23rd ANNUAL ARC PROGRAM REVIEW May 9-10, 2017

Day 1: Tuesday, May 9, 2017

8:00 Welcome & Opening Remarks
Prof. Anna Stefanopoulou, *ARC Director*

8:15 **Army Basic Research to Enable Multi-Domain Capabilities for the Future Force**
Dr. Todd Bjerke
Deputy Director of Basic Research
Office of the Deputy Assistant Secretary of the Army for Research and Technology

8:45 **Developing the Autonomous Vehicle**
Mr. Craig Stephens
Chief Engineer: Controls Engineering, Research and Advanced Engineering, Ford Motor Company

9:15 **Modeling, Estimation and Control of Freeway Traffic Corridors**
Dr. Roberto Horowitz
Chair and Professor of Mechanical Engineering, UC Berkeley

10:30 **Case Study 1**
Who's the Boss?
A Haptic Interface for Negotiating Control Authority between Human Drivers and Automation Systems

1:10 **Parallel Technical Session 1**

3:10 - 5:30 **Poster Session & Lab Tours**

Day 2: Wednesday, May 10, 2017

8:00 Welcome & Introduction
Prof. André Boehman, *ARC Associate Director*

8:10 **Sytems Engineering and Autonomy - Enabling Practice for Capability Utilization**
Mr. Robert A. Gold
Director - Engineering Enterprise
Office of the Deputy Assistant Secretary of Defense for Systems Engineering

8:40 **Case Study 2**
Finding the MARVEL in the Hay Stack: A Case Study on Modular Adaptive Resilient Vehicle Fleets

10:00 **Parallel Technical Session 2**

12:00 **Closing Remarks and Award Presentation**
Prof. Bogdan Epureanu, *ARC Associate Director*
Dr. David Gorsich, *Chief Scientist, U.S. Army TARDEC*

12:30 **Post Review Networking**

http://arc.engin.umich.edu

Venue

Chesebrough Auditorium
Chrysler Center, North Campus
The University of Michigan
2121 Bonisteel
Ann Arbor, MI 48109 -2092

In accordance with Cooperative Agreement
W56HZV-14-2-0001
U.S. Army Tank Automotive Research, Development
and Engineering Center (TARDEC)

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

SPEAKER BIOGRAPHIES

Dr. Todd Bjerke was recently appointed as the Deputy of the Basic Research Portfolio in the Office of the Deputy Assistant Secretary of the Army for Research and Technology, where he assists in coordination and oversight of all basic research within the US Army. Prior to his current assignment, Dr. Bjerke was the Chief of the Impact Physics Branch at the US Army Research Laboratory located at the Aberdeen Proving Ground, Maryland. In this prior role, Dr. Bjerke had approximately 30 years of experience conducting and managing basic and applied research in the areas of fundamental mechanisms of terminal ballistics, hypervelocity impact, dynamic deformation and failure of materials, physics-based computational mechanics, and warhead technologies. He received his BS in aerospace engineering from the State University of New York at Buffalo in 1985, his ME degree in mechanical engineering from Johns Hopkins University in 1992, and his Ph.D. degree in mechanical engineering from the University of Delaware in 2002. Todd began his career in the field of hypervelocity impact science by conducting experiments using a suite of two-stage, light-gas launchers while employed at the Arnold Engineering and Development Center in Tullahoma, TN. He continued his terminal ballistics research by joining the US Army Research Laboratory in 1988. He is author of over 50 journal articles, conference proceedings, and government technical reports and is a member of ASME. His activities in the Hypervelocity Impact Society include serving as the Co-Chair of the 2012 Hypervelocity Impact Symposium and serving as the current Society President since 2015.

Mr. Craig Stephens is Chief Engineer for Controls Engineering in the Autonomous Vehicles and Controls Research and Advanced activity in Ford Motor Company. He joined Ford Motor Company in 1987 working in Powertrain Calibration and Controls for Ford of Europe and in 1991 he moved to Dearborn, Michigan holding a variety of positions in P/T Controls and Software development. These positions have spanned the full technology cycle from Research through to Production. In his current position his work has expanded to include support for Driver Assistance Technologies and Autonomous Vehicles where his team contributes primarily in the areas of Systems Engineering, Functional Safety and Controls. He received a BEng in Electrical and Electronic Engineering from the University of Leeds and an MS in Electronics and Computer Control from Wayne State University. He is a Chartered Engineer and a Fellow of the Institution of Engineering and Technology.

Dr. Roberto Horowitz is a Professor in the Department of Mechanical Engineering at UC Berkeley and holds the James Fife Endowed Chair in the College of Engineering. He received a B.S. degree with highest honors in 1978 and a Ph.D. degree in 1983 in mechnical engineering from the University of California at Berkeley and became a faculty member of the Mechnical Engineering Department in 1982. Dr. Horowitz teaches and conducts research in the areas of adaptive, learning, nonlinear and optimal control, with applications to Micro-Electromechanical Systems (MEMS), computer disk file systems, robotics, mechatronics and Intelligent Vehicle and Highway Systems (IVHS). He is currently the Chair of the Department of Mechanical Engineering Department and is a former co-director of the Partners for Advanced Transportation Technology (PATH) research center at UC Berkeley. Dr. Horowitz is a member of IEEE and ASME and the recipient of the 2010 ASME Dynamic Systems and Control Division (DSCD) Henry M. Paynter Outstanding Investigator Award

Mr. Robert Gold serves as Director of the Engineering Enterprise within the Office of the Deputy Assistant Secretary of Defense for Systems Engineering (DASD(SE)) under the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)), Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics (OUSD(AT&L)). Mr. Gold is a member of the Senior Executive Service. He is responsible for SE-related policy and guidance, specialty engineering, engineering tools and environments, hardware and software assurance, and defense standardization. He oversees workforce development for the defense acquisition engineering career fields Engineering (ENG) and Production, Quality and Manufacturing (PQM). His specialty engineering responsibilities include reliability and maintainability, system safety, manufacturing, human systems integration, and the Department of Defense (DoD) Value Engineering program. Mr. Gold's career spans more than 30 years with the Department of Defense, focusing on combat systems engineering, software, cyber, complex networking, and satellite acquisition. He holds a Master of Science degree in systems engineering from Virginia Tech, a Bachelor of Science degree in electrical engineering from Lehigh University, and a Public Management Certificate from Indiana University-Purdue University Indianapolis.

