Smart Engines – Conventional vs. Advanced Controls for Optimized Efficiency and Emissions

M. Allain, P. Ge, N. Hakim, Y. Kalish, C. Savonen, M. Sun

Detroit Diesel Corporation

The recently announced future truck exhaust emissions regulations escalate the aggressiveness and focus required to successfully complete a competitive product technology development. There are enormous technological complexities in seeking a feasible solution to meet highly stringent emissions reduction without increasing fuel consumption or compromising the powertrain life cycle cost. There is great opportunity for controls technology to play an increasingly key role in future diesel engine advancements. Furthermore, smart controls development cycles can moderate product development cost and time, while increasing first pass yield of a reliable controls package.

This presentation will contrast model based controls (MBC) with today's popular table-based approach. Detroit Diesel Corporation (DDC) has introduced the concept of "An Engine that Thinks" at a DEER workshop in the 1990's. The intent of this presentation is to provide yet another update to previously presented DDC MBC technology developments, reflecting progress towards this ultimate goal.

The "Wired" experimental plus virtual lab combined tool set will be revisited. Efforts to develop control packages for advanced technology developments will be highlighted. Application examples will be provided reflecting the potential of MBC.

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Acknowledgements

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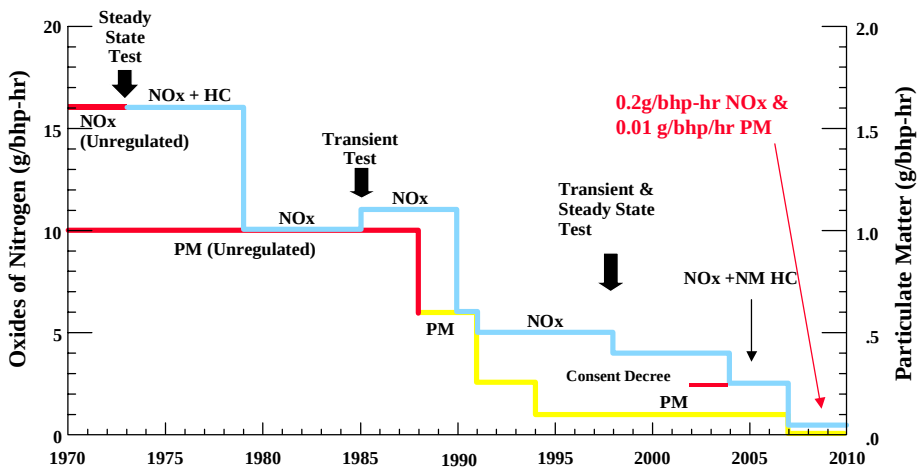
- DDC Engineering Technology Dept Teammates

Outline

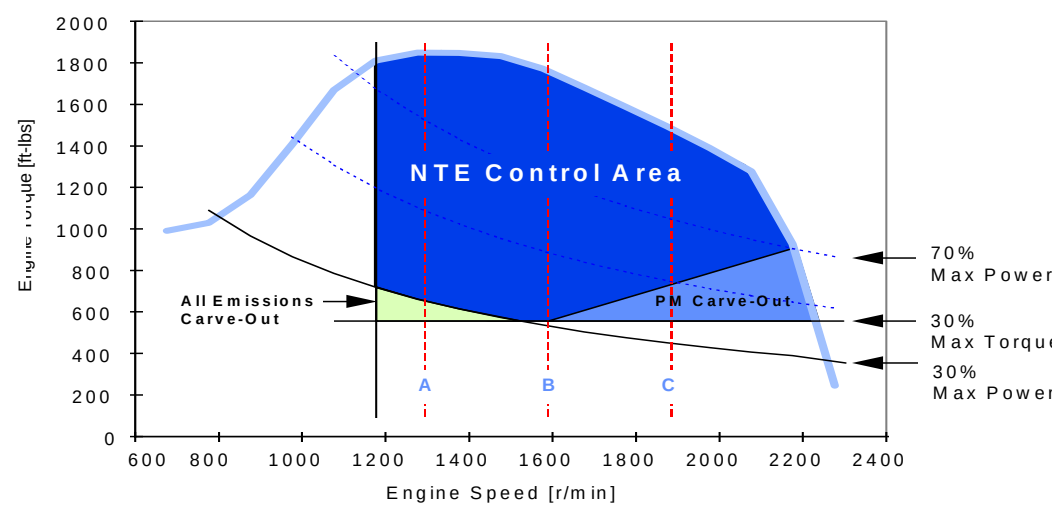
- What Are the Challenges Today?
- One Branch of Control Prototyping Tools
- Virtual Sensing Results & Applications
- What is the Future Smart Engine?

