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
Powerplant Level Simulation Framework

Effective Integration of complex systems requires MBD Integration

Aftertreatment (AT)

Base Engine

Electronic Controls

Combustion

Fuel System

Air-handling system

Waste Heat Recovery

0D, 1D, 2D, 3D Co-Simulation

Data Classification: Public
Application Diversity

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Operator characteristics

Power train components

Environment characteristics

Duty/drive cycles

Common Integration Tools & Methods

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
Cummins MBD (Controls) History

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

Advanced Engineering

Project MBD

Data Classification: Public
Model Capability Continuum

- Low Fidelity: High Speed, Non-predictive
- Mid Fidelity: Order Reduced, Transfer Function
- Hi Fidelity: Predictive Capability

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

Simulation project

Plant Model

Linearization
\[ \dot{x} = Ax + Bu \]
\[ \dot{y} = Cx + Du \]

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.
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)
Summary / Recommendations

Leadership MBD Vision
MBD Work Flow Integration
Simulation Technology Plan
Model CM Plan
Fidelity Measurement Standards
Computational Capacity
Thank you for your Attention