Dr. David Gorsich was selected for a Scientific and Professional (ST) position in January 2009 and serves as the Army's Chief Scientist for Ground Vehicle Systems. His current research interests are vehicle dynamics and structural analysis, reliability based design optimization, underbody blast modeling, terrain modeling and spatial statistics.

Prior to his current position, Gorsich served as the U.S. Army Tank Automotive Research, Development and Engineering Center's (TARDEC's) Associate Director, Modeling and Simulation (M&S), from July 2003 to December 2008. He has also served as the Acting Director, Strategic Plans and Programs, and the Team Leader for Robotics and Vehicle Intelligence. He served in various assignments at TARDEC, the Army Materiel Command, the Army Research Laboratory and for the Assistant Secretary of the Army (Acquisitions, Logistics, and Technology). Gorsich previously was an electrical engineering with McGraw Commercial Equipment Corporation in Novi, MI.

Gorsich was named a Society of Automotive Engineers (SAE) Fellow in 2008. He has served on the SAE Technical Standards Board for a 3-year term, been the chair for the SAE International Standards Committee for Ground Vehicle Reliability and also on the SAE Board of Directors. He has received several Commander's Coins, including: U.S. Army Central Command, GEN John Abizad, High Mobility Multipurpose Wheeled Vehicles Safety/Seat Experiments, 2005; Chief of Staff, GEN Peter Schoomaker, TARDEC M&S, 2005; West Virginia National Guard, 2004; U.S. Army TACOM, MG William M. Lenaers, Army-SAE Partnership, 2004; U.S. Army TACOM, MG N. Ross Thompson, Reliability, 2003. Gorsich received the Detroit Federal Executive Board Award in 2001. Gorsich was recognized with the 1997 Army Research, Development and Acquisition Award, "Innovations in Ground Vehicle Signature Research."

Gorsich is recognized in many professional organizations for his research accomplishments. Gorsich serves as an Associate Editor for the International Journal of Terramechanics, and on the Editorial Board of the International Journal for Reliability and Safety, and as past Associate Editor for the Journal of Mechanical Design. He is a member of the Massachusetts Institute of Technology (MIT) Chapter of Sigma Xi, the Material Parts and Processes Council of SAE and the Senior Executives Association, ST Chapter.

Gorsich has published more than 150 conference and journal articles including more than 50 peer reviewed journal articles. He has published in the following peer-reviewed journals: Transactions of SAE; International Journal of Vehicle Design; Journal of Mechanical Design; Journal of Commercial Vehicles; Contemporary Mathematics; Computational Statistics and Data Analysis; Physical Review D; Society of Automotive Engineers; Journal of Multivariate Analysis; Journal of Electronic Imaging; Optical Engineering; Pattern Recognition Letters; Statistics and Computing; Institute for Electrical and Electronics Engineering Transactions on Pattern Analysis and Machine Intelligence.

Gorsich holds a B.S. in electrical engineering from Lawrence Technological University. He holds an M.S. in applied mathematics from George Washington University and a Ph.D. in applied mathematics from MIT.

Student Poster Award Committee Biographies

Dr. Ravi Thyagarajan is a Science and Technology (S&T) acquisition professional in the research and development of military ground vehicles over the entire product lifecycle. He currently serves as the Senior Technical Expert in Materials/Product Lifecycle engineering in the Ground Systems Engineering Support Directorate at the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC). In his current role, he is responsible for setting the engineering and research direction for materials-related initiatives such as Light-weighting, Additive Manufacturing, Multi-material joining, Materials development, as well as Modeling and Simulation in support of the same. His most recent assignment was being the TARDEC Deputy Chief Scientist for over three years, where he was responsible for managing the basic research program portfolio. He also served on the Deputies Council chartered to be the focal point for making timely and informed enterprise-level business decisions aligned to strategic priorities and transformation His research pursuits are in the areas of structural lightweighting/optimization, occupant protection, blast modeling/design, and fast-running modeling methodologies. Dr. Thyagarajan is this year's Awards Committee Chair.

Dr. Jean Dasch is a Principal Scientist for Alion Science and Technology. For the last six years, she has worked in the Office of the Chief Scientist at the U.S. Army Tank Automotive Research, Development and Engineering Center. There, she is involved in a variety of projects dealing with basic research at TARDEC; she also coauthored a book with Dr. David Gorsich on the history of innovation at TARDEC from 1946 to 2010. Prior to TARDEC, Dr. Dasch was a Technical Fellow at the General Motors Research and Development Center in the Chemical and Environmental Sciences Laboratory. Her research interests included environmental emissions from vehicles and automotive plants, indoor air pollution, clean machining studies, and groundwater remediation. She obtained her BA from Catholic University of America in Chemistry and her PhD from the University of MD in Nuclear and Atmospheric Chemistry. She was a Postdoctoral Fellow at Argonne National Laboratory for one year prior to joining General Motors. She has one patent and over 75 publications in peer-reviewed journals.

