<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
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</thead>
<tbody>
<tr>
<td>6:00 pm</td>
<td>Briefing begins</td>
</tr>
<tr>
<td></td>
<td><em>Salad is served</em></td>
</tr>
<tr>
<td></td>
<td>ARC Overview</td>
</tr>
<tr>
<td></td>
<td>Anna Stefanopoulou, ARC Director</td>
</tr>
<tr>
<td></td>
<td>Break</td>
</tr>
<tr>
<td></td>
<td><em>Buffet entrée</em></td>
</tr>
<tr>
<td></td>
<td>Briefing on ERB Packet</td>
</tr>
<tr>
<td></td>
<td>William Lim, Program Manager</td>
</tr>
<tr>
<td></td>
<td>ARC Overview continues</td>
</tr>
<tr>
<td></td>
<td>Anna Stefanopoulou</td>
</tr>
<tr>
<td></td>
<td>Break</td>
</tr>
<tr>
<td></td>
<td><em>Dessert is served</em></td>
</tr>
<tr>
<td></td>
<td>Discussion</td>
</tr>
<tr>
<td></td>
<td><strong>End of Briefing</strong></td>
</tr>
</tbody>
</table>
AUTOMOTIVE RESEARCH CENTER

A U.S. ARMY Center of Excellence in Modeling and Simulation of Ground Vehicles
Led by the University of Michigan

http://arc.engin.umich.edu

Annual Program Review
May 8, 2017

Anna. G. Stefanopoulou
William Clay Ford Professor of Manufacturing
Professor of Mechanical Engineering
Automotive Research Center Director
**Mission:**
Develop simulation and modeling tools for discovering and assessing critical ground vehicles technologies

**Participation**
- 6 Universities
- 25 core projects
- 25 professors
- 5 research faculty
- 27 graduate students
- 4 post-doctoral students

**Disciplines**
- ME, EE, IOE, ChE, NAME, AERO
- Math & Stats

ARC projects maintain a **Quad structure** with industry, government, university professor and graduate student participation
TARDEC Quad Members:

- advise and guide PI on TARDEC needs,
- direct PI to resources and partnership opportunities that facilitate completion, sharing, technology transfer and implementation, and
- transfer research results to TARDEC/Army.

Industry Quad Members:

- advise PI on industry/commercial state-of-the-art,
- advise/guide research in directions useful for commercialization and industry,
- be research partners, collaborating in terms of software/hardware/facilities, and
- transfer research results to industry.
The Depth and Breadth

Mobility

Thrust Area 1
Intelligent Vehicle Dynamics and Control

Thrust Area 2
Human Centered Design Simulation

Design lightweight structures addressing impact protection and reliability under uncertainty

Achieve true shared and autonomous vehicle controls embedding terrain, power, vehicle & driver interactions.

Integration of human models to represent human-vehicle control interfaces, ergonomics, crash-restraint systems

Survivability

Thrust Area 3
High Performance Structures & Materials

Efficiency

Thrust Area 4
Advanced and Hybrid Powertrains

Thrust Area 5
Vehicle System Integration, Optimization and Robustness

Synthesizing and testing advanced propulsion for high power density accounting for thermal loads and fuel variability
Diverging Needs

- Fuel Uncertainty
- Thermal Constraints
- Energy & Power Requirements
- Terrain Variability
-Survivability

Converging Needs

- Vehicle
  - Shared
  - Controls & Autonomy
- Reliability
- Modularity
ARC IV Annual Cycle

Executive Committee (Xcom)
- ARC Director
- ARC Associate Directors
- TARDEC Technical Leader
- TARDEC Chief Scientist
- TARDEC NAC Univ. Programs
- Rotating School Liaison

PI addresses concerns in report
 Compile reviews, feedback to PIs
 First biannual Tech. report
 ARC Annual Program Review

Additional Effort
- High Risk
- Seed Funds
- Tech Transfer

Annual Plan Core Funding Long Term Efforts
 Accepted Annual Plan work begins/continues

