Building		Experimental Analysis of Exhaust Gas Recirculation Effects on Diesel Engine Combustion		Integration of ARC-developed powertrains models into TACOM/TARDEC RTS Environment
11:35 – 12:00		Performance of a Continuously Variable Transmission in a Medium Duty Vehicle - A Case Study		Analysis and Cancellation of Vibration Feedthrough in Manual Control of Ground Vehicles		Development and Validation of Unsteady Heat Transfer Model		Development of Network-Distributed Simulation Toolkit
12:00 – 1:00	**Lunch**							
1:00 – 1:25	Efficient NVH Analysis and Optimization of Veh. Structures	Energy Boundary Element and Hybrid Finite Element Developments	Driver Models and Simulation Environments	Further Progress in Development of a Driver Model for Heavy Vehicle Applications	Hybrid Propulsion Systems	Modeling of a Military Hybrid Vehicle	Automotive Product Development I	Optimal Design Decisions in Product Valuation Including CAFÉ Considerations
1:25 – 1:50		Component-Based Analysis of Vibration and Power Flow in Vehicle Structures		Longitudinal Human Driving Model for Advanced Vehicle Safety Systems		Analysis of Hybrid Electric and Hydraulic Hybrid Propulsion Systems for Medium Tactical Trucks		Commonality Decisions in Product Platform Design: Theory
1:50 – 2:15		Design Sensitivity Analysis and Optimization of Complex Vehicle Structures for Minimum Weight		Off-road Real-time Vehicle Simulation Environments		MATLAB-Based HD Engine Model Compatible with PSAT Platform for HEV Simulation		Commonality Decisions in Product Platform Design: Applications
2:15 – 2:40		Identification of Lowest Eigen-Systems of Large-Scale Structures		Smoothing and Simplification of Reconstructed Triangle Meshes of As-Built Automotive Parts and		Hybrid Electric Vehicle Control for Improved Fuel Economy and Emissions		A Kriging Metamodeling Algorithm for Efficient Simulation-Based Design Optimization

				Realistic Driving Scenes				
2:40 – 3:10	**Break**							
3:10 – 3:35	Modeling, Simulation and Design of Veh. Structures and Systems	Simulation of Tracked Vehicles: Developments for Robotic Vehicles and for Real-time Simulation	Modeling and Control of Vehicle Systems	A Systematic Approach to Model Quality Assessment	Engine Systems Simulation and Diagnostics	Simulation and Validation of Cold-Start Cranking and Transients	Automotive Product Development II	Multicriteria Multiscenario Design of Vehicles
3:35 – 4:00		Tire-Soil Modeling and Simulation Methods for VPG Applications		Enhanced Mobility through Cooperation		Low Temperature Tribological Behavior of a Solid Lubricating Film		Combined optimal design and control: theory and application to suspension design
4:00 – 4:25		GA-Based Multi-Material Structural Optimization Using Stepwise Mesh Refinement		Proper Models for Durability Assessment		Fast Detection Algorithm for the Identification of Faulty Cylinders in a Multi-Cylinder Diesel Engine		Contingent Weighting of Product Attributes in Interactive Decision-Making
4:25 – 4:50		Adaptive Probability Analysis by Using Performance Measure Approach		Numerical Techniques for Real-time Multi-body Dynamics Simulation		Driving Cycle Assessments of Advanced Diesel Engine Designs using Neural Network Models and Optimization Techniques		Extending Energy-based Proper Modeling for Design: Beyond Energetic Elements

Conference Program

Day 2

1 Symposium I – Vehicle Dynamics, Controls and Structures

1A Fuel Cell Power

1A-1 Control-Oriented Modeling of Automotive Fuel Cell Stack System

Jay Pukrushpan, Anna Stefanopoulou, Huei Peng

Fuel cell stack systems are under intensive development by several manufacturers since they complement heat engines and reduce the ubiquitous dependence on fossil fuels and thus have significant environmental and national security implications. To compete with ICE engines, however, fuel cell system must operate and function at least as well as conventional engines. Transient behavior is a key requirement for the success of fuel cell vehicles. The fuel cell system power response depends on the air and hydrogen feed, flow and pressure regulation, and heat and water management. During transient, the fuel cell stack control system is required to maintain optimal temperature, membrane hydration, and partial pressure of the reactants across the membrane in order to avoid degradation of the stack voltage, and thus, efficiency reduction. In this presentation, we explain the development of a fuel cell system dynamic model suitable for control study. The transient phenomena captured in the model include the flow characteristics and inertia dynamics of the compressor, the manifold filling dynamics (both anode and cathode), and consequently, the time-evolving reactant partial pressures, and membrane humidity. The effects of varying oxygen concentration and membrane humidity on the fuel cell voltage were included. Simulation results are presented to demonstrate the model capability.

1A-2 Experiments on a PEM Fuel Cell During Transient Load Conditions

Doug Goering, Anna Stefanopoulou, and Dennis Witmer

Experiments have been carried out on a hydrogen-fueled PEM fuel cell stack during transient load fluctuations in an effort to characterize various aspects of its dynamic response. The data acquisition system allowed us to observe individual cell behavior as well as overall stack response to changing conditions. Two types of experiments were performed. The first examined the reaction of the stack to changes in load current. Both small (5%) and large (80%) perturbations were utilized. In the second experiment, the reaction of the stack to changes in oxidant (air) flow rates was examined. This data also provided some insight regarding cathode filling dynamics. Variations in humidity, liquid water content, air flow velocity, and other factors lead to significant cell-to-cell variation within the stack. These variations will exacerbate problems relating to the modeling and control of these systems.

