

Model Based Controls

Moving Beyond Software Domain
MAC 2015

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Cummins Data Classification Public Information





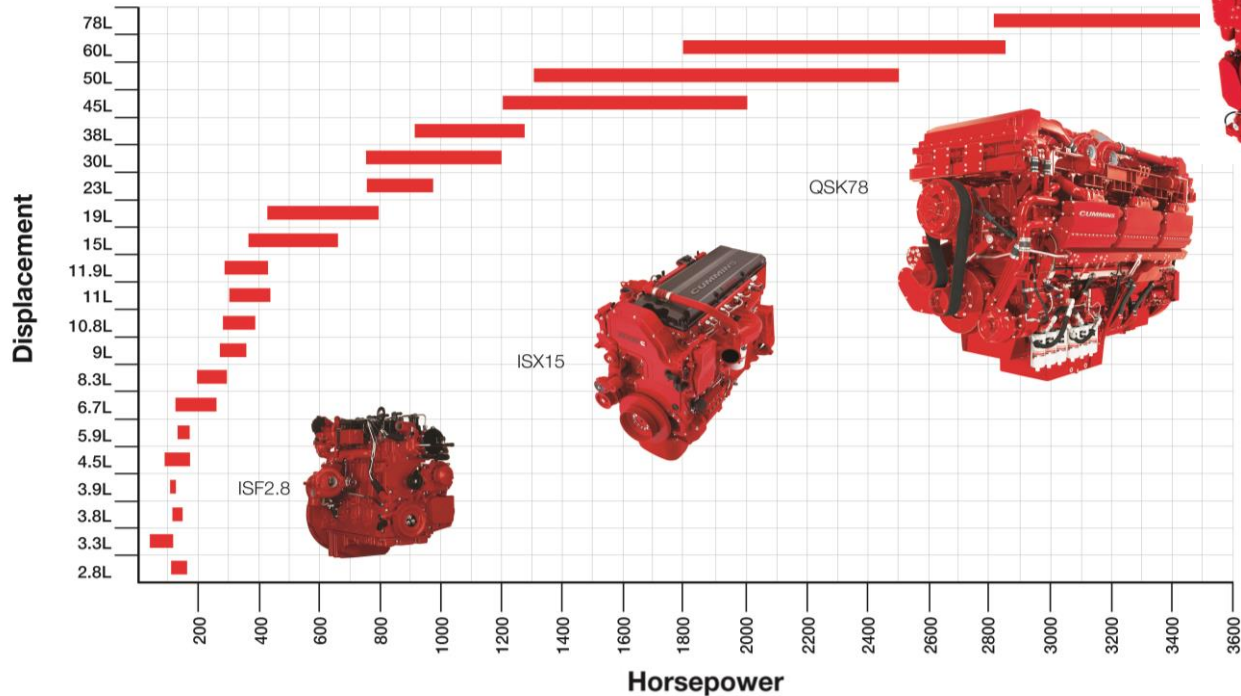
Agenda

- **Introduction to Cummins**
- **Objectives Of Model Based Development**
- **Concepts to accelerate MBD Capability**
- **Summary**

Cummins Broad Product Range



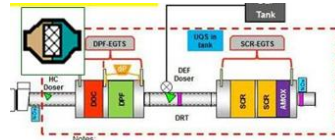
- engine platforms covering 60 to 4200 horsepower, world wide market



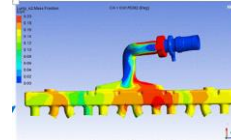
More Power.

Powerplant Level Simulation Framework

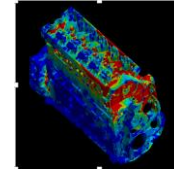
Effective Integration
of complex systems
requires MBD
Integration



Aftertreatment (AT)



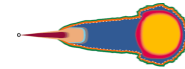
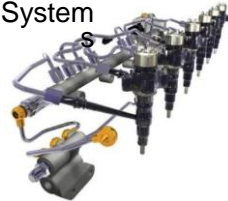
Base Engine



