Model Based Controls

Moving Beyond Software Domain
MAC 2015

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May 12th, 2015

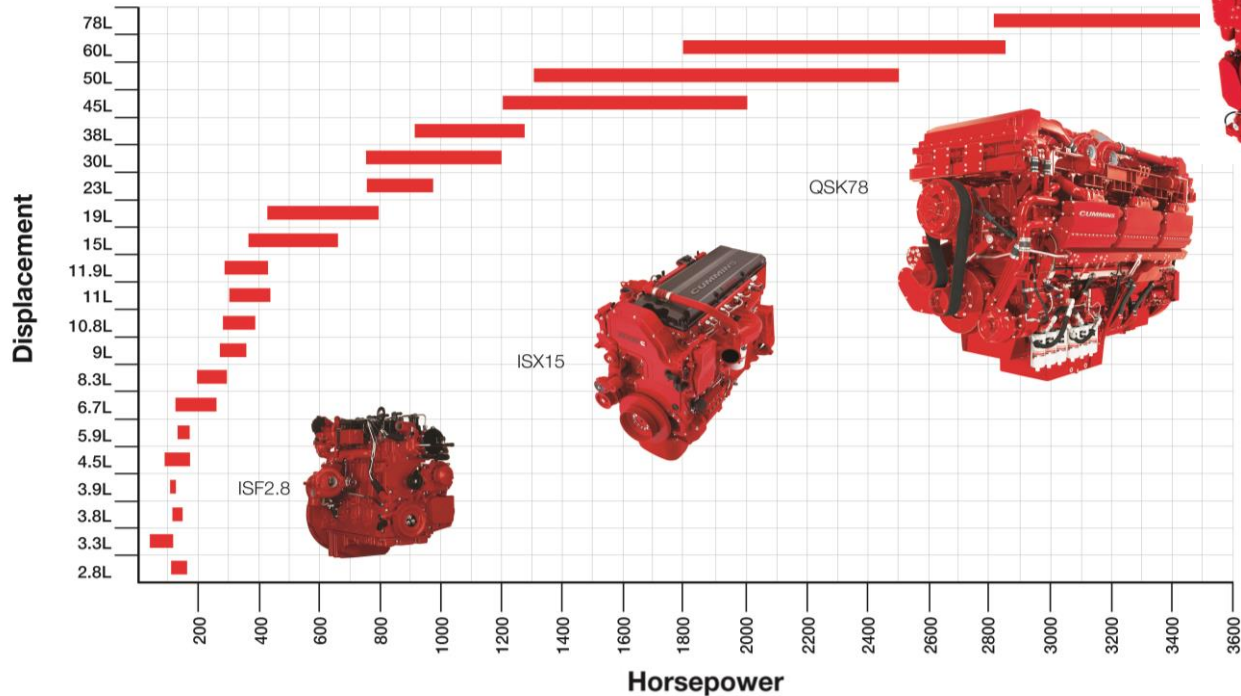Cummins Data Classification Public Information

