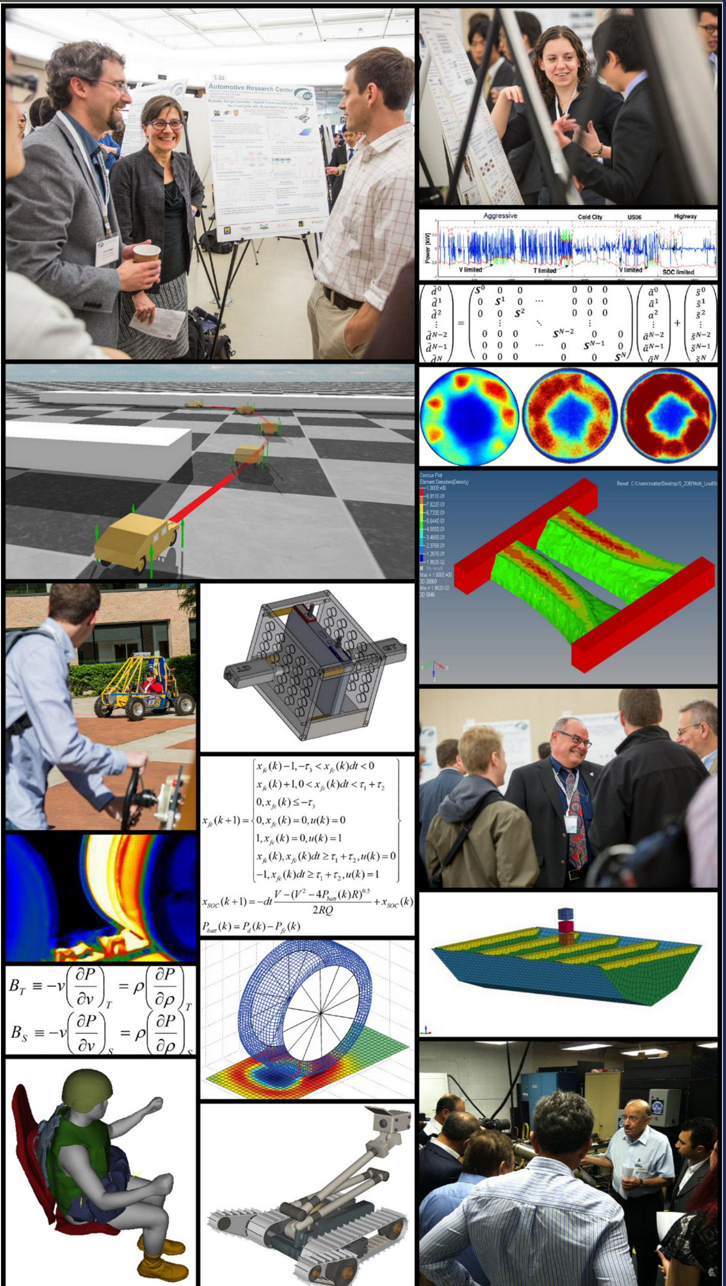
22nd Annual ARC Program Review

Event Program

May 25-26, 2016



Organized by the Automotive Research Center

A U.S. Army Center of Excellence for Modeling and Simulation of Ground Vehicles

Day 1: Wednesday, May 25, 2016

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

8:15 **Keynote**
Dr. Robert Sadowski, *Army Chief Roboticist, U.S. Army TARDEC*

8:45 **Keynote**
Dr. Lars Nielsen, *Director, Wallenberg Autonomous Systems Program, Professor of Vehicular Systems, Linköping University*

9:15 **Keynote**
Mr. John Koszewnik, *Chief Technical Officer, Achates Power*

9:45 Networking Break

10:30 **Case Study 1**
Surviving a Crash in a Light Tactical Vehicle: A Study on Airbags Combining Testing, Modeling, and Optimization

11:15 **Case Study 2**
Reliability Optimization of Tank Tread Meta-Material Design

12:00 pm Lunch

1:30 **Parallel Technical Session 1**
1A: Unmanned Ground Vehicles
1B: Advanced Powertrains - Fuels

3:00 **Technical Session 2**
2A: Vehicle Dynamics & Autonomy
2B: Structures, Systems Integration/Optimization

4:00 - 5:30 **Poster Session & Networking**

Day 2: Thursday, May 26, 2016

8:00 **Poster Session & Networking**

8:50 Welcome
Prof. André Boehman, *ARC Associate Director*

9:00 **Keynote**
Dr. Patrick McGrath, *Program Director, ARPA-E*

9:30 **Case Study 3:**
Making Stress Work for You: Advanced Battery Management based on Novel Stress/Strain Models and Measurements

10:15 Networking Break

10:45 **Technical Session 3**
3A: Advanced Powertrains - Electrification

12:00 **Closing Remarks and Award Presentation**
Dr. David Gorsich, *Chief Scientist, U.S. Army TARDEC*

12:30 - 2:00 pm **Post Review Networking**

This event is free of charge
Register at
arc.engin.umich.edu
RSVP by May 10, 2016

Inquiries
(734) 764-6579
arc-event-inquiries@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)

