Automotive Research Center

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

ARC Collaborative Research Seminar Series
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January 14th, Wednesday (9:30-11:00am)
University of Michigan, Lurie Engineering Center, Level 4, GM Room

Presented by Thrust Area 5
Vehicle System Integration, Optimization, and Robustness

Recent Developments in Time-Dependent Reliability and Design for Lifecycle Cost
Amandeep Singh, Zissimos P. Mourelatos, Jing Li
Mechanical Engineering Department, Oakland University

Reliability is an important engineering requirement for consistently delivering acceptable product performance through time. As time progresses, the product may fail prematurely due to component degradation and uncertainty in design and/or operating conditions. The degradation of reliability with time increases the lifecycle cost due to potential warranty costs, repairs and loss of market share. In design for lifecycle cost, we must account for the product quality, and time-dependent reliability. Quality is a measure of our confidence that the product conforms to specifications as it leaves the factory. Reliability depends on 1) the probability that the system will perform its intended function successfully for a specified interval of time (no hard failure), and 2) on the probability that the system response will not exceed an objectionable by the customer or operator, threshold for extended periods of time (no soft failure). Quality is time-independent, while reliability is time-dependent. Both quality and reliability are greatly affected by variability and uncertainty. In this talk, recent developments of a design methodology considering the product lifecycle cost, will be presented. Future work will be also summarized. The method determines the optimal design of time-dependent and often degrading, multi-response systems, by minimizing the cost during the life of the product. The constraints account for both hard and soft failures. The conformance of multiple responses is treated in a series-system fashion. The lifecycle cost includes the production cost, the inspection cost and an expected variable cost. These costs depend on quality and reliability. The key to our approach is the calculation of the so-called system cumulative distribution function for a series of time-variant limit-state functions. This is done using an equivalent time-invariant "composite" limit state which is then used to calculate all significant most probable points and the probability of failure.

February 18th, Wednesday (9:30-11:00am)
University of Michigan, Lurie Engineering Center, Level 4, GM Room

Presented by Thrust Area 1:
Emerging Research to Reduce, Supplement, and Control Vehicle Energy Consumption
Mohammad Daqaq, Lin Ma, Ardalan Vahidi, and John Wagner
Department of Mechanical Engineering, Clemson University

Introduction (09:30-09:40):
Jeff Stein (University of Michigan)

Presentation I (09:40-10:00):
Vehicle Thermal Management – Alternative Cooling and Payload Temperature Control
Lin Ma & John Wagner

The successful management of thermal loads within military armored vehicles (engine, payload) represents an important challenge given the presence of electronic equipment, human occupants, and hot weather operating environments. To maintain acceptable temperatures, supplemental cooling methods may be required. This presentation will focus on the use of phase change materials enhanced by metal polymer suspension as an alternative cooling strategy, and the development of simulation tools to study payload and engine smart cooling demands.

Presentation I (10:00-10:20):

Utilizing 3D Aerial Terrain Maps for Improving Energy Management of Hybrid Vehicles

Ardalan Vahidi

We present our findings on the role advanced knowledge of terrain information can have on fuel savings of a parallel-hybrid vehicle. Real-world 3D terrain maps are provided to us by our industry partner Intermap Technologies. These maps are created using Airborne IFSAR mapping technology.

Presentation III (10:20-10:40):

The Magnetostrictive Generator

Mohammad Daqaq

We present a dynamic model of a cam-driven magnetostrictive (MS) alternator designed for in- vehicle power generation. The model accounts for the dependence of the constitutive parameters on the magnetic bias (stator field) and pre-stress (axial load). Using the derived model, we study the effect of strain, drive speed, magnetic bias, and pre-stress on the output power. It is shown that, at optimal loading conditions, an MS rod subjected to 1500 microstrain at a drive speed of 3600 rpm has a power density of 50 Watt/cm3.

Presentation IV (10:40-11:00):

Ultra-Capacitors for 'Power Boost' in Heavy Vehicles

Ardalan Vahidi

Through numerical simulations, the potential of ultracapacitors to serve as a stand-alone auxiliary power source for vehicles is investigated. A mild parallel hybrid powertrain is considered in which an electric motor and an ultracapacitor-based energy source assist the combustion engine during periods of high power demand. The ultracapacitor is recharged by the engine during periods of low demand, and through regenerative braking. Standard city-cycle simulations on a detailed model of the powertrain illustrate an improvement in fuel economy enabled by the ultracapacitor-based mild hybrid configuration.

