Day 1: Monday, May 23, 2011

8:00 Welcome & Introductions:
Prof. Anna Stefanopoulou, ARC Director
Prof. Dave Munson, Dean of Engineering, University of Michigan
Opening Remarks:
Mr. Carl Levin, United States Senator, Michigan

8:20 Plenary Session 1:
Introductions by Dr. Grace Bochenek, Director, U.S. Army TARDEC
Mr. Jeffrey Singleton, Director for Basic Research, O/Asst Sec. of the Army (Acquisition, Logistics & Technology)
Major General Nick Justice, Commanding General, U.S. Army RDECOM

9:50 Break

10:20 Plenary Session 2:
Introductions by Ms. Jennifer Hitchcock, Exec. Dir., R&Tech Integration, U.S. Army TARDEC
Mr. Patrick Davis, Vehicle Tech. Program Manager, U.S. Dept. of Energy
Dr. Gary Smyth, Exec. Dir., North America Research Labs, GM R&D
Ms. Joanne Cavanaugh, Director, Maneuver Collaboration Center, GDLS

12:00 Lunch

13:30 Case Studies Introduction

13:45 Case Study 1: Multi-Physics Simulation for Electrified Vehicle Thermal Studies

14:35 Case Study 2: Vehicle Synthesis for Survivability from Impulsive Loads

15:25 ARC Poster Session

Day 2: Tuesday, May 24, 2011

8:00 Welcome by Dr. David Gorsich, Chief Scientist, U.S. Army TARDEC
Opening Remarks:
Major General Kurt J. Stein, Commanding General, U.S. Army TACOM

8:30 Plenary Session 3:
Introductions by Mr. Paul Skalny, Acting Exec. Dir., Product Devt., TARDEC
Mr. Paul Weal, Director of Business Development, LMS
Dr. Peter Lilienthal, Founder HOMER Energy

9:50 Case Study 3: Vehicle Supported Military Microgrids: Design, Scheduling, and Regulation for a Forward Operating Base

10:40 Break

11:00 Technical Symposia Part 1: 1A: Alternative Fuels 1B: Design/V&V 1C: Thermal Integration & Cooling

12:15 Lunch


15:10 Break

15:30 TARDEC S&T Portfolio Overview
Dr. David Gorsich, Chief Scientist, U.S. Army TARDEC
Presentation concludes with brief proposals for new research initiatives
ARC Conference Day 1 Schedule
Monday May 23rd 2011

7:30 am  Check-in and Continental Breakfast
8:00  Welcome & Introductions
      Prof. Anna Stefanopoulou, ARC Director
      Prof. Dave Munson Jr, Dean of Engineering, University of Michigan

Opening Remarks:
Senator Carl Levin
United States Senator (Michigan)

8:20  Plenary Session 1
      Introductions by Dr. Grace Bochenek, Director, U.S. Army TARDEC

Mr. Jeffrey Singleton
Director for Basic Research, O/Asst Sec. of the Army (Acquisition, Logistics & Tech.)

Major General Nick Justice,
Commanding General, U.S. Army Research Development and Engineering Command

9:50 Break

10:20  Plenary Session 2
      Introductions by Ms. Jennifer Hitchcock, Executive Director, Research &Technology Integration, U.S. Army TARDEC

Mr. Patrick Davis
Program Manager, Vehicle Technologies Program, U.S. Department of Energy

Dr. Gary Smyth
Executive Director, North American Science Labs, General Motors Global R & D

Ms. Joanne Cavanaugh
Director, Maneuver Collaboration Center, General Dynamics Land Systems

12:00 pm  Lunch
13:30  Case Studies Introduction
13:45  Case Study 1
      Multi-Physics Simulation for Electrified Vehicle Thermal Studies (abstract)
14:35  Case Study 2
      Vehicle Synthesis for Survivability from Impulsive Loads (abstract)
15:25  ARC Poster Session

ARC Conference Day 2 Schedule
Tuesday May 24th 2011

7:30 am  Arrival and Continental Breakfast
8:00  Welcome and Introductions
      Dr. David Gorsich, Chief Scientist, U.S. Army TARDEC

Opening Remarks
Major General Kurt J. Stein
Commanding General, U.S. Army Tank Automotive Command

8:30  Plenary Session 3
      Introductions by Mr. Paul Skalny, Acting Executive Director, Product Development, U.S. Army TARDEC

Mr. Paul Weal
Director of Business Development, LMS

Dr. Peter Lilienthal
Founder, HOMER Energy
9:50  **Case Study 3**  
Vehicle Supported Military Microgrids: Design, Scheduling, and Regulation for a Forward Operating Base *(abstract)*

10:40  Break

11:00  **Technical Symposia Part 1**  
A: Alternative Fuels  
B: Design/V&V  
C: Thermal Integration & Cooling

12:15  Lunch

13:30  **Technical Symposia Part 2**  
A: Electrical Energy Storage  
B: Survivability/Reliability  
C: Multibody Systems

15:10  Break

15:30  **TARDEC S&T Portfolio Overview**  
Dr. David Gorsich, Chief Scientist, TARDEC, U.S. Army  
*Presentation will conclude with a collection of brief proposals for new research initiatives*
OPENING REMARKS BY:

THE HONORABLE CARL LEVIN
United States Senator

MAJ. GEN. KURT J. STEIN
Commanding General
U.S. Army TACOM Life Cycle Management Command

INTRODUCTIONS BY:

GRACE BOCHENEK, PH.D.
Director
U.S. Army TARDEC

JENNIFER HITCHCOCK
Executive Director
Research & Technology Integration
U.S. Army TARDEC

PAUL SKALNY
Acting Executive Director
Product Development
U.S. Army TARDEC

SPEAKER INFORMATION

JEFFREY D. SINGLETON
Director for Basic Research
Director for Laboratory Management and Educational Outreach
Office of the Assistant Secretary of the Army (Acquisition, Logistics & Technology)

Jeff Singleton began his career as a research engineer with the Department of the Army, first in the field of experimental rotorcraft testing and analysis then later as Team Leader and Division Chief for rotorcraft dynamics, structural mechanics, and aeromechanics. His extensive background in science and technology investigation spans more than two decades of fundamental research, advanced technology development and acquisition.