22ND ANNUAL AUTOMOTIVE RESEARCH CENTER PROGRAM REVIEW

25 MAY 2016

~ DAY 1 PROGRAM ~

7:30 – 8:00	**CHECK-IN AND CONTINENTAL BREAKFAST**	Gallery
8:00 – 8:15	**WELCOME & OPENING REMARKS** **Prof. Anna Stefanopoulou**, Director, Automotive Research Center	Auditorium
8:15 – 8:45	**KEYNOTE: SHAPING THE FUTURE – ARMY ROBOTICS AND AUTONOMOUS SYSTEMS** **Dr. Robert Sadowski**, Army Chief Roboticist, U.S. Army TARDEC	Auditorium
8:45 – 9:15	**KEYNOTE: LAUNCHING THE WALLENBERG AUTONOMOUS SYSTEMS PROGRAM** **Dr. Lars Nielsen**, Professor Vehicular Systems, Dept. of Electrical Engineering, Linköping University and Program Director, Wallenberg Autonomous Systems Program	
9:15 – 9:45	**KEYNOTE: DISRUPTIVE TECHNOLOGY – RESURRECTING A HISTORIC ENGINE USING MODERN CAE TOOLS** **Mr. John Koszewnik**, Chief Technical Officer, achatesPOWER	Auditorium
9:45 – 10:30	**BREAK**	Gallery&Lobby
10:30 – 11:15	**CASE STUDY SESSION 1** **Surviving a Crash in a Light Tactical Vehicle: A Study on Airbags Combining Testing, Modeling, and Optimization** Contributors: Jingwen Hu, Jonathan Rupp, Matthew Reed (University of Michigan), Zissimos Mourelatos, Dorin Drignei (Oakland University), Rebekah Gruber, Risa Scherer (TARDEC), Marianne Kump, Brian Hansen (Takata)	Auditorium
11:15 – 12:00	**CASE STUDY SESSION 2** **Reliability-Based Design Optimization of Tank Track Pad Meta-Material using the Unit Cell Synthesis Method** Contributors: Georges M. Fadel, Gang Li, Neehar Kulkarni, Nicole Coutris (Clemson University), K.K. Choi (University of Iowa), Matthew Castanier, David Ostberg, David Lamb (TARDEC), Nicholas Gaul (RAMDO Solutions, LLC)	Auditorium
12:00– 12:15	**GROUP PHOTO**	
12:15 – 1:30	**LUNCH**	Outdoors
1:30 – 2:30	**TECHNICAL SESSION 1** (See Detailed Insert) 1A: Unmanned Ground Vehicles — Location: Chesebrough Auditorium 1B: Advanced Powertrain - Fuels — Location: Chrysler Center, Room 133	Varies
2:30 – 3:00	**ROOM TRANSITION / BREAK**	Lobby
3:00 – 4:00	**TECHNICAL SESSION 2** (See Detailed Insert) 2A: Vehicle Dynamics / Autonomy — Location: Chesebrough Auditorium 2B: Structures, Systems Integration / Optimization — Location: Chrysler Center, Room 133	Varies
4:00 – 5:30	**POSTER SESSION & QUAD NETWORKING**	
4:15 – 5:15	**Researchers Staffing Posters for Questions / Discussion**	Gallery

Duderstadt Gallery : Gallery
Chesebrough Auditorium & Lobby : Auditorium / Lobby
Duderstadt South Lawn (adjacent to Bonisteel Boulevard) : Outdoors

22ND ANNUAL AUTOMOTIVE RESEARCH CENTER PROGRAM REVIEW

26 MAY 2016

~ DAY 2 PROGRAM ~

7:30 – 8:00 **CHECK-IN AND BREAKFAST** — Gallery

8:00 – 8:50 **POSTER SESSION & QUAD NETWORKING**

8:15 – 8:45 **Researchers Staffing Posters for Questions / Discussion** — Gallery

8:50 – 9:00 **WELCOME & INTRODUCTION** — Auditorium

PROF. ANDRÉ BOEHMAN, Associate Director, Automotive Research Center

9:00 – 9:30 **KEYNOTE: PROGRAM OVERVIEW OF ARPA-E'S ADVANCED MANAGEMENT AND PROTECTION OF ENERGY-STORAGE DEVICES (AMPED) PROGRAM** — Auditorium

Dr. Russel Ross, Lead Technologist, Booz Allen Hamilton for ARPA-E, Department of Energy

9:30 – 10:15 **CASE STUDY SESSION 3** — Auditorium

Making Stress Work for You: Advanced Battery Management based on Novel Stress/Strain Models and Measurements

Contributors: Jason Siegel, Bogdan Epureanu, Anna Stefanopoulou, Jau-Ching Lu, Ki-Yong Oh, Nassim Samad (University of Michigan), Charles Monroe (Oxford University), Yi Ding, Matt Castanier (TARDEC), Brian Eagle (Amphenol), Aaron Knobloch, Jason Karp, Chris Kapusta (GE), Dyche Anderson, Arnold Mensah-Brown, Xin Fan Lin, Sung-Kwon Hong (Ford Motor Company)

10:15 – 10:45 **BREAK** — Gallery&Lobby

10:45 – 11:45 **TECHNICAL SESSION 3** (See Detailed Insert) — Auditorium

3A: Advanced Powertrain - Electrification

Location: Chesebrough Auditorium

11:45 – 12:30 **CLOSING REMARKS** — Auditorium

Prof. Anna Stefanopoulou, Director, Automotive Research Center

Dr. David Gorsich, ST / Ground Systems and Chief Scientist, U.S. Army TARDEC

POSTER AWARDS COMMITTEE

Prof. Bogdan Epureanu, Associate Director & Committee Chair, Automotive Research Center

Ms. Jillyn Alban, Engineer, U.S. Army TARDEC

Dr. Jean Dasch, Principal Scientist, Alion Science and Technology

Dr. Thomas Meitzler, ST / Survivability, U.S. Army TARDEC

Mr. Mark Rupersburg, Technology Business Development, GDLS

Dr. Ravi Thyagarajan, Deputy Chief Scientist, U.S. Army TARDEC

Dr. Edward Umpfenbach, PM ISEF Chief Architect, U.S. Army TARDEC

12:30 – 2:00 **POST REVIEW NETWORKING** — Gallery

Duderstadt Gallery : Gallery
Chesebrough Auditorium & Lobby : Auditorium / Lobby
Duderstadt South Lawn (adjacent to Bonisteel Boulevard) : Outdoors

SPEAKER INFORMATION

Dr. David J. 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, Dr. 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). Dr. Gorsich previously was an electrical engineer with McGraw Commercial Equipment Corporation in Novi, MI.