March 4th, Wednesday (9:30-11:00am)

University of Michigan, Lurie Engineering Center, Level 4, GM Room

Presented by Thrust Area 3

High Performance Structures and Materials

Advanced Models for Predicting the Nonlinear Response of Complex Structures and Novel Sensor Placement Technology for Damage Identification

Bogdan I. Epureanu

Department of Mechanical Engineering, University of Michigan

Modeling and reanalysis techniques are proposed for predicting the dynamic response of a complex structure that has suffered damage in one or more of its components. When such damages are present, the model of the healthy structure may no longer capture the system-level response or the loading from the rest of the structure on a damaged component. Hence, novel models that allow for an accurate reanalysis of the response of the damaged structure are needed in important applications, including damage detection. Herein, such models are obtained by using a reduced order modeling approach based on component mode synthesis. Because the resonant response of a complex structure is often sensitive to component uncertainties (in geometric parameters such as thickness, material properties such as Young's modulus, etc.), novel parametric reduced order models (PROMs) are developed for the general case of multiple substructures with uncertainties.

Next, PROMs are exploited for sensor placement for structural dynamic analysis and damage detection. Cracked structures are of interest. The presence of cracks leads to changes in the mode shapes and resonant frequencies compared to the healthy structure. Because the overall goal is damage detection, the frequency range of interest is established by observing the frequencies of the mode shapes that are most sensitive to the crack. To quantify this sensitivity, a novel approach for characterizing the vibration of cracked structures has been developed. When a structure has a crack, it also exhibits nonlinear dynamics. This dynamics is caused by the periodic opening and closing of the crack surface (which leads to a piece-wise linear dynamics). Hence, standard modal analyses cannot be directly employed. To address this challenge, a novel technique to characterize the spatial correlations among the vibration of various points within the structure has been developed. These correlations are akin to mode shapes but they characterize the dynamics of the cracked (nonlinear) structure. This approach is based on the observation that, when the structure has a crack and vibrates at some (nonlinear) resonant frequency, two states can be identified: crack open and crack closed. These two states correspond to two shapes for the deformation of the structure at that frequency. Next, we assume that all the shapes the structure takes during its nonlinear vibration at a resonant frequency are linear combinations of these two shapes (open and closed at that resonant frequency). This novel approach is referred to as bilinear modal approximation.

Numerical results are presented for simple cracked structures and for complex ground vehicle components. The number of required sensors is shown to depend on the number of modes to be monitored, which in turn depends on the level of sensitivity of the monitored modes to the crack. The effectiveness of the approach is demonstrated and the effects of measurement noise are discussed. Three damage cases are considered: (1) severe structural deformation (dents), (2) missing material due to fracture, and (3) cracks.

A Reactive Structure Technology for Improved Survivability of Military and Commercial Vehicles

Zheng-Dong Ma
Department of Mechanical Engineering, The University of Michigan

We invented the term “Reactive Structure” to connote a smart structure that can react to external excitations (such as vibration, crash, blast and ballistic impacts) in a carefully designed way using the energy from the excitations to counteract the hazardous loading or perform other desired tasks. One such reactive structure employs a small amount of reactive material (such as TNT), which be used to enhance the reactivity of typical reactive structures. A new reactive structure concept, called Explosively Reconfigurable Structure (ERS), is investigated under this ARC research with a focus on feasibility and development of basic design methodologies and guidelines. The basic idea of this ERS is that it reactively reconfigures the structure with the assistance of a small amount of explosive for the purpose of mitigating blast impact. Two fundamental reactive mechanisms have been virtually tested using the LS-DYNA virtual prototyping platform:

1. Deforming the structure to form a desired V-shape so it can effectively deflect the blast shockwave
2. Altering critical load paths reactively so that less impact is transferred to the area where the protection is most needed

Our current effort is to understand how explosives can be used in a safe way and what potential guidelines can be laid out for designing innovative ERS systems. Finite element models have been developed and preliminary analysis of the developed ERS concepts has been conducted to determine feasibility and effectiveness of the ERS against land explosions.

