Heavy Truck Clean Diesel (HTCD) Program

Transient Simulation of a 2007 Prototype Heavy-Duty Engine

DOE Contract DE- FC05- 00OR22806

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Caterpillar	PI's:	Kent Rutan, Josh Driscoll, Maarten Verkiel
	Prog. Mgr.:	David Milam

2004 DEER Conference
Coronado, CA

CATERPILLAR®

Presentation Overview

- HTCD Program Background
- Simulation Tools Overview
- Test Cell Model Contents
- Transient Test Cell Results
- Truck Model
- Summary
- Truck Model Movie

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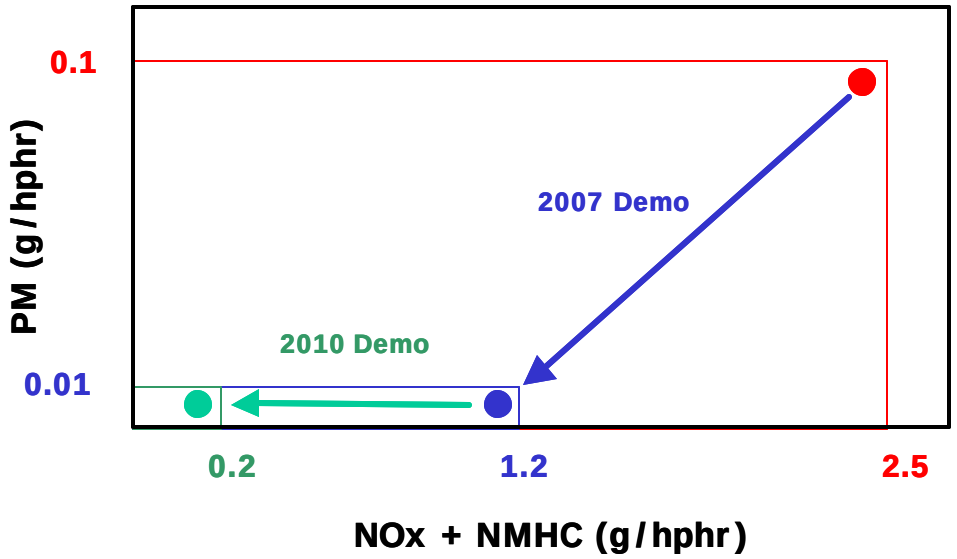
Heavy Truck Clean Diesel Goals

- Funded by HTCD CAT/DOE program
- Phase 1 goal 2007 emissions, 45% efficiency 47% identified in analysis
- 2007 In-chassis demonstration
- Phase 2 goal 2010 emissions, 50% efficiency
- 2010 In-chassis demonstration
- Simulation critical to achieving HTCD goals



More with Less – High Fidelity Simulation

Objectives	Test World $$$	Simulation World <$
Detailed Comb. + Emissions	Single Cylinder Test Cell 	
Steady-state Performance	Multi Cylinder Steady State 	
Transient/System Performance	Multi Cylinder Transient 	
Real-world System Performance	2007 Demonstrator Truck 	

Development Cycle

More with Less – High Fidelity Simulation

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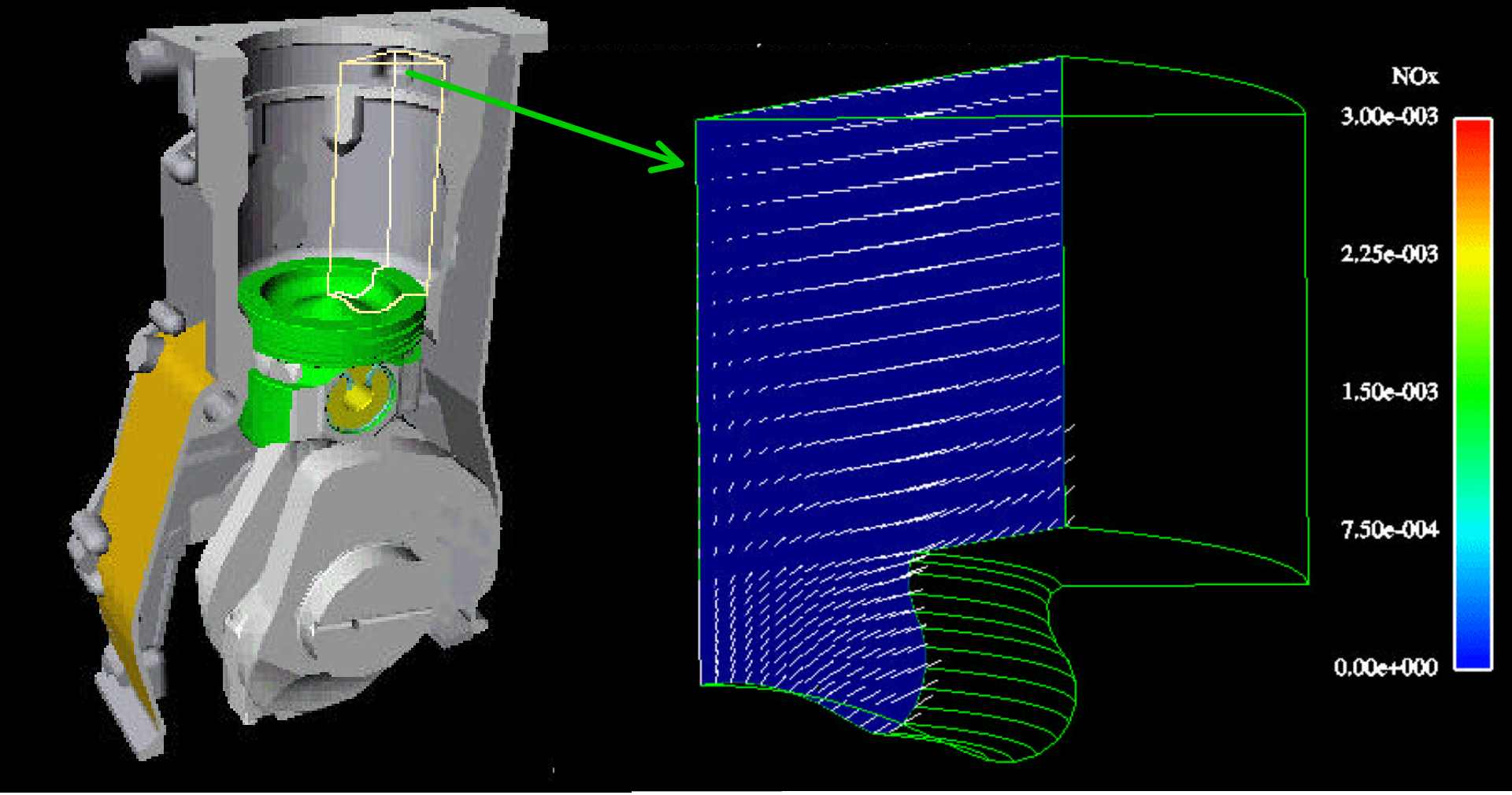
Development Cycle