Agenda

- **Introduction to Cummins**

- **Objectives Of Model Based Development**

- **Concepts to accelerate MBD Capability**

- **Summary**

Cummins Broad Product Range

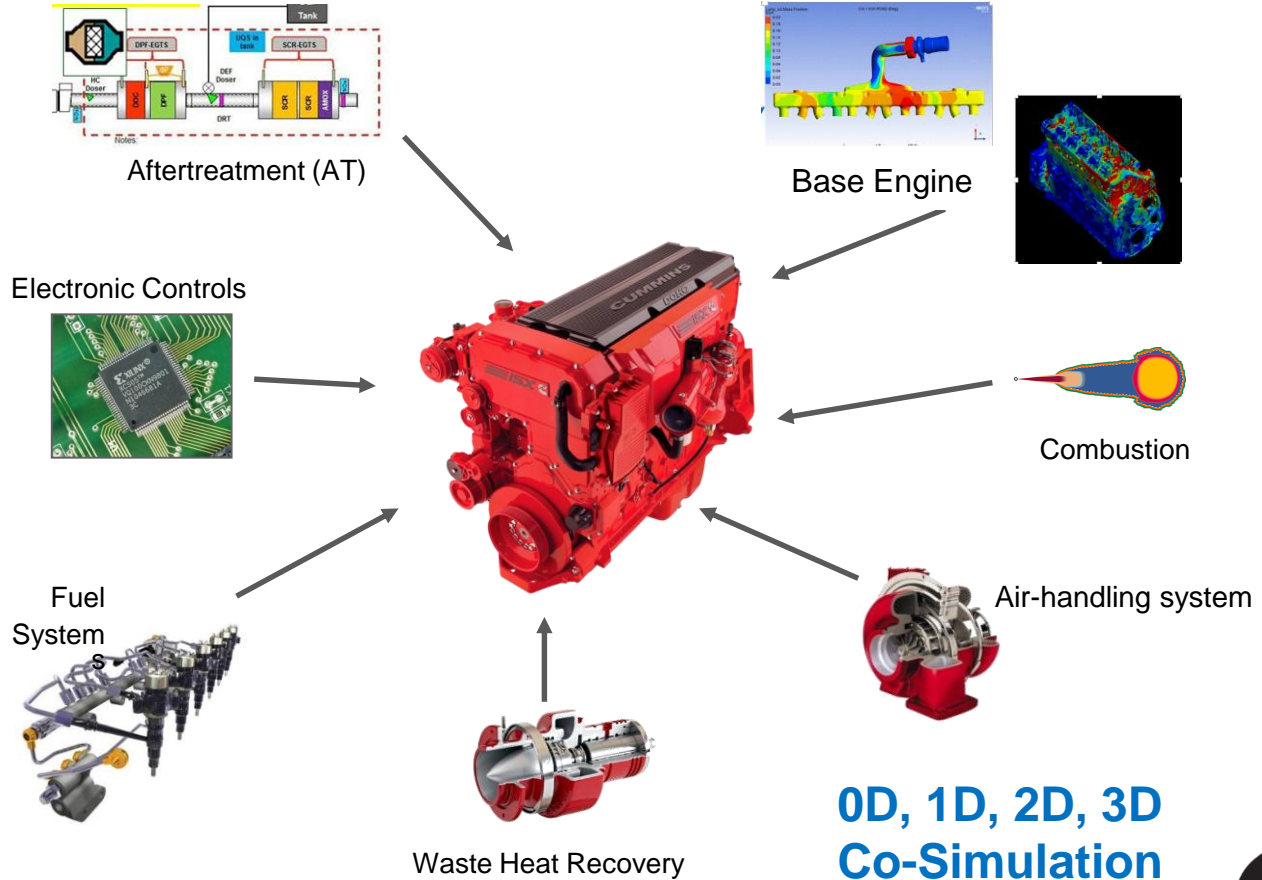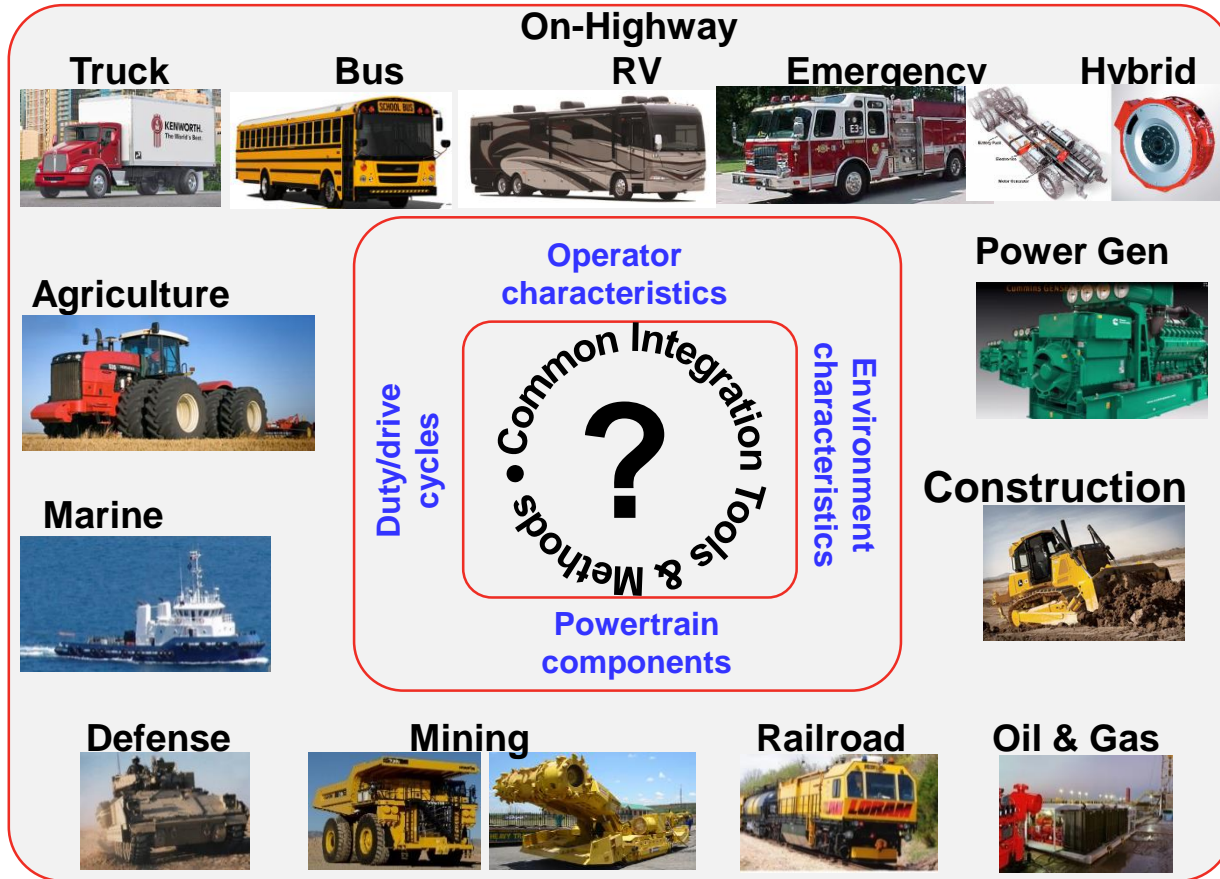- engine platforms covering 60 to 4200 horsepower, world wide market