Dr. Bogdan Epureanu is a professor of Mechanical Engineering, University of Michigan. He obtained his Ph.D. in Mechanical Engineering at Duke University, 1999; Graduate Studies at University of Valladolid, 1994; M.S. in Mechanical Engineering at Galati University, 1993; and Graduate Studies at École Nationale Supérieure des Mines de Paris, 1992. His research interests include structural health monitoring and sensors based on nonlinear dynamics and chaos, linear and nonlinear reduced order models, pattern formation and control of chaos, computer fluid dynamics of unsteady flows, and nonlinear unsteady aerodynamics.

Dr. Richard Gerth is the Deputy Chief Scientist for the U.S. Army's Tank Automotive Research Development and Engineering Center (TARDEC). The Chief Scientist's Office is responsible for managing TARDEC's basic research portfolio as well as promoting the growth and development of its research workforce. Prior to his current position, Dr. Gerth was a Senior Research Engineer on the Materials Application and Integration team responsible for conducting research in vehicle lightweighting technologies. His primary research interests are in high Manganese steels, operational metrics for weight reduction in military vehicles, and open innovation processes. Dr. Gerth has over 60 publications and presented at numerous national and international conferences. He earned his B.S. from the University of Wisconsin – Madison and his Ph.D. from the University of Michigan – Ann Arbor.

Dr. Thomas Meitzler received his B.S. and M.S. in Physics from Eastern Michigan University, completed graduate coursework at the University of Michigan, and received a Ph.D. in Electrical Engineering from Wayne State University in Detroit. His doctoral dissertation in Electrical Engineering from Wayne State University was on *Modern Methods for Computing the Probability of Target Detection in Cluttered Environments*. He is a Fellow of the American Physical Society (APS) and Senior Member of the Institute for Electrical and Electronics Engineers (IEEE). He is the Ground System Survivability Senior Science Advisor. During the time from 1988 to present, Dr. Meitzler has been a research engineer at the U.S. Army TACOM Research and Engineering Center (TARDEC) in Survivability. For the U.S. Army, Dr. Meitzler has been involved with the validation, verification, and development of infrared, electro-optical and human visual acquisition models. Dr. Meitzler was the principal scientist of the TARDEC Visual Perception Laboratory and the principal investigator on Cooperative Research and Development Agreements (CRADA's) with GM and Ford Motor Company to apply visual target acquisition models to vehicle conspicuity and novel sensors to automobile 360 degree safety. Dr. Meitzler was the principal investigator on several Space Act Agreements with NASA's Kennedy Space Center and CRADA's with the Columbia University College of Physicians and Surgeons. He has authored/co-authored many papers in the area of Electro Optic system simulation, visual detection, sensor validation, traditional nondestructive armor evaluation and embedded piezoelectric nondestructive testing of armor materials, and spintronics. Dr. Meitzler has developed and integrated technologies for embedded armor health-monitoring, armor Non-Destructive testing, and armor embedded radio signal detection.

Dr. Edward Umpfenbach is a senior research analyst with General Motors Product Development Analytics team. His current research activities involve vendor tooling capital cost estimation as well as supplier location optimization. Edward was awarded a DoD SMART Fellowship in 2011 and finished his Ph.D. in Industrial and Systems Engineering from Wayne State University in 2013. He worked as U.S. Army TARDEC 2013-2016 as active chief architect of the Integrated Systems Engineering Framework (ISEF). His research interests include systems engineering, vehicle modularity and commonality, optimization, and statistics.

CASE STUDY ABSTRACTS

CASE STUDY 1

09 MAY 2017
10:30 – 11:15
CHESEBROUGH AUDITORIUM

Who's the Boss? – A Haptic Interface for Negotiating Control Authority between Human Drivers and Automation Systems

Recognizing the potential for autonomous systems to dramatically increase mobility in both military and civilian applications and their critical role in the Third Offset Strategy of the Department of Defense, this case study brings together three projects to explore how control actions generated by an autonomous system and a human driver can be combined to achieve greater mobility than achievable when either control action acts alone. We first present an autonomous navigation algorithm designed to fully exploit the dynamic limits of a vehicle to maximize its mobility when navigating through an obstacle field. Supposing that intermittent sensor faults might preclude fully autonomous operation, we then use the steering wheel as a haptic interface to facilitate smooth negotiation of control between a remote human driver and the automation system. We explore a control sharing paradigm in which the autonomous system applies its control effort through a finite mechanical impedance such that the human driver can feel and in effect "edit" the autonomous system's control actions. Likewise, the automation can edit the human driver's control actions. We compare performance at lane keeping and obstacle avoidance under this haptic control sharing paradigm to performance under more traditional alternatives using a fixed base driving simulator. In addition, we consider communication delays between the remote human driver and the vehicle and explore the benefits of a novel predictor framework to attenuate the negative impact of delays on mobility performance in this haptic shared control paradigm.

Contributors

Faculty:	Tulga Ersal, Brent Gillespie, Jeffrey Stein (University of Michigan)
Post-Doc:	Amirhossein Ghasemi (University of Michigan)
Students:	Akshay Bhardwaj, Huckleberry Febbo, Yingshi Zheng (University of Michigan)
Government:	Paramsothy Jayakumar (U.S. Army TARDEC)
Industry:	Mitch Rohde, Steve Rohde (Quantum Signal), John Walsh (Ford Motor Company)

CASE STUDY 2

10 MAY 2017
8:40 – 9:25
CHESEBROUGH AUDITORIUM

Finding the MARVEL in the Hay Stack: A Case Study on Modular Adaptive Resilient Vehicle Fleets