Dr. 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. Dr. Gorsich received the Detroit Federal Executive Board Award in 2001. Dr. Gorsich was recognized with the 1997 Army Research, Development and Acquisition Award, "Innovations in Ground Vehicle Signature Research."

Dr. Gorsich is recognized in many professional organizations for his research accomplishments. Dr. 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.

Dr. 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 Engineers Transactions on Pattern Analysis and Machine Intelligence.

Dr. 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.

Dr. Robert W. Sadowski is a member of the Scientific and Professional (ST) cadre of the Senior Executive Service and serves as the Robotics Senior Research Scientist within the Research, Technology and Integration Directorate at the US Army Tank Automotive Research, Development and Engineering Center (TARDEC) in Warren, MI. He has been recently selected to this position after a long career within the Army culminating as an Academy Professor and Electrical Engineering Program Director in the Department of Electrical Engineering and Computer Science at the United States Military Academy where he was instrumental in developing the Academy's robotics program, facilities, and outreach. He also has over forty months of operational experience in Southwest Asia in a variety of leadership, staff, and engineering positions including Iraq and recently Afghanistan. Dr. Sadowski is a graduate of US Military Academy with a BSEE and received his M.S. and Ph.D. in electrical engineering from Stanford University as a Fannie and John Hertz Fellow. He also holds a Masters in Strategic Studies from the US Army War College.

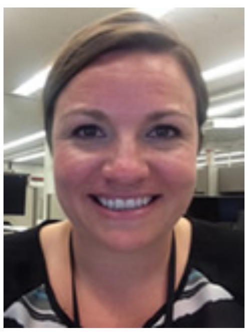
Dr. Lars Nielsen is Director of the Wallenberg Autonomous Systems Program (WASP), Sweden's largest ever individual research program, that provides a platform for academic research and education, fostering interaction with Sweden's leading technology companies. Dr. Nielsen is Professor of Vehicular Systems holding the Sten Gustafsson chair at Linköping University. His main research interests are in automotive modeling, control, diagnosis, and autonomy, and he has been active in all aspects of this field during its expansion and growth since the nineties. His supervision has led to thirty graduate exams, in many cases with significant industrial participation. The collaboration aspect has also been strong in his role as center director for two large centers of excellence (ECSEL 1996-2002, LINK-SIC 2010-). In the international research community, he was the Chairman of Automotive Control within the International Federation of Automatic Control (2002-2005), and then the Chairman of all Transportation and Vehicle Systems (2005-2011). Selected national commissions of trust are Board Member of the Swedish Research Council-NT (2001-2006), and vice chair in IVA II - the electrical engineering division of the Royal Swedish Academy of Engineering (2010-).

Mr. John Koszewnik joined Achates Power in June 2011 as chief technical officer. In this role, Koszewnik leverages his nearly 40 years of experience in the powertrain industry to further the development of Achates Power's clean, efficient internal combustion engine design. Koszewnik was previously director of production development for FEV Inc., an engineering services and consulting company, where he was responsible for ensuring that all functional requirements, quality, cost and timing of production programs were met. He also supported product development and strategic study projects for the automotive, heavy truck, locomotive and powertrain component supply industries. Prior to FEV, Koszewnik was a senior vice president at Case New Holland, an agricultural and construction equipment manufacturer, where he managed 10 engineering centers worldwide. Prior to Case New Holland, Koszewnik was at Ford Motor Co. for 30 years, most recently as director of North American Diesel. In this role, he improved quality and customer satisfaction with the power stroke diesel engine and implemented design and manufacturing strategies that resulted in significant cost savings. While at Ford, Koszewnik also was responsible for the engine engineering of all Ford's gasoline V6, V8 and V10 engines. Koszewnik earned a bachelor's degree in engineering from Stevens Institute of Technology and a master's degree in general management from Harvard University.

Dr. Russel Ross is a physicist with seven years of battery research program experience, working on technology advancement. Currently, he serves as a technical advisor to the Department of Energy's Advance Research Projects Agency - Energy (ARPA-E), where he has been instrumental in the development and execution of the Advanced Management and Protection of Energy Storage Devices (AMPED) program. In addition to his portfolio in battery management systems and battery fault detection under the AMPED program, Dr. Ross supports programs and projects in the technical areas of non-turbine wind energy devices, solid-state thermal energy conversion devices, advanced textiles for building occupant thermal regulation, and indoor sensor systems for building automation.

POSTER AWARDS COMMITTEE

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. Epureanu is the chair of this year's Awards Committee.



Ms. Jillyn Alban is currently an Electrical Engineer at the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC). She is working with the Ground Domain Planning and Integration group to develop the 30-year strategy and funding associated to the prioritization within the strategy.

Prior to joining the GDPI team, Ms. Alban represented TARDEC as a Liaison Officer at Office of Assistant Secretary of the Army (Acquisitions Logistics and Technology) where she was responsible for any TARDEC related occurrence within Army Headquarters. She then moved to the Office of Secretary of Defense to engage with the tri-service ground vehicle related efforts focusing on the ground vehicle platforms going through the DoD acquisition cycle and energy and power technology development. Her final assignment in Washington DC was with the Office of Naval Research (ONR) serving as a project engineer in Expeditionary Maneuver Warfare and Combating Terrorism Department. At ONR she focused on the Survivability, Advanced Mobility and Maneuver Enablers within the Maneuver Thrust.

Ms. Alban has a B.S. in Electrical Engineering and a M.S. in Engineering Management from Oakland University as well. She received the Army Research and Development Achievement Award for Ground Vehicle Control Aids for Improved Mobility with Indirect Vision, Drive-By Wire Crew Stations. She is also an Army Acquisition Corps Member.

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. 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. 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 Technical Expert.

During the time from 1988 to present, Dr. Meitzler has been a research engineer at the US 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 and atmospheric simulation. Dr. Meitzler was the principal scientist of the TARDEC Visual Perception Laboratory and the principal investigator on a CRADA 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 has been the lead on several CRADA's with NASA's Kennedy Space Center and with the Columbia University College of Physicians and Surgeons. He has authored/co-authored many papers in the area of Electro Optic system simulation and visual detection, sensor validation, nondestructive testing or armor materials, spintronics and metamaterials.