Powerplant Level Simulation Framework

Effective Integration of complex systems requires MBD <u>Integration</u>

Aftertreatment (AT)

Base Engine

Electronic Controls

Combustion

Fuel Systems

Air-handling system

Waste Heat Recovery

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

Application Diversity

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

Common Integration Tools & Methods — ?
- Operator characteristics
- Environment characteristics
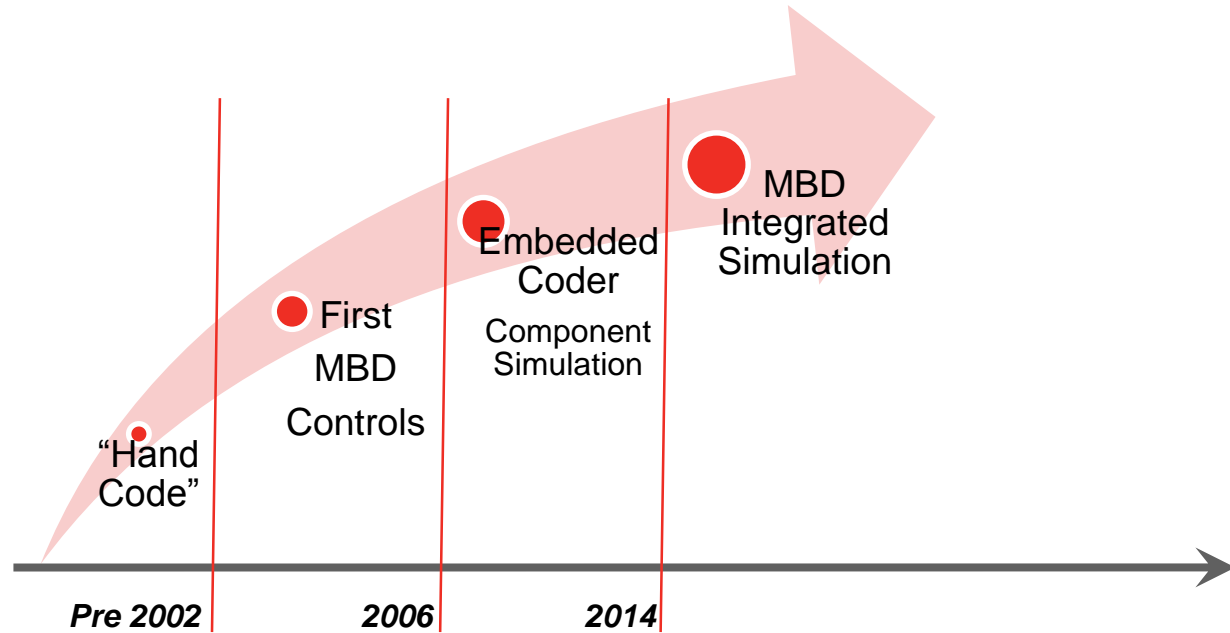- Powertrain components
- Duty/drive cycles

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

"Hand Code"

First MBD Controls

Embedded Coder
Component Simulation

MBD Integrated Simulation

Pre 2002   *2006*   *2014*

MBD capability growth takes continual process improvement and Investment

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*

MIL

HIL
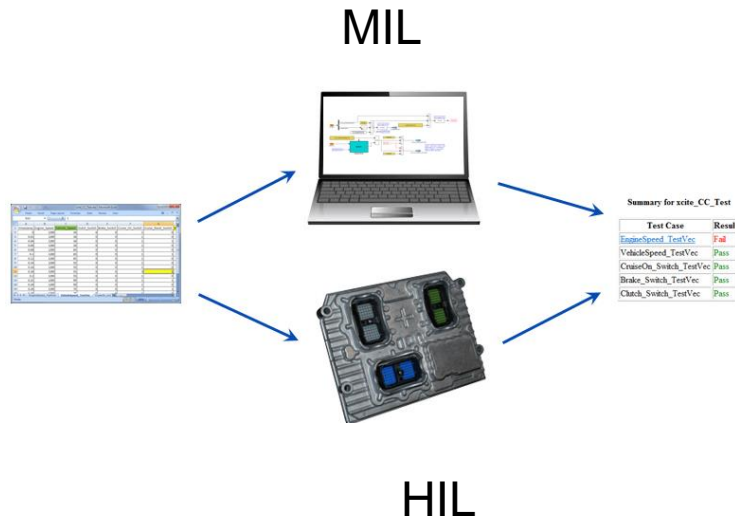
Accelerating MBD, Improved Product
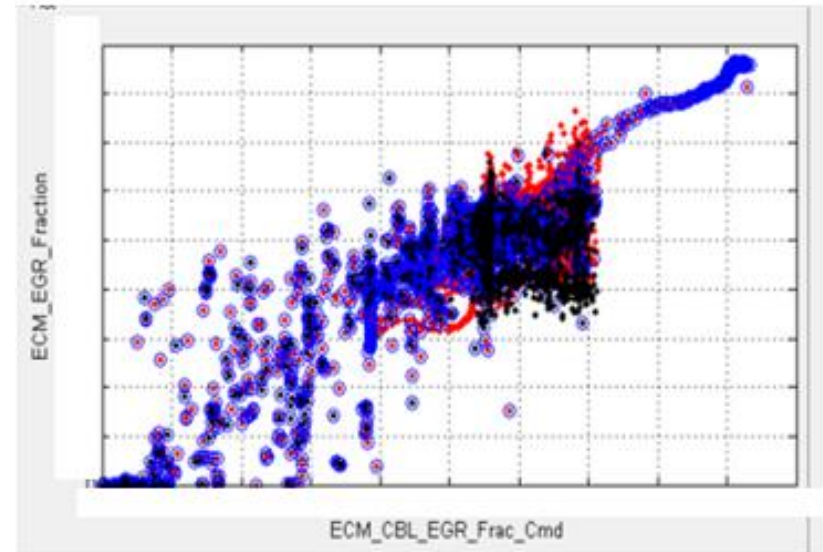
- **Product Robustness**