ARC Annual Program Review
- May
- First biannual Tech. report
- ARC Annual Program Review

Executive Committee (Xcom) consensus meeting on Annual Plan
- Oct
- Second biannual Tech reports and continuation requests, new proposals
- Research projects evaluated by TARDEC based on relevance, productivity, and scientific merit

External Review Board provides feedback on the center’s strengths and weaknesses
- Jan
- Accepted Annual Plan work begins/continues
- End-Dec
- ARC Annual Plan Issued (Includes All Active ARC Projects)
- Final Reports for completing projects

External Review Board provides feedback on the center’s strengths and weaknesses
- Jun
- Compile reviews, feedback to PIs
- First biannual Tech. report
- ARC Annual Program Review

External Review Board provides feedback on the center’s strengths and weaknesses
- End-Sep
- PI addresses concerns in report
- Compile reviews, feedback to PIs
- First biannual Tech. report
- ARC Annual Program Review

External Review Board provides feedback on the center’s strengths and weaknesses
- Nov
- XCom consensus meeting on Annual Plan
- End-Sep
- PI addresses concerns in report
- Compile reviews, feedback to PIs
- First biannual Tech. report
- ARC Annual Program Review

External Review Board provides feedback on the center’s strengths and weaknesses
- End-Dec
- ARC Annual Plan Issued (Includes All Active ARC Projects)
- Final Reports for completing projects
- Jan
- Accepted Annual Plan work begins/continues
Keynote Plenaries
Case Studies
Technical Sessions
Student Poster Competition

May 25-26, 2018 ARC Annual Program Review in Ann Arbor, Michigan
<table>
<thead>
<tr>
<th>Year</th>
<th>Members</th>
</tr>
</thead>
</table>
| 2010 | Dr. David E. Foster  
Dr. Karl Hedrick  
Dr. Mark Linne  
Dr. Raju Namburu  
Dr. Ahmed Shabana  
Dr. Ren Jye Yang  |
| 2011 | Dr. Stuart Daw  
Dr. David Foster  
Dr. Abhinandan Jain  
Mr. Robert Larsen  
Dr. Raju Namburu  
Mr. Paul Weal  
Dr. Ren-Jye Yang  |
| 2012 | Dr. Stuart Daw  
Dr. Thomas Doligalski  
Dr. Lino Guzzella  
Dr. Karl Hedrick  
Dr. Abhinandan Jain  
Dr. Raju Namburu  
Dr. Dan Negrut  
Dr. Harold Schock  |
| 2013 | Dr. Raju Namburu  
Dr. Chris Rahn  
Mr. Doug Rogers  
Dr. Wei Chen  
Mr. Robert Larsen  
Dr. Takeshi Abe  
Dr. Ping Liu  
Dr. Chuck Mueller  
Dr. Raju Namburu  |
| 2014 | Dr. Raju Namburu  
Dr. Chris Rahn  
Mr. Doug Rogers  
Dr. Wei Chen  
Mr. Robert Larsen  
Dr. Avoki Omekanda  |
| 2015 | Dr. Raju Namburu  
Dr. Chris Rahn  
Mr. Doug Rogers  
Dr. Wei Chen  
Mr. Robert Larsen  
Dr. Avoki Omekanda  |
| 2016 | Dr. Raju Namburu  
Dr. Chris Rahn  
Mr. Doug Rogers  
Dr. Wei Chen  
Mr. Robert Larsen  
Dr. Avoki Omekanda  |
## ERB Packet

### Information for 2017 External Review Board

#### Table of Contents:

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<th>Section</th>
<th>Page</th>
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<td>Schedule</td>
<td>p. 1-2</td>
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<tr>
<td>Poster Session Layout</td>
<td>p. 3</td>
</tr>
<tr>
<td>Poster Session Projects</td>
<td>p. 4</td>
</tr>
<tr>
<td>Technical Sessions</td>
<td>p. 5</td>
</tr>
</tbody>
</table>