Mr. Mark Rupersburg currently works in Technology Business Development at General Dynamics Land Systems (GDLS), a company he joined in 2004. He supports the pursuit of advanced programs and develops collaborative relationships with outside businesses, universities, and other resources. He works with internal programs to help identify enabling technologies and emerging technologies for creating break-through new products. Mr. Rupersburg holds a Bachelor's degree in Mechanical Engineering from Wayne State University (1979) and undertook graduate studies in Mechanical Engineering, Dynamics at Stanford University (1982-1983). He previously founded two companies Simulation Dynamics (1985-1994) and Emerging Technologies (1994-2004). Mr. Rupersburg serves on the Business Advisory Board at the Macomb-Oakland University INCubator which provides entrepreneurial resources, business solutions and proactive support to businesses in an effort to help startups on their path to success. He is also on the Industry Process Control Board (IPCB), and the Education Subcommittee of Lightweight Innovations for Tomorrow (LIFT), a public-private partnership that will develop and deploy lightweight materials-manufacturing technologies, and implement education and training programs to prepare the workforce.

Dr. Ravi Thyagarajan serves as Deputy Chief Scientist at the US Army Tank Automotive Research, Development and Engineering Center (TARDEC), and was selected to the Researcher Review Board as a Senior Technical Specialist in June 2012. His research pursuits are in the areas of underbody blast modeling and design, occupant protection and fast-running modeling methodologies. He received his PhD in Applied Mechanics from Caltech in 1990, and has over 15 years of prior experience in the automotive industry at Ford and Visteon. He is a past recipient of the Forest R. McFarland Award from SAE, holds two patents and has co-authored over 40 technical papers.

Dr. Edward Umpfenbach is the acting Chief Architect for the PM Integrated Systems Engineering Framework (ISEF) at the Tank-Automotive Research, Development, and Engineering Center (TARDEC). He was awarded a DoD SMART Fellowship in 2011 and finished his PhD in Industrial and Systems Engineering from Wayne State University in 2013. Dr. Umpfenbach has experience working in several automotive assembly plants prior to joining TARDEC. His research interests include systems engineering, vehicle modularity and commonality, optimization, and statistics.

CASE STUDY 1

Surviving a Crash in a Light Tactical Vehicle: A Study on Airbags Combining Testing, Modeling, and Optimization

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. Two full vehicle crash tests in frontal and rollover impacts were conducted to understand vehicle kinematics. Three series of (a total of 50) sled tests were used to quantify the effects from occupant body size, military gear, and seatbelt and airbag characteristics on occupant kinematics and injury risks. These tests have been used to validate a set of finite element (FE) models of occupants, body armor, body borne gear, and restraints. Hundreds of FE simulations and design optimization were conducted, which demonstrated the benefit of using airbags for protecting tactical vehicle occupants.

Contributors

Faculty: Jingwen Hu, Jonathan Rupp, Matthew Reed (University of Michigan)
Zissimos Mourelatos, Dorin Drignei (Oakland University)

TARDEC: Rebekah Gruber, Risa Scherer

Industry: Marianne Kump, Brian Hansen (Takata)

CASE STUDY 2

Reliability-Based Design Optimization of Tank Track Pad Meta-Material using the Unit Cell Synthesis Method

A meta-material with low hysteresis loss and compliance comparable to that of a tank track pad elastomer is currently being designed. The goal is to eliminate hysteretic losses, conduct heat away and mimic the behavior of the elastomer. A new method is proposed to design geometries of unit cells for an elastic meta-material by combining structural components that exhibit geometric nonlinearities under deformation. A design obtained by carrying out deterministic optimization which closely meets the application specific requirements is presented and compared to the original track pad under both uniform compression and dynamic wheel loading conditions. Considering variabilities in geometry and material properties in the manufacturing process, a final design that meets the target reliability is obtained by carrying out reliability-based design optimization using RAMDO.

Contributors

Faculty: Georges M. Fadel, Gang Li (Clemson University), K.K. Choi (University of Iowa)

Students: Neehar Kulkarni, Nicole Coutris (Clemson University)

TARDEC: Matthew Castanier, David Ostberg, David Lamb

Industry: Nicholas Gaul (RAMDO Solutions, LLC)

CASE STUDY 3

Making Stress Work for You: Advanced Battery Management based on Novel Stress/Strain Models and Measurements

This case study presents a success story of combining basic research results from multiple ARC projects to launch a multi-disciplinary 4-year program funded by ARPA-E with industrial support. Enabled by structural models for predicting vibrations of stacked battery cells, health monitoring methods for estimating cell aging, and experimental techniques using neutron imaging for visualizing electrode expansion, the ARC investigators constructed a phenomenological thermo-mechanical battery model describing cell swelling due to Lithium intercalation and thermal expansion.

Model-based estimation of critical states—using data from thin-film temperature and strain sensors developed by GE—led to multiple innovations in real time power limits, fast warm-up, and state of health estimation of capacity fading based on monitoring shifts in bulk stress.

These innovations can allow downsizing of the battery with associated increase in energy utilization by 19% per cell and a projected decrease in capacity of only 0.5% after 100,000 miles. Testing and validation with a hybrid-electric vehicle battery pack is currently underway at Ford.