Revolutionary adaptability and resilience are two of the key needs of the 3rd offset. Paradigm changes are required in fleet operation and design to accomplish these needs. Modularity promises to provide significant benefits in terms of adaptability and resilience especially when combined with autonomy through self-assembly and self-reconfiguration. Modular autonomous systems are complex systems of systems, which require advanced design and management approaches. This case study presents a unique approach to the design, dynamic operation and reliability of modular vehicle systems. The design study refers to a systematic process for decisions to generate modular design concepts to create the vehicle fleets of the 3rd offset; dynamic operation addresses the fleet management to schedule and conduct on-base and in-theatre missions such as vehicle assembly, resupply and convoy operations considering the entire fleet dynamics; and reliability analysis models the failures in the fleet as a repairable system based on limited observations, and provides quantitative predictions for future failures based on previous ones to enhance the overall system reliability. The analysis in this case study is applied to the Vehicle Agnostic Modularity (VAM) program of the Office of Naval Research to support decisions from design to deployment and operation of innovative modular vehicle fleet concepts; VAM seeks to assess the efficacy of modularity to the USMC ground vehicle fleet.

Contributors

Faculty:	Bogdan Epureanu, Panos Papalambros (University of Michigan), Zissimos Mourelatos (Oakland University)
Post-Doc:	A. Emrah Bayrak, Mert Egilmez (University of Michigan)
Students:	Xingyu Li, Arianne Collopy (University of Michigan) Themistoklis Koutsellis (Oakland University)
Government:	Matthew Castanier, Richard Gerth, Michael Kerr, Chad Wilson (U.S. Army TARDEC), Jeff Bradel (Code 30), Ra'ed Seifeldin (Vencore)
Industry:	Edward Umpfenbach (General Motors), Terrance Wagner (Ford Motor Company), Randy Jaeger, Clint Hope (Applied Minds), William Ross (Nevada Automotive Test Center)

23RD ANNUAL AUTOMOTIVE RESEARCH CENTER PROGRAM REVIEW

09 May	**1A: Autonomy** Session Leads: Dr. Paramsothy Jayakumar, Dr. Matt Castanier	**1B: Fuels & Engines** Session Leads: Dr. Peter Schihl, Mr. Eric Gingrich
1:10 - 1:40	Project 1.18 PI: Dr. Ardalan Vahidi Improving Energy Efficiency and Mobility of Off-Road Connected Fleets via Route Preview and Cooperative Control	Project 4.21 PI: Dr. André Boehman Bulk Modulus of Compressibility Measurements of Conventional and Alternative Military Fuels
1:40 - 2:10	Project 5.11 PI: Dr. Kira Barton Enhanced Multi-Robot Reconnaissance Through Terrain-Based Energy Prediction	Project 4.25 PI: Dr. Jason Martz Simulations for JP-8 Mechanism Optimization and Validation
2:10 - 2:40	Project 5.A46 PI: Dr. Dimitra Panagou SQUAD: Situational Awareness and Sustained Survivability through Man/Unmanned Teaming	Project 4.26 PI: Dr. Angela Violi Combustion Chemistry of Jet Fuels: From Atomistic Simulations to Mechanism Development
2:40 - 3:10	Project 1.16 PI: Dr. Hiroyuki Sugiyama Flexible Multibody Dynamics Approach for Tire Dynamics Simulation	Project 4.A45 PI: Dr. Marcis Jansons Thermal Barrier Coatings for Reduction of Cooling Loads in Military Vehicles

10 May	**2A: Electrification, Thermal Management** Session Leads: Mr. Aric Haynes, Mr. Scott Shurin	**2B: Structures, Reliability, Safety** Session Leads: Dr. David Lamb, Dr. Ravi Thyagarajan, Mr. Victor Paul
10:00 - 10:30	Project 4.22 PI: Dr. Anna Stefanopoulou Optimal Warm-up of Lithium-Ion Battery from Sub-Zero Temperatures	Project 3.10 PI: Dr. K. K. Choi Confidence-based Reliability Assessment Accounting for Both Parameter Uncertainty and Model Bias for Insufficient Input and Output Experimental Data
10:30 - 11:00	Project 4.24 PI: Dr. Jason Siegel Robotic Range Extender: Power and Energy Management for a Hybrid Powertrain with Quantized Power Sources	Project 3.11 PI: Dr. Nick Vlahopoulos Modeling of Materials for the Design of Lightweight and Resilient Vehicle Structures
11:00 - 11:30	Project 4.27 PI: Dr. John Wagner Thermal Bus with Passive and Active Cooling Strategies for Vehicle Thermal Management	Project 5.10 PI: Dr. Zissimos Mourelatos Reliability Assessment and Warranty Forecasting of Repairable System
11:30 - 12:00	Project 4.28 PI: Dr. Heath Hofmann Computationally-Efficient Heat Convection Model for Electric Machines	Project 2.A36 PI: Dr. Jingwen Hu Restraint System Optimization for Occupant Protection in Tactical Vehicles: Full Vehicle Crash Tests

TECHNICAL SESSION ABSTRACTS

TECHNICAL SESSION 1A – AUTONOMY

LOCATION: CHESEBROUGH AUDITORIUM

Session Chairs: Dr. Paramsothy Jayakumar, Dr. Matt Castanier

Project 1.18

Improving Energy Efficiency and Mobility of Off-Road Connected Fleets via Route Preview and Cooperative Control

Quad members: Ardalan Vahidi (PI), Shahab Karimi,
Angshuman Goswami, Alireza Fayazi (*Clemson University*),
Paramsothy Jayakumar (*U.S. Army TARDEC)*,
Chen Zhang (*Ford Motor Company)*

Improvements in fleet energy efficiency and safety are of paramount importance to the Army. A novel path-planning algorithm as part of a decision support tool for off-road scenarios was developed last year based on low-order vehicle models. To capture interactions with off-road terrain with higher fidelity, a three-dimensional 14-degree of freedom model for off-road vehicle dynamics is developed and tested while traversing a pre-designed off-road surface. The model will be used to define vehicle dynamic constraints for the path-planning algorithm. On the experimental front, a scaled vehicle-in-the-loop testbed is built in which a scaled autonomous vehicle communicates and collaborates with other (simulated) vehicles. Exchange of information between the real and simulated vehicles via a backend computational server complements existing soil and terrain maps to improve fleet mobility.