  – Ability to simulate system

    • Off nominal operation

    • Subsystem/component uncertainty

  – Goals

    • Reduced warranty cost

    • Improved product performance

  – Controls Architecture Selection

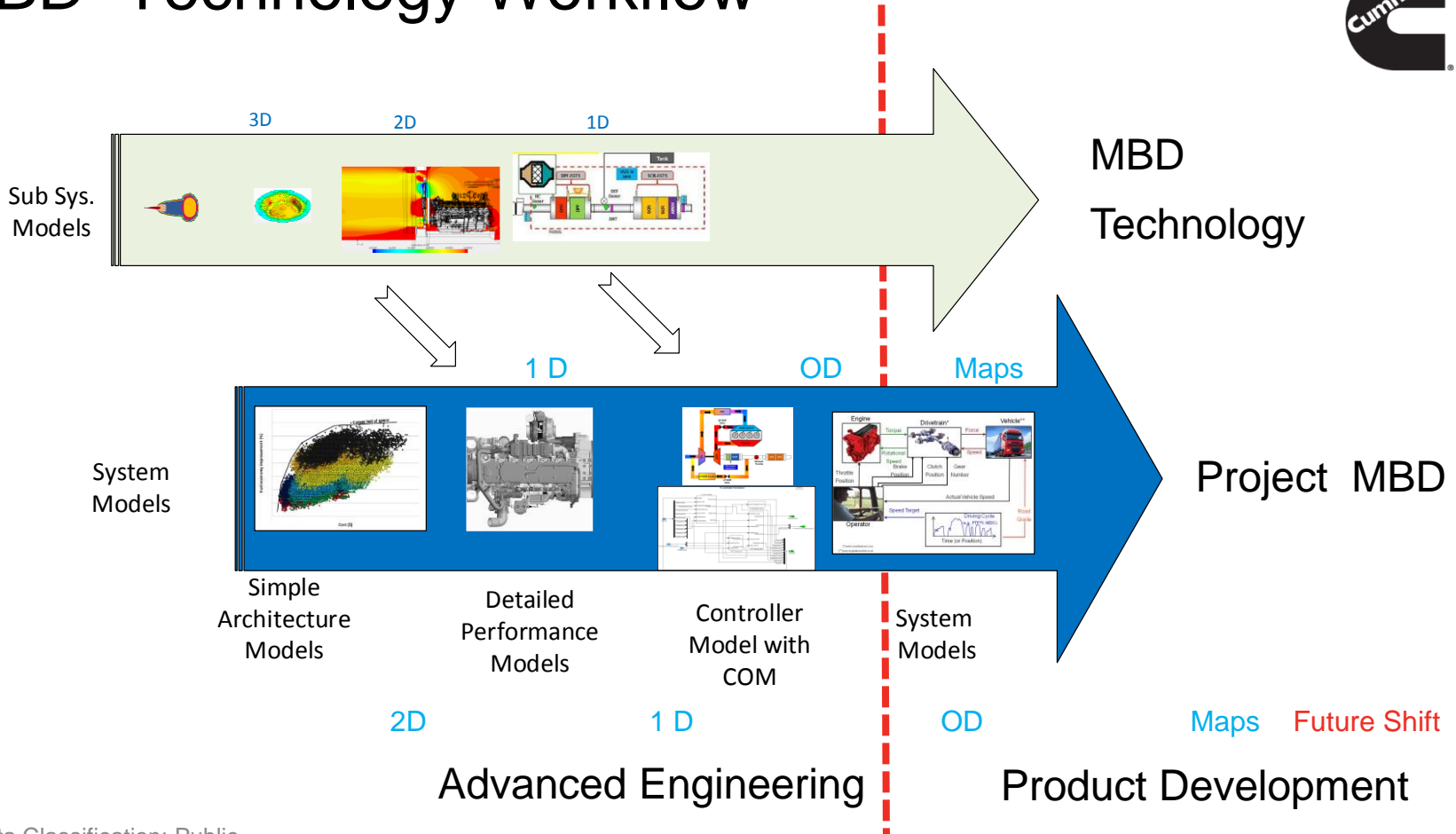"Intellectuals solve problems, geniuses prevent them.".