Contributors

Faculty: Jason Siegel, Bogdan Epureanu, Anna Stefanopoulou (University of Michigan)
Charles Monroe (Oxford University)

Students: Jau-Ching Lu, Ki-Yong Oh, Nassim Samad (University of Michigan)

TARDEC: Yi Ding, Matt Castanier

Industry: Brian Eagle (Amphenol), Aaron Knobloch, Jason Karp,
Chris Kapusta (General Electric),
Dyche Anderson, Arnold Mensah-Brown, XinFan Lin
Sung-Kwon Hong (Ford Motor Company)

22ND ANNUAL AUTOMOTIVE RESEARCH CENTER PROGRAM REVIEW – Technical Session Matrix

May 25TH	**1A: Unmanned Ground Vehicles** **Session Chairs:** Dr. Paramsothy Jayakumar, Mr. Victor Paul	**1B: Advanced Powertrains — Fuels** **Session Chairs:** Dr. Pete Schihl, Mrs. Sonya Zanardelli
1:30 - 1:50	**1.17** PI: Dr. Tulga Ersal Improving Mobility through Latency Compensation in Teleoperated Ground Vehicles	**4.21** PI: Dr. André Boehman Bulk Modulus of Compressibility Measurements of Conventional and Alternative Military Fuels
1:50 - 2:10	**2.7** PI: Dr. Dawn Tilbury Teleoperation with Semi-Autonomous Obstacle Avoidance and Delay	**4.6** PI: Dr. Angela Violi, Dr. Jason Martz Jet Fuel Surrogate Development for Diesel Combustion – Reacting Spray Simulations of Conventional and Alternative Jet Fuel Surrogates
2:10 - 2:30	**2.8** PI: Dr. Brent Gillespie Haptic Shared Control for Teleoperated Ground Vehicles	**4.19** PI: Dr. Marcis Jansons Validation of JP-8 Surrogates in an Optical Engine

May 25TH	**2A: Vehicle Dynamics / Autonomy** **Session Chairs:** Dr. Paramsothy Jayakumar, Dr. Amandeep Singh	**2B: Structures, Systems Integration / Optimization** **Session Chairs:** Dr. David Lamb, Dr. Matt Castanier
3:00 - 3:20	**1.15** PI: Dr. Jeff Stein, Dr. Tulga Ersal Vehicle-Dynamics-Conscious Real-Time Hazard Avoidance in Autonomous Ground Vehicles	**3.8** PI: Dr. Nick Vlahopoulos A Reduced-Order Model for Investigating the Dynamic Response of Multi-layered Plates Under an Impulse Load
3:20 - 3:40	**1.18** PI: Dr. Ardalan Vahidi A Novel Hierarchical Approach to Path-Planning for Connected Fleets in Off-Road Scenarios	**3.10** PI: Dr. K.K. Choi Reliability-Based Design Optimization Using Confidence-Based Model Validation for Insufficient Experimental Data
3:40 - 4:00	**1.16** PI: Dr. Hiroyuki Sugiyama Flexible Multibody Dynamics Approach for Tire Dynamics Simulation	**5.A24** PI: Dr. Bogdan Epureanu Ground and Sea-Based Strategic Adaptive Vehicle Systems

May 26TH	**3A: Advanced Powertrains — Electrification** **Session Chairs:** Dr. Denise Rizzo, Dr. Yi Ding
10:45 - 11:05	**4.23** PI: Dr. Lin Ma Powertrain Thermal Management Strategies Based on Active Monitoring and Control – Towards Higher Temperature and Larger Scale
11:05 - 11:25	**4.24** PI: Dr. Jason Siegel Robotic Range Extender: Power and Energy Management for a Hybrid Powertrain with Quantized Power Sources
11:25 - 11:45	**4.20** PI: Dr. Levi Thompson Towards Robust, High Capacity Insertion Compounds

TECHNICAL SESSION ABSTRACTS

TECHNICAL SESSION 1A – UNMANNED GROUND VEHICLES
Session Chairs: Dr. Paramsothy Jayakumar, Mr. Victor Paul

1A1: Improving Mobility through Latency Compensation in Teleoperated Ground Vehicles

Quad members: Tulga Ersal (PI), Jeffrey Stein (co-PI),
Yingshi Zheng *(University of Michigan*);
Paramsothy Jayakumar, Mark J. Brudnak *(U.S. Army TARDEC);*
Mitchell Rohde, Steve M. Rohde *(Quantum Signal LLC)*

This project is motivated by the Army's need to increase the mobility performance of teleoperated unmanned ground vehicles. One difficulty with teleoperation is that communication delays can significantly affect the mobility performance of the vehicle and make the teleoperated driving tasks very challenging especially at high speeds. This project is developing a platform-independent predictor framework to compensate for the negative impact of communication delays. The proposed approach has the advantage of not requiring information about the platform or human operator dynamics and pilot tests have shown the effectiveness of the approach in improving vehicle mobility with large roundtrip delays of 0.9s. This talk will first highlight the past results on analyzing the predictor's performance and stability under constant delays. It will then focus on the predictor's stability under variable delays, as well as the closed-loop stability of the entire teleoperated system.

1A2: Teleoperation with Semi-Autonomous Obstacle Avoidance and Delay

Quad members: Dawn Tilbury (PI), Justin Storms *(University of Michigan);*
Dave Daniszewski, Paul Muench, Ben Haynes *(U.S. Army TARDEC);*
Mitch Rohde, Steve Rohde *(Quantum Signal)*

Teleoperation of unmanned ground vehicles (UGVs) in distant environments is plagued with difficulties including communication delay and poor perception of the UGV's environment. This project has explored the impact of delay on teleoperation performance, as well as methods for automating portions of the UGV operation. We have considered navigation for tasks involving path following and less structured exploration of environments. Operation modes ranging from pure teleoperation to semi-autonomous control have been tested with human subjects. One key finding has been that while semi-autonomy can improve teleoperation performance, the improvement is highly dependent on operation conditions, such as delay and task. For example, semi-autonomy has negligible improvement over teleoperation at low delay; however there are significant improvements at high delay.