Electronic Controls



Fuel System



Combustion

Air-handling system



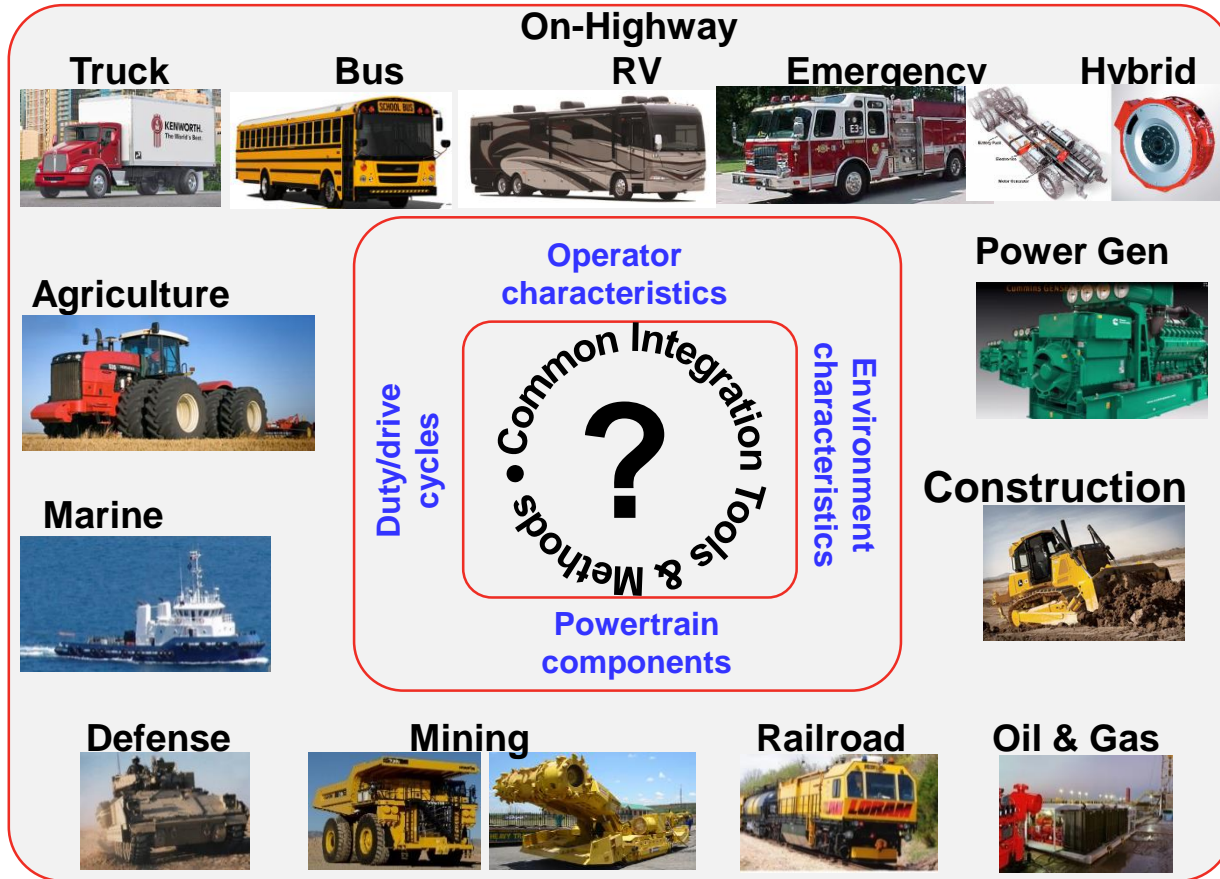
Waste Heat Recovery



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



Application Diversity



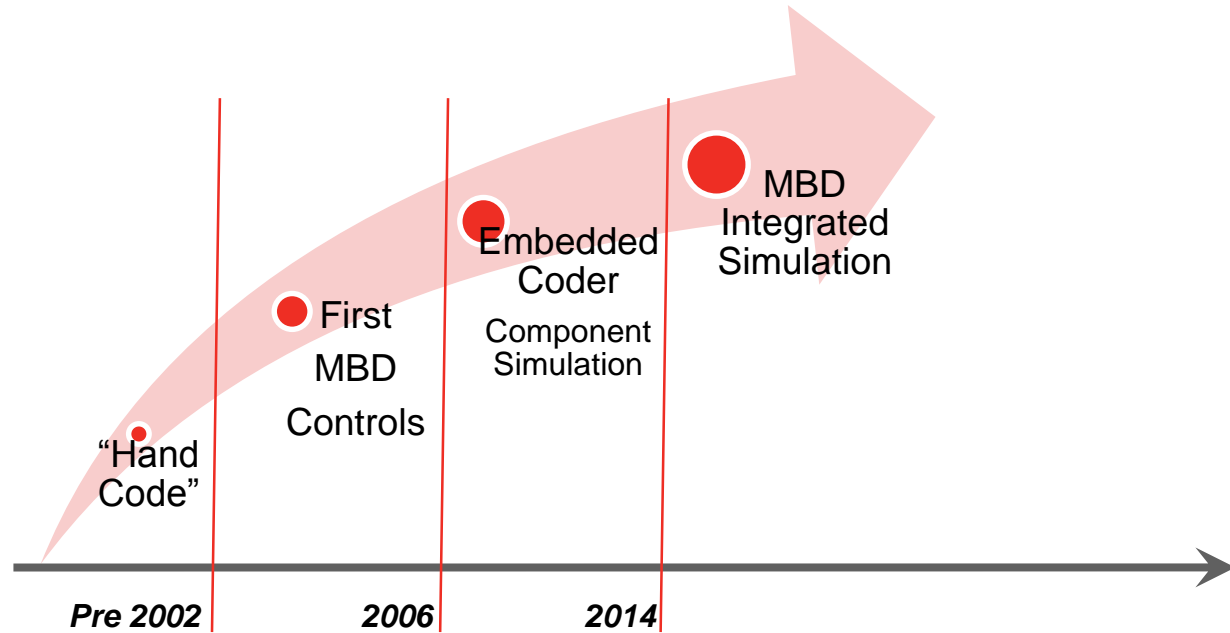
Control System Development Problem Statement



