Model Based Controls
Moving Beyond Software Domain
MAC 2015

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Cummins Data Classification Public Information
Agenda

- Introduction to Cummins
- Objectives Of Model Based Development
- Concepts to accelerate MBD Capability
- Summary
Cummins Broad Product Range

- engine platforms covering 60 to 4200 horsepower, world wide market
Effective Integration of complex systems requires MBD Integration

**Powerplant Level Simulation Framework**

- **Aftertreatment (AT)**
- **Base Engine**
- **Electronic Controls**
- **Combustion**
- **Fuel System**
- **Waste Heat Recovery**
- **Air-handling system**

**0D, 1D, 2D, 3D Co-Simulation**
Application Diversity

- Truck
- Bus
- On-Highway
- RV
- Emergency
- Hybrid
- Agriculture
- Marine
- Power Gen
- Construction
- Defense
- Mining
- Railroad
- Oil & Gas

Operator characteristics
Powertrain components
Environment characteristics
Duty/drive cycles

Data Classification: Public
Control System Development Problem Statement

- For complex, highly engineered/regulated products:
  - “Traditional” embedded software centric development methods do not provide:
    - Sufficient means to manage increase system complexity
    - Integration with OEM Modeling/Analysis

- For Cummins MBD is our strategy for improvement
  - Integration of the physical modeling is the challenge
What increases the calibration effort?

MBD capability growth takes continual process improvement and investment.

Data Classification: Public
Accelerating MBD, Reducing Development Cost

- Software workflow improvements
  - Reduction in engineering SW builds by 80%
  - Integration of Control MIL with HIL, work flows ($xM/yr)
    - But more importantly, improved test coverage

- Calibration Workflow
  - MIL Transient Engine Calibration
    » **50% Test Cell Reduction**
Accelerating MBD, Improved Product

- **Product Robustness**
  - Ability to simulate system
    - Off nominal operation
    - Subsystem/component uncertainty
  - Goals
    - Reduced warranty cost
    - Improved product performance
  - Controls Architecture Selection

"Intellectuals solve problems, geniuses prevent them."

– Albert Einstein

Modeled Variation in EGR Flow
Integrated MBD Workflow
MBD Technology Workflow

Sub Sys. Models

Simple Architecture Models

Detailed Performance Models

Controller Model with COM

System Models

1D

2D

3D

Future Shift

Project MBD

Advanced Engineering

Product Development

MBD Technology

System Models

Maps

Data Classification: Public
Model Capability Continuum

- **Low Fidelity**
  - High Speed
  - Non-predictive

- **Mid Fidelity**
  - Order Reduced
  - Transfer Function

- **Hi Fidelity**
  - Predictive Capability

Project Progression:
- **Software Test**
- **Controls**
- **Engine Design**

Data Classification: Public
Modeling in Adv. Control Design - MPC

Plant Model

Simulation project

Linearization

Torque Desired

Speed

Control Design

Cummins MBC Design tool (Matlab)

Control Deployment

EC Code Gen

Control verification in rapid prototyping or ECM (HIL, Test cell, or Vehicle)

Model in the Loop Simulation (control verification and initial calibration)
Data Management and Visualization

- TBytes of data! Tools needed make rapid, effective, assessments of results.

Data Classification: Public
Model Fidelity and Simplification

- Required model fidelity?
  - Dynamic fidelity needs more rigor
  - Also: Need to understand the predictive capability

- Simplification
  - Easy migration to reduced order models is required.
  - Still need frequency domain capability
Plant Model Configuration Management

- Models need the same CM rigor as the embedded software.
  - Model State / capability/source needs to be clear
  - Local copies, tuning adaptations make model validity difficult to access.
  - Model revisions should include validation, fidelity documentation.

Source MAB 2014
Co-sim Compatibility

- Sharing of plant and controller models is becoming increasingly important.
- Solution: FMI standard or integrated tools (Simulink/Simscape)

Software Integration

<table>
<thead>
<tr>
<th>Versions</th>
<th>Time scales</th>
<th>Multi-fidelity</th>
<th>Multi-processors</th>
<th>Solvers</th>
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Simulink Machine Model
- Detailed Engine Model
- Controls
  - Simulink

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Data Classification: Public
Summary / Recommendations

Leadership MBD Vision
MBD Work Flow Integration
Simulation Technology Plan
Model CM Plan
Fidelity Measurement Standards
Computational Capacity

Increasing Importance
Cost$^{-1}$
Thank you for your Attention