1A3: Haptic Shared Control for Teleoperated Ground Vehicles

Quad members: Brent Gillespie (PI), Sile O'Modhrain, Amirhossein Ghasemi, Paul Boehm *(University of Michigan);*
Paramsothy Jayakumar, Keith Briggs *(U.S. Army TARDEC);*
John Walsh *(Ford Motor Company)*

Haptic shared control is a powerful means of combining the best of human manual control and automatic control, keeping humans in the loop while avoiding automation pitfalls. This study is focused on creating an interface that enables negotiation of control authority between a human and automation system through the modulation of mechanical impedance. We present a model of a human driver that captures both backdriveability as well as the capacity to produce motion or force. An identification technique is developed that quantifies human impedance in real time. Finally, a tele-operational platform in the form of a mini-baja car is presented that supports control sharing with dynamic allocation of authority using impedance modulations.

TECHNICAL SESSION 1B – ADVANCED POWERTRAINS – FUELS

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

1B1: 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);*
James Anderson *(Ford Motor Company)*

In order to investigate the impact of bulk modulus of fuel on the inadvertent injection timing shift in pump-line-nozzle type fuel supply system, this project seeks to measure the bulk modulus of conventional and alternative jet fuels, and jet fuel surrogates. The isothermal bulk modulus of three conventional JP-8 fuels, three alternative jet fuels, two UM JP8 surrogates, and five components of UM surrogates are measured at 313.15K under varying pressures up to 27.68MPa (4000psig). Compressed liquid density values of all liquids are also calculated from the measured values of atmospheric density and isothermal bulk modulus up to 4000psig. A single cylinder diesel engine will be set up soon, and used for investigating the impact of different bulk modulus values of jet fuels on injection timing shifts.

1B2: Jet Fuel Surrogate Development for Diesel Combustion – Reacting Spray Simulations of Conventional and Alternative Jet Fuel Surrogates

Quad members: Angela Violi (PI), Jason Martz (Co-PI), Doohyun Kim *(University of Michigan);*
Peter Schihl, Eric Sattler *(U.S. Army TARDEC);*
Peter Attema *(Detroit Diesel/Daimler)*

Reacting spray simulations for UM jet fuel surrogates have been conducted to assess the suitability of the kinetic and computational framework we developed for Jet-A, IPK, S-8 and JP- 8. A skeletal version of a detailed chemical mechanism was generated for the six-component surrogate palette - n-dodecane, n-decane, iso-cetane, iso-octane, decalin, toluene, in order to be used in CFD simulations. Ignition delay times for Jet-A, S-8, and JP-8 were in good agreement with experimental measurements above 1000 K. For the IPK surrogate the ignition delays were over-predicted in the temperature range tested. Numerical experiments with Jet-A and S-8 surrogates were carried out to investigate the relative importance of physical processes in liquid phase vs. oxidation chemistry in gas phase on the ignition delay period.

1B3: Validation of JP-8 Surrogates in an Optical Engine

Quad members: Marcis Jansons (PI), Taewon Kim, Xin Yu,
Andrew Abdul-Nour *(Wayne State University);*
Peter Schihl, Eric Gingrich *(U.S. Army TARDEC);*
Taylor Hansen *(Controlled Power Technologies, Inc.)*

An experimental fuel surrogate validation approach is developed for a compression ignition application. The agreement of both physical and chemical properties of surrogate and target jet fuels is examined in an optical engine under temperature and pressure histories approaching those found in military engines. Optical diagnostic measurements are applied to compare liquid penetration lengths, early mixture formation and low temperature reactivity, and high temperature ignition characteristics of a set of Jet A, IPK and S-8 jet fuels and their surrogates that have a wide range of ignition quality. Target and surrogate fuels are also compared in an indirect-injection metal cetane engine over a range of inlet temperatures and compression ratios. The approach provides validation data for the use of the surrogates in numerical combustion models.

TECHNICAL SESSION 2A – VEHICLE DYNAMICS / AUTONOMY

Session Chairs: Dr. Paramsothy Jayakumar, Dr. Amandeep Singh

2A1: Vehicle-Dynamics-Conscious Real-Time Hazard Avoidance in Autonomous Ground Vehicles

Quad members: Jeffrey Stein (PI), Tulga Ersal (co-PI), Jiechao Liu *(University of Michigan);*
Paramsothy Jayakumar *(U.S. Army TARDEC);*
Mitchell Rohde, Steve M. Rohde *(Quantum Signal LLC)*

This project is concerned with the Army's need for their large vehicles to navigate autonomously as fast as safely possible in unstructured environments. A model predictive control based obstacle avoidance algorithm is being developed to allow an AGV to operate close to its dynamic limits by taking into account the vehicle, powertrain, and brake dynamics explicitly in a nonlinear optimization formulation to simultaneously optimize the reference speed and steering angle. After introducing the basics of the algorithm, this talk will focus on the algorithm's robustness to parametric and state estimation uncertainties and report the progress on experimental validation taking place at Quantum Signal. Efforts to extend the algorithm's capability to include avoiding moving obstacles will also be highlighted.

2A2: A Novel Hierarchical Approach to Path-Planning for Connected Fleets in Off-Road Scenarios

Quad members: Ardalan Vahidi (PI), Judhajit Roy, Nianfeng Wan *(Clemson University);*
Paramsothy Jayakumar *(U.S. Army TARDEC);*
Chen Zhang *(Ford Motor Company)*

Availability of precise 3D elevation profiles and reliable soil trafficability information, advances in connected vehicle technologies, and real-time access to computational clouds create new opportunities for safer and more efficient fleets. A novel path-planning algorithm for off-road scenarios is presented here. The proposed hierarchical path-planning algorithm distributes the computational cost to find the optimal path over a large terrain. A dynamic programming (DP) method generates the globally optimal path approximation based on soil condition and low resolution elevation information. A model-predictive algorithm finds the locally optimal path over moving radial horizon using the DP computed globally optimal cost-to-go map and high resolution elevation map. Scenarios involving obstacles avoidance, condition-time-variant environment, and connected fleets cooperation demonstrate the efficacy of the algorithm.