Mr. Singleton earned his Bachelor of Science degree in Aerospace Engineering from West Virginia University where he graduated magna cum laude in 1980. He also earned a Master of Science in Aerospace Engineering from the Georgia Institute of Technology in 1988, specializing in aeroelasticity.

He currently serves as Director for Basic Research and acting Director for Laboratory Management and Educational Outreach for the US Army, directing the basic research program as well as laboratory management policy for all Army laboratories, research, development and engineering centers—including the Army’s Basic Research programs spanning 12 basic research disciplines and 14 technology areas at the Army Research Laboratory, Army Research Institute, the Army Corps of Engineers, the Medical Research and Materiel Command,
and the Space and Missile Defense Technical Center. He also oversees Environmental Quality technology, Manufacturing Technology, Small Business Innovative Research, and Army High Performance Computing programs—with a combined annual budget of approximately $500M. His responsibility encompasses policy for workforce development, personnel systems, laboratory infrastructure, and laboratory security.

From July 1984 to May 2006, Mr. Singleton was employed by the Army Aviation Systems Command and the Army Research Laboratory Vehicle Technology Directorate located at NASA Langley Research Center in Hampton, Virginia. During this time, Mr. Singleton was primarily responsible for experimental and analytical research exploring new technologies and designs for advanced rotor performance, reducing rotor vibrations, and measurement and prediction of rotor aeromechanical stability for both conventional helicopters as well as tiltrotor configurations. From May 2006 to January 2007, Mr. Singleton served as the Army Research Laboratory liaison officer to the Office of the Deputy Assistant Secretary of the Army, Research and Technology. In January 2007, Mr. Singleton returned to the Vehicle Technology Directorate to serve as the acting Division Chief for the Mechanics Division, leading a group of researchers in the fields of structural mechanics, loads and dynamics testing and analysis, and rotor aeromechanics. From November 2007 through May 2010, Mr. Singleton served as the Deputy Director for Research in the Office of the Deputy Assistant Secretary of the Army (Research and Technology). In May 2010 to January 2011, he was temporarily appointed to the Senior Executive Service as acting Director for Research and Laboratory Management for the Army.

Mr. Singleton’s awards include the 2006 Army Research Laboratory Honorary Award for Leadership, and in 2007 he received the Superior Civilian Service Award for his contributions to the US Army as Liaison Officer to the Office of the Deputy Assistant Secretary of the Army, Research and Technology. Also in 2007 he was awarded the American Helicopter Society’s Howard Hughes Award as team leader for the Army/NASA/Bell Quad Tiltrotor Aeroelastic Test Team given in recognition of an outstanding improvement in fundamental helicopter technology. Mr. Singleton has authored more than 50 journal articles, conference publications and presentations.

**Maj. Gen. Nick Justice**

Commanding General

U.S. Army Research, Development and Engineering Command and Aberdeen Proving Ground, MD

Major General Nick Justice began his nearly 41-year Army career as an enlisted Soldier. He was commissioned upon graduation from Officer Candidate School in 1977.

He earned a bachelor's degree in history from the University of Maryland, a master's degree in Institutional Management from Pepperdine University and a master's degree in International Relations from Salve Regina College.

His military education includes the Industrial College of the Armed Forces, the Senior Acquisition Course of the Armed Forces, the Adjutant General Basic and Advanced Course, Systems Automation Course, and the United States Naval War College.

Before serving as Research, Development and Engineering Command commanding general, Maj. Gen. Justice was the Program Executive Officer for the Program Executive Office Command, Control and Communications-Tactical at Fort Monmouth, NJ.

His experiences include significant joint service and acquisition assignments. His joint service experience includes a two-year assignment to the Sixth Allied Tactical Air Force as Chief, Project Management for Command and Control Systems. During this assignment, he participated in Operation Desert Storm as part of the North Atlantic Treaty Organization.

During Operation Iraqi Freedom, he served as Commander of the Information Management Task Force in Kuwait and Iraq. His 20 years of acquisition experience includes assignments as Project Manager, Transportation
Coordinator’s Automated Information for Movement Systems and Project Manager, Force XXI Battle Command Brigade and Below (PM FBCB2).

As the PM FBCB2, Maj. Gen. Justice fielded 1,100 battlefield-tested systems to Soldiers deployed in Operation Iraqi Freedom and Operation Enduring Freedom.

His awards and decorations include the Legion of Merit with two oak leaf clusters, Bronze Star Medal, Defense Meritorious Service Medal, Meritorious Service Medal with three oak leaf clusters, Army Commendation medal with an oak leaf cluster, Army Achievement Medal, and the Army Staff Identification Badge.

In 2010, the Association of Defense Communities named Maj. Gen. Justice Military Leader of the Year. He was singled out for the prestigious award for work inside and outside the APG gates as the installation transforms itself into one of the premier science and technology hubs on the east coast and in the Department of Defense, according to nominating officials.

In 2009, Maj. Gen. Justice was inducted into the 2009 Officer Candidate School Hall of Fame at Fort Benning, Ga. The general received the 2002 Army Acquisition Excellence PM of the Year Award. He won Federal Computer Weekly’s Federal 100 Award in 2004 and 2008, as well as its Monticello Award in 2004. He was awarded the 2008 Armed Forces Communications and Electronics Association Award of Excellence in Information Technology.

Mr. Davis is a Chemical Engineer (University of Maryland, 1983) with 28 years of experience in the development of vehicle, alternative fuel, and electrochemical technologies.

J. Gary Smyth, Ph.D.
Executive Director, North America Science Labs, GM Global Research & Development

Smyth began his career with GM in 1989 as a senior project engineer with GM Advanced Product Engineering in Warren, Michigan. He has held numerous positions in the Advanced Powertrain organization and was named Engineering Director, Advanced Propulsion System Controls in 1999, with responsibilities including advanced diesel and advanced emission development. In September 2004, he transferred to GM R&D as Director, Powertrain Systems Research Lab, where his responsibilities included directing all research and development globally for conventional and hybridized propulsion systems. In June 2010, Gary was promoted to Executive Director, North American Science Labs, GM Global R&D.