More with Less – High Fidelity Simulation

Caterpillar 3D Combustion Simulation Software



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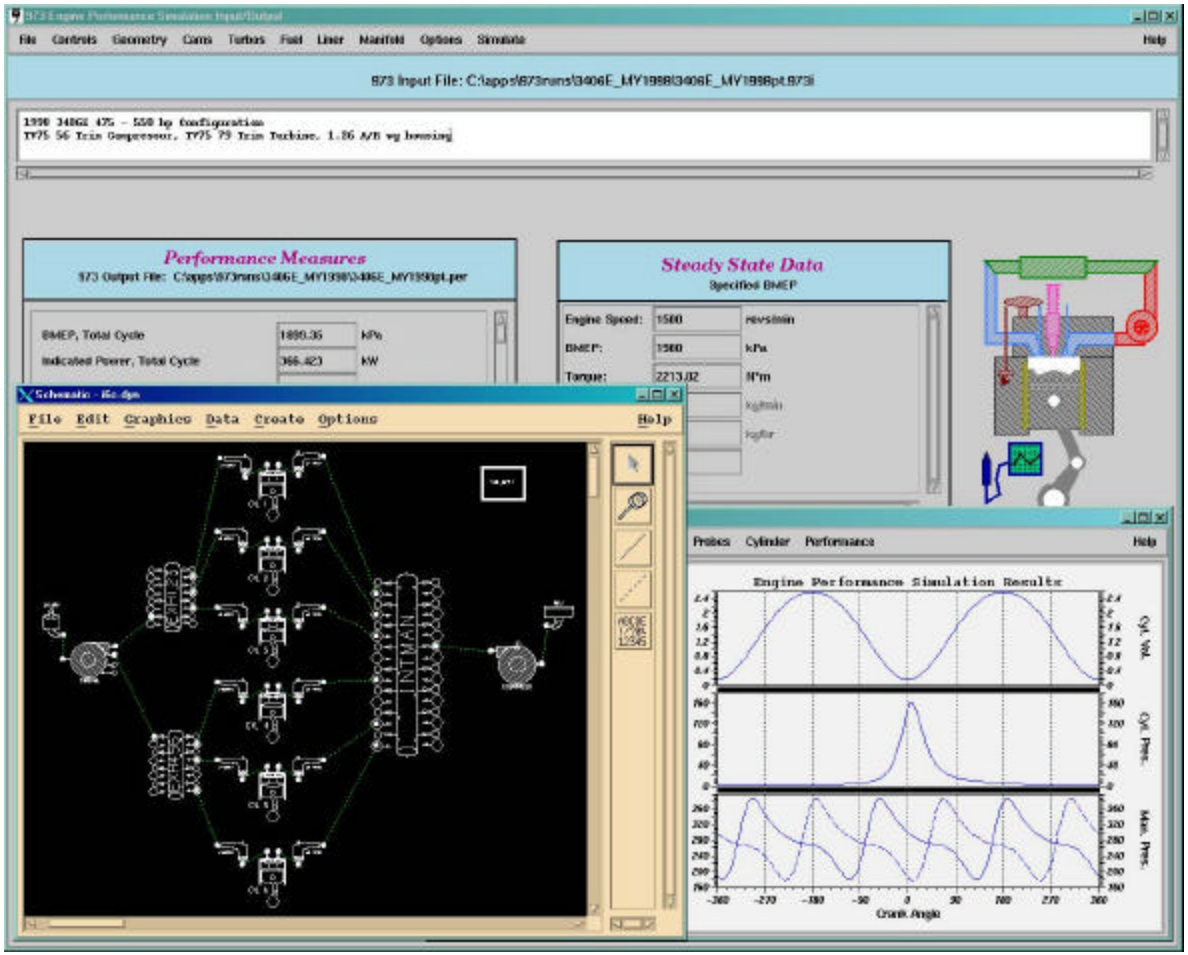
Development Cycle

More with Less – High Fidelity Simulation

Caterpillar Engine Cycle Simulation Software



- Thermodynamics
- Heat Transfer
- Fueling
- Combustion
- Air systems
- Components

More with Less – High Fidelity Simulation

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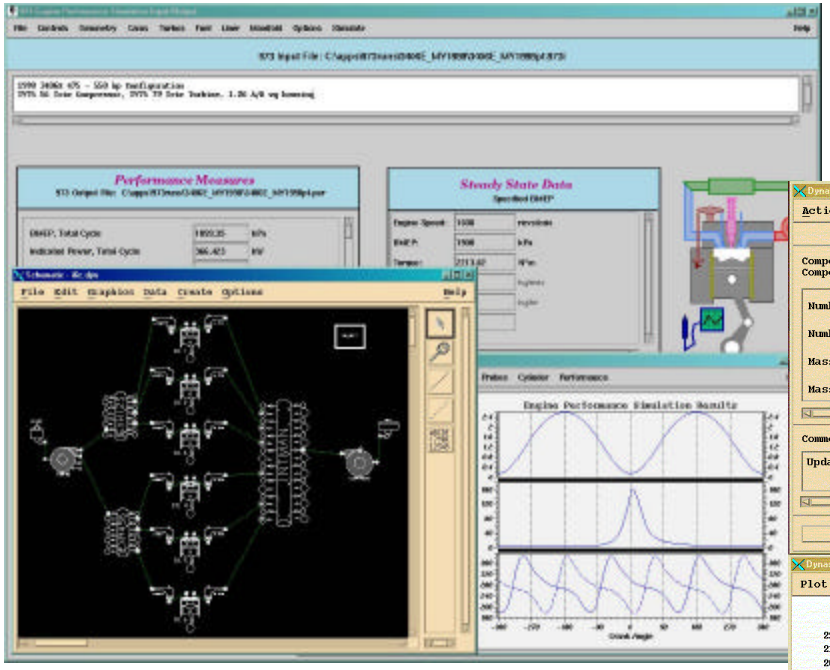
Development Cycle

More with Less – High Fidelity Simulation

Engine Simulation Software



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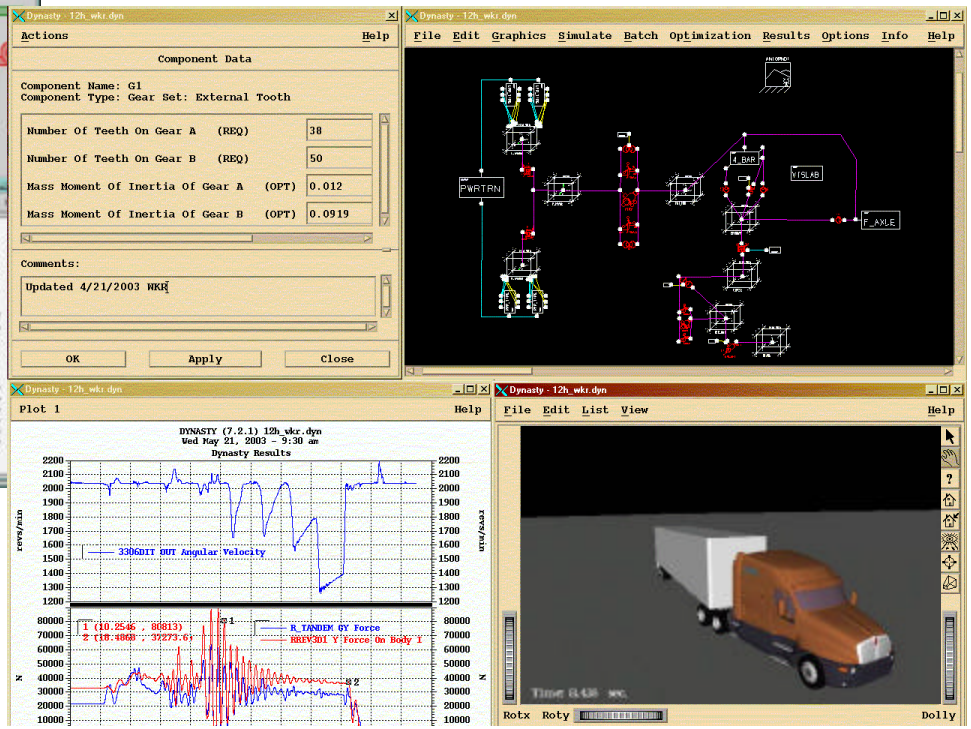
Caterpillar Dynasty™