2A3: Flexible Multibody Dynamics Approach for Tire Dynamics Simulation

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

A physics-based high-fidelity computational model for tire and soil interaction is essential to demonstrate mobility capability in various operational military scenarios on deformable terrains. Use of existing finite element tire models requires co-simulation techniques in most cases for integration with multibody vehicle simulation models, and are computationally intensive procedure due to small macro step size needed to ensure numerical stability and energy balance of the entire vehicle model. In this study, a physics-based flexible tire model that can be fully integrated into multibody dynamics computer algorithms is proposed using the laminated composite shell element based on the absolute nodal coordinate formulation and the distributed parameter LuGre tire friction model for transient vehicle maneuvers. The tire model developed is validated against test data. Furthermore, a continuum soil model using multiplicative finite strain plasticity theory is integrated with the flexible tire model for deformable tire/terrain interaction simulation. Soil bin tests conducted for validation of the tire/soil simulation capability are also outlined.

TECHNICAL SESSION 2B – SYSTEMS INTEGRATION / OPTIMIZATION

Session Chairs: Dr. David Lamb, Dr. Matt Castanier

2B1: A Reduced-Order Model for Investigating the Dynamic Response of Multi-Layered Plates Under an Impulse Load

Quad members: Nickolas Vlahopoulos (PI), Weiran Jiang,
Alyssa Bennett *(University of Michigan);*
Matthew P. Castanier, Ravi Thyagarajan *(U.S. Army TARDEC);*
Nam Purush *(BAE Systems)*

Assessing the dynamic performance of multilayer panels subjected to impulsive loading is of interest for identifying configurations that mitigate the through-thickness energy propagation. A Reduced-Order Modeling (ROM) approach is presented for rapidly evaluating the structural dynamic performance of a large number of alternative panel designs. The new approach is based on the reverberation matrix method (RMM) with the theory of generalized rays for fast analysis of the structural dynamic characteristics of multilayer plates. The dynamic response of the plate is calculated by employing the generalized ray theory and an inverse Fourier Transformation. The ROM is utilized for conducting optimization studies and the results are validated through comparison with much more computationally expensive Nastran simulations.

2B2: Reliability-Based Design Optimization Using Confidence-Based Model Validation for Insufficient Experimental Data

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

Conventional reliability-based design optimization (RBDO) assumes that the simulation model represents the real physics accurately. However, the simulation model could be biased. Therefore, model validation, which corrects the model bias, should be integrated in the RBDO process to obtain the reliable optimum design. However, if only insufficient experimental data is available, the model bias correction suffers uncertainty due to insufficiency. Hence, the optimum design may not satisfy the target reliability, and the designers lose confidence in the design even with the model validation. We propose an RBDO using confidence-based model validation to achieve a conservative design in compensation for the uncertainty. Because carrying out RBDO and model validation together becomes a moving-target problem, a practical RBDO process is proposed to resolve this issue.

2B3: Ground and Sea-Based Strategic Adaptive Vehicle Systems

Quad members: Bogdan Epureanu (PI), Panos Papalambros (Co-PI), A. Emrah Bayrak, Mert Egilmez, Xingyu (Gavin) Li, Jong Min (Sky) Park *(University of Michigan);* Edward Umpfenbach, Richard Gerth *(U.S. Army TARDEC);* Ra'ed Seifeldin, Robert Maline *(Office of Naval Research);* Mark Rupersberg *(General Dynamics Land Systems)*

Military vehicles are designed to perform in a variety of mission scenarios. To meet all mission requirements, the Army and the Marines maintain a large and diverse inventory of vehicles leading to a significant budget burden. Modularity can be a solution to meeting such diverse mission requirements in a cost effective manner. The goal of this research is to create a modeling and simulation environment for a fleet of modular vehicles to be used for evaluating costs and benefits of modularity under a Marine Corps operation scenario. A plug-and-play modularity provided by industrial concept developers is used as a case study. Cost and benefits are evaluated with respect to a conventional fleet designed to function under the same operation scenario.

TECHNICAL SESSION 3A – ADVANCED POWERTRAINS – ELECTRIFICATION

Session Chairs: Dr. Denise Rizzo, Dr. Yi Ding

3A1: Powertrain Thermal Management Strategies Based on Active Monitoring and Control – Towards Higher Temperature and Larger Scale

Quad members: Lin Ma (PI), Haoting Wang, Tyler Capil *(Virginia Tech)*
Peter Schihl, Matthew Castanier, Nathan A. Tison,
Yi Ding (*US Army TARDEC*)
Kim Yeow (*AVL Powertrain Engineering*),
Ed Hodge (*Rolls-Royce LibertyWorks)*

Past work of battery thermal management has been predominately conducted under mild environmental temperatures (T) and at a relatively small scale. Therefore, this work investigated the powertrain cooling with a special focus on its behavior under higher T and in a larger pack. An experimental platform was developed by combining dummy and real prismatic cells so that controlled tests can be performed with T ranging from ~50 to 70 0C in a battery pack consisting of 16 or more cells. Results have shown the effectiveness of this platform to study various cooling issues under extreme conditions in a large pack, ranging from T non-uniformity, active control, package optimization, and cell-to-cell interactions.

3A2: Robotic Range Extender: Power and Energy Management for a Hybrid Powertrain with Quantized Power Sources

Quad members: Jason Siegel (PI), Anna Stefanopoulou (co-PI)
Yuanzhan Wang, Miriam Figueroa *(University of Michigan);*
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 (due to endurance), 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 thermal model of the tubular solid oxide fuel cell running on propane fuel is used to predict stress based stack degradation mechanisms during startup and operation. The power profiles for PackBot driving cycles provided by TARDEC have been used to develop statistical models of the required power and evaluate the impact of battery sizing, and the State of Charge thresholds for FC startup-shutdowns on stack and battery cell life.