–Albert Einstein
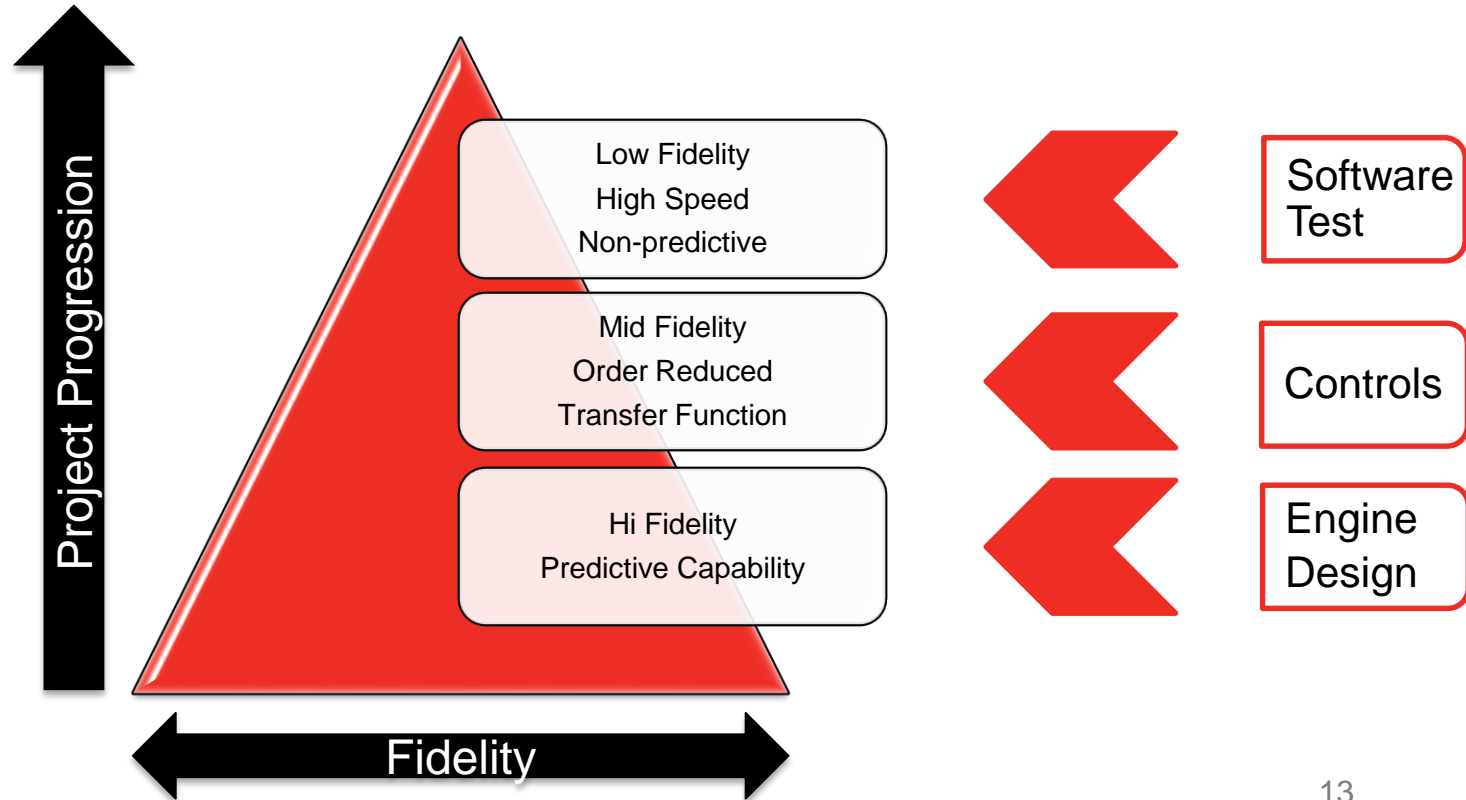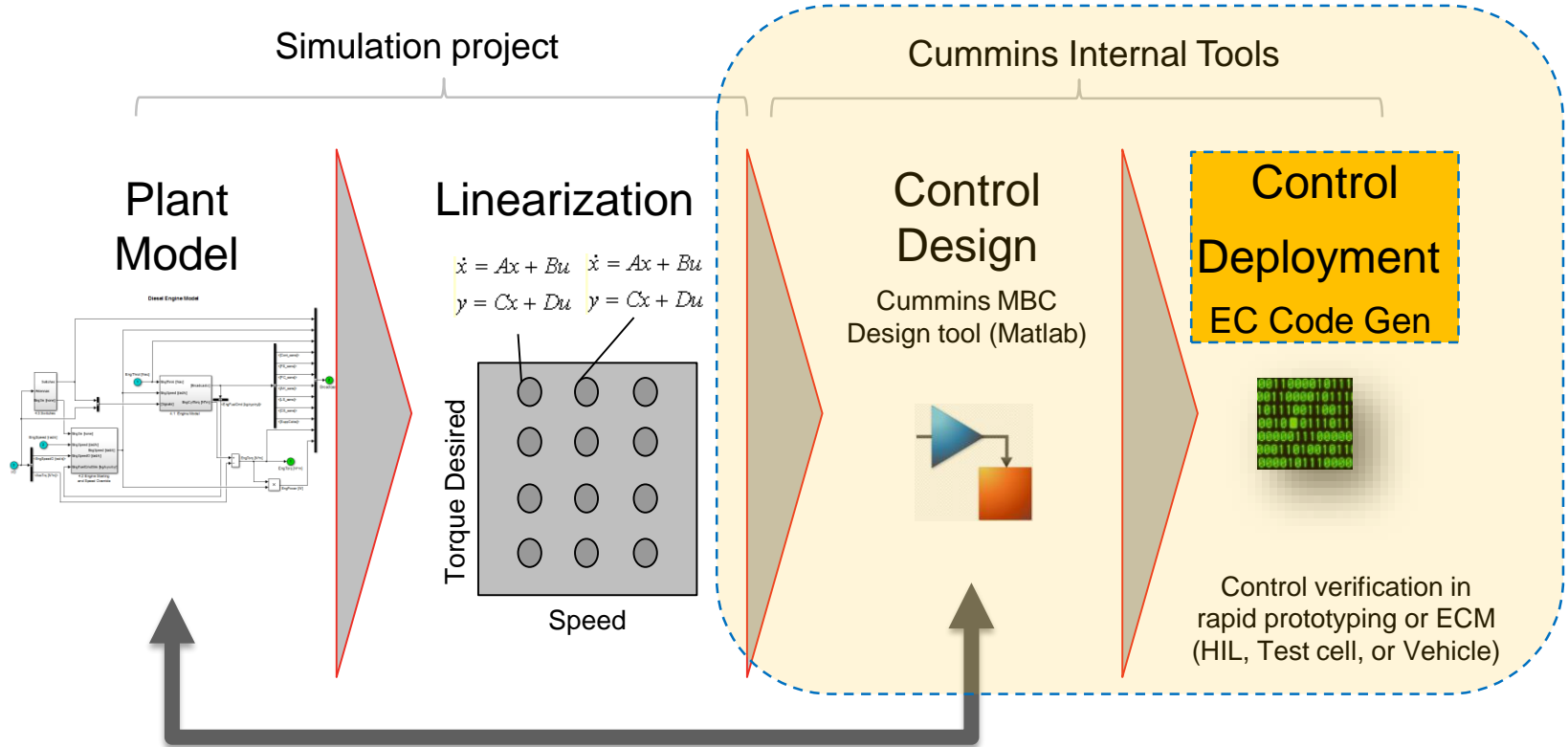
Modeled Variation in EGR Flow