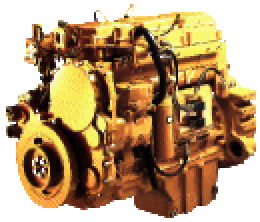
“for toolbox of components to simulate the whole system”



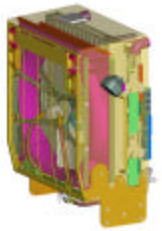
Dynasty Components and Applications

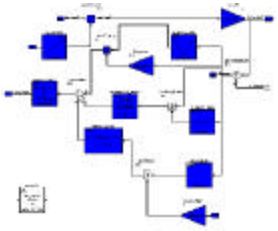
Component-based architecture supports diverse modeling applications

Engine Systems
- Cycle simulation
- Valve trains
- Crankshafts
- Aftertreatment



Cooling Systems
- Radiators
- ATAAC
- Fans
- A/C
- Parasitics

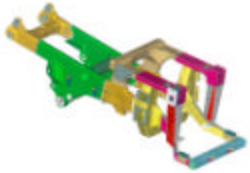




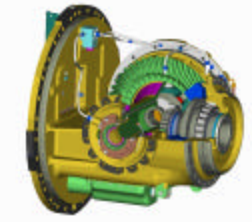
Controls & Electronics
- Component & full vehicle simulation
- Algorithm development
- User programming
- Co-simulation

Fluid Systems
- Fuel
- Hydraulic
- Lube
- Brake
- Steering

Linkages & Structures
- 2D & 3D rigid bodies
- Flexible body dynamics



Drivelines
- Transmissions
- Clutches
- Final drives
- Wheels & Tires
- Gear dynamics



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Development Cycle

Focus of presentation

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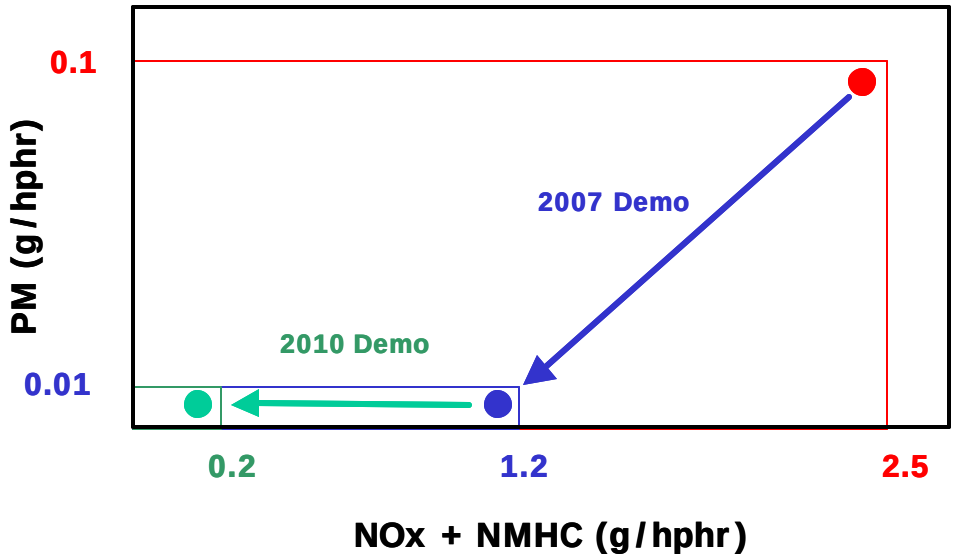
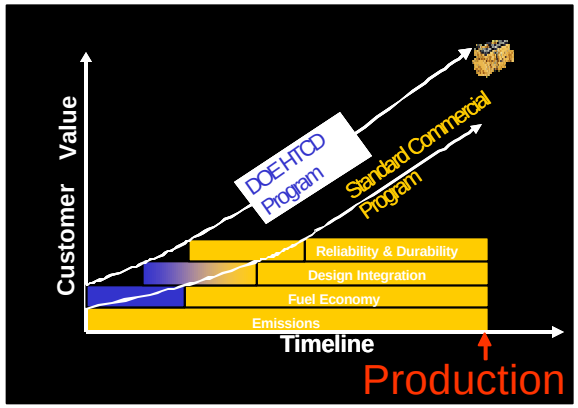
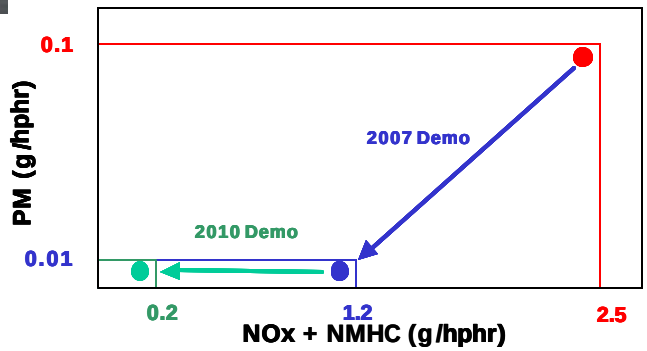


Simulation Process Follows HTCD Goals

- Model validation on 2007 demo engine, truck
- Feed into production process
- Basis for 2010 system models