### 2017

- **Dr. Mary Frecker**  
  Penn State
- **Mr. Bruce Geil**  
  US Army Research Lab.
- **Dr. Roberto Horowitz**  
  UC Berkeley
- **Dr. Robert Koch**  
  Naval Undersea Warfare Center
- **Dr. Kaleb McDowell**  
  US Army Research Lab.
- **Dr. Raju Namburu**  
  US Army Research Lab.
- **Dr. Gordon Parker**  
  Michigan Tech
- **Dr. Harold Schock**  
  Michigan State U.
### 23rd Annual Automotive Research Center Program Review – Day 1 Schedule

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:30</td>
<td>Check-in and breakfast</td>
</tr>
<tr>
<td>8:00</td>
<td>Welcome &amp; Opening Remarks – Prof. Steven Ceccio</td>
</tr>
<tr>
<td>8:15</td>
<td>Keynote—Dr. Todd Bjerke</td>
</tr>
<tr>
<td>8:45</td>
<td>Keynote—Mr. Craig Stephens</td>
</tr>
<tr>
<td>9:15</td>
<td>Keynote—Dr. Roberto Horowitz</td>
</tr>
<tr>
<td>9:45</td>
<td>Networking Break</td>
</tr>
<tr>
<td>10:30</td>
<td>Case Study 1</td>
</tr>
<tr>
<td>11:15</td>
<td>Group photo</td>
</tr>
<tr>
<td>11:30</td>
<td>Lunch</td>
</tr>
<tr>
<td>1:10</td>
<td>Technical Session 1</td>
</tr>
<tr>
<td>3:10 - 5:30</td>
<td>Poster Session, Lab Tours, and Networking</td>
</tr>
</tbody>
</table>
**Lurie Engineering Center**  
1221 Beal Ave  
Ann Arbor, MI 48109  
Johnson Rooms, 3rd Floor

**Chrysler Center**  
Chesebrough Auditorium  
1238 Murfin Ave  
Ann Arbor, MI 48109

---

### May 10th – Day 2  
**Chrysler Center**

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>7:30</td>
<td>Check-in and breakfast</td>
</tr>
<tr>
<td>8:00</td>
<td>Welcome – Prof. André Boehman</td>
</tr>
<tr>
<td>8:10</td>
<td>Keynote – Mr. Robert A. Gold</td>
</tr>
<tr>
<td>8:40</td>
<td>Case Study 2</td>
</tr>
<tr>
<td>9:25</td>
<td>Break</td>
</tr>
<tr>
<td>10:00</td>
<td>Technical Session 2</td>
</tr>
<tr>
<td>12:00 - 1:30</td>
<td>External Review Board meets to finalize reports</td>
</tr>
<tr>
<td>1:30 - 3:00</td>
<td>External Review Board debriefing with ARC Executive Committee</td>
</tr>
</tbody>
</table>

*Meet in Meeting Room for finalizing and debriefing*

*Project 5.A24 participating in case study 2. See also poster.  
See slide 5 for technical talks to evaluate.*
Venue: Gallery

Reviewers, below are areas suggested for your attention.