ECM_EGR_Fraction

ECM_CBL_EGR_Frac_Cmd

Integrated MBD Workflow

MBD Technology Workflow

3D   2D   1D

Sub Sys. Models

MBD Technology

1 D   OD   Maps

System Models

Project MBD

Simple Architecture Models

Detailed Performance Models

Controller Model with COM

System Models

2D   1 D   OD   Maps   Future Shift

Advanced Engineering   Product Development

Data Classification: Public

Model Capability Continuum

Modeling in Adv. Control Design - MPC

Simulation project

Cummins Internal Tools

Plant Model

Linearization

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

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

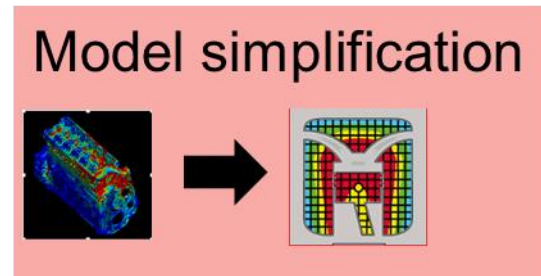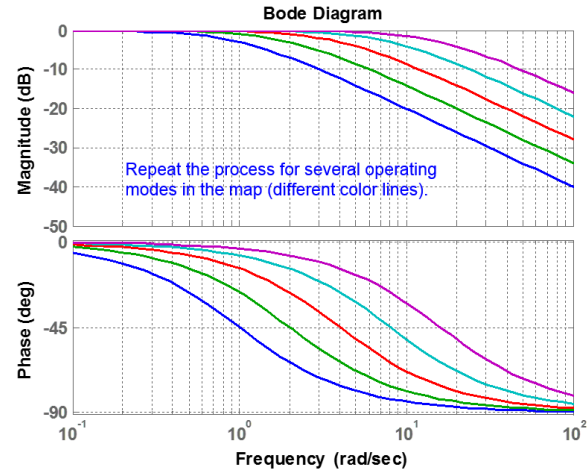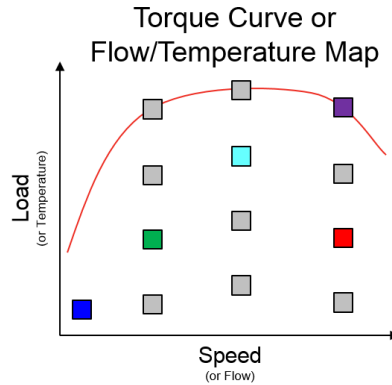- TBytes of data! Tools needed make rapid, effective, assessments of results.