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Development Cycle

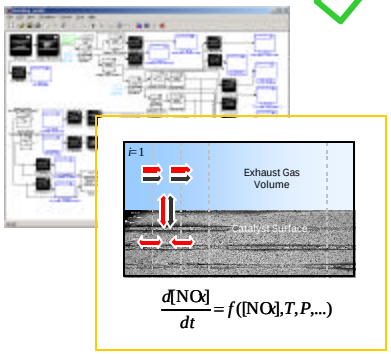
2007 Demo Builds on ACERT® Technology

Combustion

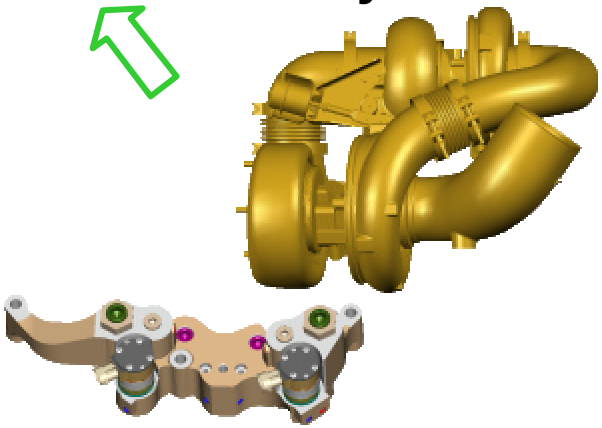
Aftertreatment

Integrated Engine System

Electronics and Controls

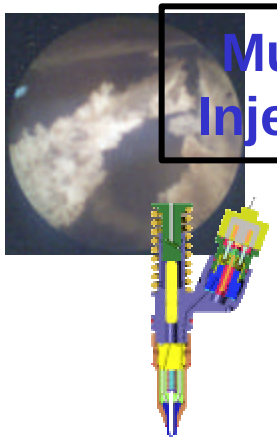


Air Systems



Details Included in Simulation

Combustion



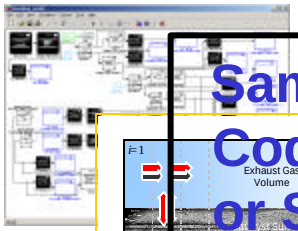
Multiple Injections

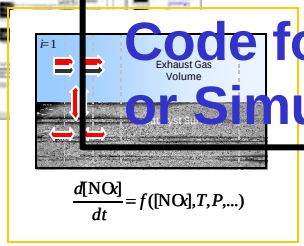
Integrated Engine System

Aftertreatment

Particulate Filter

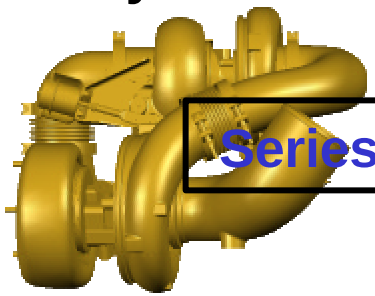
Electronics and Controls



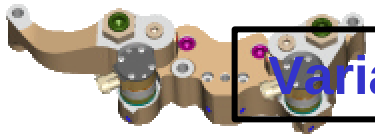


Same Control Code for Test or Simulation

Air Systems

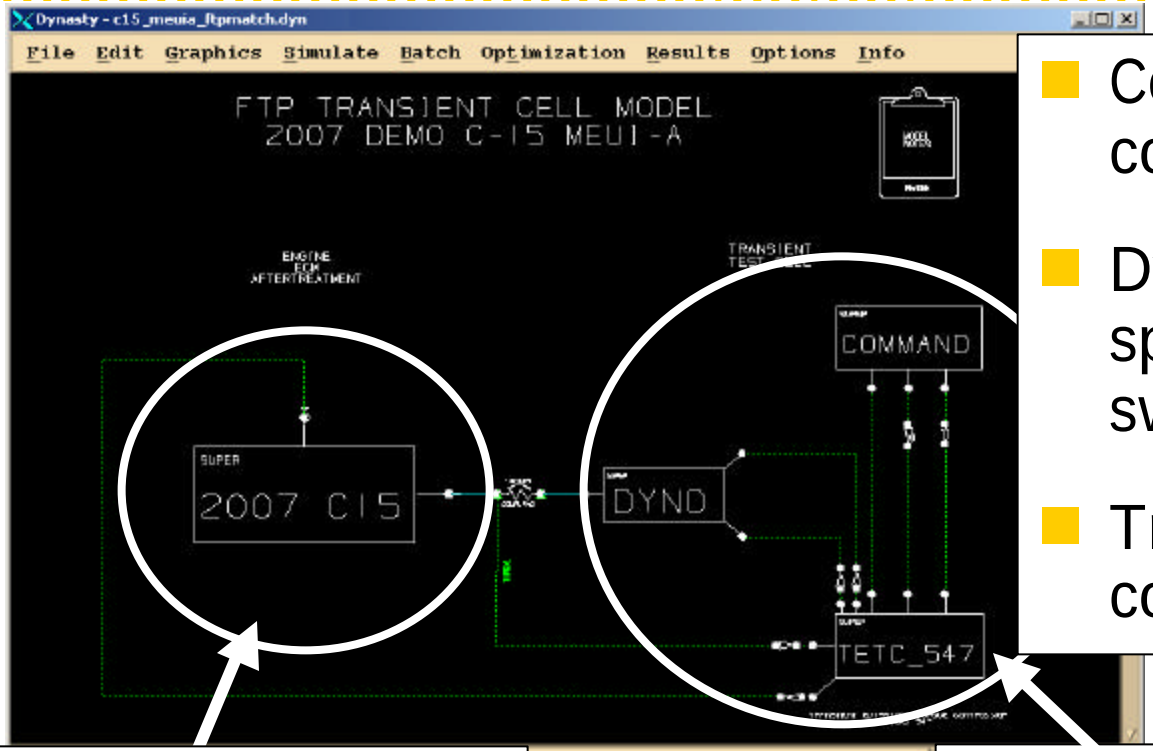


Series Turbos



Variable Valve Timing

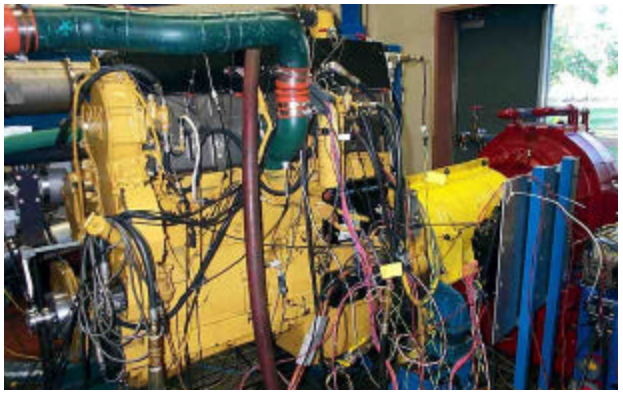
Engine + A/T + Test Cell Simulation



- Computer cycle command
- Dynamometer with speed/torque mode switching
- Transient torque controller