Transient and Steady State Test Criteria

US FTP Emission Test



Steady State ESC Test



Transient NTE Test

In-Use Vehicle Testing

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	Primary Test	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
US	ESC & ETC	NOx+HC: 3.35 g/kWh (2.5) PM: 0.13 g/kWh (0.10)				NOx: 1.48 g/kWh (1.1) PM: 0.013 g/kWh (0.01)			NOx: 0.27 g/kWh (0.2) PM: 0.013 g/kWh (0.01)		
Europe	ESC & US FTP	NOx: 5.0 g/kWh (3.7) PM: 0.10/0.16 g/kWh (0.07/0.12)			NOx: 3.5 g/kWh (2.6) PM: 0.02/0.03 g/kWh (0.015/0.022)			NOx: 2.0 g/kWh (1.5) PM: 0.02/0.03 g/kWh (0.015/0.022)			Similar to US 2010 ?
ADVANCED CONTROLS & SENSORS	**FUEL INJECTION**										
	CHARGE AIR SYSTEM										
	EGR SYSTEM										
	AFTER TREATMENT SYSTEM(S)										
	ADVANCED COMBUSTION SYSTEM										
	OBD +										

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Enabling Objectives for 2007+ Smart Controls

- Substantially More Consistent Emission Control
  - Sub-System Level
  - Total System Level
- Efficient System Interrelationships Under Dynamic Operation.
- Self Learning/Adjusting for Manufacturing, Environmental, and Wear Variances.
- On-Board Diagnosis & Prognosis.

What is Required of a Smart Engine?

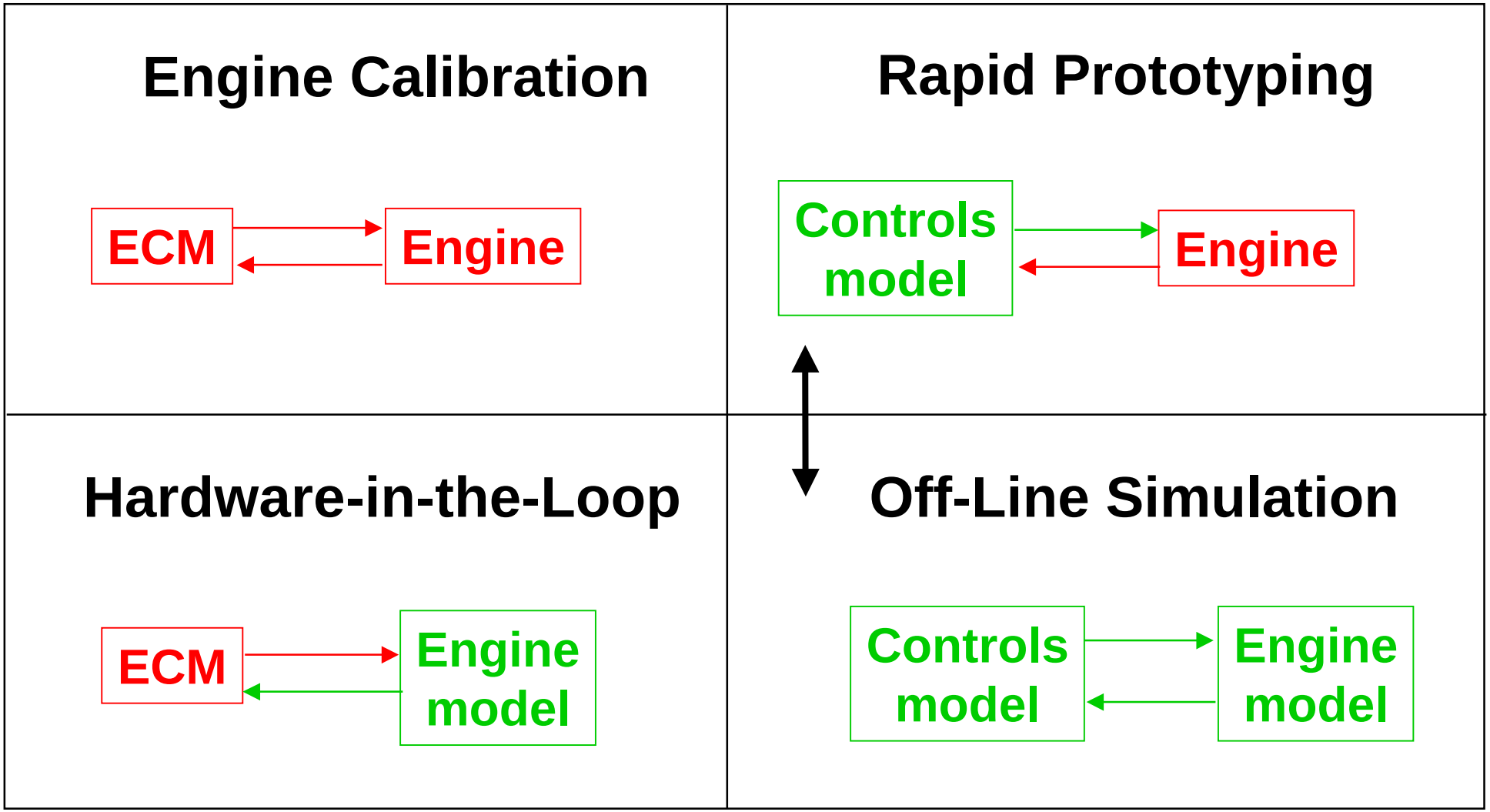
- **Simultaneously Exceeding Requirements of:**
  - **Customer Life Cycle Costs.**
  - **Regulatory Requirements.**