A native of Northern Ireland, Smyth attended The Queen’s University of Belfast (QUB). He studied Mechanical Engineering and received a B.Sc. in 1985 and a PhD in 1991. He is an active member of SAE International, including a founding member of the Executive Leadership Team for the SAE North American International Powertrain Conference (NAIPC).
JOANNE F. CAVANAUGH
Director, Maneuver Collaboration Center mc²
General Dynamics Land Systems

Ms. Joanne F. Cavanaugh was appointed director of General Dynamics Land Systems’ Maneuver Collaboration Center, or mc², Feb. 28, 2011. In this post, she is responsible for all aspects of mc² management and operations to accelerate product improvement through collaboration and innovation. She is General Dynamics Land Systems’ lead interface and key advocate for the mc² community.

Building on General Dynamics Land Systems’ strong foundation of systems engineering and integration, the mission of the mc² is to create a collaborative environment to foster innovative solutions and enable rapid transition of mature technologies into vehicles and programs to address the Armed Forces’ immediate needs.

Cavanaugh joined General Dynamics Land Systems in 2004, and during her tenure, she has held positions in its Engineering, Design and Technology and the Ground Combat Systems organizations. In her most recent position, she served as program manager for the Stryker Program.

Hailing from a family of West Pointers, Cavanaugh was in the fourth year group to accept and graduate women; earning a Bachelor of Science degree from the United States Military Academy at West Point, N.Y. Her military assignments included the 82nd Airborne Division and the US Army Tank Automotive Command.

Cavanaugh currently resides in Rochester MI and has four children.

PAUL WEAL
Director of Business Development, LMS

Paul has over 25 years of engineering experience in vehicle & product development, and is currently Director of Business Development, LMS International, a leading partner in test and mechatronic simulation. Paul has gained key expertise through execution and program management of projects across several engineering domains including durability, energy management, noise & vibration, vehicle dynamics and other key performance attributes. His recent relevant experience includes projects on vehicle thermal and energy management, plant modeling for hybrid vehicles, subsystem modeling for vehicle level controls development, vehicle dynamics and loads using multi-body systems, correlation, and structural fatigue assessment. He also has experience in multi-attribute balancing of these engineering domains using model based systems engineering approaches.

PETER LILIENTHAL, PH.D.
President/CEO of HOMER Energy

Since 1993 Dr. Lilienthal has been the developer of the National Renewable Energy Laboratory’s HOMER hybrid power optimization software, which has been used by over 55,000 energy practitioners in 193 countries. NREL has licensed HOMER Energy to be their sole world-wide commercialization licensee for distributing and enhancing the HOMER model.

Dr. Lilienthal was the Senior Economist with the International Programs Office at NREL from 1990 - 2007. He has a Ph.D. in Management Science and Engineering from Stanford University. He has been active in the field of renewable energy and energy efficiency since 1978. This has included designing and teaching courses at the university level, project development of independent power projects, and consulting to industry and regulators. His technical expertise is in utility modeling and the economic and financial analysis of micro-grid projects. He was the lead analyst and one of the creators of NREL’s International and Village Power Programs.
CASE STUDY 1

Multi-Physics Model Synthesis of Electrified Vehicle Thermal Studies

Hybridization provides a critical pathway for improving the fuel efficiency and augmenting adaptability of military vehicles. Battery electric hybridization, specifically, allows integration of controllable ancillaries and export of electric power beyond supporting various on-board electric and electronic sub-systems. New models and integrated predictive simulation tools are needed to address particular challenges related to military powertrains, such as: large and uncertain energy flows through the system, high thermal loads, and survivability-related constraints of the cooling system packaging. Predictive abilities for the analysis of the complex systems comprising an array of mechanical, thermal, electrical and electro-chemical devices are critical for addressing the challenges upfront, in the concept evaluation or system design stage.

This study demonstrates a multi-physics modelling and simulation approach for the analysis, design optimization, and control of hybrid propulsion systems. The work cuts across disciplines, since contributions on the component level include: (i) scalable and parameterizable thermal model of Li-ion battery cells, capable of on-board estimation of the 1-D thermal radial gradient of cylindrical cells as a function of the current drawn and the coolant temperature and flow; (ii) thermal observers for electric machines based upon dynamic finite element models of the stator and rotor of the machine, and yet fast enough to be used either in vehicle simulations or as part of a real-time control system.

Next, the complete series HEV propulsion system and vehicle cooling systems are created in Simulink, and the signal flow is analyzed in order to develop interfaces for the co-simulation framework. The Mine Resistant Ambush Protected All Terrain Vehicle (M-ATV) and military driving schedules are considered to demonstrate a novel frequency-shaping supervisory control and trade-off studies in thermal management and packaging. In particular, we show that embedding parameterizable multi-physics models in the virtual propulsion system enable system-level studies of powertrain efficiency and layout, along with on-board estimation for diagnosis and prognosis under realistic operation.

CASE STUDY 2

Vehicle Synthesis for Survivability from Impulsive Loads

Occupant safety and survivability is a top priority in military vehicle design. The recent requirement to include protection against underbody explosives in addition to ballistic threats and rough terrain mobility has motivated new technologies and strategic decisions. ARC research addresses four main topics: (1) optimal attachment of armor to existing vehicle structures, (2) design of lightweight composite structures against blast events, (3) integrated design of vehicle structure, restraint and seating systems, and (4) the strategic impact of using heavier blastworthy vehicles and the associated increased fuel convoy requirements.

Armor joint locations affect structural dynamic performance such frequency response and static compliance. To account for joint fatigue, optimal joining locations are determined by accounting for the strain energy concentrated in the joints while minimizing the total amount of energy input into the structure from external forces. Reduced-order models are used to handle the intensive computational requirement of complex structural optimization. Results indicate that the optimal joining solutions significantly improve the baseline design. They can reduce the strain energy in the joints and the energy input in the structure by 50-70 %.

Composite material armor is an attractive manufacturing solution for increasing survivability against blast without a significant weight penalty. ARC research has focused on coupling micromechanics
analysis (i.e. fiber failures, matrix damage, inelasticity, interfacial debonding) with the macromechanical response of the structure. This multi-scale approach allows high fidelity modeling of structural damage due to explosion and opens opportunities for design optimization. The case study examines an all-metal and a metal-composite structure and demonstrates that an optimized matrix-fiber configuration and laminate orientation reduces weight by 16% with no changes in survivability.