1A-3 Control of Fuel Cell Stack Air Supply System and DC/DC Converter

Jay Pukrushpan, Wei Xi, Anna Stefanopoulou, Huei Peng

To gain satisfactory system power response during transient conditions, fuel cell system controller needs to manage and coordinate reactant supply, heat and temperature, and water supply subsystems. The interactions between these subsystems limit performance of de-centralized control scheme; thus, require multivariable control technique to better achieve control goals. Tradeoffs exist both among the subsystems and within an individual subsystem. In this study, a nonlinear fuel cell system dynamic model is used to analyze and design an air flow controller for the fuel cell stack air supply system that allows fast and robust air flow supply to the fuel cell cathode. Control difficulties arise even during small current demands since the power utilized by the supercharger is a parasitic loss to the fuel cell stack. We show that minimizing the parasitic loss and providing fast airflow regulation are conflicting objectives. An observer based feedback and feedforward controller that manages the tradeoff during rapid current demand will be presented. To overcome the tradeoff during transient, another degree of freedom could be added by coordinating stack DC/DC converter with the air supply system. In this talk, we will also present a model of the DC/DC converter and related control issues.

1B Hybrid Component Modeling

1B-1 Modeling of Integrated Hybrid Vehicle Systems

Loucas Louca

Abstract

1B-2 Modeling and Control of an Alternative Steering System for Hybrid Vehicles

Pradeep Setlur, Val Mills, Dr. John Wagner, and Dr. Darren Dawson

Hybrid vehicles integrate an electric motor with accompanying battery pack and generator, an internal combustion engine, and potentially fuel cells to acquire greater fuel economy and reduced emission levels. Automotive subsystems such as hydraulic power steering cannot be consistently powered by a conventional hydraulic pump as the engine may be frequently turned-off to conserve energy. A need exists to investigate the dynamic behavior and control of these alternative steering systems. In this presentation, empirical and analytical mathematical models will be offered for a steer-by-wire rack and pinion steering unit. A continuous time-varying tracking controller will then be presented to ensure that the vehicle's position and orientation follow a reference vehicle trajectory. In this controller design, the tracking error is globally exponentially forced to a neighborhood about zero that can be made arbitrarily small (i.e., global uniformly ultimately boundedness). The controller also solves the set-point or "parking" problem as an extension of the tracking problem. Representative numerical results will be presented.

1B-3 Performance of a Continuously Variable Transmission in a Medium Duty Vehicle - A Case Study

Bernard Samuels, Pradeep Setlur, Nilabh Srivastava, Dr. John Wagner, Dr. Darren Dawson, and Dr. Imtiaz Haque

The continuously variable transmission (CVT) offers a continuum of infinitely variable gear ratios between established minimum and maximum limits. This continuous gear ratio spectrum eliminates the unwanted jerks associated with manual and automatic transmissions while better accommodating the vehicle's speed demands with the available engine power. Vehicles utilizing continuously variable transmissions offer improved engine efficiency over traditional vehicle powertrains. Although basic CVT designs have difficulty with high torque/low speed requirements, a power split continuously variable transmission (PSCVT) configuration offers both fixed gearing and adjustable pulleys to satisfy driving demands. Effective control of the variable radius pulleys allows the designation of engine torque/speed operating ranges to optimize overall system efficiency for the given operating condition. A multiple inertia power split continuously variable transmission model will be presented and integrated into the Vehicle Engine Simulation (VESIM) environment developed by the Automotive Research Center at the University of Michigan to facilitate the investigation of powertrain systems. Representative numerical results will be presented and discussed to demonstrate the performance of the PSCVT model for a class VI vehicle

1C Efficient NVH Analysis and Design Optimization of Vehicle Structures

1C-1 Energy Boundary Element and Hybrid Finite Element Developments

N. Vlahopoulos and S.-B. Hong

The Energy Boundary Element Analysis (EBEA) constitutes a new formulation for computing high frequency acoustic radiation. It has been utilized in one of the recent ARC case studies for evaluating the airborne noise in the vicinity of the vehicle and for making a comparison of the airborne acoustic field between a conventional and a hydraulic hybrid truck. The theoretical background and the validation of the EBEA will be presented. The EBEA constitutes a significant improvement over the traditional Statistical Energy Analysis (SEA) for high frequency exterior acoustic analysis. The SEA approximates an exterior domain as an assembly of several enclosed cavities and requires the definition of artificial damping and non-physical coupling loss factors between subsystems. The new EBEA formulation eliminates all these approximations. In addition, the hybrid FEA development effort is continued for coupling conventional FEA with EFEA. Analyses are performed using a conventional dense FEA model and a hybrid FEA approach for an assembly of plates spot-welded on a frame structure. Results between the two methods are compared successfully in the mid-frequency range.

1C-2 Component-Based Analysis of Vibration and Power Flow in Vehicle Structures

C. Pierre, M. P. Castanier, G. Zhang, and S.-Y. Lee

In this presentation, recent developments are shown for the efficient analysis of vibration and power flow in vehicle structures. Key results of this research are presented for two different vehicles, a pickup truck and a sport utility vehicle. A component-based modeling approach is used, which is based on component mode synthesis but also employs modes characterizing the vibration of the interface between components. By selecting component and interface modes for the frequency range of interest, highly reduced order models of vibration and power flow are obtained. For example, a 2100-DOF model is generated from a 1.5-million-DOF finite element model for the 0-200 Hz range. It is demonstrated that the transfer of vibration energy in a vehicle structure can be visualized by using power flow maps, which provide valuable physical insight. Furthermore, recent progress in predicting the effects of parameter uncertainties is highlighted.

1C-3 Design Sensitivity Analysis and Optimization of Complex Vehicle Structures for Minimum Weight

K. K. Choi, J. Dong, N. H. Kim, C. Pierre, N. Vlahopoulos, Z. D. Ma, and M. P. Castanier

Design optimization of a complex vehicle structure, which minimizes the vehicle weight and reduces the interior noise level inside cabin, is presented. In this research, a design sensitivity analysis of a sequential structural-acoustic problem is carried out, in which the structural and the acoustic behaviors are de-coupled. NASRTRAN finite element analysis code and Component Mode Synthesis (CMS) method are used to analyze the dynamic behavior of an automotive structure, while the boundary element method (BEM) is used to solve the pressure response of an interior, acoustic domain. In the sequential structural-acoustic analysis, frequency response is used to analyze the dynamic behavior of the vehicle structure, while the boundary element method is used to solve the pressure response of an interior, acoustic domain. An adjoint variable method is used in design sensitivity analysis, with the adjoint load obtained from the acoustic boundary element re-analysis, and the adjoint response calculated from the structural dynamic re-analysis. The evaluation of pressure sensitivity only involves the numerical integration of the structural part. Sequential quadratic programming algorithm is applied in design optimization process, with the design objective defined as minimizing vehicle weight, and design constraints defined as the interior noise level at critical frequency ranges. Two different optimization cases are studied, in each of them the vehicle weight is minimized and the noise level is reduced.