Project 5.11

Enhanced Multi-Robot Reconnaissance Through Terrain-Based Energy Prediction

Quad members: Kira Barton (PI), Lauro Ojeda (Co-PI),
Michael Quann (Presenter, *University of Michigan*),
William Smith, Denise Rizzo (*U.S. Army TARDEC*),
Frank Koss, Andrew Dallas (*Soar Technology, Inc.*)

Autonomous robots have significant potential for reconnaissance and environmental monitoring applications. Ground robots, in particular, are performing reconnaissance missions in places that are too hazardous for humans. However, these robots are constrained by energy limitations that are impacted by uncertain environments are harsh terrains. The purpose of this work is to develop methods for improving the efficiency of reconnaissance missions through energy awareness. To address such limitations, robot energy usage is spatially modeled with a Gaussian Process (GP) through measurements collected during the mission. The resulting energy predictions are incorporated into a centralized waypoint-based strategy with the goal of minimizing the uncertainty of a spatial-temporal field, subject to ensuring the robots' return to recharging locations. We present simulation and experimental results for a multi-robot system to demonstrate the effectiveness of incorporating energy predictions into reconnaissance missions.

Project 5.A46

SQUAD: Situational Awareness and Sustained Survivability through Man/Unmanned Teaming

Quad members: Dimitra Panagou (PI),
William Bentz, James Usevitch, Mitchell Coon (*University of Michigan*),
Thomas Meitzler, Neil Cooper, Bob Severinghaus (*U.S. Army TARDEC*),
Andrew Dallas (*Soar Technology, Inc.*)

The SQUAD project is motivated by the need for protection of Ground Vehicle systems against Aerial Threats, and in particular, against small Unmanned Aerial Vehicles (UAVs). It is thus of vital importance that GVs are equipped with systems that can detect and act against small UAVs. The project aims thus at developing proactive and reactive countermeasures against aerial threats. In this talk we will review our recent algorithmic developments and experiments towards an aerial sensing/surveillance system of UAS that relies on our notion of dynamic coverage control, our initial algorithmic developments on resilient communication topologies in swarms of UAS, as well as our algorithmic developments on multi-player (UAS) target-attacker-defender games.

Project 1.6

Flexible Multibody Dynamics Approach for Tire Dynamics Simulation

Quad members: Hiroyuki Sugiyama (PI), Hiroki Yamashita (*The University of Iowa*),
Paramsothy Jayakumar (*U.S. Army TARDEC*),
Ryoji Hanada (*Yokohama Rubber*), SeeChew Soon (*Caterpillar Inc.*)

A high-fidelity physics-based deformable tire-soil interaction model that can be fully integrated into a monolithic multibody dynamics solver is developed for off-road mobility simulations and validated against test data. A locking-free nine-node brick element is proposed for modeling deformable terrains using the multiplicative finite strain plasticity theory along with the capped Drucker-Prager failure criterion. The soil model is validated against the triaxial soil compression test data. The moving soil patch technique is applied such that the soil behavior only in the vicinity of the rolling tire is solved to reduce the model dimensionality. Finally, the proposed off-road tire-soil interaction simulation capability is validated against test data obtained from an indoor soil bin mobility test facility, including the effect of wheel loads and tire inflation pressures on the tire forces and rolling resistances.

TECHNICAL SESSION 1B – FUELS & ENGINES

LOCATION: 165 CHRYSLER CENTER

Session Chairs: Dr. Peter Schihl, Mr. Eric Gingrich

Project 4.21

Bulk Modulus of Compressibility Measurements of Conventional and Alternative Military Fuels

Quad members: Andre Boehman (PI), Taemin Kim *(University of Michigan),*
Eric Sattler *(U.S. Army TARDEC),* Peter Attema *(Detroit Diesel/Daimler)*

This project concerns the bulk modulus of conventional and alternative jet fuels, and jet fuel surrogates and investigation of the impact of bulk modulus of fuel on fuel injection timing in pump-line-nozzle type fuel supply systems. A single cylinder, direct-inject, pump-line-nozzle type fuel supply engine is being configured for the purpose of the investigation of the different injection timing shifts with these alternative and conventional jet fuels. During the past year, the engine has been installed in a test cell, instrumented for combustion and fuel system dynamics analysis. Testing is ongoing. The outcome will be a correlation of the relationship between the isothermal bulk modulus and the injection timing shift, which can help guide the calibration and design of fuel injection systems.

Project 4.25

Simulations for JP-8 Mechanism Optimization and Validation

Quad members: Jason Martz (PI), Jordan Lee, Shuqi Cheng (*University of Michigan*),
Peter Schihl (*U.S. Army TARDEC*), Tim Edwards (*AFRL*),
Jim Anderson (*Ford Motor Company*)

Detailed chemical kinetic mechanisms are needed for CFD simulations used to design Diesel engine combustion systems. Despite tremendous progress, state of the art Jet-A and JP-8 mechanisms remain inaccurate within the low temperature heat release (LTHR) and negative temperature coefficient (NTC) ignition regimes relevant to Diesel ignition. This project is focused on improving these mechanisms, in particular within the Diesel relevant ignition regimes. To this end, sensitivity analysis and optimization are used to identify and then modify relevant mechanism reaction rate parameters in order to reduce ignition delay errors. Combined with the atomistic computational project of Violi focused on mechanism reaction pathway development and the motored engine ignition studies of Boehman et al., our efforts will lead to more accurate Jet-A and JP-8 chemical kinetic models needed for the development of future Army engines.