Material Point Method Modeling and Simulation of Snow and Mud

Jonah H. Lee
Department of Mechanical Engineering, University of Alaska Fairbanks

The mechanical properties of soft terrains such as snow and saturated soils (mud), important for vehicle-terrain interaction, can depend strongly on their micro-scale properties which are a function of their microstructure. In this talk, we summarize our recent results in finding the micromechanical properties of soft terrains using the open-source parallel code Uintah developed at the Center for the Simulation of Accidental Fires and Explosions (C-SAFE) of the University of Utah. Uintah implements the Generalized Interpolation Material Point (GIMP) Method which is an emerging meshfree method for solid mechanics adapted from the particle-in-cell method for fluid mechanics. Unconfined compression and indentation tests of saturated soils were modeled using a fluid-structure interaction approach where both the soil grains and interstial water were discretized as material points. Load-displacement curves were obtaind and the key features of the deformation were discussed. 3D indentation tests of low-density snow were modeled using Uintah where the geometry of snow collected in the field was obtained using 3D X-Ray Microtomography images discretized into material points. A physically-based viscoplastic ice model with damage was implemented into Uintah to represent the matrix of snow as a porous material. The load-displacement relationships were obtained and interpreted by the deformation and failure mechanisms of the indentation tests using different sizes of indentors. Future work will include the modeling and simulation of penetration, traction of rubber on soft terrains and triaxial tests.

March 18th, Wednesday (9:30-11:00am)
University of Michigan, Lurie Engineering Center, Level 4, GM Room

Presented by Thrust Area 2:
Human Centered Modeling and Simulation

The Virtual Driver: Modeling the Experimental Results of Convoy Driving with a Secondary In-Vehicle Task

Helen Fuller, Matthew Reed, Yili Liu, *University of Michigan*

Digital human models (DHMs) are vitally important tools for studying tasks that occur in environments that are too complex or dangerous to investigate experimentally. Many tasks have significant physical and cognitive components, necessitating a DHM that can interact both physically and cognitively with its environment. One example is driving while performing an in-vehicle task, such as tuning a radio, entering coordinates into a GPS system, or operating a communications device in a military vehicle.

The goal of this project is to integrate a physical human model (HUMOSIM Framework running in the Jack human modeling environment) with a computational cognitive model (QN-MHP) to study complex human-machine interactions. A driving simulator experiment was conducted to generate data that will be used to tune and validate the integrated model. Men and women with a wide range of body size followed a lead vehicle that changed speed continuously as they entered information on a touch-screen display located in each of four positions. Driving behavior and secondary task performance results will be presented. In addition, methods for modeling the combined task and preliminary modeling work will be discussed.

Effects of Posture and Movement on Vibration Transmissibility Affecting Human Reach Performance under Vehicle Vibration

Heon-Jeong Kim and Bernard J. Martin, *University of Michigan*

Vibration transmissibility to the human body is a function of both vehicle vibration characteristics and postures associated with the performance of movements. The majority of earlier studies investigating upper body vibration transmissibility considered only a static posture excluding dynamic limb movements (Amirouche, 1987; Wei and Griffin, 1998; Rosen and Arcan, 2003; Yoshimura et al, 2005; Liang and Chiang, 2006). A few recent studies reported the effect of vehicle vibration on arm reaching movements through the description of fingertip deviation from a desired trajectory (Rider and Chaffin, 2003, 2004). The present work investigates the variation of vibration transmissibility to upper extremities as a function of dynamic posture changes along the intended reach trajectory. Dynamic reach movements in the direction of targets distributed in the right hemisphere of a vehicle operator are analyzed as a function of vibration characteristics and movement directions.. Thirteen subject performed right hand reach movements in various directions to final/end target location as well as intermediate target locations selected along the trajectory of movement performed to the end target. The established database of upper body segments transmissibility is used to develop an active biodynamic human model.

Incorporating Drivability Metrics into Optimal Energy Management Strategies for Hybrid Vehicles Hybrid

Dan Opila

Vehicle fuel economy performance is highly sensitive to the energy management strategy used to select among multiple energy sources. It is very challenging to compute controllers that yield good fuel economy for a class of drive cycles representative of typical driver behavior. Additional challenges come in the form of constraints on powertrain activity, like shifting and starting the engine, which are commonly called "drivability" metrics, and can adversely affect fuel economy. Shortest Path Stochastic Dynamic Programming is used to design optimal controllers that respect constraints and are directly implementable in real-time. The design process is highly automated and allows rapid evaluation of hardware configurations and the tradeoffs between performance attributes. Robustness to different driving conditions is demonstrated by simulating large numbers of real-world drive cycles. An industrial controller is used as a benchmark for comparison.