1C-4 Identification of Lowest Eigen-Systems of Large-Scale Structures

N. Kikuchi and H. Li

Image-based FEA emerges as a powerful tool in the rapidly changing automotive industry due to its high efficiency. It has been successfully applied to statics and thermal analyses. Besides these analyses, engineers are often interested in the lowest eigen-systems of structures. The identification of those eigen-systems is the objective of this research. This talk presents the two critical techniques together with some numerical simulations: (1) Modified Euler Time Integration Method with Modified K-Proportional Damping; (2) Improved Ibrahim Time Domain Method with Embedded Total Least Squares Method.

1D Modeling, Simulation and Design of Vehicle Structures and Systems

1D-1 Simulation of Tracked Vehicles: Developments for Robotic Vehicles and for Real-time Simulation

N. Perkins, Z. D. Ma, J.-H. Lee, D. Akcabay and B. Ross

This presentation will review studies of both small-scale (robotic) and full-scale (manned) tracked vehicles. Our studies of robotic vehicles employ simple, reduced-order models as well as large, multi-body models. The objective of these studies is to simulate the mobility of robotic vehicles on aggressive “urban terrain surfaces.” Simulations will show how these vehicles can climb staircases and clear high obstacles. These results may be used to evaluate existing designs (such as iRobot’s “Urbie”) as well as future design concepts. The study of full-scale vehicles advances the science of modeling the interface between the track and the terrain. The challenges in modeling this interface result from the mechanics of the terrain, the nonlinear mechanics of the track, and the coupling of the interface model to the remainder of the vehicle. We will review a novel formulation of the track/terrain interface that represents the track as a continuum. Reduction of this model leads to simple analytic approximations of the track/terrain interface that may be used for real-time simulations.

1D-2 Tire-Soil Modeling and Simulation Methods for VPG Applications

W. Pan, D. Solis, and L. Chi

An efficient tire-soil interaction model for real-time vehicle simulation is reported in this presentation. The major features of the model are (1) the resultant force due to soil compaction is computed using a pressure-sinkage relation that distinguishes loading and unloading/reloading and accounts for energy loss; (2) terrain unevenness is dealt with by creating a locally equivalent even terrain on the fly; (3) empirical traction and side force equations are used to compute resultant forces due to soil shearing and bulldozing. The model is validated in cooperation with Caterpillar. Future work required to improve the model is identified in the presentation. Another effort, three-dimensional finite element tire-soil interaction modeling, is also reported. This work aims at developing tire/soil modeling approaches and virtual tire/soil testing methodology to enable generation of parameters in the proposed real-time tire-soil interaction model as well as other real-time tire/soil models.

1D-3 GA-Based Multi-Material Structural Optimization Using Stepwise Mesh Refinement

J. Y. Neal, V. Y. Blouin, and G. M. Fadel

Optimally designed multi-material structures offer the potential for increased functionality. The present paper describes a modeling and optimization procedure based on the finite element method (FEM) combined with an evolutionary genetic algorithm (GA). The GA offers the possibility of finding the global optimum in a multi-modal design space. This advantage, however, is counterbalanced by the high computational expense of utilizing many FEM evaluations, as is often required in structural optimization. Furthermore, in the context of multi-material optimization, the large number of material possibilities for each finite element can render the conventional GA-based optimization prohibitively costly in computational time and inconclusive. In this research, a stepwise mesh refinement technique is presented. Coupled to the GA using a multi-objective fitness function, the method is shown to have a significantly lower computational time and leads to satisfactory designs of heterogeneous objects of arbitrary shapes. Design issues related to the use of this method are discussed and exemplified with the design of a three-dimensional heterogeneous connector.

1D-4 Adaptive Probability Analysis by Using Performance Measure Approach

K. K. Choi and B.-D. Youn

Difficulties in obtaining accurate distribution function of system uncertainties have underscored the development for very effective method to identify uncertainty propagation. The Monte Carlo simulation is very comprehensive but prohibitively expensive for large-scale problems. For reliability index method, existing probability analysis tools are not only ineffective in reliability analysis, but also unable to properly set the number of probability levels. To overcome these limitations, in this research, reliability analysis is carried out using the proposed performance measure approach. For this, an MPP locus is first approximated and a reliability analysis starts from an initial search point on the approximated MPP locus at each probability level, rather than from the origin in U-space (i.e., the design point in X-space). The number of probability levels is increased and adaptively decided on until all initial search points from MPP locus approximation are close to all MPPs, depending on the nonlinearity of probabilistic system performances. The proposed method is demonstrated using several examples and comparisons are made with existing probability analysis methods.

2 Symposium II – Human Centered Modeling and Simulation

2A Human Centered Design I

2A-1 Overview of Human Centered Design Simulation - Progress and Challenges

Don B. Chaffin

It is very apparent that vehicle designs must consider a wide range of human attributes early in the design process. Only by doing so can costly mistakes be avoided that would later be detected when people are asked to evaluate various hardware prototypes, or worse yet, operate a vehicle that is not designed from an informed human design perspective. This paper outlines the growing trend in using digital human models to simulate various human characteristics when performing various task in a computer generated vehicle. It is proposed that recent research in the HUMOSIM Laboratory, supported by both the ARC and a consortium of vehicle manufactures, has made excellent progress in predicting how people reach and manipulate objects within a virtual vehicle. These dynamic human models can be readably accessed by a designer to produce initial estimates about the physical layout of a proposed vehicle's interior. The paper also outlines some of the research and technological steps necessary to produce valid and useful human simulation software for future vehicle design senarios.