TA1 Dynamics and Control
Drs. Horowitz, Parker

TA2 Human Centered Modeling
Dr. McDowell

TA3 Structures & Materials
Drs. Frecker, Koch, Namburu

TA4 Fuels and Combustion Engines
Dr. Schock

TA4 Electrification and Thermal Management
Mr. Geil, Dr. Parker

TA5 Integration, Optimization & Robustness
Drs. Frecker, Namburu

* Indicates a planned new project but has not received funding at this time.
Reviews are waived.
<table>
<thead>
<tr>
<th>#</th>
<th>Poster Title</th>
<th>PI</th>
</tr>
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<tbody>
<tr>
<td>1.16</td>
<td>Flexible Multibody Dynamics Approach for Tire Dynamics Simulation</td>
<td>Sugiyama</td>
</tr>
<tr>
<td>1.17</td>
<td>Improving Mobility through Latency Compensation in Teleoperated Ground Vehicles</td>
<td>Ersal</td>
</tr>
<tr>
<td>1.18</td>
<td>Improving Efficiency and Mobility of Off-Road Connected Fleets via Route Preview and Cooperative Control</td>
<td>Vahidi</td>
</tr>
<tr>
<td>1.21*</td>
<td>Physics-Based Multiscale Continuum-Discrete Deformable Terrain Model for Off-Road Mobility Simulation</td>
<td>Sugiyama</td>
</tr>
<tr>
<td>1.A44</td>
<td>Modeling Human Performance in Operating Unmanned Ground Vehicles</td>
<td>Ersal</td>
</tr>
<tr>
<td>1.A47</td>
<td>Optimal Control, Pairing, and Scheduling for Manned-Unmanned Vehicles Teaming based on RoboTrust Algorithms</td>
<td>Wang, Wagner</td>
</tr>
<tr>
<td>1.A49</td>
<td>Fast numerical algorithms for robust, high-fidelity simulation of terramechanics</td>
<td>Veerapaneni</td>
</tr>
<tr>
<td>1.A51</td>
<td>Advanced Hazard Avoidance in Autonomous Ground Vehicles</td>
<td>Stein</td>
</tr>
<tr>
<td>2.8</td>
<td>Haptic Shared Control for Teleoperated Ground Vehicles</td>
<td>Gillespie</td>
</tr>
<tr>
<td>2.9*</td>
<td>Modeling Bi-directional Trust in Semi-Autonomy for Improved System Performance</td>
<td>Tilbury, Robert</td>
</tr>
<tr>
<td>2.A36</td>
<td>Airbag Benefit in Occupant Crash Protection for Tactical Vehicles</td>
<td>Hu</td>
</tr>
<tr>
<td>3.7</td>
<td>Advanced Models for Fatigue Life Predictions of Hybrid Electric Vehicle Batteries</td>
<td>Epureanu</td>
</tr>
<tr>
<td>3.10</td>
<td>Confidence-Based Reliability Assessment Accounting for Insufficient Input and Output Experimental Data</td>
<td>Choi</td>
</tr>
<tr>
<td>3.11</td>
<td>Effects of reduced order model of viscous damping on energy absorption</td>
<td>Vlahopoulos</td>
</tr>
<tr>
<td>3.12*</td>
<td>Novel Hybrid Electric Powertrains Enabled by Models of Electro-Magnetic-Structural Dynamics</td>
<td>Epureanu, Hofmann</td>
</tr>
<tr>
<td>3.13*</td>
<td>Testing and Analysis of Tank Track Pad Meta-Material</td>
<td>Fadel</td>
</tr>
</tbody>
</table>

* Indicates a planned new project but has not received funding at this time. Reviews are waived.
### May 9

#### 1A: Autonomy

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

<table>
<thead>
<tr>
<th>Time</th>
<th>Presenter</th>
<th>Title</th>
<th>Session Leads: Dr. Peter Schihl, Mr. Eric Gingrich</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:10 - 1:40</td>
<td>Dr. Ardalan Vahidi</td>
<td>Improving Energy Efficiency and Mobility of Off-Road Connected Fleets via Route Preview and Cooperative Control</td>
<td></td>
</tr>
<tr>
<td>1:40 - 2:10</td>
<td>Dr. Kira Barton</td>
<td>Enhanced Multi-Robot Reconnaissance Through Terrain-Based Energy Prediction</td>
<td></td>
</tr>
<tr>
<td>2:10 - 2:40</td>
<td>Dr. Dimitra Panagou</td>
<td>SQUAD: Situational Awareness and Sustained Survivability through Man/Unmanned Teaming</td>
<td></td>
</tr>
<tr>
<td>2:40 - 3:10</td>
<td>Dr. Hiroyuki Sugiyama</td>
<td>Flexible Multibody Dynamics Approach for Tire Dynamics Simulation</td>
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</table>