Blast protection needs have led to design and deployment of the MRAP multipurpose ground vehicles in addition to the much lighter HMMWV. However, MRAP consumes twice as much fuel and a significant percentage of fuel convoys that supply current military operations experience casualties en route. Thus, while heavier vehicles provide better safety against blast, they contribute to casualties elsewhere by requiring more fuel convoys. This leads to a strategic-level optimization framework that uses physics-based simulations of vehicle blast events and empirical fuel consumption data to minimize combined total expected injuries from blast events and fuel convoys. For example, exercising this framework quantifies the inverse relationship between occupant injury probability and vehicle weight: Increasing vehicle weight from 2500 kg (unloaded HMMWV) to 3500 kg reduces the optimized seating-system probability of injury by 87%; however, increasing a 10000 kg vehicle to 11000 kg decreases injury probability by 15%. This indicates that adding weight has diminishing returns on occupant blast protection improvement.

**CASE STUDY 3**

**Vehicle Supported Military Microgrids: Design, Scheduling, and Regulation for a Forward Operating Base**

Integration of vehicle-to-grid and microgrid technologies can transform energy generation and management in military bases, supporting autonomous and sustainable operation through the use of renewable power sources while reducing costs and improving reliability and stability of electricity supply. The successful implementation of such a paradigm-shifting technology requires an integrated approach to design and control at different time scales. In the long time-scale, it is important to predict future operating conditions and determine optimal configurations, component sizes, and dispatch strategies to ensure reliable electricity supply while minimizing cost. In the short time-scale, it is important to develop controllers that regulate grid voltage and frequency to maximize stability under unpredictable disturbances.

In this case study, we highlight these challenges within the context of forward operating bases (FOBs) requiring completely autonomous operation. First, we present a multi-dimensional analysis of alternative grid configurations, and illustrate our systematic selection process. Next, we describe our approach to modeling, design, scheduling, and regulation of microgrids. This approach is applied to the chosen FOB configuration to show the coupling between design, scheduling, and regulation despite their different time scales. Finally, we highlight the outstanding challenges and potential directions for future research.
## TECHNICAL SYMPOSIA PART 1

### May 24th

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<tr>
<th>Time</th>
<th>Session A: Alternative Fuels</th>
<th>Session B: Design/V&amp;V</th>
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| 11:00 | Autoignition Characteristics of Fuels with a Wide Range of Autoignition Qualities  
*PI: Naeim Henein* | The Impact of Normality and Information Content on Bayesian Model Confidence Quantification  
*PI: Michael Kokkolaras, Panos Papalambros, Greg Hulbert* | Impact of Battery Thermal Management System on Series Hybrid Electric M-ATV  
*PI: Dohoy Jung* |
| 11:25 | Multi-Fuel Operation of Advanced Diesel Engines: On Board Fuel Identification  
*PI: Dinu Taraza* | Ground Vehicle Safety Optimization Considering Blastworthiness and Weight  
*PI: Michael Kokkolaras, Panos Papalambros* | Battery Thermal Packaging Design  
*PI: Georges Fadel* |
*PI: Dennis Assanis* | Accelerated Testing and Preventive Maintenance in Acquisition, Maintenance, and Operation of Vehicle Systems using Time-Dependent Reliability/Durability Principles  
*PI: Lin Ma, John Wagner* |

## TECHNICAL SYMPOSIA PART 2

### May 24th

<table>
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<th>Time</th>
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*PI: Zoran Filipi* | Topology Optimization of Component Joining for Complex Vehicle Structures with Uncertainties  
*PI: Bogdan Epureanu* | Internet-Distributed Hardware-in-the-Loop Simulation: Development of a Linear Experimental Platform  
*PI: Jeffrey Stein* |
| 13:55 | Part B: Computationally Efficient Thermal Observers for Electric Machines  
*PI: Heath Hofmann* | A Blast Event Simulation Process for Multi-Scale Modeling of Composite Armor for Light Weight Vehicles  
*PI: Nickolas Vlahopoulos* | Off-Road Soft Soil Tire Model Development, Validation, and Interface to Commercial Multibody Dynamics Software  
*PI: Corina Sandu* |
| 14:20 | In Situ Measurements of Lithium Concentration in Iron Phosphate Battery Pouch Cells  
*PI: Anna Stefanopoulou* | Conservative Surrogate Model using Weighted Kriging Variance for Sampling-based RBDO  
*PI: John Ferris* |
| 14:45 – 15:10 | Control and System Integration of an SOFC/GT-based APU with Extended Dynamic Capabilities for Military Vehicle  
*PI: Jing Sun* | Equivalent Standard Deviation to Convert High-reliability Model to Low-reliability Model for Efficiency of Sampling-based RBDO  
*PI: K. K. Choi* | Modeling of the Piston-Ring Assembly Using Curved Beam Finite Elements  
*PI: Nabil Chaloub* |
1A1: Autoignition Characteristics of Fuels with a Wide Range of Autoignition Qualities  
Naeim A. Henein (PI), Rafik Rofail (Wayne State U.), Peter Schihl, Laura Hoogterp (TARDEC), Inderpal Singh (Detroit Diesel)

Military engines are required to operate properly on fuels that have a wide range of ignition qualities. JP-8 can have Cetane Number (CN) of 70 and as low as 25. Low CN fuels affect engine operation and cause serious problems that impact mission readiness and survivability in the field. Such problems are mainly caused by the long delay between the start of injection and the start of combustion. Analysis of the ignition delay of low CN JP-8 showed a cool flame precedes combustion. In many cases the cool flame is associated with the NTC (Negative Temperature Confident) regime, which adds to the length of the ignition delay. This presentation examines in some details the processes that delay the combustion process and presents some concepts to enable the engine to operate properly using low cetane fuels. Proof of concept has been achieved by computer simulation and experimental investigations on a single-cylinder research diesel engine as well as on a heavy-duty diesel engine operating on a multitude of fuels including JP-8 of 31 CN.

1A2: Multi-Fuel Operation of Advanced Diesel Engines: On Board Fuel Identification  
Dinu Taraza (PI), Naeim A. Henein, Florin Mocanu (GSRA-Presenter), Elena Florea (Wayne State U.), Peter Schihl (TARDEC), Rodica A. Baranescu (Navistar-International, Retired)

Different physical and chemical properties of the fuels used in diesel engines, mainly cetane number, volatility and bulk modulus, are influencing ignition and combustion resulting in different characteristics of the cylinder pressure history. In turn, cylinder pressure variation determines the motion of the crankshaft and its measured speed variation contains information regarding cylinder pressure variation. The conversion of the measured speed variation into cylinder pressure variation requires good knowledge of the crankshaft dynamics and methods based on the dynamic model of the crankshaft are presented in this work. While these methods are quite successful in the cases of the single and four cylinder engines, where the operation of the cylinders is well separated, they lack the required accuracy in the case of 6 and 8 cylinder engines. Another approach is used in this case, based on Artificial Neural Networks. The application of this method is first demonstrated on a single cylinder engine and then adapted to identify the operation on different fuels in a six cylinder truck diesel engine.