2A-2 Biomechanical Modeling of Shoulder Loading and Perceived Effort during Reaching Task Performance

Clark Dickerson

Shoulder injuries associated with vehicle use are increasingly a concern. While models of the shoulder mechanism have been developed, they do not address fundamental issues concerning the underlying causes of shoulder muscle tissue loading and injury. This study addresses two factors to be considered when evaluating potential injury to the shoulder. The first factor to consider is shoulder muscle tissue loading, and its reliable characterization. While this has been accomplished for a set of static exertions, no prediction method exists for dynamic exertions. The second factor to consider is the effort perceived while performing a task, which has been shown to relate to injury incidence. Novel biomechanical models will be applied to experimentally performed tasks to predict shoulder tissue loading. The predictions made by these models will then be correlated with reported perceived effort at the shoulder joint. Relationships between the quantities could provide insight into both the nature of perception of shoulder joint effort as well as the loading present in the shoulder tissues during motions. This could impact prospective vehicle interface design, as it would allow designers to preview the impact that design changes would have on shoulder discomfort and loading, while also allowing evaluation of existing environments.

2A-3 Modeling the Difficulty of Seated Reaches

Mathew Reed

Vehicle interior layouts are assessed using models of human reach capability such as the SAE J287 curves and the reach simulation capability of digital human figure models. These approaches do not provide accurate guidance concerning the percentage of operators who can reach to a specified control location and do not give any information about movement difficulty for those who are able to complete the reach. This project uses an innovative technique for mapping the reach difficulty envelope of a seated operator. A computer-controlled target-positioning apparatus places a reach target in a wide range of positions with respect to a volunteer. The participant rates the difficult of the reach or reports that the reach is unattainable. Analysis of the data yields a three-dimensional reach difficulty function for the participant that is integrated with the maximum reach envelope. Following pilot testing with 12 participants, a study with 40 truck drivers will be conducted to develop a population-based reach difficulty model for the heavy truck workspace.

2B Human Centered Design II

2B-1 Task Based Posture Prediction

Karim A. Malek

A general methodology and associated computational algorithm for predicting realistic postures of humans is presented. The basic plot for this effort is a task-based approach, where we believe that humans assume different postures for different tasks. The underlying problem is characterized by the calculation (or prediction) of the joint displacements of the human body in such a way to accomplish a specified task. Using biomechanically accurate models with a large number of degrees of freedom and taking into consideration joint constraints, each task is been defined by a number of human performance measures that are mathematically represented by cost functions that evaluate to a real number. Cost functions are then optimized, (i.e., minimized or maximized) subject to a number of constraints. The problem is formulated as a multi-objective optimization algorithm where one or more cost functions are considered as objective functions that drive the model to a solution set. The formulation is demonstrated and validated using empirical data obtained from experiments. We present this computational formulation as a broadly applicable algorithm for predicting postures using one or more human performance measures.

2B-2 Surface Reconstruction from Multiple View Range and Color Images for Automotive Parts Reverse Engineering and 3D Scene Building

Yiyong Sun, David L. Page, Andreas Koschan, Mongi Abidi

The objective of this research is to reconstruct 3D models from multiple range and color images, which can be used for automotive parts reverse engineering or 3D scene generation for driving simulations. The raw range images are first preprocessed by adaptive regularization using the concept of a minimal surface. The proposed area decreasing flow avoids the curvature computation in traditional smoothing by mean curvature flow. The second step is pose estimation of multiple range images by finding point correspondences using features from the local geometry. Point's fingerprint is proposed to represent each point and used to find the corresponding points. In the third step the registered range and color images are integrated using a volumetric fusion approach in which the surfaces can be post-processed by removing outliers and filling holes. The multi-view reconstructed surfaces are segmented into parts that can be further used for object recognition. The surface mesh segmentation is based on the 3D watershed algorithm. An “edge strength” is used to determine ridges on the surface. Experimental results are presented for real range data of small parts and more complex indoor and outdoor scenes.

2B-3 Analysis and Cancellation of Vibration Feedthrough in Manual Control of Ground Vehicles

Szabolcs Sovenyi

Manual control on-board a moving vehicle is often encumbered by the action of inertia forces on the arm and hand. Especially in joystick-driven vehicles such as helicopters, electric wheelchairs, bulldozers, and tanks, undesired oscillations can arise in the coupled driver/vehicle system dynamics. The phenomenon is known as biodynamic feedthrough or vibration feedthrough. We propose to use a force-reflecting manual control interface together with a model-based controller to cancel the feedthrough forces. We have tested the proposed solution using a single-axis haptic interface (joystick) on two motion platforms. In initial studies, we modeled the human biomechanics as a lumped second order system, and tested a physical model attached to the joystick. The vibration feedthrough phenomenon was demonstrated for this scenario in experiments carried out on the U.S. Army’s Ride Motion Simulator and also on a small vibration test bed at the University of Michigan. Further tests on feedthrough cancellation were carried out on the test bed. In forthcoming studies, human subject experiments will be used to verify the vibration feedthrough cancellation during tracking tasks.

2C Driver Models and Simulation Environments

2C-1 Further Progress in Development of a Driver Model for Heavy Vehicle Applications

Frank Schaefer and Imtiaz Haque

Abstract

2C-2 Longitudinal Human Driving Model for Advanced Vehicle Safety Systems

Kangwon (Wayne) Lee and Huei Peng

Active safety systems have been a focus area within the Automotive Research Center. To evaluate these safety systems accurately, it is necessary to have an accurate human driving model to generate surrounding vehicles. Accurate models for human driving are not available and in particular no models are able to predict vehicle behavior accurately both macroscopic and microscopic viewpoint. Recently, high fidelity human driving data became available, which has made it possible to develop and evaluate human driving models. Several human driving models were evaluated in our research. Among them, Gipps' model was found to be most robust and was further analyzed. An improved version of this model was suggested and evaluated using the same selected data sets and a larger set of data. The modified model was implemented in the microscopic traffic simulator. It was found that the proposed model accurately predict vehicle behavior both from microscopic (vehicle-vehicle) and macroscopic (traffic flow) viewpoints. The proposed model is subsequently used to evaluate the behavior of an Adaptive Cruise Control (ACC) vehicle.