While : "Elegant in its Simplicity"

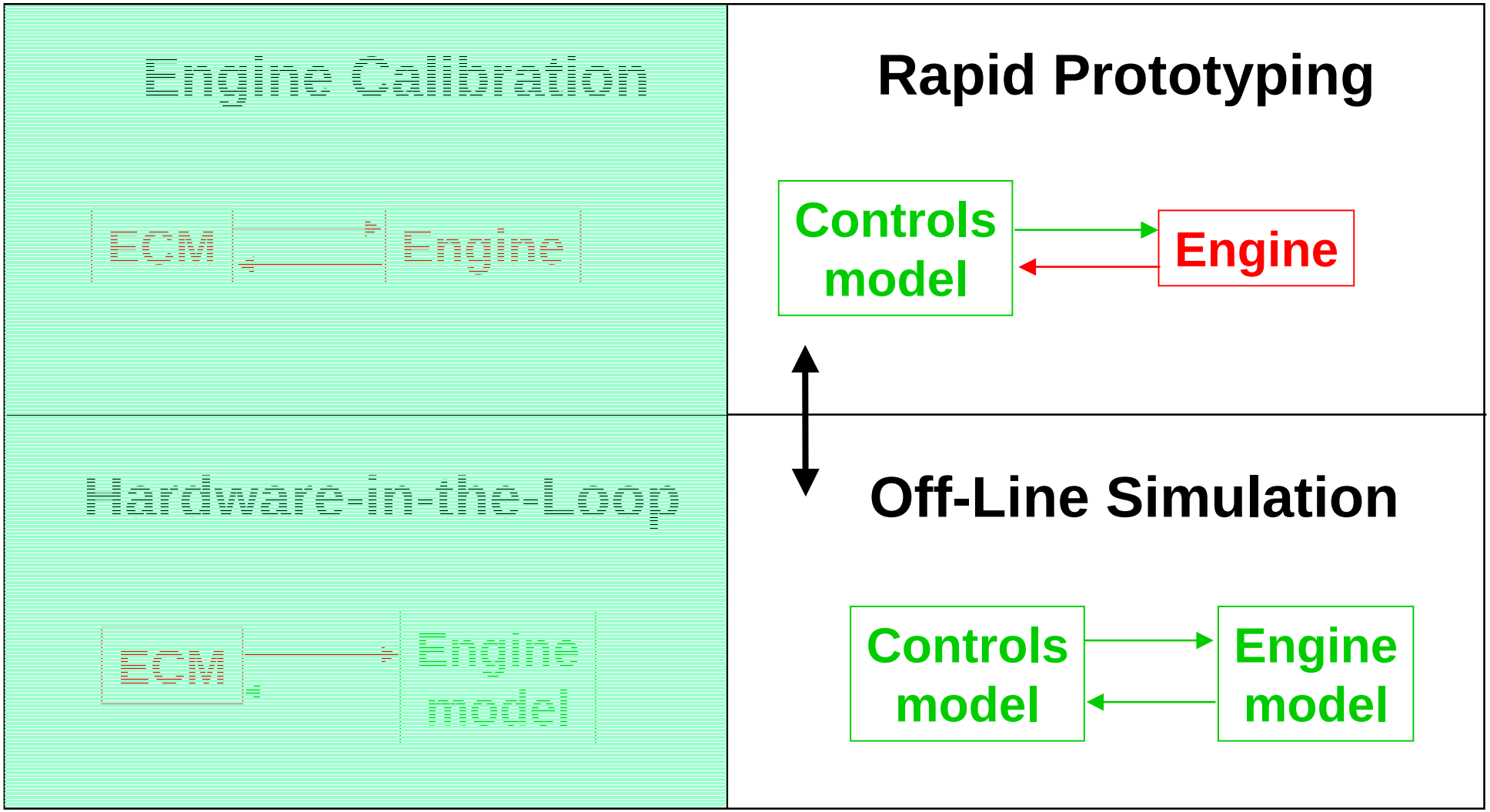
Or : "Creeping Elegance"