Dennis Assanis (PI), Jason Martz, Doohyun Kim, Kyoung Hyun Kwak (U. of Michigan), Peter Schihl, Patsy Muzzell, Denise Kramer, Laura Hoogterp (TARDEC), Admir Kreso, Craig Savonen, Rakesh Aneja, Kevin Sisken (Detroit Diesel/Daimler)

Understanding the behavior of compression ignition engines operating on JP-8 fuels has become paramount given the Army’s “single battlefield fuel” mandate. The lower cetane number of JP-8 relative to standard diesel fuel (DF-2) may lead to significant differences in combustion phasing, mode and rate. Variations in density and energy content of the fuels may also require modifications to the fuel injection event in order to maintain engine load. In turn, these differences may significantly affect engine fuel economy and performance. The current experimental work presents the results of initial studies of JP-8 and DF-2 fuels within a modern heavy-duty diesel engine.

In addition, a multi-zone, quasi-dimensional combustion model is under development for the simulation of JP-8 fueled compression ignition engines within the GT-Power framework. As a
preliminary step in the model development, the differences between JP-8 and DF-2 fuel properties and their effects on combustion are identified from experimental results obtained from the open literature. In addition, model predictions with JP-8 and DF-2 are compared in terms of ignition delay, heat release and engine performance trends. Finally, the effect of fuel properties on the spray and evaporation sub-models are further investigated to enhance model fidelity.

Technical Session 1B – Design/V&V
Session Chair: Dr. David Lamb

1B1: The Impact of Normality and Information Content on Bayesian Model Confidence Quantification
Hao Pan and Michael Kokkolaras (Presenters), Greg Hulbert, Panos Papalambros (U. of Michigan), Zissimos Mourelatos (Oakland U.), Ren-Jye Yang (Ford), David Gorsich (TARDEC)

The simulation-based framework we have been developing in this project for vehicle design and test validation relies on Bayesian hypothesis testing to quantify model confidence. This approach is based on comparisons between multivariate computational and test data, and is suited to multiple sources of errors and uncertainties because it combines multiple sources of information and updates validation assessments as new knowledge and/or information is acquired. To our knowledge all Bayesian-based approaches reported in the literature use a Gaussian error model. We investigate the soundness of this assumption and assess its impact on quantifying model confidence by using normality tests and data transformation techniques. In addition, we also discuss techniques for deciding how much information to use when feature extraction methods such as probabilistic principal component analysis (PPCA) are used to reduce data dimensionality and remove multivariate correlation.

1B2: Ground Vehicle Safety Optimization Considering Blastworthiness and Weight
Steven Hoffenson (Presenter), Panos Papalambros, Michael Kokkolaras (U. of Michigan), Sudhakar Arepally (TARDEC)

Occupant safety is a top priority of military vehicle designers, and recent trends have shifted this focus from the threats of ballistics and missiles toward those of underbody explosives. One major response to this heightened threat is the shift of multipurpose ground vehicles from the HMMVV to the much heavier MRAP, which consumes twice as much fuel as its predecessor. However, recent reports have shown that fuel consumption is no longer solely an environmental or economic issue, but also a safety concern; a significant percentage of fuel convoys that supply current military operations experience a casualty en route. While heavier vehicles tend to fare better for safety in blast situations, they contribute to casualties elsewhere by requiring more fuel convoys. This study develops an optimization framework that uses physics-based simulations of vehicle blast events and empirical fuel consumption data to minimize combined total expected injuries from blast events and fuel convoys. Results are presented as a function of two input parameters, and the utility of the framework is discussed in a dynamic context and for evaluating casualty-reduction strategies.

Zissimos P. Mourelatos (Presenter, Oakland U.), Amandeep Singh (TARDEC), Jing Li (OU), Igor Baseski (TARDEC / OU)

Reliability is an important engineering requirement for consistently delivering acceptable product performance through time. The reliability degrades with time increasing the lifecycle cost due to warranty costs, repairs and loss of market share. Using time-dependent reliability, we will present a methodology to obtain an optimal schedule for preventive maintenance considering the lifecycle cost, and an importance sampling method for accelerated testing of vehicle systems. For the latter, we
calculate the cumulative probability of failure of a random dynamic system driven by an input random process using time-series modeling and the concept of decorrelation length. Many failures are artificially induced using a sampling distribution with a high variance. The failure rate estimation is then corrected using weights which are proportional to the likelihood ratio between the actual and sampling distributions. Examples will demonstrate the benefits of the preventive maintenance method and the importance sampling method for accelerated testing. We are currently developing an accelerated testing capability in the TARDEC Physical Simulation Laboratory, to estimate the actual failure rate of vehicle components by artificially inducing high failure rates in a controlled environment.

**Technical Session 1C – Thermal Integration & Cooling**

**Session Co-Chairs:** Mr. Rob Smith, Dr. Matt Castanier

**1C1: Impact of Battery Thermal Management System on Series Hybrid Electric M-ATV**

_Dohoy Jung, Sungjin Park, Dennis Assanis, Tae-Kyung Lee, Youngki Kim, XinFan Lin, Zoran Filipi, Anna Stefanopoulou (U. of Michigan), Pete Schihi (TARDEC), Bashar AbdulNour (GDLS), John Myers (Hyundai)_

We have previously studied the design and optimization of the Vehicle Thermal Management System (VTMS) for better performance and fuel economy of advanced powertrains. This year, we expanded our scope to include the Battery Thermal Management System (BTMS) because proper battery thermal management is critical for battery safety, performance, and durability in Hybrid Electric Vehicles. A numerical model was developed for the control of battery temperature and BTMS power consumption under transient vehicle operations, and used to study BTMS optimization as well as comparing air and oil cooling methods. Parametric study of the battery module aspect ratio was conducted and it was found that an optimal aspect ratio exists to minimize BTMS power consumption within the battery cell temperature distribution constraint. The BTMS model is integrated with the vehicle powertrain model developed for an M-ATV with series hybrid electric powertrain to simulate the interaction between powertrain and VTMS components, and to predict the fuel economy. The result shows that the impact of BTMS on fuel economy is significant in the electrified M-ATV.