#### 1B: Fuels & Engines

<table>
<thead>
<tr>
<th>Time</th>
<th>Presenter</th>
<th>Title</th>
<th>Session Leads: Dr. Peter Schihl, Mr. Eric Gingrich</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.18</td>
<td>PI: Dr. André Boehman</td>
<td>Bulk Modulus of Compressibility Measurements of Conventional and Alternative Military Fuels</td>
<td></td>
</tr>
<tr>
<td>4.21</td>
<td>PI: Dr. Jason Martz</td>
<td>Simulations for JP-8 Mechanism Optimization and Validation</td>
<td></td>
</tr>
<tr>
<td>4.25</td>
<td>PI: Dr. Angela Violi</td>
<td>Combustion Chemistry of Jet Fuels: From Atomistic Simulations to Mechanism Development</td>
<td></td>
</tr>
<tr>
<td>4.26</td>
<td>PI: Dr. Marcis Jansons</td>
<td>Thermal Barrier Coatings for Reduction of Cooling Loads in Military Vehicles</td>
<td></td>
</tr>
</tbody>
</table>

### May 10

#### 2A: Electrification, Thermal Management

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

<table>
<thead>
<tr>
<th>Time</th>
<th>Presenter</th>
<th>Title</th>
<th>Session Leads: Dr. David Lamb, Dr. Ravi Thyagarajan, Mr. Victor Paul</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:00 - 10:30</td>
<td>Dr. Anna Stefanopoulou</td>
<td>Optimal Warm-up of Lithium-Ion Battery from Sub-Zero Temperatures</td>
<td></td>
</tr>
<tr>
<td>10:30 - 11:00</td>
<td>Dr. Jason Siegel</td>
<td>Robotic Range Extender: Power and Energy Management for a Hybrid Powertrain with Quantized Power Sources</td>
<td></td>
</tr>
<tr>
<td>11:00 - 11:30</td>
<td>Dr. John Wagner</td>
<td>Thermal Bus with Passive and Active Cooling Strategies for Vehicle Thermal Management</td>
<td></td>
</tr>
<tr>
<td>11:30 - 12:00</td>
<td>Dr. Heath Hofmann</td>
<td>Computationally-Efficient Heat Convection Model for Electric Machines</td>
<td></td>
</tr>
</tbody>
</table>

#### 2B: Structures, Reliability, Safety

<table>
<thead>
<tr>
<th>Time</th>
<th>Presenter</th>
<th>Title</th>
<th>Session Leads: Dr. David Lamb, Dr. Ravi Thyagarajan, Mr. Victor Paul</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.10</td>
<td>PI: Dr. K. K. Choi</td>
<td>Confidence-based Reliability Assessment Accounting for Both Parameter Uncertainty and Model Bias for Insufficient Input and Output Experimental Data</td>
<td></td>
</tr>
<tr>
<td>3.11</td>
<td>PI: Dr. Nick Vlahopoulos</td>
<td>Modeling of Materials for the Design of Lightweight and Resilient Vehicle Structures</td>
<td></td>
</tr>
<tr>
<td>5.10</td>
<td>PI: Dr. Zissimos Mourelatos</td>
<td>Reliability Assessment and Warranty Forecasting of Repairable System</td>
<td></td>
</tr>
<tr>
<td>2.4</td>
<td>PI: Dr. Jingwen Hu</td>
<td>Restraint System Optimization for Occupant Protection in Tactical Vehicles: Full Vehicle Crash Tests</td>
<td></td>
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</tbody>
</table>
### Individual Project Review Questionnaire

**Project # and Title:**  
*PI:*

<table>
<thead>
<tr>
<th></th>
<th>Excellent</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Relevance to ARC Mission</td>
<td>☐ ☐ ☐ ☐ ☐</td>
<td>☐</td>
</tr>
<tr>
<td>2. Technical Quality</td>
<td>☐ ☐ ☐ ☐ ☐</td>
<td>☐</td>
</tr>
<tr>
<td>3. Comments/Suggestions</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[Box for comments/suggestions]
Sample of Project Review / PI Response