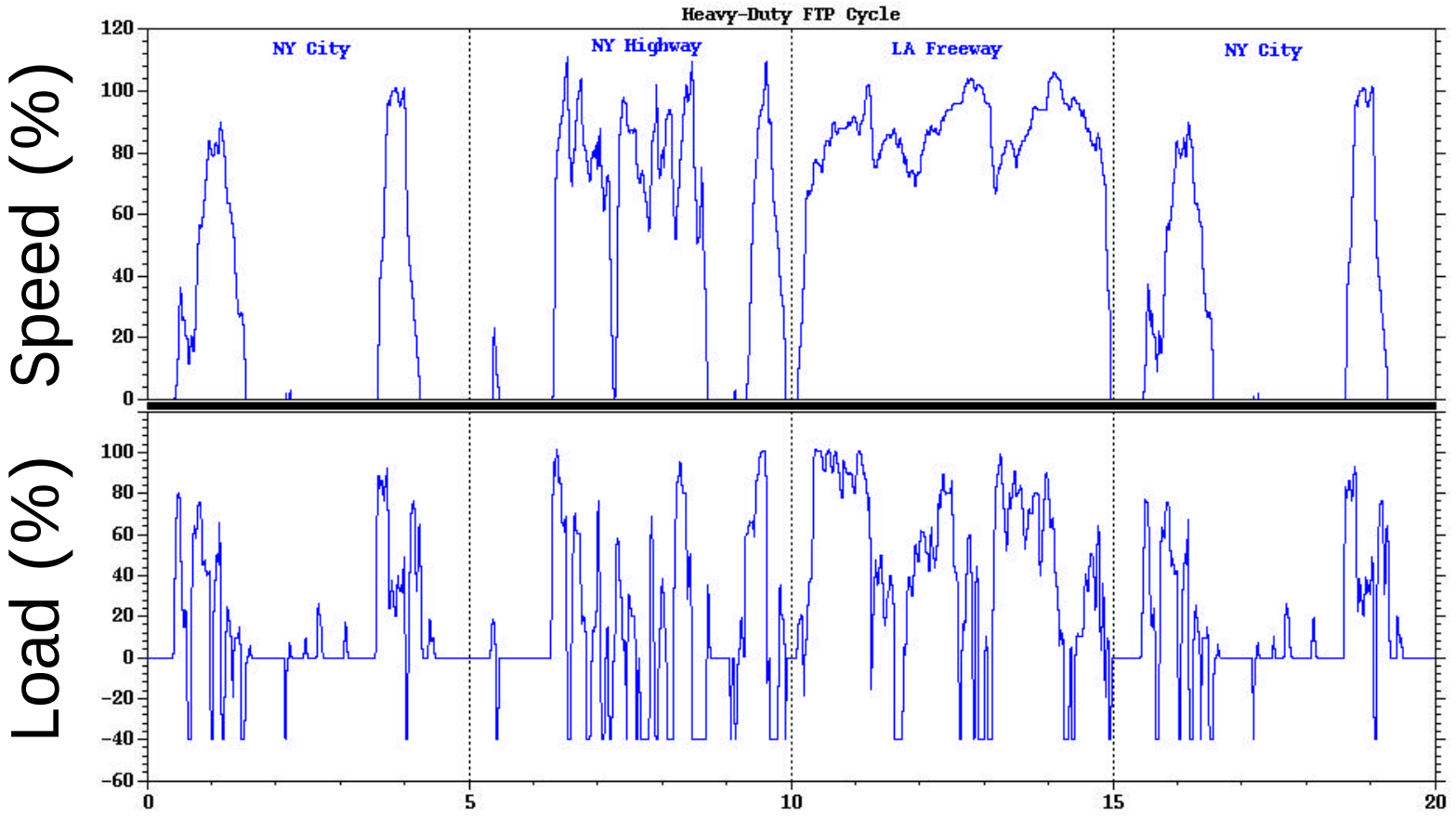
Engine & Aftertreatment System

Transient Test Cell



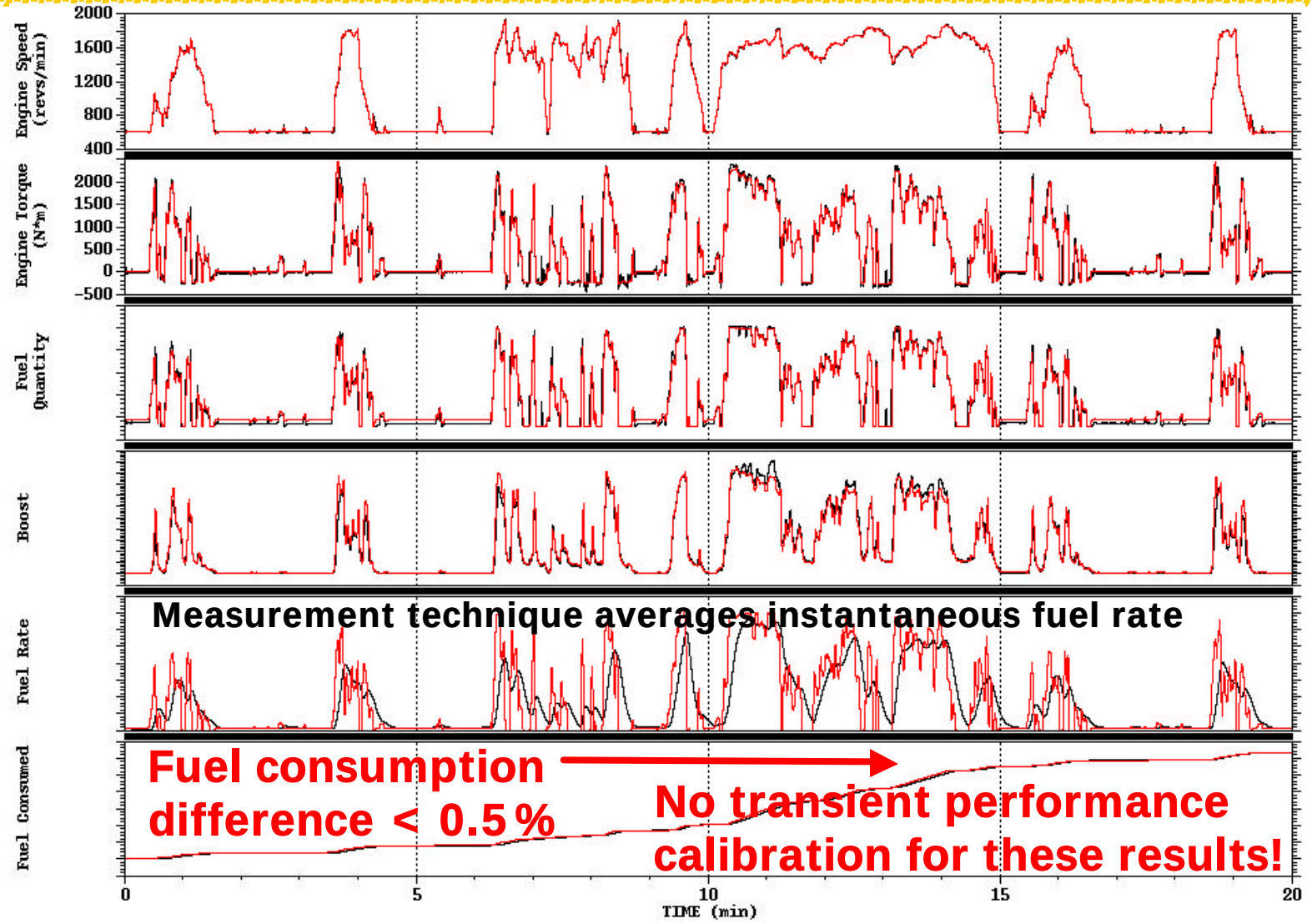
Next Slides: FTP Cycle Results

20 minute Heavy-Duty Federal Test Procedure



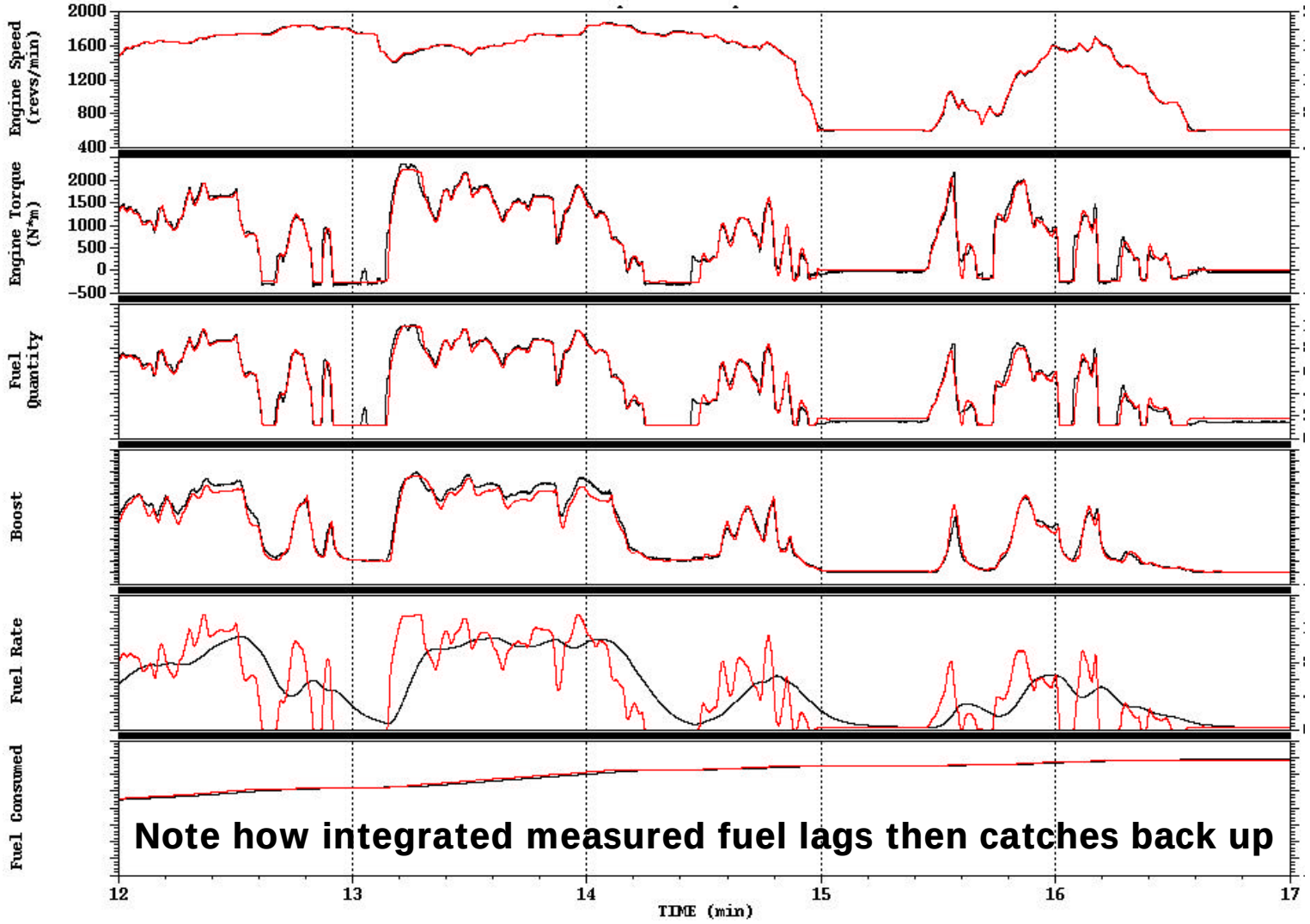
System Performance Results