2C-3 Off-road Real-time Vehicle Simulation Environments

Dario Solis

The main goal of real-time modeling and simulation activities at The University of Iowa is to enable soldier-in-the-loop simulation experiments in the NADS and TARDEC simulator environments. Due to the complexity of these systems, a number of key technologies are being currently developed under ARC funding in close collaboration with industry and government partners. This presentation will give a summary of how vehicle modeling and simulation techniques are being integrated and used in real-time simulation environments with emphasis on enabling numerical simulation methods, tire-soil interaction modeling and simulation, and hybrid electric powertrain modeling. Two vehicle examples will be presented, a conventional HMMWV model and a hybrid-electric FMTV model. Both models will be exercised in a synthetic testing environment for military applications using low-cost PC hardware.

2C-4 Smoothing and Simplification of Reconstructed Triangle Meshes of As-Built Automotive Parts and Realistic Driving Scenes

David Page, Andreas Koschan, and Mongi Abidi

Reverse engineering of automotive parts and realistic scenes for driving simulations often use 3D computer vision algorithms from range and stereo imaging to generate as-built computer models of the real world. Unfortunately, these reconstructed imaging techniques introduce measurement error and oversample the surfaces of interest. Subsequently, noise corrupts these models and the representations themselves are much larger and more complex than necessary. To account for these two problems, this presentation shows a novel algorithm for smoothing and simplifying these large, noisy triangle mesh models. Smoothing algorithms attempt to minimize surface noise while simplification algorithms try to reduce mesh complexity. Typically, these algorithms are distinct and separate steps in the model generation pipeline. The proposed algorithm, however, combines these steps into a single step to smooth and simplify simultaneously. The resulting output is a multiple level-of-detail representation with minimal noise artifacts for computer aided design programs and simulation displays. This presentation outlines this algorithm and shows results for both simulated and real data.

2D Modeling and Control of Vehicle Systems

2D-1 A Systematic Approach to Model Quality Assessment

Polat Sendur

Dynamic models of physical systems with physically meaningful states and parameters have become increasingly important, for design, control and even procurement decisions. The successful use of models in these contexts requires that the models be of sufficient quality. However, while algorithms have been developed to help formulate and integrate physical system models, as well as to generate minimum complexity physical system models; algorithms to assess the “quality” of dynamic system models have not been produced. This is true even if the attributes of model are limited to accuracy and validity.

The objective of this presentation is to introduce a new methodology that systematically quantifies the accuracy of a predicted system response and determines the validity of the physical system model used to predict the system response. The accuracy and validity of the model are evaluated using statistical properties of measured system response. The new algorithm is called Accuracy & Validation Algorithm for Simulation (AVASIM), and is a time-domain perspective comparing the model’s time trajectories at user-defined points of interest as well as over the entire simulation horizon.

To illustrate AVASIM, the quality of a handling model of a M1086 FMTV Truck is compared to the measurements obtained from that vehicle subjected to known steering inputs. Results demonstrate that the accuracy and validity of the model can be systematically assessed using the proposed methodology, and, thus, AVASIM appears to be a powerful tool for assessing the quality of system models.

2D-2 Enhanced Mobility through Cooperation

Ashish Deshpande and Jonathan Luntz

Mobile robots can be used for applications such as search and rescue, urban infiltration etc, where the goal is to explore unknown, potentially hazardous terrain. Large teams of small, cheap robots have advantages over small numbers of large robots such as covering more ground in less time, access to tight spaces, redundancy, and expendability. One of the major challenges in employing small mobile robots is their restricted mobility on rough terrain. We are working to design mechanisms and behaviors for a team of small, cheap robots that cooperate to enhance the team's overall mobility. Robots link up and push or pull on each other to overcome obstacles. For example, one robot can pull on another to help it "pop a wheelie" to span a wide gap or climb a tall step. Simplicity is the underlying design principle: each team member will be cheap and hence disposable, the physical connection between the robots will be passive, the communication protocols among the robots will be simple (or nonexistent), and each robot will control its own state. A feasibility analysis for cooperation shows how motor torque and ground friction limits drive the mechanical and control design. Simulation demonstrates a decoupled, distributed control architecture.

2D-3 Terrain Characterization for Durability Predictions

Girish Mudgal, Loucas Louca, Jeff Stein, David Gorsich and Milt Chaika

Currently, the accuracy achieved by the US Army in predicting durability of ground vehicle components is poor leading to false predictions. The terrain specification standards used lack the richness needed to get accurate loading time histories which are critical for durability predictions. This in turn affects the fatigue life predictions by a very large factor. This project studies the terrain-vechile model coupling in detail. Both, the "stochastic terrain roughness model" as well as the "multi-body simulation model" need to be of comparable fidelity for accurate results. The effects of various terrain characterization methods on the suspension forces of a 'half-car' model are analyzed. It is realized that methods used to characterize paved roads are not suitable to characterize off-road terrains for durability purposes. From the results, some insight is gained towards developing appropriate "terrain-vechicle" models. The future work would be to come up with some standardized specifications to be given to ground vehicle manufacturers to help design "durable" components.

2D-4 Numerical Techniques for Real-time Multi-body Dynamics Simulation

Dale Holtz

When using a Cartesian formulation for multibody dynamics one of the most expensive operations is the factorization of the constraint Jacobian. This matrix is large and very sparse. Using commercially available sparse matrix factorization methods has proven to be too inefficient for real-time simulations. Therefore a special purpose method has been developed that exploits the topology of the mechanical system to achieve greater efficiency. This new method uses the topology to reduce the fill-in and avoid costly symbolic factorizations usually needed to determine the fill-in pattern when pivoting for numerical stability. Speedups of a factor of 10 over commercially available software have been achieved. Another possible method for achieving real-time simulation is parallel processing. A method has been implemented that can efficiently solve relatively small models on a dual processor computer. This method effectively partitions the model so that two processors can be used with very little communication between them, a key factor in attaining efficiency. A speedup of 1.78 on a dual processor machine for a 22-body HMMWV model has been achieved.