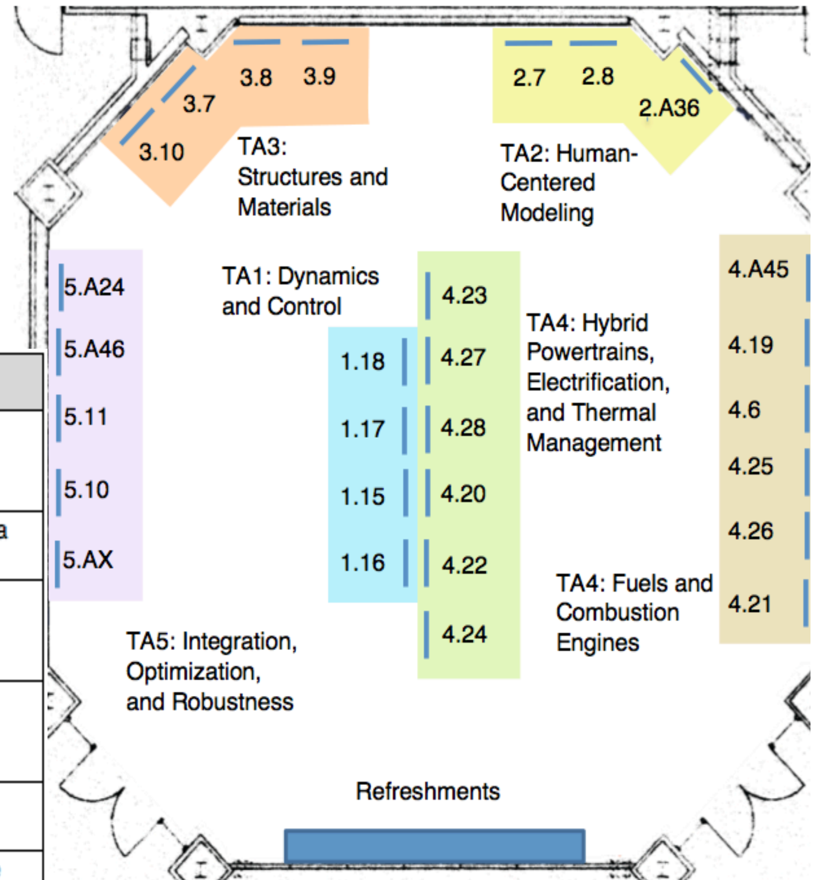
3A3: Towards Robust, High Capacity Insertion Compounds

Quad members: Levi Thompson (PI), Krista Hawthorne, Ryan Franck,
Siu on Tung *(University of Michigan);*
James Mainero, Yi Ding *(U.S. Army TARDEC);*
Les Alexander *(Inmatech, Inc.)*

Vehicles require more energy dense and stable batteries as demands for longer range and lower cost increase and on-board technologies become more complex. Layered oxides are commonly used in the cathode, however, these materials typically suffer from capacity fade due to poor thermal stability and mechanical fracture due to repeated insertion of lithium ions. We hypothesized that incorporation of pillaring agents between the layers would increase cycling and thermal stability by supporting the layers during cycling. In addition we expected that pre- lithiation would increase stability. This presentation will describe our progress in characterizing the electrochemical, thermal and mechanical properties of pillared and pre-lithiated materials We also will present preliminary results for a magnesium ion battery employing the plllared cathode materials.

22ND ANNUAL ARC PROGRAM REVIEW

Poster Session Map



#	Poster Title	PI
1.15	Vehicle-Dynamics-Conscious Real-Time Hazard Avoidance in Autonomous Ground Vehicles	Stein
1.16	Flexible Multibody Dynamics Approach for Tire Dynamics Simulation	Sugiyama
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
2.7	Modeling the Impact of Semi-Autonomy and Delay on UGV Operation	Tilbury
2.8	Haptic Shared Control for Teleoperated Ground Vehicles	Gillespie
2.A36	Airbag Benefit in Occupant Crash Protection for Tactical Vehicles	Hu
3.7	Advanced Models for Fatigue Life Predictions of Hybrid Electric Vehicle Batteries	Epureanu
3.8	Light Weight Vehicle Structures that Absorb and Direct Destructive Energy Away from the Occupant	Vlahopoulos
3.9	Design Optimization of Tank Track Pad Meta-Material	Fadel
3.10	Reliability-Based Design Optimization using Confidence-Based Model Validation for Insufficient Test data	Choi
4.19	Validation of JP-8 Surrogates in an Optical Engine	Jansons
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	JP-8 Combustion Chemistry Cluster – Developing Reduced Mechanisms for Classes of Hydrocarbons	Violi
4.6	Jet Fuel Surrogate Development for Diesel Combustion–Reacting Spray Simulations of Conventional/Alternative Jet Fuel Surrogates	Violi
4.A45	Thermal Barrier Coatings for Reduction of Cooling Loads in Military Vehicles	Jansons

#	Poster Title	PI
4.20	Towards Robust, High Capacity Insertion Compounds	Thompson
4.22	Energy-Conscious Warm-Up of Li-Ion Cells from Sub-Zero Temperatures	Stefanopoulou
4.23	Powertrain Thermal Management Based on Active Monitoring and Control: Toward Higher Temperature and Larger Pack	Ma
4.24	Robotic Range Extender: Hybrid Power and Energy Management for Fuel Cells with Quantized Power Levels	Siegel
4.27	Heat Rejection Using Advanced Materials – Passive and Active Cooling Strategies	Wagner
4.28	Computationally-Efficient Thermal Models for Electric Machines	Hofmann
5.10	Modeling and Simulation of Repairable Systems for Depot Maintenance and Warranty Forecasting Using an Effective Age Approach	Mourelatos
5.11	Energy-Based Cooperative Vehicle Control for Intelligent Reconnaissance	Barton
5.A24	Ground and Sea Based Strategic Adaptive Vehicle Systems	Epureanu
5.A46	Situational Awareness and Sustained Survivability through Man/Unmanned Teaming	Panagou
5.AX	New Fatigue Reliability and Random Vibration Methods for Linear and Non-Linear Systems	Mourelatos