April 15th, Wednesday (9:30-11:00am)
University of Michigan, Lurie Engineering Center, Level 4, GM Room

Presented by Thrust Area 4:
Advanced and Hybrid Powertrains

Thermal Management System Architecture Design for Advanced Vehicles

Sungjin Park, Dohoy Jung, Zoran Filipi, Dennis Assanis, The University of Michigan

Advanced powertrain systems such as electric hybrids and fuel cell systems have been considered for military applications due to their higher efficiency, lower acoustic and thermal signatures, enhanced low speed maneuverability, and more exportable power compared with conventional counterparts. The advanced vehicle systems, however, need additional powertrain components which make the Vehicle Thermal Management System (VTMS) more complicated. For example, a hybrid electric vehicle powertrain has additional heat sources including a generator, driving motors, a battery pack, and a power controller. Thus, a more strategic approach is required when designing the VTMS for the advanced vehicle. In this study, numerical simulations of the VTMS and the powertrain system of the advanced vehicles are developed to investigate the thermal response and power consumptions of the VTMS. The output data from the powertrain system simulation are fed into the VTMS simulation to provide the operating conditions of powertrain components as input for the VTMS simulation. Although this simulation procedure is computationally efficient in design and optimization of the thermal management system, it has a limitation on predicting the fuel economy and the performance of the vehicle. Thus, the powertrain system simulation and VTMS simulation are integrated to evaluate the VTMS architecture design based on the fuel economy and performance of the vehicle. This VTMS architecture design approach is applied to the series hybrid electric vehicle and the fuel cell vehicle. The results show that the VTMS architecture design of the advanced vehicle should be developed considering various cooling requirements of powertrain components, power management strategy, performance, parasitic power consumption, and the effect of driving conditions. It is also demonstrated that a numerical model of the VTMS of the advanced vehicle is an efficient tool to assess design concepts and architectures of the system during the early stage of system development.

Diesel Engine Performance Operated by Alternative Fuels

Dinu Taraza, Florin Mocanu, Elena Florea, Bumpreet Singh, Wayne State University

Fleet operators and vehicle manufacturers are increasingly interested in assuring safe and efficient operation of diesel engines with different alternative and renewable fuels. For the army, an omnivore engine capable to run on any fuel available in the field is highly desirable. A high power diesel truck engine, the six cylinder common rail and turbocharged Mercedes 925 has been heavily instrumented and run on Ultra-low sulfur diesel fuel (ULSD), jet fuel JP8 and synthetic fuel S8. The engine was run at steady-state operating conditions for different speeds and loads and also tested for cold starting at room temperature. The engine behaved normally with all tested fuels, but differences have been noticed in the rate of heat release, engine efficiency and exhaust emissions. the behavior of the engine is analyzed based on the different physical and chemical properties of the utilized fuels and conclusion are presented for fuel injection optimization for each tested fuel.

Further work will be conducted on different blends of biodiesel and a method of identifying, on board, the fuel used will be developed together with the adaptive control of injection strategy to assure safe and efficient operation.

Comparison between the Autoignition, Combustion and Emissions Characteristics of Soy Bean based Biodiesel and ULSD fuels

Naeim A. Henein, Kaushik Acharya and Walter Bryzik, Wayne State University

There is a national interest in using Biodiesels to reduce the dependence on petroleum derived fuels and reduce carbon emissions and its effect on global warming. This project examines the effect of properties of soy-bean derived biodiesel on basic combustion processes and their impact on performance, fuel economy and emissions of a single-cylinder research engine. A detailed analysis of the rate of heat release showed the effect of biodiesel on fuel evaporation, endothermic reactions, early exothermic reactions leading to autoignition, premixed combustion fraction, mixing controlled and diffusion controlled combustion fractions. To ensure the proper combustion phasing, injection timing was adjusted to keep the peak rate of heat release due to premixed combustion at a constant location with respect to top dead center (TDC) under all of the test conditions. The effects of biodiesel on fuel economy, peak cylinder pressure NO_x, HC, CO and particulate emissions are also determined.

Effect of High Sulfur Military JP-8 Fuel on Heavy Duty Diesel Engine Emissions and EGR Cooler Condensate

Dennis N. Assanis, Zoran Filipi, Michael Smith, University of Michigan

Due to logistical issues in various theaters of operation, the Army is often forced to rely on local fuel supplies, which exposes vehicles to diesel fuel or jet fuel (JP8) with elevated levels of sulfur. An experimental study has been setup to investigate the EGR heat exchanger condensate in a heavy duty diesel engine running on JP-8 fuel doped with 3500 ppm of sulfur. A condensate collection device was developed and setup according to a modified ASTM 3226-73T standard. Combustion and emissions are analyzed in parallel with a traditional emissions bench and FTIR. A technique for accounting of sulfur emissions is proposed based on fuel properties and engine measurements. Analysis of results includes assessment of sources of uncertainties and shows the effect of coolant temperature on sulfuric acid concentration in the exhaust stream, and guidance for future work to check major sulfur reactions.