(Simulation: Red Curves) (Test: Black Curves)



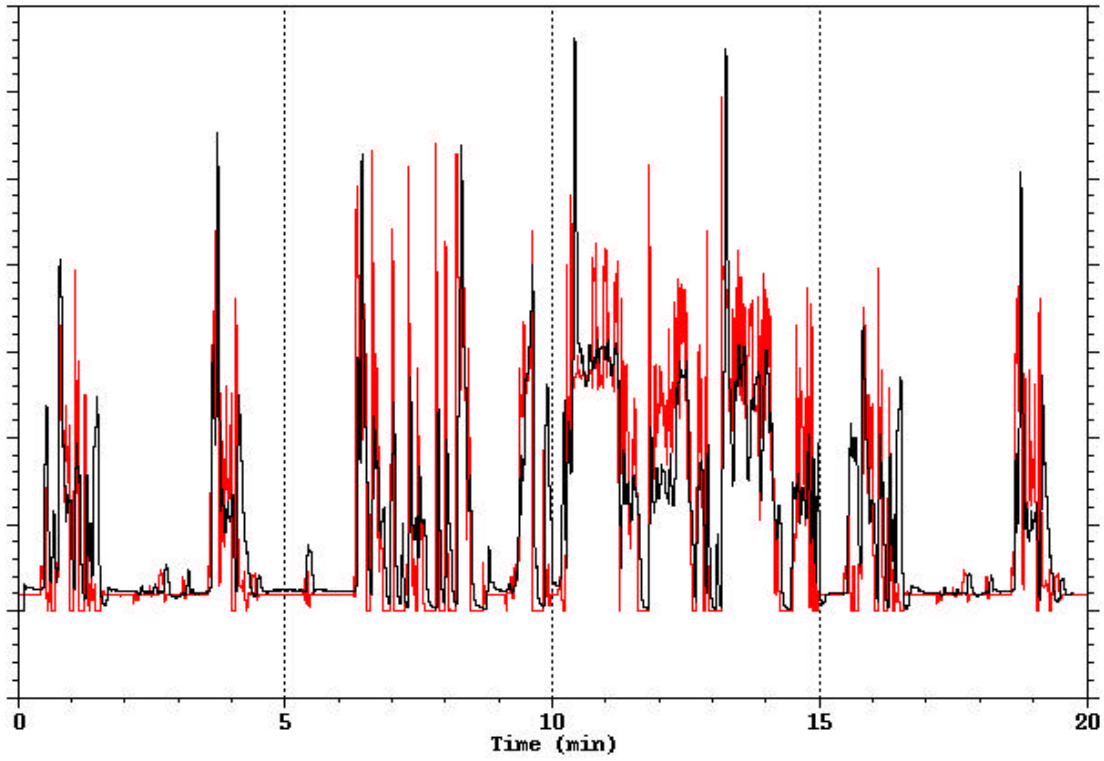
System Performance Results – Zoomed In

(Simulation: Red Curves) (Test: Black Curves)



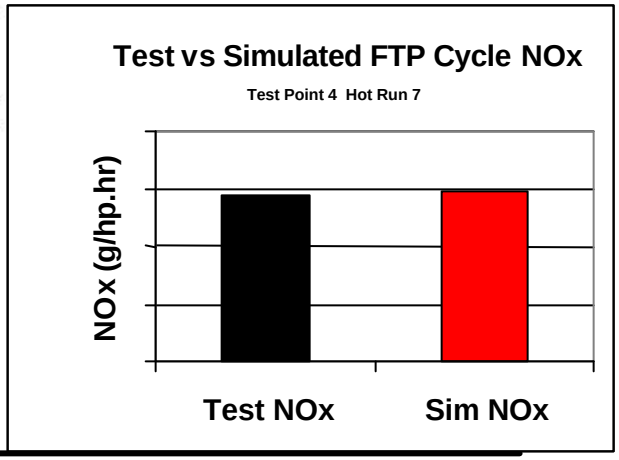
Engine-Out NOx Results

(Simulation: Red Curves) (Test: Black Curves)