3 Symposium III – Advanced Powertrain Systems

3A Diesel Combustion Process

3A-1 Introduction and Future Directions

N. A. Henein and Walt Bryzik

Abstract

3A-2 Correlating Nozzle Design to the Spray Performance in DI Injectors

Ming-Chia Lai

Abstract

3A-3 Refined Model for Combustion and Emissions Predictions in a Heavy-Duty Diesel Engine

Dohoy Jung

Phenomenological models for DI diesel engine emissions including NO, soot, and HC are implemented into a full

engine cycle simulation and validated with experimental data obtained from representative heavy-duty DI diesel engines. The cycle simulation presented last year features a quasi-dimensional, multi-zone, spray combustion model to account for transient spray evolution, fuel-air mixing, ignition, combustion and NO and soot formation. In this study, additional models for HC emissions are newly implemented and the effort was focused on validating the models against experimental data. It is demonstrated that the models can predict the emissions with reasonable accuracy. However, additional effort is required to enhance the fidelity of models across a wide range of operating conditions and engine types.

3B Control of In-Cylinder Processes

3B-1 Optimization of Parameters in a HSDI Engine for Minimum Engine-Out Emissions

N. A. Henein

Abstract

3B-2 Experimental Analysis of Exhaust Gas Recirculation Effects on Diesel Engine Combustion

Timothy Jacobs

The deadline for meeting the new NOx and PM regulations for heavy duty Diesel engine manufacturers is fast approaching for this October. With nearly all manufacturers relying on exhaust gas recirculation to meet NOx targets, considerable emphasis has been placed on understanding EGR effects on Diesel combustion. In particular, isolated research on highly controlled experimental engines verifies the specific impacts of EGR on combustion and NOx reduction. However, very little research has shown the global performance and emission impacts of an EGR system integration on a production sized Diesel engine. This presentation will highlight the performance and emissions effects of integrating an EGR system using variable geomtry turbocharging and EGR cooling. This study confirms the expected decreases in NOx and performance associated with EGR, however illustrates the impacts of the EGR system on pumping losses, heat rejection, and combustion.

3B-3 Development and Validation of Unsteady Heat Transfer Model

Pin Zeng

Abstract

3C Hybrid Propulsion Systems

3C-1 Modeling of a Military Hybrid Vehicle

D. Goering, J. Lee, and J. Li

AM General, in conjunction with PEI is currently in the process of producing the second generation of the Hybrid Electric (HE) HMMWV. In order to better understand the basic operational characteristics of this vehicle and predict performance in extreme climates, the PSAT modeling package is being utilized to carry out drive cycle simulations. PSAT modules have been formulated for specific HE-HMMWV components, including engine, generator, traction motors, battery array, transmission components, and basic vehicle structure. In order to better understand performance in extreme environments, both high temperature and low temperature tests have been carried out on the HE-HMMWV battery. A summary of these component models will be presented and preliminary modeling results will be discussed.

3C-2 Analysis of Hybrid Electric and Hydraulic Hybrid Propulsion Systems for Medium Tactical Trucks

Zoran Filipi, Loucas Louca, Dennis Assanis, Berrin Daran, Dohoy Jung, Joe Lin, William Lim, Michael Kokkolaras, Bin Wu, Umut Yildir

The new initiatives, such as Future Combat Systems and the 21st Century Truck call for significantly improved fuel efficiency of trucks, while preserving or improving the mobility. Hybrid propulsion systems are one of the critical technologies on the road to future ultra-efficient trucks. While there is a significant body of work related to hybrid passenger cars and small commercial trucks, there are many open issues related to hybridization of heavier trucks intended for both on and off-road use. This work addresses those questions through a systematic analysis of two proposed parallel hybrid powertrains for the Family of Medium Tactical Vehicles (FMTV), one utilizing electric components and the other hydraulics. Representative duty cycle for the FMTV is generated based on the information about the typical vehicle mission. A methodology for sequential optimization of hybrid propulsion system design and power management is developed and applied to both the electric and the hydraulic hybrid. In addition to evaluating the fuel economy potential of candidate hybrid concepts, the study examines in more depth the behavior of both systems in order to better explain the phenomena leading to specific fuel economy numbers.

3C-3 MATLAB-Based HD Engine Model Compatible with PSAT Platform for HEV Simulation

Nabil Chalhoub

Abstract

3C-4 Hybrid Electric Vehicle Control for Improved Fuel Economy and Emissions

Chan-Chiao (Joe) Lin and Huei Peng

In this presentation, a rigorous design procedure for the creation of a sub-optimal power management control strategy is proposed. The design procedure is illustrated using a parallel hybrid electric truck. However, the methodology is general enough to be applicable for other hybrid configurations such as hydraulic hybrid, fuel cell hybrid, etc. The design procedure includes two major parts. First, the control problem is formulated as a optimal control problem by defining a desired performance index, such as minimizing fuel consumption and/or emissions. Dynamic Programming techniques are then utilized to determine the optimal control actions for the target vehicle. A tradeoff study for fuel economy and emissions is performed. It was found that significant emission reduction can be achieved with small increase in fuel consumption. The second part of the design procedure involves knowledge extraction to obtain implementable rule-based control algorithms. Several sub-optimal, rule-based control schemes are obtained for different driving scenarios through careful analysis of the optimization results. A real-time driving pattern recognition algorithm is developed to select the proper set of rules. The performance of the final power management control strategy is verified by using a validated hybrid vehicle model (HE-VESIM) developed at the Automotive Research Center of the University of Michigan.

3D Engine Systems Simulation and Diagnostics

3D-1 Simulation and Validation of Cold-Start Cranking and Transients

N. A. Henein

Abstract

3D-2 Low Temperature Tribological Behavior of a Solid Lubricating Film

H. Xu, J. Lee, H. Wang, and H. Liang

Abstract

3D-3 Fast Detection Algorithm for the Identification of Faulty Cylinders in a Multi-Cylinder Diesel Engine

Dinu Taraza.