### External Review Board Recommendations and Researcher Feedback

<table>
<thead>
<tr>
<th>Relevance to ARC Mission</th>
<th>Excellent</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technical Quality Comments/Suggestions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nice approach of using metamaterial design approach to improve material design in tire rubber peel design.</td>
</tr>
<tr>
<td>The project team made reasonable simplification to identify the optimal solution to match with desired property.</td>
</tr>
<tr>
<td>The project team is encouraged to further explore the solution using topology optimization and refine their design objectives to match with the failure modes and analysis. Gathering test results would be helpful too.</td>
</tr>
</tbody>
</table>

In response to ERB recommendations, this approach has a broader impact than just Army tank track pads. With the push for lightweight metals, this type of approach may prove essential for any location where vibrations are an issue such as at bushings, at engine mounts, etc. Test will be conducted in house in the coming year with the designs optimized.
2017 Annual Plan:
45 Submissions
• 10 New projects approved
• 15 Continuations approved
• 54 Graduated (PhD)
• 21 Graduated (MS)
• 147 Journal articles
• 163 Conference proceedings

• 10 Best paper awards
• 15 Book chapters

• 27 University faculty awards
• 24 External faculty research and educational awards

• 14 Presidents, chairs, and executive board members of technical societies
• 17 Fellows of technical societies (ASME, IEEE, SAE, etc)
• Dawn Tilbury appointed Assistant Director of NSF Directorate for Engineering

• Anna Stefanopoulou and Jason Siegel receives 2016 Control Systems Technology Award

• Georges Fadel wins ASME Design Automation Award

• Simona Onori receives NSF CAREER award Integrated Modeling and Control of Aftertreatment Systems for Clean, Efficient and High-Performing Gasoline Direct Injection Engines
• Anna Stefanopoulou presented keynote lectures at
  • 3rd Conference on Powertrain Modelling and Control
  • 2nd Symposium for Combustion Control, and
  • 2016 Advances in Automotive Control - 8th IFAC.

• Dawn Tilbury had invited plenary talks at
  • 2017 IFAC World Congress,
  • 2016 IEEE Conference on Automation Science and Engineering (CASE).

• Levi Thompson interviewed in PBS Nova special “Search for the Super Battery”.

• Angela Violi gave a keynote talk “Challenges in soot modeling” at the 2017 Computational Chemistry for Pollutant Mitigation.

• Brent Gillespie gave a keynote presentation at the First International Conference on Robotics and Automation for Humanitarian Applications (RAHA 2016).

• Jingwen Hu was a keynote speaker at the 2016 China Conference of Automotive Safety Technology.

• Tulga Ersal gave an invited talk at the 2016 IEEE Robotics and Automation Meeting.
1. Delay compensation for high-speed teleoperation
PI: Ersal
Project 1.17
2. Operator modeling to enable M&S
PI: Ersal
Project 1.A44
3. Haptic feedback for improved decision making
PI: Gillespie
Project 2.A38
4. Human-automation interaction for increased safety and speed
PI: Tilbury
Project 2.7
5. High-speed obstacle avoidance in unknown, unstructured environments
PI: Stein
Project 1.15
Project 1.A51
PI: Brent Gillespie  
Sponsor: Toyota Research Institute  
Project: TRI – It’s the transitions: Supporting Shared Control in Vehicle Steering Across Routine and Off-Nominal Conditions  
Duration: 01/01/2017 - 12/31/2019  

PI: Dawn Tilbury  
Sponsor: Toyota Research Institute  
Project: TRI - Trust, Control and Risk in Autonomous Vehicles  
Duration: 01/01/2017 - 12/31/2017  

PI: Tulga Ersal  
Sponsor: Toyota Research Institute  
Project: TRI - Collision Avoidance Guardian at the Dynamic Limits of Handling  
Duration: 01/01/2017 - 12/31/2017  

TRI funding ~$750,000
Michigan’s Robotics program offers Master’s and PhD degrees, #2 in the nation.