**1C2: Battery Thermal Packaging Design**

_Georges Fadel, Margaret Wiecek, Paolo Guarneri (Clemson U.), Matthew Castanier (TARDEC), Bahram Khalighi (GM)_

The cell optimal layout inside the battery pack is optimized while considering thermal aspects. Due to large number of function evaluations, CFD models are not suitable and a simplified model must be used to reduce the optimization computational effort. The lumped parameter thermal model developed by other teams collaborating in the project is integrated in the optimization.

The battery position into the vehicle environment needs to be optimized as well to improve vehicle dynamics, component accessibility and passenger survivability while considering geometric constraints such as collision between the components. The geometry of the battery is defined by the cell packing, resulting in a two level optimization procedure.

Such a formulation with physically homogeneous and comparable objectives can be addressed in terms of the equitability criterion instead of the well known Pareto optimality criterion. The mathematical aspects are investigated and results are provided to show the applicability of the equitable sets criterion to engineering problems.

A JAVA code has been developed to solve in terms of Genetic Algorithms the layout design while including a collision detection algorithm.
Electronic payloads have become an integral part of modern military ground vehicles. These electronics often feature high thermal densities that must be effectively managed, especially under demanding operating conditions, to maintain system reliability. Therefore, new strategies to effectively remove heat from these integral electronic systems must be employed to meet the thermal management challenges raised. This presentation will describe the modeling and analysis of a proposed thermal management system combining cooling fluids augmented by nanoparticle suspensions and thermal electric devices. Since modeling the nanofluid effects remains a debated issue in current literature, a sensitivity analysis will evaluate each model’s effect on the convective heat transfer coefficient enhancement and the overall peak computer chip temperature reduction for one electronic device within a system. The results will demonstrate that modeling the overall system performance is relatively insensitive to the complexity of the nanofluid model used in the analysis. Also, the overall cooling system’s superiority t

Technical Session 2A – Electrical Energy Storage
Session Co-Chairs: Dr. Yi Ding, Mr. Erik Kallio

2A1: Control and System Integration of an SOFC/GT-based APU with Extended Dynamic Capabilities for Military Vehicle
Soryeok Oh (Presenter), Jing Sun (U. of Michigan), Herb Dobbs (TARDEC), Joel King (Pittsburgh Electrical Engines)

Turbo-charging a solid oxide fuel cell (SOFC) engine is a natural and effective way to enhance the efficiency of SOFC systems. For military vehicles, the combined SOFC/GT (gas turbine) system offers many attractive features, such as silent watch capability, flexible fueling strategy, high system efficiency, and clean exhaust. The research activities of this project entail two major components: First, the part-load operation and load transition dynamics that have significant implications on control, optimization, and integration have been identified. Special attention has been paid to understand load following characteristics and the impacts of various constraints on the system dynamic operation. Second, the research has been focused on developing control strategies for 5kW-Class SOFC/GT hybrid systems. The objectives of the control design include (i) achieving fast power tracking, (ii) handling multiple constraints that are imposed by the SOFC/GT system physical and operational limitations, and (iii) minimizing the fuel consumption. The control design space is explored for several different control structures through model-based simulations.

2A2: In Situ Measurements of Lithium Concentration in Iron Phosphate Battery Pouch Cells
Jason B. Siegel, Xinfan Lin, Anna G. Stefanopoulou (U. of Michigan)

Neutron imaging is a non-destructive In Situ measurement technique that can be used to validate electrochemical models of Lithium-Ion batteries that could be consequently used for State of Charge (SOC) and State of Power (SOP) estimation. This measuring technique is at its infancy, yet very powerful allowing direct observation of the mobile lithium within the battery structure. Stroboscopic imaging technique is used to overcome the long-time exposures needed to reduce counting noise in the image, hence overcoming the limitation of Poison counting statistics for measuring fast transients such as pulse discharging. The measured Li concentration along the thin commercial electrodes is then used to guide model order reduction suitable for battery management.
Electrification and hybridization show great potential for improving fuel economy and reducing visual signature in military vehicles. Specific challenges related to military applications include severe duty cycles, large and uncertain energy flows through the system and high thermal loads. Predictive tools and novel approaches to supervisory control are necessary to maximize the fuel efficiency potential, while ensuring reliable operation, minimal visual signature and acceptable cost. It is particularly important to avoid harmful peak electric loads on the battery, without the need to oversize it. Our study proposes two alternative paths for achieving the described objectives, namely: 1) vehicle level power management with frequency-shaping; and 2) battery level power management with Li-Ion concentration feedback. The proposed vehicle level strategy splits the propulsion power demand in the frequency domain, utilizing the engine to track smoothly the long term power demand profile, while proving the high frequency-low amplitude component by the battery. This simultaneously reduces severity of engine transients and peak currents experienced by the battery, thus eliminating the negative impact of engine transients on soot emissions and protecting the battery health. The battery level power management adjusts the allowable battery power limits through the feedback of the estimated electrode-averaged Li-ion concentration information. The approach is enabled through a collaborative ARC effort on advancing the state-of-the-art of battery electro-chemical models. The proposed strategies are implemented into the series HEV simulation of the Mine Resistant Ambush Protected All Terrain Vehicle (M-ATV) and their impact is demonstrated over relevant military driving schedules.

The power capabilities of electric machines depend strongly upon temperature. Knowledge of the internal temperatures of the machine is therefore highly desirable in military automotive applications in order for the system-level controller to determine appropriate torque commands for the machine. In this work we present thermal observers for electric machines that are sufficiently fast to be used either in vehicle simulations or as part of a real-time control system. The observer is based upon dynamic finite element models of the stator and rotor of the machine. These models are coupled to each other and to cooling systems through appropriate convection models. The eigenmodes of the stator and rotor are determined, and only the dynamics of the slowest eigenmodes are modeled, allowing a dramatic reduction of the number of states of the model. Furthermore, by limiting the number of temperatures calculated in the machine to a few "hot spots", overall computations required for the model are dramatically reduced. Simulation results using actual drive cycles show that the proposed models possess the accuracy of finite element models while being orders of magnitude faster.
joining locations is to place the joints such that the total amount of energy input into the structure (from external forces) is minimized. However, such an approach does not account for the fatigue in the bolts. Therefore, in this work, the amount of strain energy concentrated in the bolts is also considered. The minimization of the cost function is time consuming (because it requires the calculation of the displacements of all candidate bolt locations by using full-order models). To address this, parametric reduced-order models are used to compute the cost function with significant gains in computational speed especially for the case of structural and geometrical variations. Numerical results for the optimal joining are presented for representative complex structures with uncertainties.