Project 4.26

Combustion Chemistry of Jet Fuels: Identifying New Reaction Pathways for Mechanism Development

Quad members: Angela Violi (PI), Paolo Elvati (*University of Michigan*),
Peter Schihl (*U.S. Army TARDEC*), Tim Edwards (*AFRL*),
James Anderson (*Ford Motor Company*)

In recent years, there has been an increasing effort to incorporate complex reaction mechanisms in simulation of reacting flows. Indeed, computational fluid dynamic calculations of reactive flows have become an important part of the design of combustion devices, such as engines. One of the key components is the accurate description of the network of reactions that can happen during combustion. Current models are developed and optimized for specific conditions, and have little chance of producing reliable extrapolations to other conditions. There are two main major problems related to the development of predictive reaction models: accuracy of rate constants and ability to obtain a complete detailed mechanism. The former is usually addressed using high-level *ab initio* simulations to compute reaction rates; the latter represents a big challenge and almost no literature is available on this topic. In our project, we aim at addressing this challenge and developing a novel computational procedure to identify missing reaction pathways as well as main reaction pathways for the combustion chemistry of JP-8, using atomistic simulations.

Project 4.A45

Thermal Barrier Coatings for Reduction of Cooling Loads in Military Vehicles

Quad members: Marcis Jansons (PI), David Gatti (*Wayne State University*),
Eric Gingrich (*U.S. Army TARDEC*), Shawn Dolan (*Henkel of America, Inc.*)

Reductions in cooling loads are sought to reduce the considerable under-armor volume devoted to thermal management systems compromising ballistic grilles, fans, ductwork and radiators. Thermal barrier coatings (TBC) have military applications as a means of re-distributing energy from the cooling load to engine exhaust. Titanium-based coatings applied with a novel aqueous electro-deposition process show promise in overcoming the durability issues characteristic of previously researched materials. This presentation will discuss a simulation and experiment-based project that evaluates desirable TBC properties, the durability and thermal shock response of TiO2-based and other potential TBCs, and examines their thermal properties and in-cylinder behavior using optical diagnostic techniques.

TECHNICAL SESSION 2A – ELECTRIFICATION, THERMAL MANAGEMENT

LOCATION: CHESEBROUGH AUDITORIUM

Session Chairs: Mr. Aric Haynes, Mr. Scott Shurin

Project 4.22

Optimal Warm-up of Lithium-Ion Battery from Sub-Zero Temperatures

Quad members: Anna Stefanopoulou (PI), Jason Siegel, Shankar Mohan (*University of Michigan*), Yi Ding (*U.S. Army TARDEC*), Dyche Anderson (*Ford Motor Company*)

Operation at low temperature degrades battery performance, reducing available power and usable energy. To address these issues, we posed and solved two energy-optimal warm-up strategies in addition to developing decision tools on whether warm-up is feasible if the battery energy state falls too low. The first warm-up scenario involves a receding horizon optimal control problem for the bi-directional pulses that charge and discharge the cell at relatively high frequencies via an external capacitor. The results also define the capacitor size, time, and lost energy. The second control policy computes the optimal power discharge for self-heating the cell while minimizing the loss in state of charge. The methods are demonstrated via simulations and experiments on two Li-ion chemistries with high power capability typically used for conventional internal combustion engine starter (12V) or micro-hybrid in start-stop (48V) vehicle applications.

Project 4.24

Robotic Range Extender: Power and Energy Management for a Quantized Hybrid Powertrain

Quad members: Jason Siegel (PI), Anna Stefanopoulou (co-PI),
Yuanzhan Wang, Miriam Figueroa (*University of Michigan*),
Serhat Yesilyurt (*Sabanci University*),
John (Jack) Hartner, Denise Rizzo (*U.S. Army TARDEC*),
Tom Westrich (*Ultra AMI Fuel Cells*), Buz McCain (*Ballard Power Systems Inc.*)

This project addresses the need for quiet, long-life power sources for robotic vehicles which cannot be met by batteries alone (due to range), or with combustion engines (due to noise). A hybrid power source that combines a battery (BB2590) with small (245 Watt), propane-fueled solid oxide fuel cell (SOFC) is considered. A system model that takes into account degradation, which is particularly important and challenging for these systems due to the thermal stresses from the start-stop operation, was developed using physics based modeling techniques. The models are used to evaluate the impact of battery sizing and power split strategy on fuel efficiency, SOFC stack life, and battery cell life over realistic synthetic cycles. These cycles were developed using statistical models of the power measured from an instrumented PackBot, provided by TARDEC engineers.

Project 4.27

A Thermal Bus with Passive and Active Cooling Strategies for Vehicle Thermal Management

Quad members: John Wagner (PI), Richard Miller (co-PI),
Shervin Shoai Naini, Junkui (Allen) Huang (*Clemson University*),
Denise Rizzo, Katie Sebeck, Scott Shurin (*U.S. Army TARDEC*),
Arun Muley, David Blanding (*Boeing Research and Technology*)

Thermal management solutions for military vehicles remain a challenge due to the variety of heat loads, payloads, propulsion system configurations and operation cycles. Cooling systems should meet the heat rejection requirements while minimizing the power consumption under adverse conditions. This study examines the integration of passive and active heat rejection strategies in a hybrid thermal bus architecture (e.g. heat pipes, composites, high conductivity materials, etc.) in parallel with traditional fluid designs. In an initial case study, pulsating and capillary heat pipes have been integrated as passive heat rejection pathways in the thermal bus. Mathematical models establish a basis for the numerical evaluation of the thermal performance during a convey escort driving profile. An experimental test bench is being designed to validate the computational results.