Controller Error Distribution
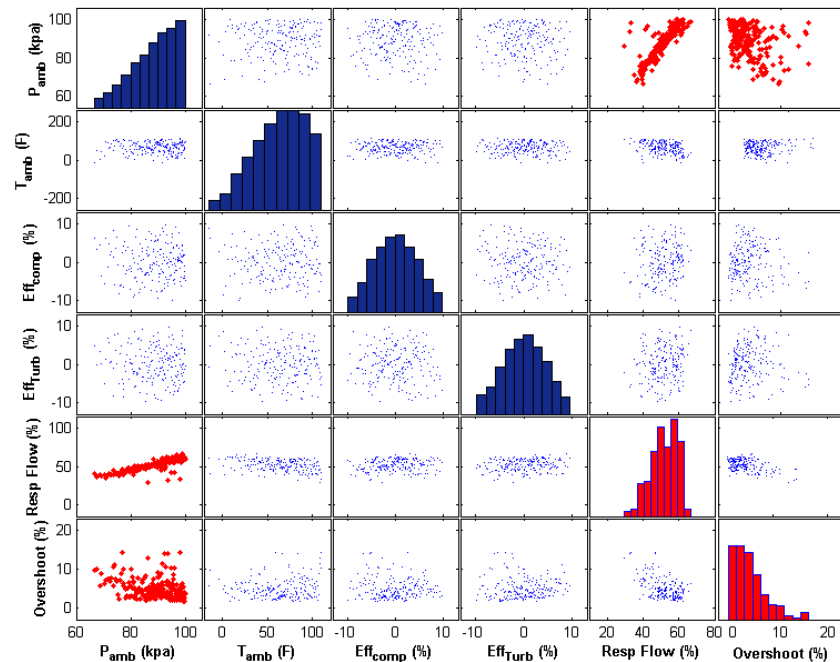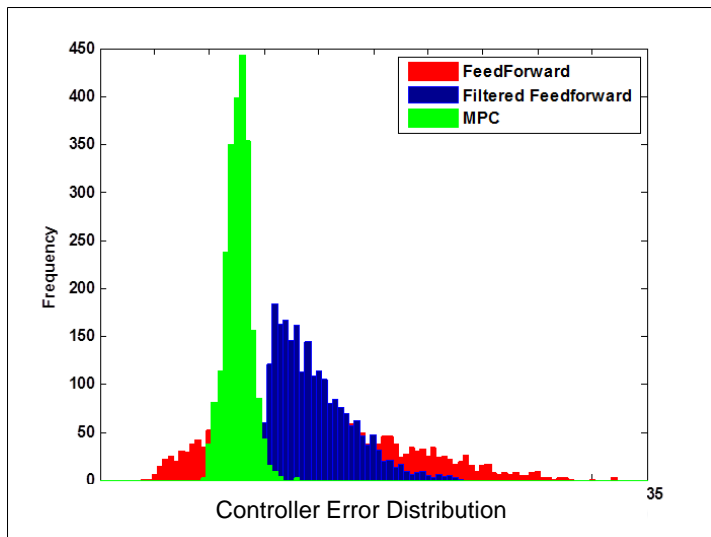
Model Fidelity and Simplification

- 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

Torque Curve or Flow/Temperature Map

Bode Diagram

Repeat the process for several operating modes in the map (different color lines).

Model simplification

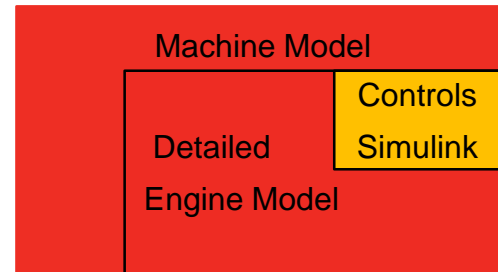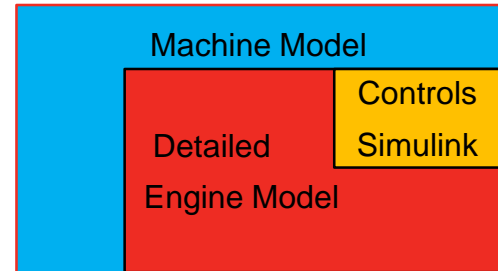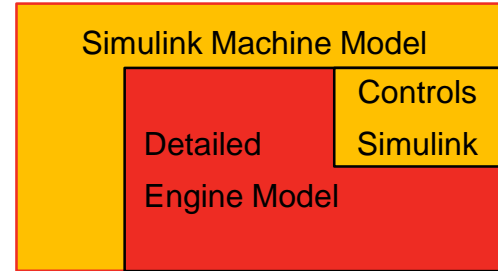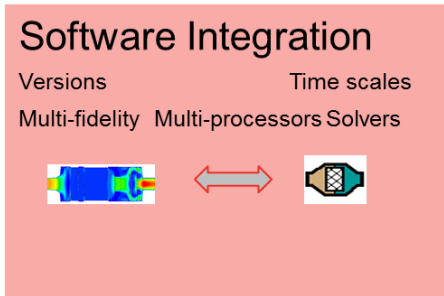# Plant Model Configuration Management

- **Models need the same CM rigor as the embedded software.**

  – Model State / capability/ source needs to be clear

  – Local copies, tuning adaptions make model validity difficult to access.