- 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

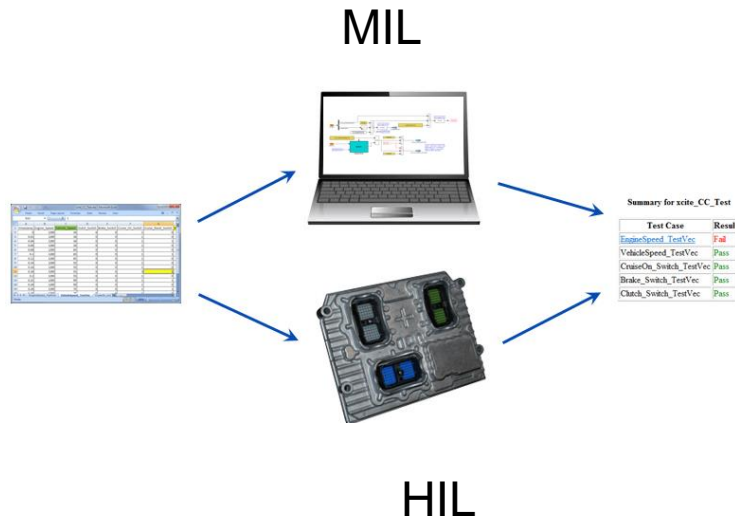
Accelerating MBD, Reducing Development Cost