Project 4.28

Computationally-Efficient Heat Convection Model for Electric Machines

Quad members: Heath Hofmann (PI), Yuanying Wang (*University of Michigan*),
Denise Rizzo, Scott Shurin (*U.S. Army TARDEC*),
John Wagner, Richard Miller (*Clemson University*), Ma Lin (*Virginia Tech*),
Xiao Hu (*Ansys Inc.*), Arun Muley (*Boeing Research and Technology*)

Knowledge of the internal temperatures of electric machines is very important since the performance of these machines, such as their torque capability and efficiency, are greatly affected by these temperatures. In our previous work an FEA-based, computationally-efficient model of thermal conduction in the electric machine components was developed. In this project, a complementary computationally-efficient model of heat convection in the air regions of an electric machine is proposed. The model is based upon the exploitation of certain properties of the heat transfer equations (i.e., conservation of mass, momentum, and energy), which we have discovered exist under certain conditions as seen in electric machines. This in turn leads to the formulation of a system identification technique, the end result being a computationally-efficient heat convection model with very high accuracy.

TECHNICAL SESSION 2B – STRUCTURES, RELIABILITY, SAFETY

LOCATION: 165 CHRYSLER CENTER

Session Chairs: Dr. David Lamb, Dr. Ravi Thyagarajan, Mr. Victor Paul

Project 3.10

Confidence-Based Reliability Assessment Accounting for Both Parameter Uncertainty and Model Bias for Insufficient Input and Output Experimental Data

Quad members: K.K. Choi (PI), Min-Yeong Moon, Hyunkyoo Cho (*University of Michigan*),
David Lamb, David Gorsich (*U.S. Army TARDEC*),
Nicholas Gaul (*RAMDO Solutions, LLC*)

Conventional reliability analysis methods have been developed given (1) accurate input distribution models (i.e. no input distribution model uncertainty) and (2) accurate simulation model (i.e., no simulation model bias). However, in practical applications, insufficient input data are available and only limited output physical testing can be provided. As a result, there exist both uncertainties caused by limited input and output data. To handle both uncertainties, we propose a confidence-based reliability assessment that accounts for both uncertainty in input distributions model and simulation model. Both uncertainties are combined using hierarchal Bayesian model to obtain uncertainty distribution of the reliability. At user-specified target confidence level, confidence-based reliability and target output distribution are selected. After that, the validated simulation model is obtained using confidence-based bias correction.

Project 3.11

Modeling of Materials for the Design of Lightweight and Resilient Vehicle Structures

Quad members: Nick Vlahopoulos (PI), Alyssa Bennett (Presenter, *University of Michigan*),
Ravi Thyagarajan, Matthew Castanier (*U.S. Army TARDEC*),
Nam Purush (*BAE Systems*)

This project pursues the development of modeling strategies for materials that can contribute to the blast mitigation of structures. Implementing shear thickening fluids (STFs) in plate armor may provide a new means of shock absorption mechanism in ground vehicles; the viscosity of STFs increases significantly at high shearing rates. The work which will be presented focuses on determining whether the behavior of STFs can be utilized for blast mitigation in ground vehicles by studying the effects of Coulomb damping in a multilayer plate. A multi-layer plate model was constructed in LS-DYNA with Coulomb damping between layers and then was subjected to blast loads generated by the Friedlander equation and CONWEP. The results of these simulations provide sufficient encouragement to pursue the multi-scale modeling of STFs types of materials.

Project 5.10

Reliability Assessment and Warranty Forecasting of Repairable Systems

Quad members: Zissimos P. Mourelatos (PI), Vijitashwa Pandey (co-PI),
Themistoklis Koutsellis (*Oakland University*),
Matt Castanier (*U.S. Army TARDEC*),
Mohammad Hijawi (*Fiat Chrysler Automobiles*)

Most engineering systems are repairable. Their components can be renewed or repaired if system failure occurs, to put the system back into service. In this work, a Generalized Renewal Process (GRP) model quantifies the reliability of a repairable system based on the concept of virtual or effective age. The model accounts for repair assumptions such as “same-as-old,” “good-as-new,” “better-than-old-but-worse-than-new” and “worse-than-old,” and is suitable for reset and depot maintenance strategies as well as warranty predictions and forecasting of vehicle fleets. In warranty forecasting, it is desired to predict the Expected Number of Failures (ENF) after a censoring time using collected failure data before the censoring time. We will present a forecasting method to predict the ENF of a repairable system using observed data. First, a GRP model is calibrated using the observed data and then the model is used to forecast failures. All developments will be demonstrated using vehicle production data.

Project 2.A36

Restraint System Optimization for Occupant Protection in Tactical Vehicles: Full Vehicle Crash Tests

Quad members: Jingwen Hu (PI), Matthew Reed (co-PI, *University of Michigan*),
Zissimos Mourelatos, Dorin Drignei (*Oakland University*),
Rebekah Gruber, David Clark, Risa Scherer (*U.S. Army TARDEC*),
Marianne Kump, Brian Hansen (*TAKATA*)

The objective of this study is to optimize the restraint systems for tactical vehicle occupants using an innovative combination of simulation and physical testing guided by calibration-based optimization. In the previous years of this study, two full vehicle crash tests in frontal and rollover impacts, over 50 sled tests, and hundreds of FE simulations were conducted to optimize seatbelt and airbag designs for occupants with different sizes and military gear configurations. In the last year of this study, we focused on conducting full vehicle frontal and rollover crash tests with optimized restraint systems. Comparisons between the tests with the baseline and optimized restraint systems clearly demonstrated the benefit of using airbags and advanced seatbelt technologies for protecting tactical vehicle occupants.