John Kim, Nickolas Vlahopoulos (PI) (U. of Michigan)

Lighter weight military vehicles facilitate faster transport, higher mobility, fuel conservation, and a reduced ground footprint of supporting forces. Composite materials provide some of the most viable options for manufacturing composite armor that can increase survivability without significant weight penalty. NASA Glenn developed the Micro-mechanics Analysis Code (MAC) which enables coupled multi-scale analysis of advanced composite structures. Local phenomena (i.e. fiber failures, matrix damage, inelasticity, interfacial debonding, etc.) can be modeled on local level and their effects can be propagated throughout the structural response. The MAC code determines the effective properties of composite materials based on the arrangement and properties of the constituent materials and the state of stress and strain. Work has been completed for fully coupling the ABAQUS software with the MAC code for multi-scale modeling of structures subjected to loads from an explosion. Further, a case study associated with the analysis of a generic all metal structure and a metal-composite structure is presented. It is demonstrated that the new simulation approach can determine a matrix-fiber configuration and the orientation of the laminates at the micro level in order to maximize the protection offered by the composite armor while reducing the weight.

2B3: Conservative Surrogate Model using Weighted Kriging Variance for Sampling-based RBDO
Liang Zhao (Presenter), K.K. Choi (PI), Ikjin Lee (U. of Iowa), David Gorsich, David Lamb (TARDEC)

When applying sampling-based RBDO to practical complex engineering applications, the Monte Carlo simulation (MCS) for stochastic sensitivity analysis and probability of failure calculation are based on the prediction from the surrogate model for the performance functions. When the number of samples used to construct the surrogate model is small, the prediction from the surrogate model becomes inaccurate. To count in the prediction error from the surrogate model and assure the obtained optimum from sampling-based RBDO satisfy the probabilistic constraints, a conservative surrogate model is needed. A new conservative surrogate model is proposed using the weighted Kriging variance where the weight is determined by the relative change in Akaike information criterion (AICc) of the dynamic Kriging model. The proposed conservative surrogate model performs better than the traditional Kriging prediction interval approach because it does not generate unnecessary local optimum; and it performs better than the constant safety margin approach because it adaptively counts in the uncertainty of the surrogate model in the place that the samples are sparse. Numerical example shows that using the proposed conservative surrogate model for sampling-based RBDO is necessary to assure the optimum design satisfies the probabilistic constraints when the number of samples is limited.

2B4: Equivalent Standard Deviation to Convert High-reliability Model to Low-reliability Model for Efficiency of Sampling-based RBDO
Ikjin Lee (Presenter), K.K. Choi (PI) (U. of Iowa), David Gorsich, David Lamb (TARDEC)

This study presents a methodology to convert an RBDO problem requiring very high reliability to an RBDO problem requiring relatively low reliability by increasing input standard deviations for efficient
computation in sampling-based RBDO. First, for linear performance functions with independent normal random inputs, an exact probability of failure is derived in terms of the ratio of the input standard deviation, which is denoted by $\delta$. Then, the probability of failure estimation is generalized for any random input and performance functions. For the generalization of the probability of failure estimation, two coefficients need to be determined by equating the probability of failure and its sensitivity with respect to the standard deviation at the current design point. The sensitivity of the probability of failure with respect to the standard deviation is obtained using the first-order score function for the standard deviation. To apply the proposed method to an RBDO problem, a concept of an equivalent standard deviation, which is an increased standard deviation corresponding to the low reliability model, is also introduced. Numerical results indicate that the proposed method can estimate the probability of failure accurately as a function of the input standard deviation.

Technical Session 2C – Multibody Systems
Session Chair: Dr. P. Jayakumar

2C1: Development of a Linear Experimental Platform
Tulga Ersal (Presenter), Brent Gillespie (UM), Mark Brudnak (TARDEC), Zoran (UM), Marcella Haghighoie (Applied Dynamics International), Jeffrey Stein (UM, PI)

Internet-distributed hardware-in-the-loop simulation (ID-HILS) refers to bilaterally coupling geographically-distributed hardware, software, and human resources over the Internet to achieve an integrated simulation. This technology could provide dramatic improvements on the existing systems engineering, integration, and testing process by providing high-fidelity simulations unprecedentedly early in the process and thus greatly benefit both the Army and industry.

In our previous work, we built and analyzed an ID-HILS platform, coupling a driveline model and a real engine with a vehicle model and a ride motion simulator over the Internet. We also developed a linear framework to analyze transparency in ID-HILS systems and investigate the efficacy of feedback and feedforward control techniques to improve transparency.

In this talk, we will describe our efforts on building a new, linear experimental platform to test and validate the linear theory we have developed. Preliminary experimental results will be presented regarding the effect of coupling point selection on the transparency of the setup. These experimental findings will be compared to the theoretical predictions. This setup will also allow for the controlled inclusion of nonlinear effects in the future, thereby helping with extending the linear results to nonlinear systems, as well.

2C2: Off-Road Soft Soil Tire Model Development, Validation, and Interface to Commercial Multibody Dynamics Software
Corina Sandu (PI), Eduardo Pinto (co-presenter), Scott Naranjo (co-presenter) (Virginia Tech), Paramsothy Jayakumar (TARDEC), Brant Ross (MotionPort), Archie Andonian, Dave Hubbell (Goodyear Tire & Rubber Company)

The goal of this project is to develop an accurate, comprehensive, but efficient, off-road tire model for soft soil applications (handling, traction, ride, and vehicle durability), as needed to support current Army mobility goals. Through a literature review it has been determined that, while finite element methods lead to the most detailed tire-soil interaction models, their complexity and extensive computational effort make them less than ideal approaches for the applications envisioned. Consideration of such models is precluded due to the limited scope of the current project. The proposed approach is a detailed semi-analytical tire model for soft soil that utilizes tire construction details that parallel commercially available on-road tire models. The novelty of this project relies in improving the tire-soil interface model, by enhancing the resolution of the tire model at the contact patch and by accounting for soil effects and phenomena not considered in existing models.
The model will be validated against experimental data. For low speed, testing will be performed on a single tire on sandy loam in a terramechanics rig. The influence of tire and vehicle parameters on the forces in the contact patch and on those transmitted to the axle, will be investigated. The effect of soil characteristics on the tire dynamics will be studied.