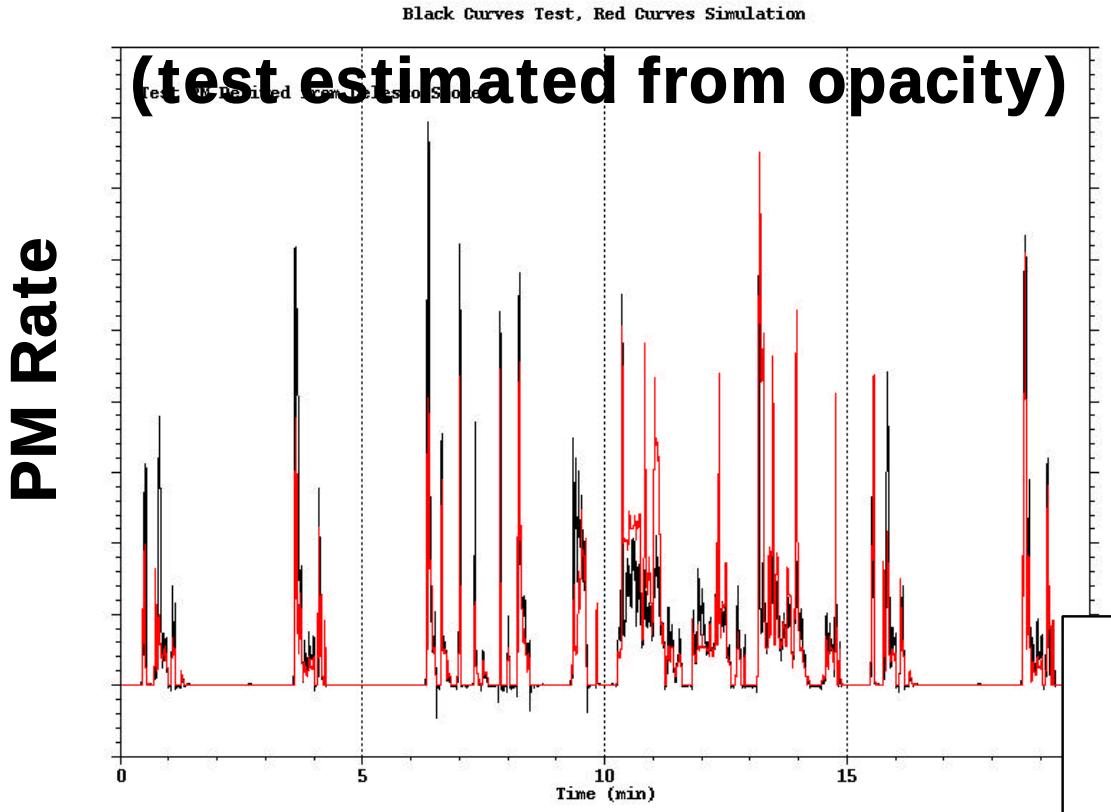
- **Modified Plee NOx model**
- **"Standard" coefficients with some transient matching**

FTP Cycle NOx →



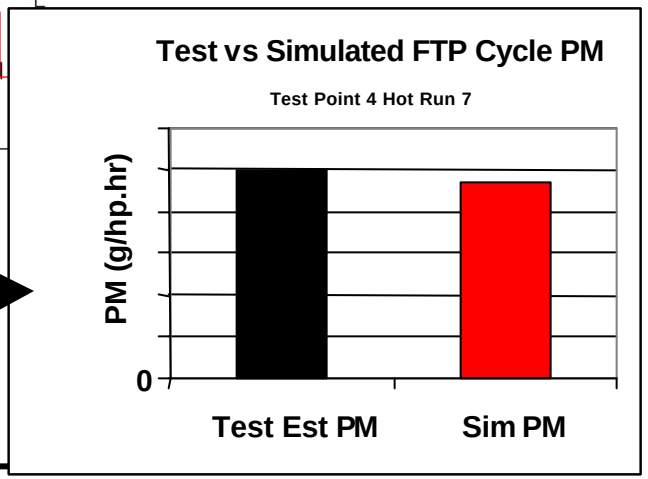
Engine-Out PM Results

(Simulation: Red Curves) (Test: Black Curves)



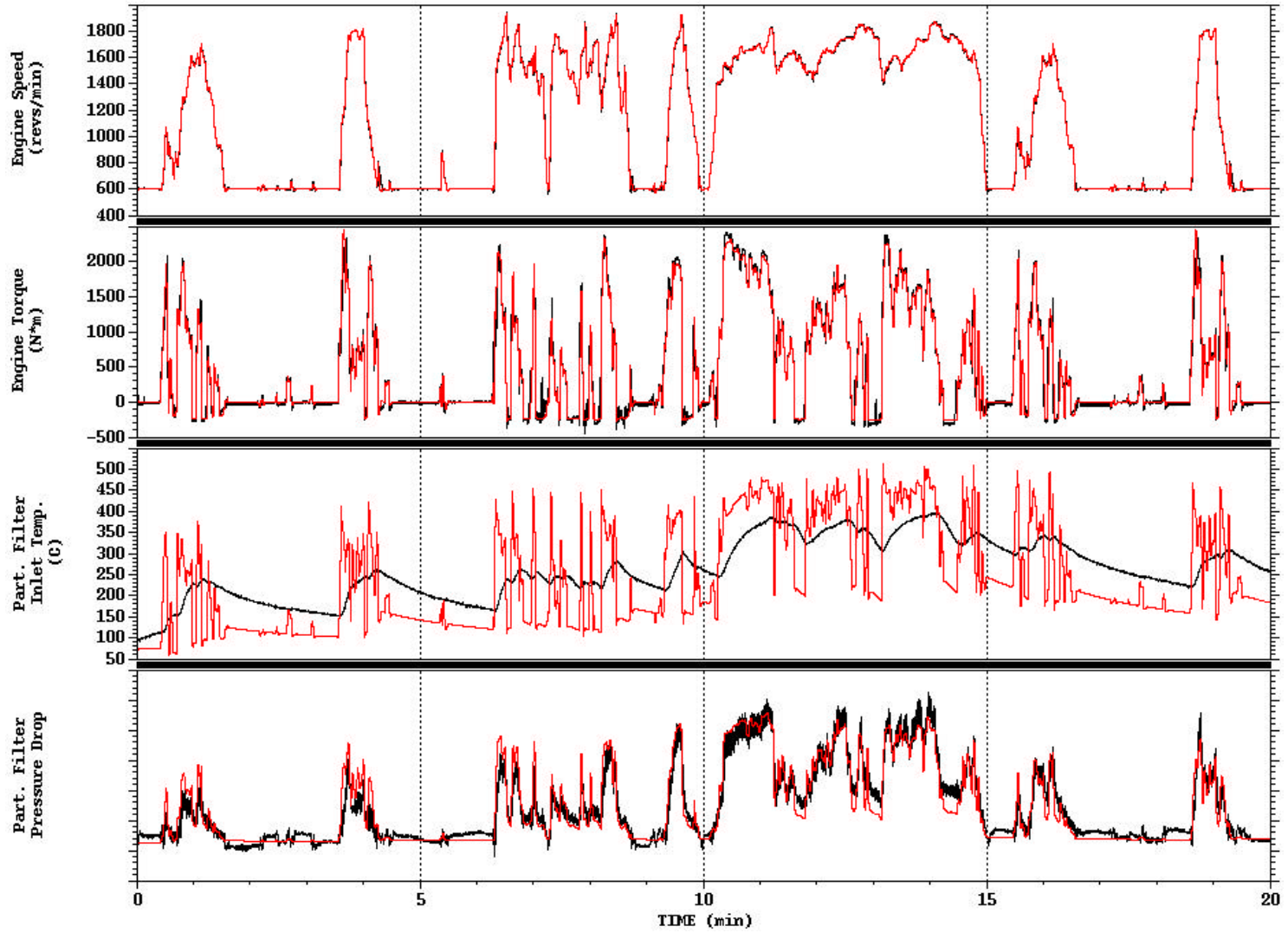
- **Test-based steady-state PM map**
- **Transient A/F multiplier**
- **Transient match**