– 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



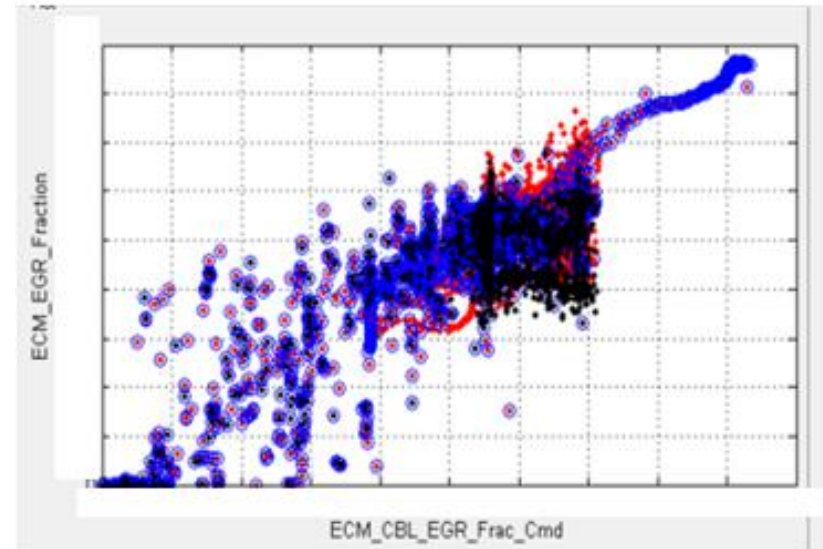
■ Product Robustness

- 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