**2C3: Terrain Characterization, Modeling, Analysis, and Synthesis Software: TerrainSim**  
John B. Ferris (PI, Presenter), Rebecca Bandy (Virginia Tech), Al Reid (TARDEC), Tana Tjhung (Chrysler)

Researchers continue to develop mathematical model for terrain profiles so that terrain can be characterized and synthesized. However, terrain topology is a very rich signal that has significant physical characteristics over a wide range of wavelengths. The project goal is to develop a software tool, TerrainSim, which analyzes each model’s effectiveness when applied to different terrain types at different resolutions. Using these models will improve the simulation capability for ground vehicle dynamics, durability, reliability, and mobility. TerrainSim analyzes measured terrain (profiles, left and right wheel paths, or full surfaces) using a comprehensive set of statistical tests (e.g., Homogeneity, Gaussianity, and Linearity). These measured terrains are modeled using several mathematical frameworks, including Autoregressive Models, Markov Chains, and Wavelets. Synthetic terrain is then generated from each model and statistically analyzed. The measured terrain is compared to the resulting synthetic terrain and the appropriateness of each model can be quantitatively studied. The approach was developed with the SAE Ground Vehicle Reliability Committee Task Force on Terrain Modeling (one means by which tools and methodologies are being transitioned to government and industry).

**2C4: Modeling of the Piston-Ring Assembly Using Curved Beam Finite Elements**  
Mohannad Hakeem, Nabil G. Chalhoub (PI), Naeim A. Henein (Wayne State U.), Pete Schihi (TARDEC)

The dynamic behavior of the piston-assembly can significantly influence the performance of IC engines. It affects fuel efficiency through frictional losses, thermal efficiency through blow-by, emissions through oil consumption, and durability through wear. A dynamic model for the crankshaft/connecting-rod/piston-assembly has been developed by accounting for the rigid and flexible motions of the ring, the primary and secondary motions of the piston along with the piston-liner and piston-ring interactions. The longitudinal and in-plane transverse deformations of the ring are approximated by implementing two-node shear deformable curved beam elements, which account for the strong coupling between the longitudinal and transverse deformations. Moreover, the derivation accounts for the hydrodynamic lubrication of the piston skirt and the elasto-hydrodynamic lubrication regime of the rings. The simulation results illustrate the clearance between the deformable configuration of the ring and the liner, the piston tilting angle, the tilting angles of the ring with respect to the piston, the axial displacement of the ring relative to the surfaces of the piston groove, and the hydrodynamic frictional losses of the piston-assembly throughout the engine cycle.
Gamma Technologies Inc. is the developer of the GT-SUITE virtual engine/powertrain/vehicle simulation program. Unique in the industry, GT-SUITE is the only simulation tool developed specifically for the transportation industry that provides a single analysis tool for performing integrated analyses of multiple physical phenomena that take place within a vehicle. Anchored by the market leading engine simulation GT-POWER for engine performance, acoustics, combustion, cylinder pressure analysis, emissions, and aftertreatment modeling, GT-SUITE provides a comprehensive set of modeling libraries applicable to cooling circuits, vehicle thermal management systems, lubrication systems, hydraulic and fuel injection systems, air conditioning and waste heat recovery systems, controls systems (including Mil, SiL, and HiL modeling), valvetrain, cranktrain, and gear/chain/belt systems, and conventional, hybrid, and electrical vehicle modeling.

LMS, the leading partner in test and mechatronic simulation in the automotive, aerospace and other advanced manufacturing industries, helps customers get better products to market faster. With a unique combination of mechatronic simulation software, testing systems and engineering services, LMS tunes into mission critical engineering attributes, ranging from system dynamics, structural integrity and sound quality to durability, safety and power consumption.

National Instruments is committed to enhancing engineering and science education worldwide by providing educators and students with powerful graphical system design software and modular hardware to connect the curriculum with the real world. Professors and students benefit from industry-leading, professional tools such as NI LabVIEW graphical development software, which helps students visualize and implement engineering concepts. National Instruments offers a full suite of tools for enhancing controls, mechatronics, and robotics education and research including the LabVIEW Control Design and Simulation, MathScript RT, and Robotics Modules. The NI LabVIEW graphical development environment allows students to quickly design, simulate, and implement a variety of real-time controllers. The LabVIEW environment supports multiple programming approaches, allowing students to use the most effective syntax – graphical, textual (including user-developed .m files and C code), or a combination – for their projects. For more information about NI academic products, curriculum resources, and discounts, visit www.ni.com/academic/controls or www.ni.com/robotics

The University of Michigan’s Ground Robotics Reliability Center (GRRC), launched in 2008, conducts research in autonomous ground vehicles and mobile robots. Our vision is to help establish Southeastern Michigan as a center of activity for these emerging new technologies through supporting programs in research and education.

The GRRC research projects are primarily funded by the US Army’s Tank-Automotive Research Development and Engineering Center (TARDEC). The University of Michigan leads the GRRC, which also includes partners from other academic institutions as well as industry. To learn more about the center, visit http://grrc.engin.umich.edu

The University of Michigan Solar Car Team (UMsolar) is an entirely student-run organization that designs and builds solar-powered vehicles. The team races both nationally and internationally. Since its establishment in 1990, the team has built 10 vehicles, won the American Solar Challenge six times, and placed third in the World Solar Challenge four times. UMsolar is widely recognized as the most successful team in North America.
Conference Information

Venue: The 17th Annual ARC Conference will be held at
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Hotel web-site: http://www.annarbormarriott.com

Registration: Online registration is free but compulsory due to venue capacity. It is now closed. For inquiries about the waiting list, please email: arc-conference-inquiries@umich.edu

Fees: There are no fees for this year’s conference.

Lodging: Rooms are available at the venue. Attendees who wish to book rooms should identify themselves with the ARC Annual Conference for the special rate.

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