Abstract

3D-4 Driving Cycle Assessments of Advanced Diesel Engine Designs using Neural Network Models and Optimization Techniques

George Delagrammatikas

The development of an artificial neural network model (ANN) of an advanced, turbocharged diesel engine, and its implementation within an overall vehicle simulation are addressed in this work. The purpose of this research was to create a model that would help drastically reduce in-vehicle engine design cycle time, improve numerical robustness, and maintain the predictive capability of its physically-based counterpart. Ease of integration within an optimization framework for preliminary investigations of engine designs was also a critical need. A design of experiments (DOE) was first used to sample the engine's feasible design domain. The high-fidelity model calculated engine responses at these DOE designs; the DOE inputs and engine model responses were subsequently used to train a radial basis function ANN. An error study was performed to minimize the network training time while ensuring response accuracy. A typical, vehicle-level optimization study is presented which compares results and time requirements of the ANN and high-fidelity models. Trade-offs between computational expense and accuracy between both models are compared. Critical issues in the development of an ANN engine model are detailed and generic guidelines are presented which would expedite the implementation of this modeling technique to other complex subsystems and components.

4 Symposium IV – Integrated Product Design

4A Analytical Target Cascading

4A-1 Analytical Target Cascading for the Design of an Advanced Technology Heavy Truck

Loucas Louca, Michael Kokkolaras, George Delagrammatikas, Nestor Michelena, Zoran Filipi, Panos Papalambros, and Dennis Assanis

Analytical target cascading (ATC) is a methodology that can be used during the early development phase of large and complex systems for propagating desirable overall product targets to appropriate individual specifications for the various subsystems and components. The ATC process is applied to the design of an advanced technology heavy truck. A series hybrid-electric propulsion system, in-hub motors, and variable height suspensions are introduced with the intention of improving both commercial and military design attributes according to a dual-use design philosophy. Emphasis is given to fuel economy, ride, and mobility characteristics. The latter are predicted by analytical and simulation models developed appropriately. This article is an extension to previous work: the engine is now included at the bottom level, several battery types are considered to study their effect on fuel economy, and a more demanding driving schedule is used to assess regenerative braking benefits and ride quality. Results are presented for target values associated with a 100\% improvement on fuel economy while maintaining performance attributes relative to existing designs.

4A-2 Convergence Properties of the Analytical Target Cascading Process

Nestor Michelena, Alan Park, and Panos Papalambros

Analytical target cascading (ATC) is a relatively new methodology for the design of engineering systems. ATC deals with the issue of propagating desirable top level product design specifications (or targets) to appropriate targets at lower levels in a consistent and efficient manner. Most existing formulations for multilevel design of hierarchical systems often exhibit convergence difficulties. In this presentation, global convergence properties of the ATC formulation, when used together with optimization algorithms, are proved under convexity assumptions---hence establishing ATC as a robust process for multidisciplinary optimal design.

4A-3 A Duality Perspective on Analytical Target Cascading

Julie Lassiter and Margaret Wiecek

Analytical Target Cascading (ATC) is a method for designing engineering systems which decomposes a problem into two or more levels and propagates targets from the top level to appropriate lower-level targets. A modification of ATC based on Lagrangian duality theory is developed. Convergence conditions of this approach are examined and a resulting dual algorithm is proposed.

4B Distributed Computer-Aided Engineering

4B-1 Volumetric Part Decomposition of 3-D Triangulated Complex Models for Inspection and Reverse-Engineering of Automotive Parts

Yan Zhang, Andreas Koschan, and Mongi Abidi

Object recognition is a task typically involved in inspection and reverse-engineering. In autonomous navigation and robot-assisted manufacturing, object recognition is also an indispensable step which facilitates the following obstacle avoidance and object manipulation steps. The initial object recognition task could be very difficult and time consuming when the objects involved are very complex. Structural object recognition techniques simplify the initial object recognition problem by assuming that the complex objects are pre-segmented into simpler and more typical shapes such as cubes and cylinders. The objective of this research is to decompose an articulated multi-part model or object into single meangingful parts, and furthermore, to simplify the original task by dealing with simpler single-part objects. 3-D triangulated models are used as input in this work since the triangle mesh has been the most common representation form for a 3-D model. The models could be synthetic models created from CAD programs, or real models constructed from multiple real range/stereo images. Considering the transversality regularity, two arbitrary surfaces always interpenetrate along a contour of concave discontinuity of their tangent planes, it can be derived that points of highly negative Gaussian curvature form boundaries between two parts. Based on this principle, a boundary-based part decomposition algorithm is proposed in this work. The algorithm consists of Gaussian curvature estimation, boundary detection, and region growing. A postprocessing is finally performed to merge isolated vertices, and eliminate regions containing too few vertices. Experimental results obtained from both synthetic and real 3-D models demonstrate the accuracy and robustness of the proposed algorithm.

4B-2 Integration of ARC-developed powertrains models into TACOM/TARDEC RTS Environment

Shawn Burney

The motivation for this work lies in the importance of having effective vehicle subsystem models for real-time simulation. The National Automotive Center (NAC) Ground Vehicle Simulation Laboratory (GVSL) is developing and applying engineering simulators and simulations for the evaluation of ground vehicles during all stages of a weapon system's life-cycle. As a cost-effective alternative to physical testing, the Automotive Research Center (ARC) has been pursuing the development of a flexible vehicle simulation system composed of a hierarchy of models of varying resolution. Development time and cost can be significantly reduced through the use of simulation-based design. With the use of a predictive vehicle system simulation, designers can test for a variety of conditions and be guided toward the preferred solution prior to the building of physical models. This presentation will discuss the creation and demonstration of a framework that will facilitate the analysis of powertrain design problems by examining and documenting the process of decomposing a powertrain subsystem from the 20-sim modeling environment and transforming it into executable ANSI-C code. The transformed powertrain submodel is coupled to a separate virtual dynamometer via a common interface. The establishment of this interface will expedite the integration of ARC powertrain systems into the TACOM real-time simulation modeling environment.

4B-3 Development of Network-Distributed Simulation Toolkit

Jinzhong Wang

Previous ARC research has established the fundamental need for and framework for network-distributed simulation. Gluing algorithms were established that represent the foundation upon which to interconnect dynamical systems. In this presentation, we describe alternate forms of glue that may be more amenable to implementation with legacy code and present an implementation using a research finite element code. In addition, we have developed a general and efficient model description for simulation, using XML. Finally, we present a distributed architecture design using SOAP as the interconnectivity tool and demonstrate the implementation with a vehicle frame model.