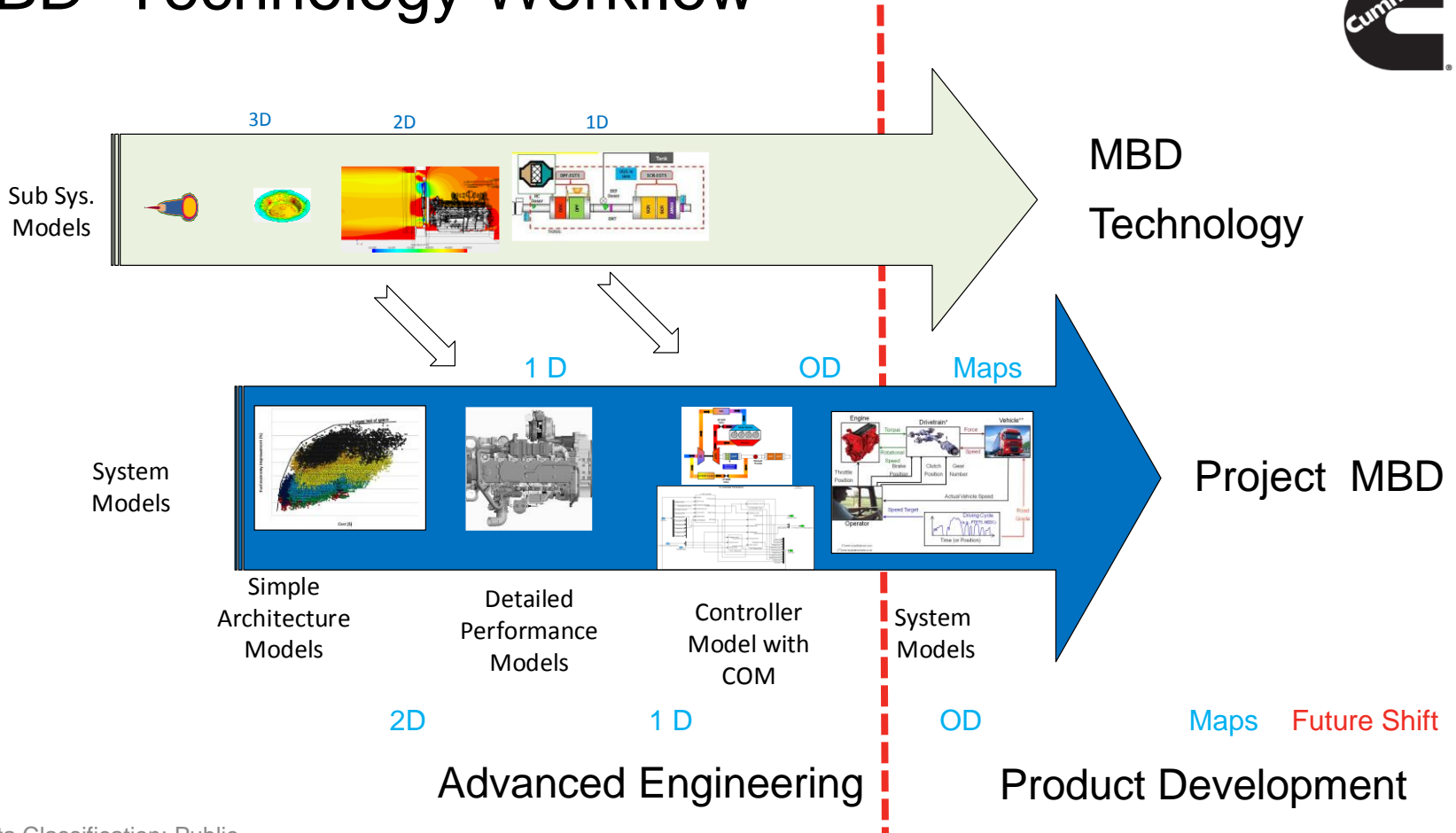
Modeled Variation in EGR Flow



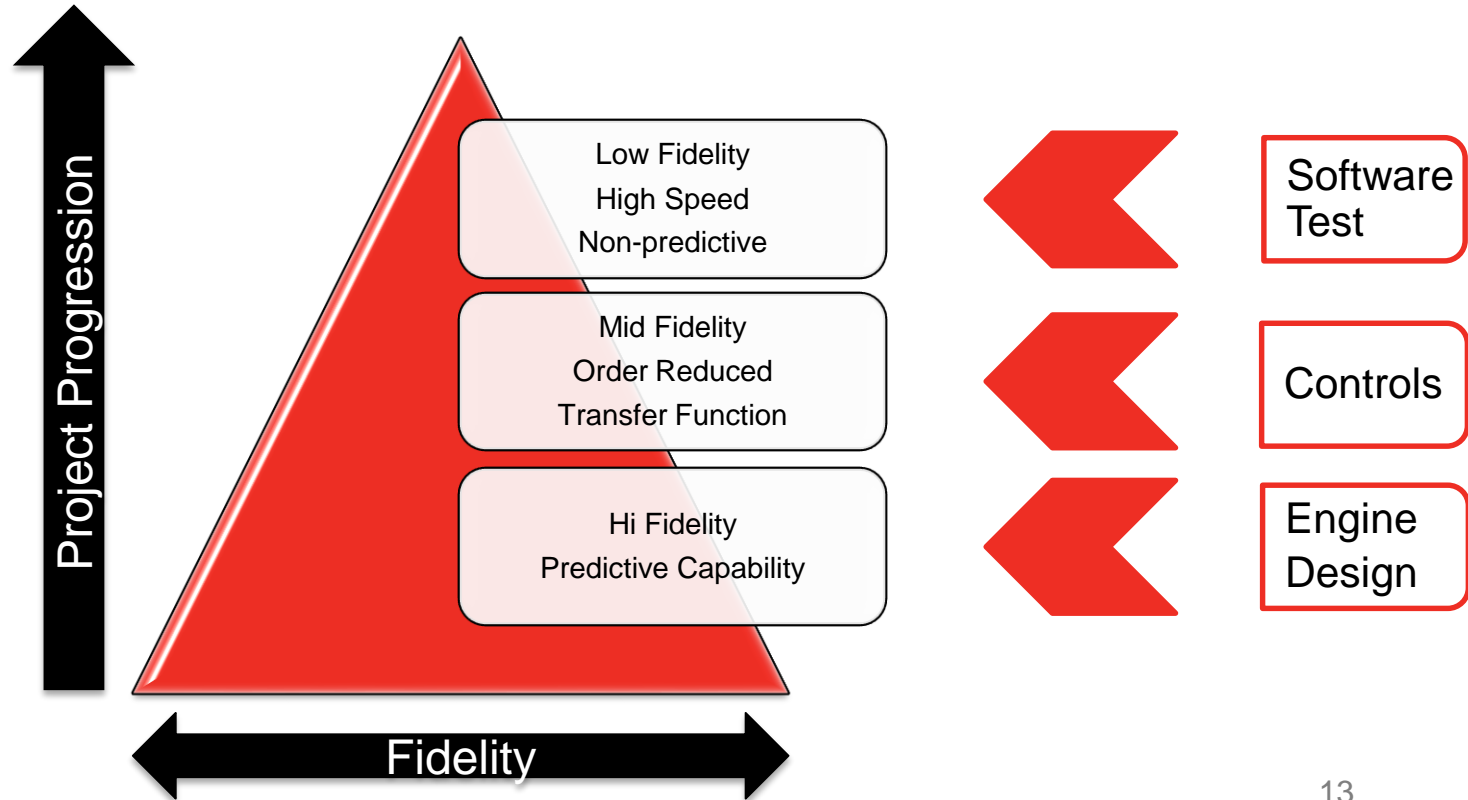


Integrated MBD Workflow

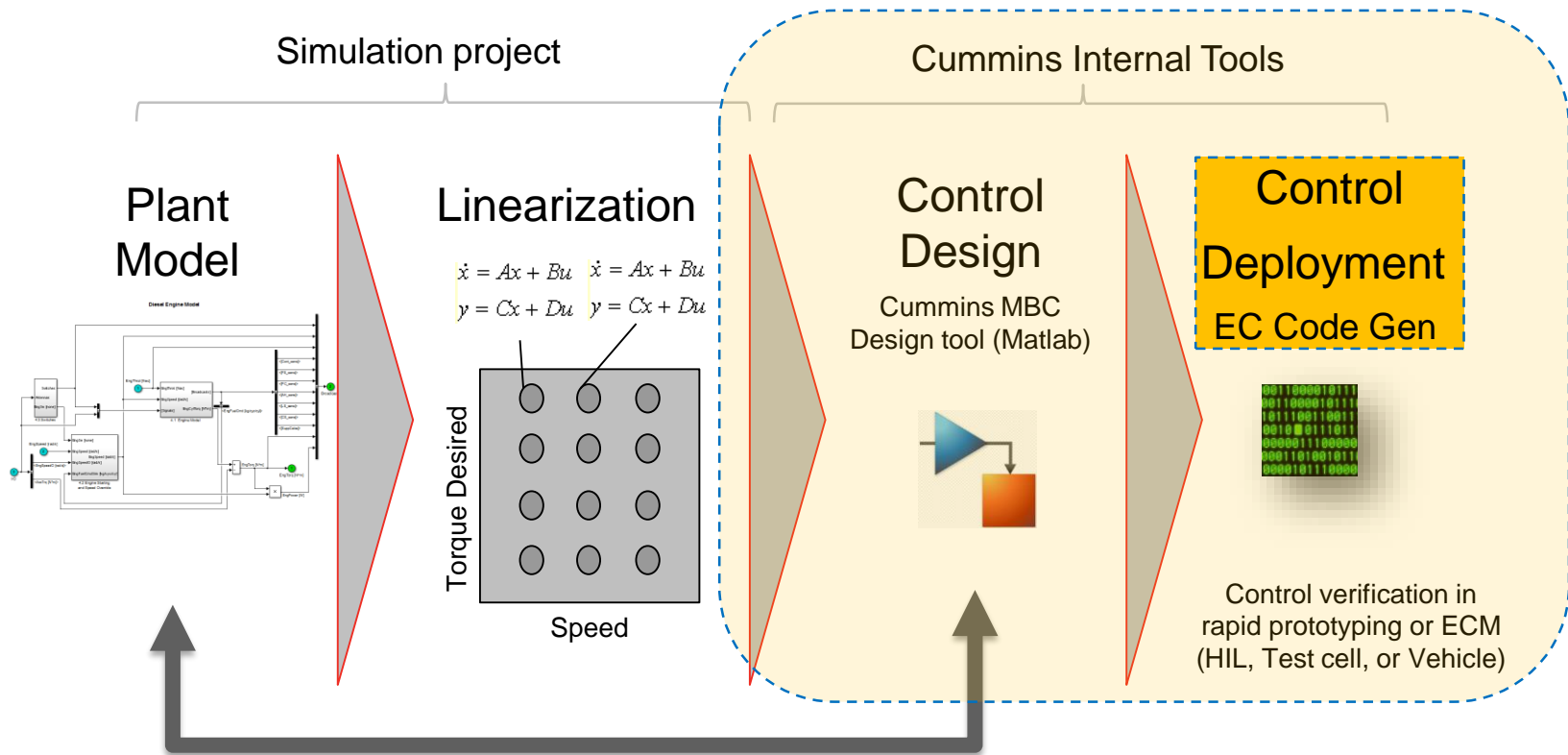