FTP Cycle Engine-Out PM →



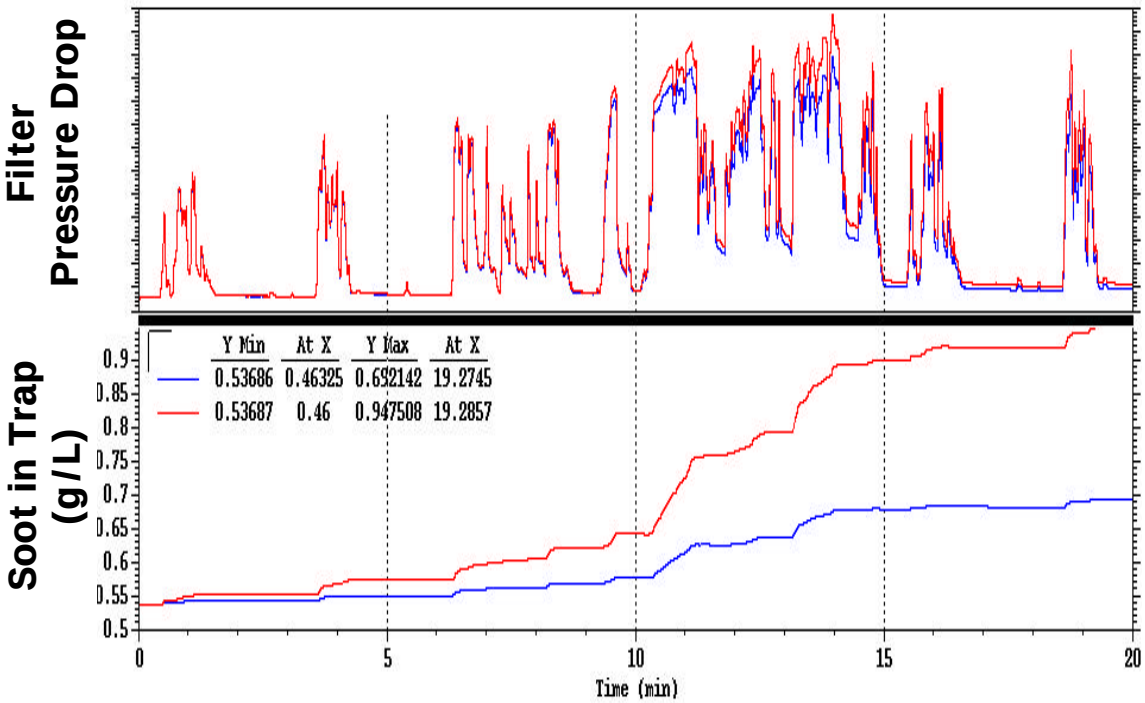
Diesel Particulate Filter Results

(Simulation: Red Curves) (Test: Black Curves)



Engine-Out PM Reduction – System Effect

- High engine-out PM rate to accelerate filter loading
- Red: baseline
- Blue: ½ steady-state engine-out PM rate across board



For this particular system, 2X higher engine-out PM rate gives about 2.6X faster filter loading due to increasing backpressure on engine. Leads to increased fuel consumption and increased need for regeneration.

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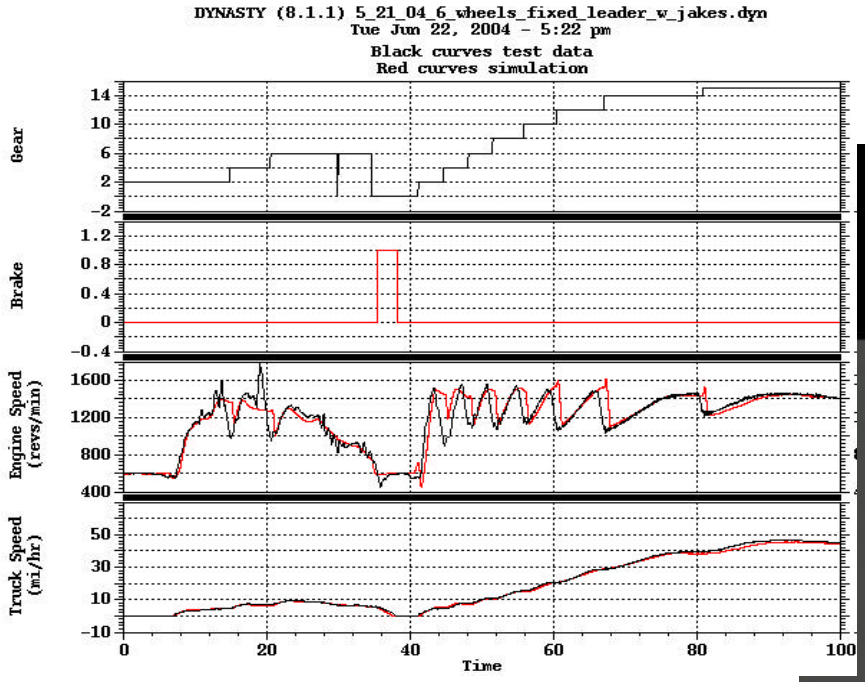
Development Cycle

2007 Demonstrator Truck Model

- Engine from test cell model drops into truck
- Similar level of detail in truck model
- More in video at end of presentation



Summary – Transient Simulation

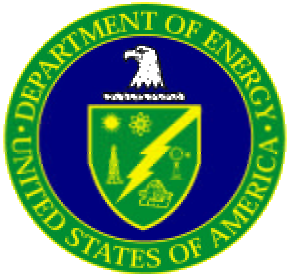
- Need to model details – accuracy, relevancy
- Need to include more than just engine
- Caterpillar has been practicing this for years with the help of excellent simulation tools
- Need to improve modeling of measurements (measurement error and dynamics become even more significant for 2007/2010)
- Need to pay attention to engine-out PM for best engine/particulate filter system

Acknowledgements

- These results are built on the work of 100's of Cat people over decades. Inventors of the basic computing tools are:

  James R. Weber, Scott A. Leman, and Kem D. Ahlers, William L. Brown, and Eric C. Fluga.

- Cost share provided by the United States Department of Energy



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Truck Simulation Movie