Or : "Just Plain Out of Control" ?

MBC FOUR Quadrants



Prototyping Tool Utilization



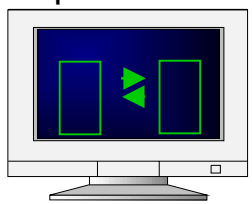
Controls Development Quad

Increase 1st Pass Yield on New Algorithm Sets

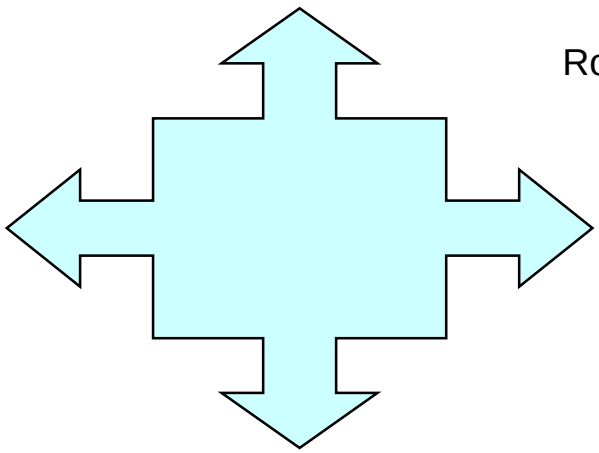
Reduce Risk to Prototype Hardware

Merge Acquired Data into Singular Environment

Operator I/O



Engine