The **Robotics Institute** will be housed in a $75M, 140,000 SQF facility with a three-story fly zone for autonomous aerial vehicles, an outdoor obstacle course for walking ‘bots, and high-bay garage space for self-driving cars, among other features. The new building will be named the Ford Motor Company Robotics Building. 9/15/2016

**Mobility Transformation Center**’s [Mcity](#), with simulated urban and suburban roads and supporting infrastructure covering 18 acres. It provides a safe and controlled environment for testing and discovering autonomous and connected vehicle technologies. 7/15/2015

**American Center for Mobility** (Willow Run Airport) 335-acre site dedicated to mobility research and validation at the federal and commercial level

**Toyota Research Institute** (TRI) will provide an initial $22M over four years for collaborations with U-M faculty in the areas of enhanced driving safety, partner robotics and indoor mobility, autonomous driving and student learning and diversity. 8/10/2016
Current ARC Projects in Autonomous and Connected Vehicles

**Inter-system Concepts**

- Intelligent Decisions in Uncertain Terrains, PI: Barton
- Distributed Coordination and Coverage Control, PI: Panagou
- Connected Fleets and Route Preview, PI: Vahidi
- Trusted Manned-Unmanned Vehicles Teaming, PI: Wang

**Intra-system Concepts**

- Vehicle-Dynamics-Conscious Real-Time Hazard Avoidance, PI: Stein
- Latency Compensation in Teleoperated Vehicles, PI: Ersal
- Teleoperation User Modeling to Maximize Performance, PI: Tilbury
- Haptic Feedback for Decision Making, PI: Gillespie
2013 Embedding Energy Intelligence in Robotic Mobility

Tulga Ersal, Huei Peng, Dawn Tilbury, Ella Atkins, Jason Siegel, Anna Stefanopoulou, Galip Ulsoy, Judy Jin, Johann Borenstein, et al

The Research
Coverage planning with energy constraints; battery management with thermal and electrical constraints; efficient terramechanics modeling; mission energy prediction leveraging prior knowledge

The Results
- Mission failures due to energy limitations prevented
- Safety problems due to battery overheating prevented
- Framework transferred to TARDEC


Annual Case Studies
Connected Vehicles Connected Laboratories

Shared Autonomy
Modular Vehicle Fleets


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**2009 Internet-Distributed Hardware-in-the-Loop Simulation for Cyber-Enabled Concurrent Powertrain Systems Engineering**

Tulga Ersal, Zoran Filipi, Brent Gillespie, Jeffrey L. Stein, Dennis Assanis, et al.

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**The Research**
An event-based communication framework; networked hardware- and human-in-the-loop experiments; 4 different drivers, 2 different courses; an analysis of variation based approach for evaluating networked integration fidelity

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**The Results**
- A new methodology for geographically dispersed concurrent systems engineering
- Stable and high-fidelity integration of UM’s engine and TARDEC’s ride motion simulator setups

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2012 Remote Control of Vehicle Power across Networked Labs

Tulga Ersal, Jason Siegel, Anna Stefanopoulou, Brent Gillespie, Jeffrey L. Stein, Zoran Filipi, et al.

The Results
- 70+% improvement in the fidelity of the networked simulation
- Experimental validation of the new power management strategy: 5.6% improvement in fuel economy; 28% reduction in soot; 25% reduction in battery aging

The Research
- A novel Model Predictive Control based hybrid power management strategy; a coupling error based metric to evaluate networked integration fidelity; an Iterative Learning Control based approach to improve fidelity

1. **Create a connected testbed** with multiple engines in the loop (Ersal-NSF)

2. **Adaptive cruise control in convoy (platoons)** optimize the speed and separation of vehicles accounting for road inclines and traffic (Ersal-TARDEC-ARC).

3. **Driver advisory** for pulse and glide versus smoothing (Anna- EPA).

4. **After-treatment control** manage the engine thermal and urea dosing with trip and load preview (Anna- NSF+Ford).