MBD Technology Workflow



Model Capability Continuum



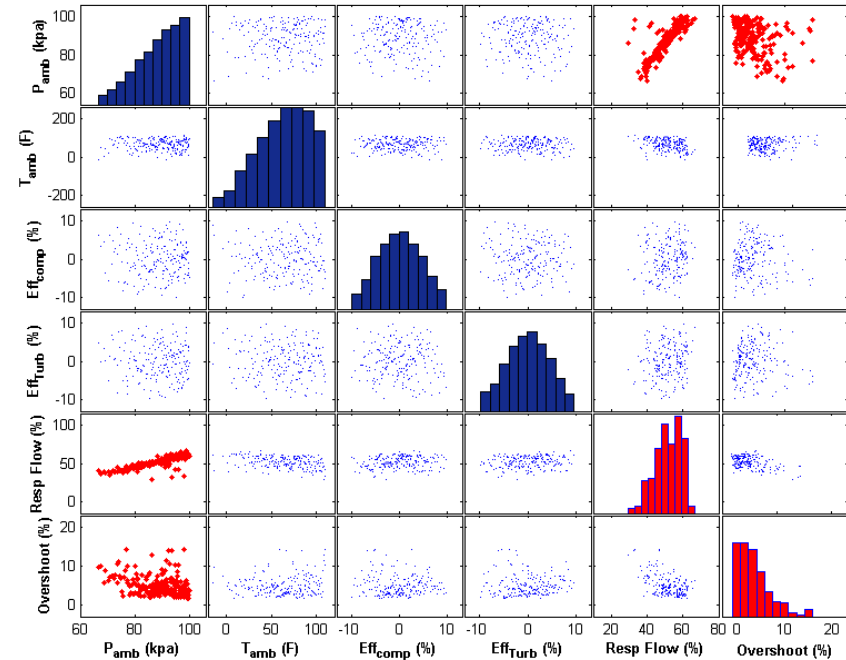
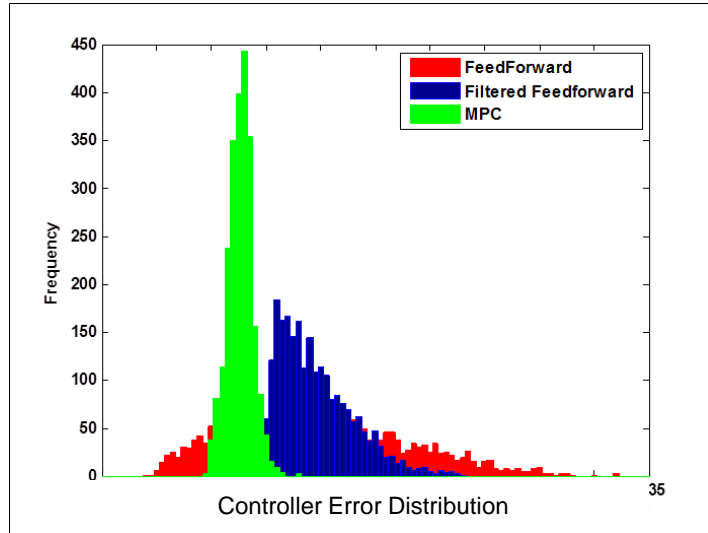
Modeling in Adv. Control Design - MPC