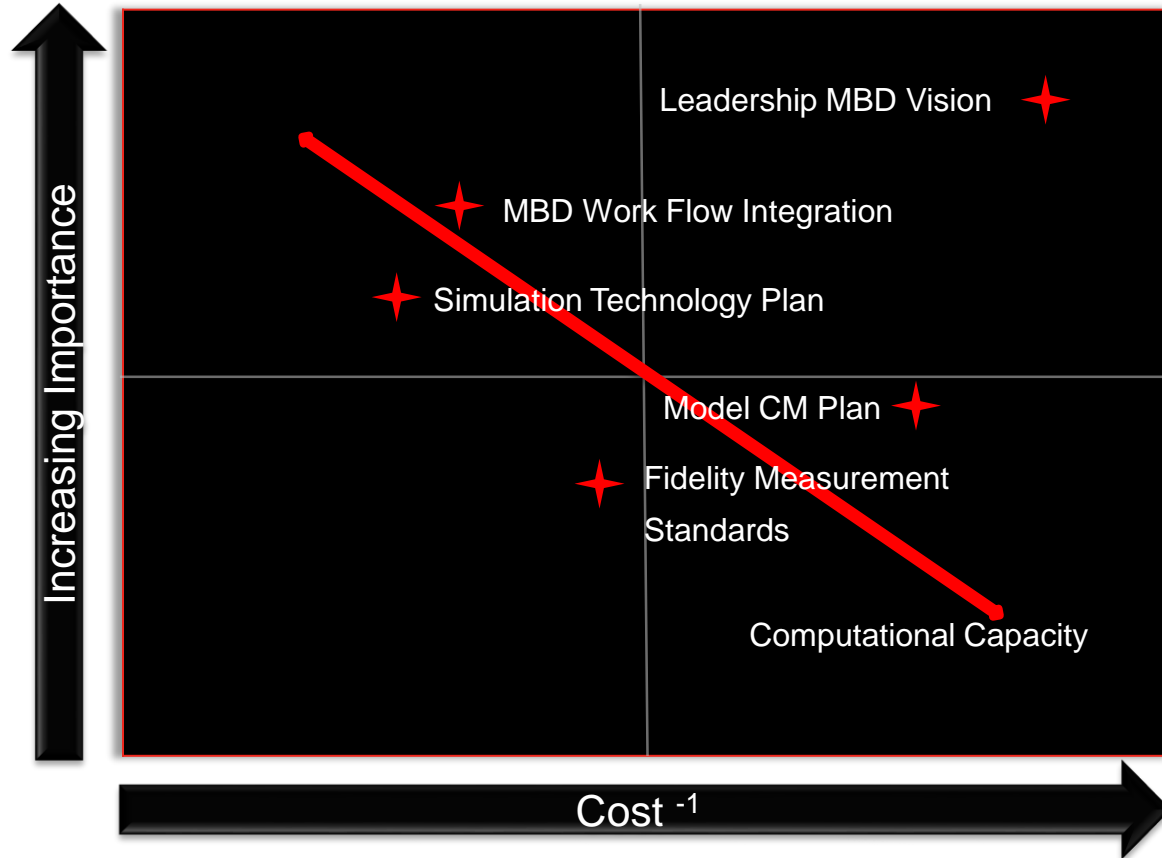 – Model revisions should include validation, fidelity documentation.
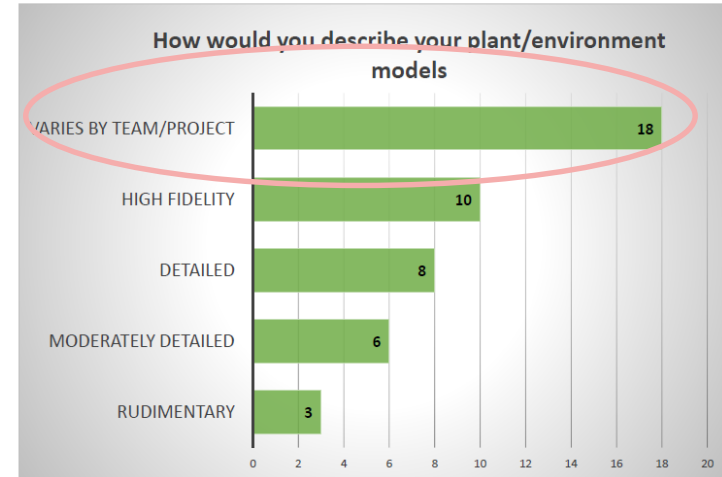
Source MAB 2014

Co-sim Compatibility

- Sharing of plant and controller models is becoming increasingly important.

- Solution: FMI standard Or Integrated tools (Simulink/Simscape)

Software Integration

Versions   Time scales

Multi-fidelity Multi-processors Solvers

Simulink Machine Model

Detailed

Controls

Simulink

Engine Model

Machine Model

Detailed

Controls

Simulink

Engine Model

Machine Model

Detailed

Controls

Simulink

Engine Model

Summary / Recommendations

Thank you for your Attention