5. **Engine-Aftertreatment** coordination and real time optimization (Anna – DDC –DOE-Supertruck II)

6. **Stretching start-stop** for medium-heavy duty vehicles (Anna- N/A)

7. **Blending & charge sustaining** in Light-Duty hybrids with trip preview (Anna- ARPA-E-NEXTCAR-SWRI+Toyota)
**Tech Transfer through Education**

**TARDEC**  Igor Baseski, Eric Blash, Matthew Castanier, Brooke Haueisen, Laura Hoogterp-Decker, James Mainero, Monica Majcher, Annette G. Skowronska-Kurec, Amandeep Singh, David Skalny, William Smith

**Military**  Dean Rotenberg, Aberden Proving Grounds; Chad Jagmin, HHC, 10th Mountain Division; Wesley Williamson, CERDEC, RDECOM, Army Materiel Command; Keegan R. Kinkade, USMC; Joseph Hays, U.S. Naval Research Lab.; Scott Lathrop, A.Prof. West Point;

**National Labs**  Jeongwoo Han, Krista Hawthorne, Dongil Kang, Argonne; Ian Darnell, Ed Kokko, Lawrence Livermore; Rachael Bis, NASA Glenn; Andreas Malikopoulos, Jason Pries, Oak Ridge;

**Defense Related**  Sam Homsy, Navistar Defense; Samuel Wintermute, Soar Technology; Richard Lee, Technomics;


**Academia Outside U.S.**  Miles Chan, National Cheng Kung U., Taiwan; Mircea Teodorescu, Cranfield U., UK; Yoojeong Noh, Keimyung University, Korea; M. Salah, Hashemite U., Jordan;

**Automotive Industry**  Hakan Yilmaz, Gerald Fernandes, Sun Ung Kim, Bosch; Scott Fiveland, Michael Smith, Kaushik D. Asharya, Sukhbir Khaira, Anubhav Sinha, Xiaping Cai, Caterpillar; Mohannad Al-Hakeem, Kaushik Acharya, Chrysler; Mukul Girotra, Burit Kiritungsi, Eduardo Pinto, Anshul Sharma, Cummins; Inderpal Singh, Daimler/DDC; Jiechao Liu, Delphi; Vasilios Tsourapas, Joe Lin, Eaton; Swapnil Bodele, Ziliang Zheng, Fiat Chrysler; Lurun Zhong, Aditya Kastury, Anamitra Bhattacharyya, Mufaddel Dahodwala, Vinay Nagaraju, FEV; Weiran Jiang, Ben Pence, Chang Qi, Chandrasekharan Jayakumar, Ford; Yusuf M. Poonaivala, Ki-young Yi, General Electric; Michael Alexander, Andreas Malikopoulos, Jin Ming Liu, Young Jae Kim, Matthew Ma, Jinghong Liang, Daniel Wehrwein, Heather Chemistruck, Patricia Laskowsky, General Motors; Ramon Kuczer, GKN Driveline Americas; Geunsoo Ryu, Hyundai; Akshar Tandon, Nianfeng Wan, IAV; Sampath Dangeti, Mando Corp; Geunsoo Ryu, Kyung Won Suh, Bin Wu, Mercedes-Benz Hybrid; Jasmeet Singh, Donghong Jia, Jagdish Nargunde, Navistar; Jonathan Hagen, PACCAR; Shahrav Taheri, Pratt & Miller; Seneca Schepmann, Proterra; Dong Wook Lee, Samsung Motors; Ercan Dede, John Kim, Brandon Moore, Toyota; Yuanzhan Wange, ZF Group;

**Software**  Todd McDevitt, Ansys; Zachery Satterfield, Corvid Tech.; Jun Dong, LMS Intl.; James Allison, Mathworks; Jinzhong Wang, MSC Software; Hong Dong, Santosh Tiwari, Vanderplaats R&D;

**Other Industry**  Yan Zhao, Air Products & Chemicals; Jun Zhou, Alstom Power; Sujay Kawale, Altair; Buzz McCain, Ballard Power Systems; Xiaoyan Yan, Chevron; Josh Titus, EDAK; Josh Langfeld, Energetics Tech Ctr; Yogita Pai, NetXert; Hector Perez, Northrop Grumman; Liang Zhao, Schlumberger; Harshit Sarin, Stoneridge;
Thank you for your attention.