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

Data Management and Visualization

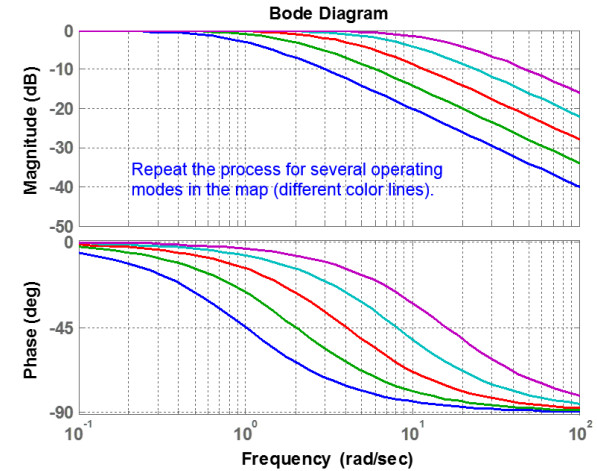
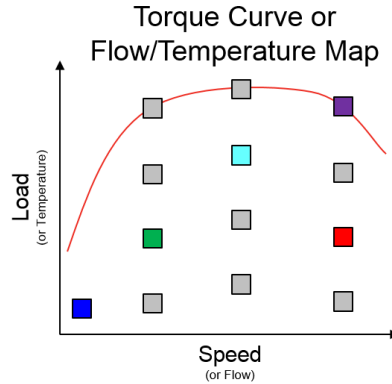
- TBytes of data! Tools needed make rapid, effective, assessments of results.



