Systems Engineering Activities at Clemson University’s International Center for Automotive Research (CU-ICAR) and Wind Turbine Drivetrain Testing Facility

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Public /Private Partnerships Focused on Meeting Industry’s Needs

- Full Scale Testing / Applied Research
- Multidisciplinary Education (MS & PhD)/ Workforce Development
- Collaboration with Industrial Partners and Government
- Protection of Customer Intellectual Property
Changing Focus of Automotive Engineering
<table>
<thead>
<tr>
<th>Professor</th>
<th>Field</th>
<th>Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Johnell Brooks</td>
<td>Phys</td>
<td>Abnormal Human-Automotive Interaction and aging driver studies</td>
</tr>
<tr>
<td>Pierluigi Pisu</td>
<td>EE</td>
<td>Develop a real-time in-vehicle energy management control strategy</td>
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<tr>
<td>David Smith</td>
<td>CE</td>
<td>Rapid prototyping of vehicle cockpit for human-technology interaction</td>
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<tr>
<td>Paul Venhovens</td>
<td>ME</td>
<td>Deep Orange</td>
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</tbody>
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Grid power management

Communication network protocol
Collect info on power demand/priority

Traffic management
Deep Orange: Innovations in Automotive Engineering Education

Dr. Paul Venhovens
Background: Mechanical Engineering
Deep Orange: A New Teaching Paradigm

Market Analyses
Start: Day 1

Target Validation
Graduation

Validation
End: Day 712

System Design
Day 193

New prototype vehicle releases from two-year Development Cycles

An integral feature of our MS/PhD Research & Education Program

System Integration
Day 523
A Neutral Platform for Academic, Industry and Government Collaboration
Innovations that will be Integrated, Proven and Showcased
Collaboration with the Art Center College of Design, Pasadena, CA
Business model based on proven CU-ICAR model

- Multidisciplinary
- Full Scale Testing
- Applied Research
- Graduate Education

Automotive Engineering  Energy Systems

+ Zucker Family Graduate Education Center
Objective: Accelerate the development of new technology into the wind market to reduce the cost of energy delivered.

Mission: Provide (1) High Value, (2) High Quality and (3) Cost Competitive testing and validation services to industry.

Establish long term partnerships with industry for work force development, research and education.
Rendering vs. Actual

- 7.5 MW gearbox on test stand
Rendering vs. Actual

- Load application unit housing being assembled
- Notice people in both images
Dynamic Systems Modeling

Mechanical

Electrical

Fluid

Thermal
Control Loop Concept

Reference Signal
(Where you want to be)

Outputs
(Where you are)

Controller

Inputs
(How you alter your current state or position)

Plant
Integrated Test Rig Model

- **Motor Controller**
  - Desired Speed → Motor Controller
  - Speed Command

- **LAU Controller**
  - Desired Load Vector → LAU Controller
  - Measured Load Vector

- **Torque Controller & Measurement**
  - Desired Torque → Torque Controller
  - Torque Command
  - Torque Measurement

- **Grid Simulator**
  - Power Recirculation
  - Utility Supply

**Flowchart Details**:
- Desired Speed
- Speed Command
- Measured Speed
- Load Vector Command
- Desired Load Vector
- Utility Supply
Modeling Objectives

1. Characterize the accuracy of the load application unit and determine how non-torque loading affects the test bench and unit under test.
2. Develop both linear and non-linear models for the test bench and unit under test that capture time domain behavior (transient and steady state) and frequency domain behavior (vibration and limit cycle).
3. Simulate and evaluate automated behavior such as automated test sequence execution and purposely tripping automatic safety systems.

High Priority    Middle Priority    Low Priority

1. Characterize the stiffness of the test bench and the unit under test.
2. Analyze individual control system performance as well as the interaction between the various different controllers.
3. Model the various hydraulic systems including the hydraulic pumps, the load application unit's force actuation pistons, the hydraulic slide bearings, and the lubrication systems.
4. Quantify the resultant load vectors acting on the bearings throughout the test rig and unit under test.
5. Evaluate and improve model fidelity.

1. Develop nacelle models specific to customer test articles as opposed to generic or general purpose nacelle models.
2. Seek an in depth understand of how the high speed shaft behaves and affects the components it is attached to.
3. Simulate instantaneous power loss and heat rejection during operation.
Model Development Strategy

• Always use the best modeling environment for the particular task
• Fully exploit data exchange or co-simulation capabilities
Virtual Operation Visualization

- Simultaneous Multi-body and control system simulations

Resultant Force on main shaft

Vantage Point
Analysis Approach Comparison

Analysis Approach

- Pure Simulation
- Hardware in the Loop
- Test Bench
- Field Testing
- Farm Operation

Cost

- $  
- $$  
- $$$  
- $$$$  
- $$$$$$$

Validity

- Less  
- More

Duration

- Short  
- Long
Hardware in the Loop

Desired Speed → Motor Controller → Measured Speed

Speed Command
Hardware in the Loop

Desired Speed

Measured Speed

Speed Command

[Diagram of hardware in the loop, showing desired speed, measured speed, and speed command]
Hardware in the Loop

- Control Hardware is now “in the loop.”
- Cost effective...
- Faster...
- Safer...
- And more flexible than using actual equipment
- Low risk (actual) equipment exercised with simulation of high risk equipment
Comprehensive and Virtual Test Operation

Input Test Vector

Motor Controller

Output Test Vector

LAU Controller

Grid Simulator

Utility Supply

Torque Controller
Thank you