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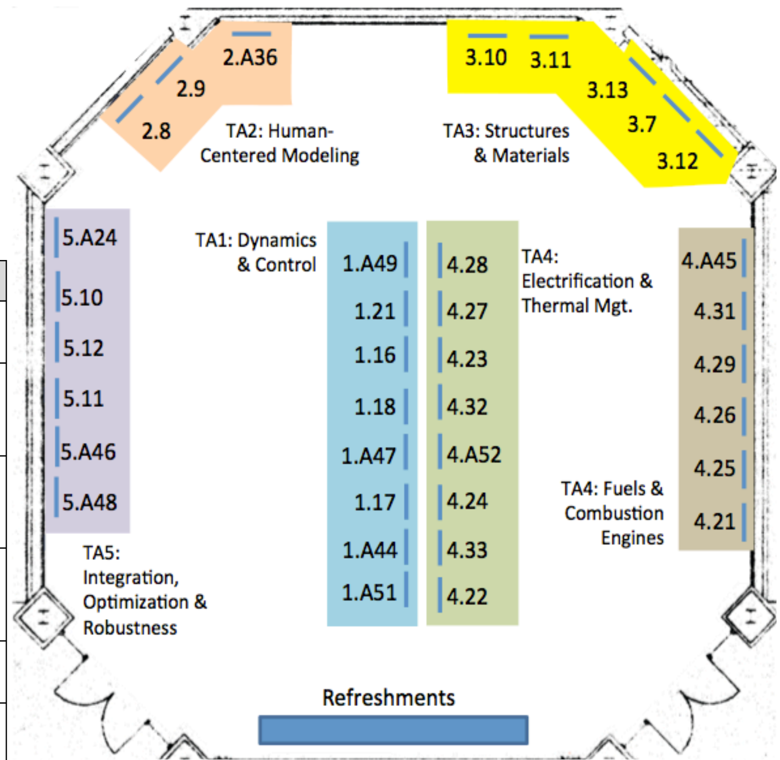
Poster Layout



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1.17	Improving Mobility through Latency Compensation in Teleoperated Ground Vehicles	Ersal
1.18	Improving Efficiency and Mobility of Off-Road Connected Fleets via Route Preview and Cooperative Control	Vahidi
1.21	Physics-Based Multiscale Continuum-Discrete Deformable Terrain Model for Off-Road Mobility Simulation	Sugiyama
1.A44	Modeling Human Performance in Operating Unmanned Ground Vehicles	Ersal
1.A47	Optimal Control, Pairing, and Scheduling for Manned-Unmanned Vehicles Teaming based on RoboTrust Algorithms	Wang, Wagner
1.A49	Fast numerical algorithms for robust, high-fidelity simulation of terramechanics	Veerapaneni
1.A51	Advanced Hazard Avoidance in Autonomous Ground Vehicles	Stein
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2.9	Modeling Bi-directional Trust in Semi-Autonomy for Improved System Performance	Tilbury, Robert
2.A36	Airbag Benefit in Occupant Crash Protection for Tactical Vehicles	Hu
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3.11	Effects of reduced order model of viscous damping on energy absorption	Vlahopoulos
3.12	Novel Hybrid Electric Powertrains Enabled by Models of Electro-Magnetic-Structural Dynamics	Epureanu, Hofmann
3.13	Testing and Analysis of Tank Track Pad Meta-Material	Fadel
4.21	Bulk Modulus of Compressibility Measurements of Conventional and Alternative Military Fuels	Boehman
4.25	JP-8 Combustion Chemistry Cluster – Simulations for JP-8 Mechanism Optimization and Validation	Martz
4.26	Combustion chemistry of Jet Fuels: from atomistic simulations to mechanism development	Violi
4.29	Ignition Studies for Kinetic Mechanism Development and Validation	Boehman, Wooldridge
4.31	Simulation and Control of Combustion to Improve Cold Start of Military Diesel Engines	Henein
4.A45	Thermal Barrier Coatings for Reduction of Cooling Loads in Military Vehicles	Jansons

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4.23	2D lumped parameter thermal model of large Li-ion battery pack – Fast, accurate, and comprehensive	Ma
4.24	Robot Range Extender: Solid Oxide Fuel Cell Hybrids	Siegel
4.27	Heat Rejection Using Advanced Materials – Passive and Active Cooling Strategies	Wagner, Miller
4.28	Computationally-efficient Thermal Models for Electric Machines	Hofmann
4.32	Tools for Optimal Selection of Energy Storage Technology in Electrified Military Vehicles	Onori
4.33	Identification of Electrode Aging Mechanisms Using Mechanical Particle Model (MPM) for Lithium-Ion Batteries	Stefanopoulou, Siegel
4.A52	Optimization of Scalable Military Fuel Cell Hybrid Vehicles	Siegel
5.10	Modeling and Simulation of Repairable Systems for Depot Maintenance and Warranty Forecasting Using An Effective Age Approach	Mourelatos, Pandey
5.11	Enhanced Multi-Robot Reconnaissance Through Terrain-Based Energy Prediction	Barton, Ojeda
5.12	New Fatigue Reliability and Random Vibration Methods for Linear / Non-Linear Systems under Non-Gaussian Excitation	Mourelatos, Drignei
5.A24	Stochastic Optimization and Analysis of Dynamic Modular Vehicle Fleet Systems	Epureanu, Papalambros
5.A46	Situational Awareness and Sustained Survivability through Man/Unmanned Teaming	Panagou
5.A48	Connected Laboratories for Connected Automated Vehicles	Ersal