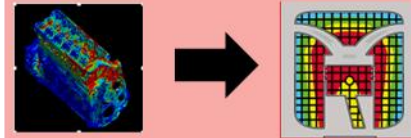
Model Fidelity and Simplification



- 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

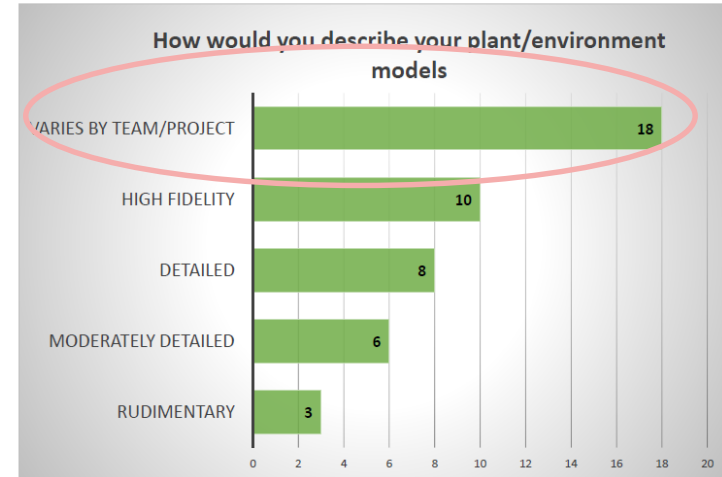


Model simplification



Plant Model Configuration Management

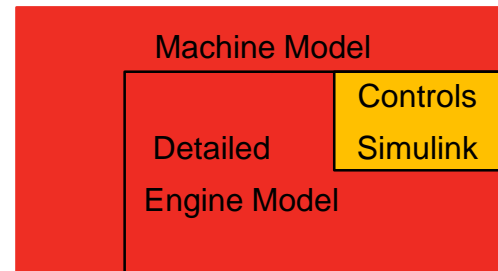
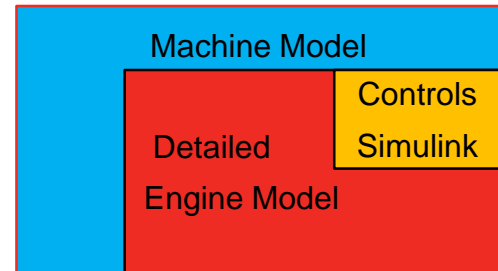
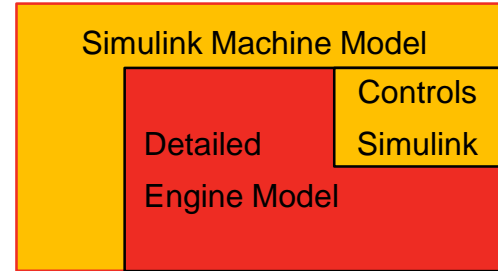
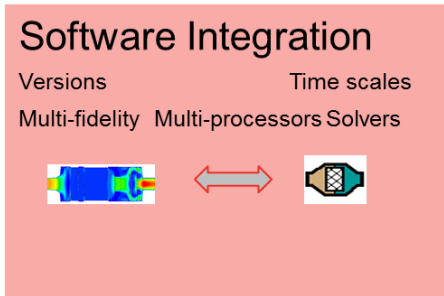
- Models need the same CM rigor as the embedded software.
 - Model State / capability/ source needs to be clear
 - Local copies, tuning adaptations make model validity difficult to access.
 - Model revisions should include validation, fidelity documentation.



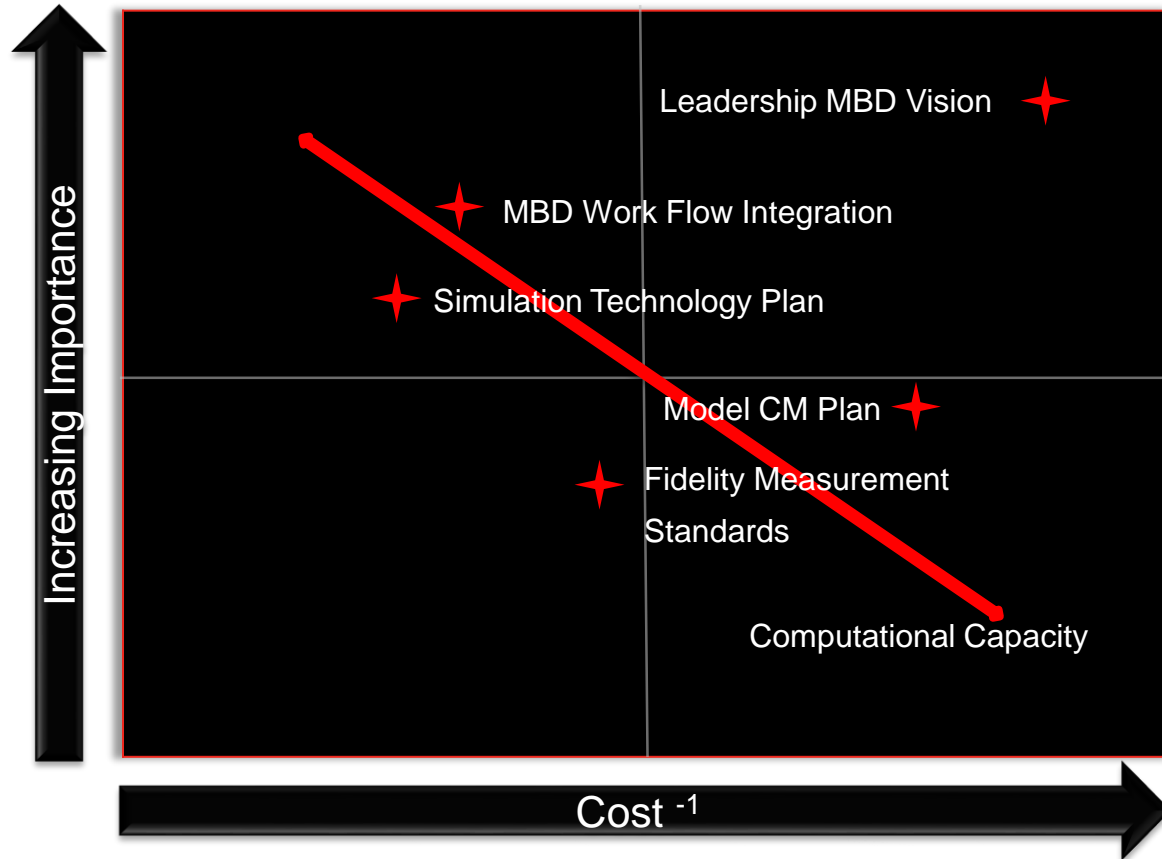
Source MAB 2014

Co-sim Compatibility

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



Summary / Recommendations





Thank you for your Attention