4C Automotive Product Development I

4C-1 Optimal Design Decisions in Product Valuation Including CAFE Considerations

Panayiotis Georgiopoulos and Panos Papalambros

Product portfolio valuation is a core business milestone in a firm's product development process: Determine what will be the final value to the firm derived from allocating assets into an appropriate product mix. Optimal engineering design typically deals with determining the best product based on technological (and, occasionally, cost) requirements. Linking technological with business decisions allows the firm to follow a product valuation process that directly considers not only what assets to invest but also what are the appropriate physical properties of these assets. Thus, optimal designs are determined within a business context that maximizes the firm's value. The presentation demonstrates how this integration can be accomplished analytically using a simple example in automotive product development.

4C-2 Commonality Decisions in Product Platform Design: Theory

Ryan Fellini, Alexis Perez-Duarte, Michael Kokkolaras, Nestor Michelena, and Panos Papalambros

Sharing components between products is an effective way to save costs. Cost savings are incurred through the reduced time to design and engineer components as well as savings in manufacturing and inventory. Previous work in the area of platform-based product design is reviewed. Recently developed methods for making commonality decisions are discussed along with future work in platform and modular-based products.

4C-3 Commonality Decisions in Product Platform Design: Applications

Ryan Fellini, Alexis Perez-Duarte, Michael Kokkolaras, Nestor Michelena, and Panos Papalambros

Two applications, both involving automotive body structures are discussed. Both examples illustrate the use of new methodologies for addressing the commonality decision problem in platform design. Previous work has involved designing platform-based products with platforms specified a priori. The current work proposes methods for determining optimal platforms prior to final design.

4C-4 A Kriging Metamodeling Algorithm for Efficient Simulation-Based Design Optimization

Michael Sasena, Pierre Goovaerts, and Panos Papalambros

Global optimization of constrained, nonlinear problems has proven a challenging field of research that is still quite active. Specialized algorithms have been developed to address the difficulties that arise when the functions to be optimized come at significant computational expense. One such class of algorithms, known as Bayesian analysis, uses global approximations of the functions to compute a statistics-based criterion for selecting the next iterate. The Efficient Global Optimization (EGO) algorithm of Jones, Schonlau and Welch is the Bayesian analysis algorithm that forms the basis of this work. This proposed methodology advances the state-of-the-art in Bayesian analysis in four ways: improving the abilities and accuracy of the global approximations, increasing the flexibility of the search strategy, improving the ability to solve constrained problems, and increasing the efficiency and accuracy of the solutions by considering the computational burden of each response function.

4D Automotive Product Development II

4D-1 Multi-scenario Multi-criteria Optimization and Relative Importance of Criteria in Heavy Vehicle Design

Imtiaz Haque, Margaret Wiecek, Georges Fadel, Vincent Blouin, Chakravartula, and Hunt

The performance of a vehicle is evaluated with respect to a set of performance criteria over a set of distinct driving scenarios. In past work, trucks were optimized for roll-over resistance in a particular scenario. Our work continued to include performance indices related to handling and apply these in different driving scenarios. For each individual scenario, certain criteria may be considered relatively more important than the others in evaluating performance. We first present a brute force method to improve results, then use linear transformations and convex cones to model the relative importance and allow tradeoffs for improving the overall performance of the vehicle in specific driving scenarios.

4D-2 Combined optimal design and control: theory and application to suspension design

Hosam Fathy, Galip Ulsoy, and Panos Papalambros

The problems of optimizing an engineering system's plant and controller are presented. The strategies used in the literature for solving these two problems are classified into sequential, iterative, nested and simultaneous strategies. Set theory and an experimental demonstration are used to show that the plant and controller optimization problems are coupled in the sense that solving them sequentially (or iteratively) does not guarantee system-level optimality. Nested optimization is then shown to guarantee system-level optimality under some special assumptions, which are explored. To quantify the coupling between the plant and controller optimization problems, the first-order necessary conditions for combined plant/controller optimality are derived and compared to the combined set of necessary conditions for plant and controller optimality (namely the KKT and Pontryagin conditions). The conditions for system-level optimality are shown to contain a new term that quantifies the plant/controller optimization coupling and is hence called the coupling term. Using this coupling term, physical explanations are presented for the coupling between the plant and controller optimization problems, and two special scenarios where the problems decouple are identified, namely interior-decoupling and boundary-decoupling. These results are applied to the optimization of plants and the LQR and LQG controllers. Specifically, a nested strategy is presented for optimizing a plant and its LQR/LQG controller in a way that guarantees system-level optimality. This strategy is used to optimize the plant and controller of a combined passive/active car suspension in an integrated manner. The passive and active suspension optimization problems are combined into an integrated, system-level suspension optimization problem. The model is analyzed and modified to capture the influence of the passive suspension stiffness on the suspension's mean square rattlespace. Nested optimization is then used to find a suspension design that is superior not only to purely passive and purely active suspensions but also to sequentially optimized combined passive/active suspensions in terms of both performance and robustness.

4D-3 Contingent Weighting of Product Attributes in Interactive Decision-Making

Olena Sinkevich, Richard Honzalez, and Panos Papalambros

We provide a new test of the psychological theory of the choice and matching discrepancy using a known-groups design. Engineering students and industrial design students were given choice and matching questions on several products that were described on two dimensions: technical and aesthetic. We predicted that the engineering students would value the technical dimension greater than the aesthetic dimension, but the the industrial design students would value both dimensions because their training emphasizes aesthetic features under technical constraints in product design. Attribute importance data supports this prediction. Differential weighting of attributes in these two groups has implications for interactive decision making in real-world design settings in real world design settings where engineers and designers must arrive at mutual decisions.

4D-4 Extending Energy-based Proper Modeling for Design: Beyond Energetic Elements

Geoff Rideout, Jeff Stein and Loucas Louca

Abstract