Room Data Acquisition

Rapid Prototyping S/W System

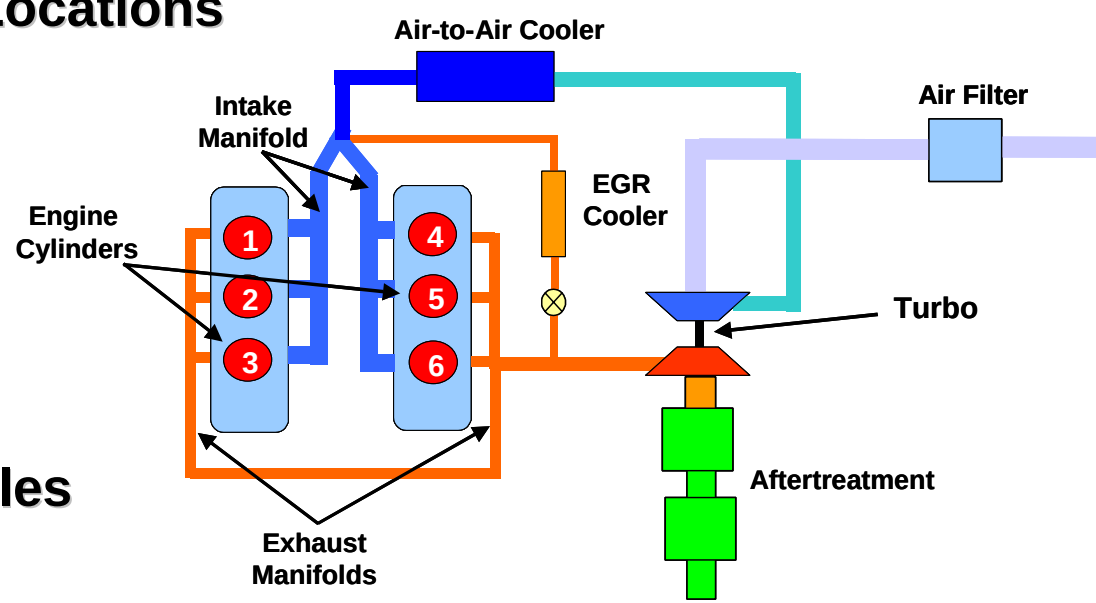
Screen Concepts Efficiently

Increase Fidelity of New Logic

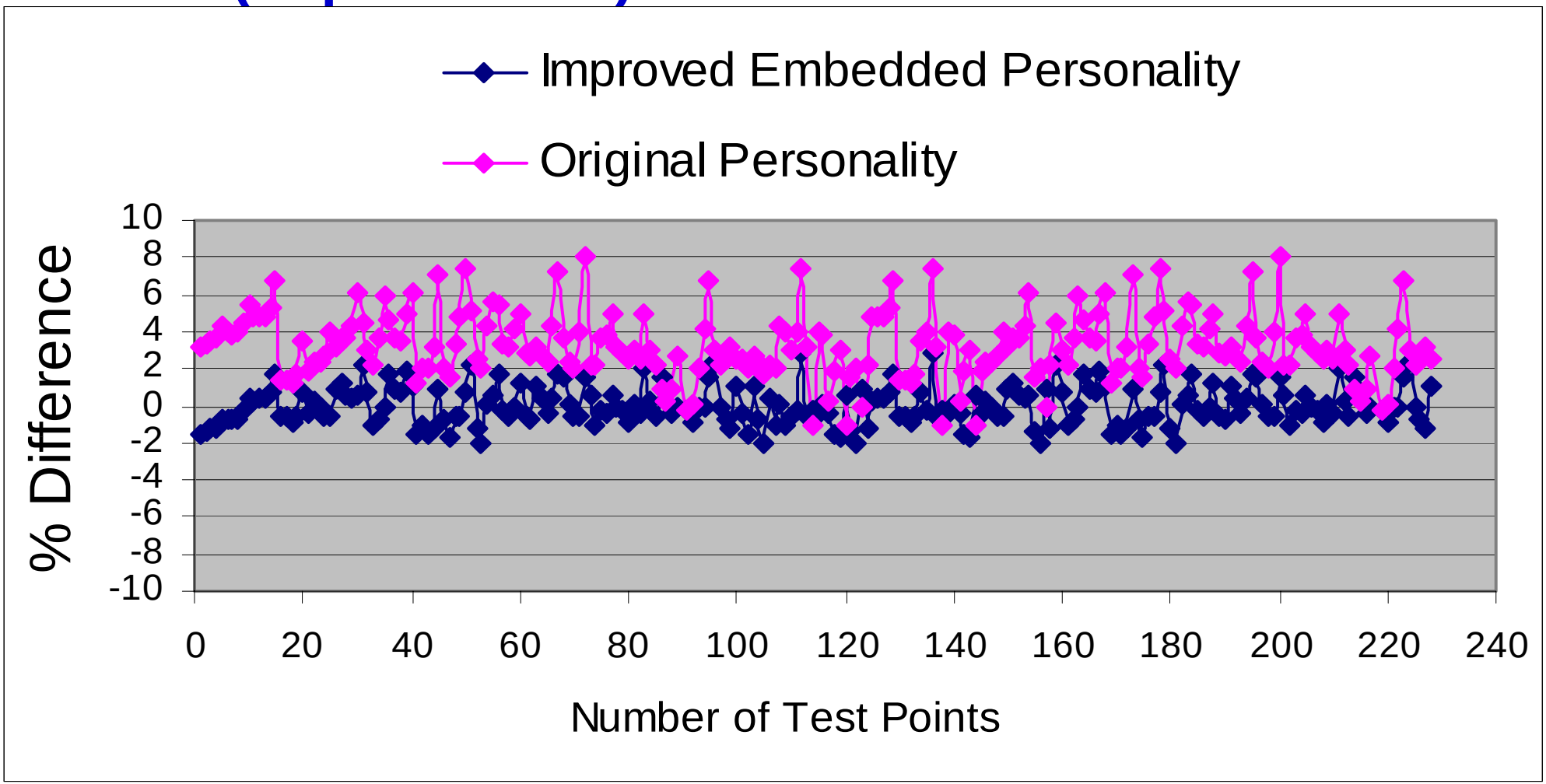
Apply Same Models On Line and Off Line

On Board Virtual Sensing: One Facet of A Smart Controls System

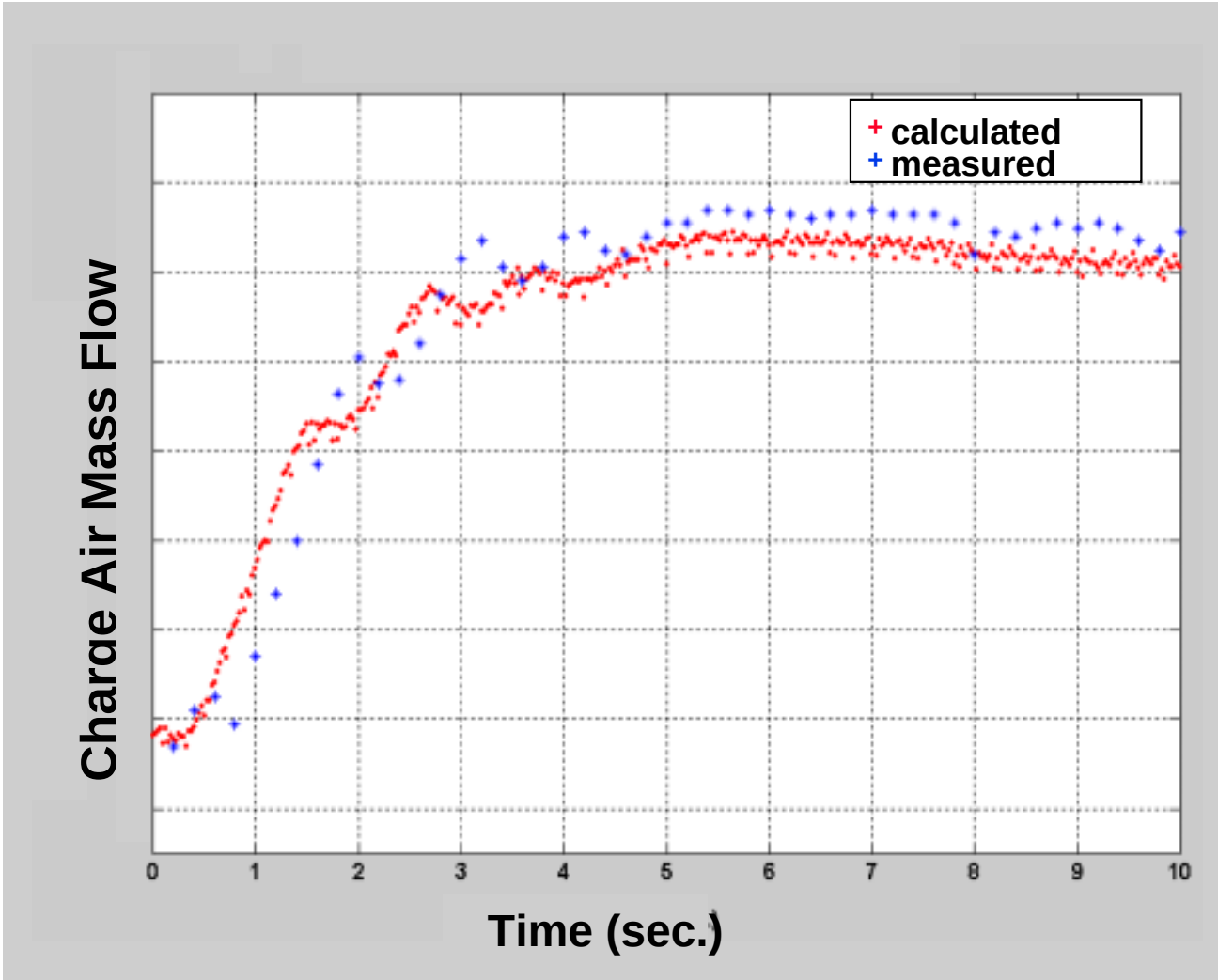
- State Variable Monitor @ Multiple Locations
- Intake and Exhaust Side
- Species Tracking
- Steady State and Transient
- Diagnostic Cross Check
- Engine Engineering Related Variables



On-Board (Virtual) vs Test Facility (Experimental) Mass Flow Measurement



Transient Air System Response to a Load Step Input



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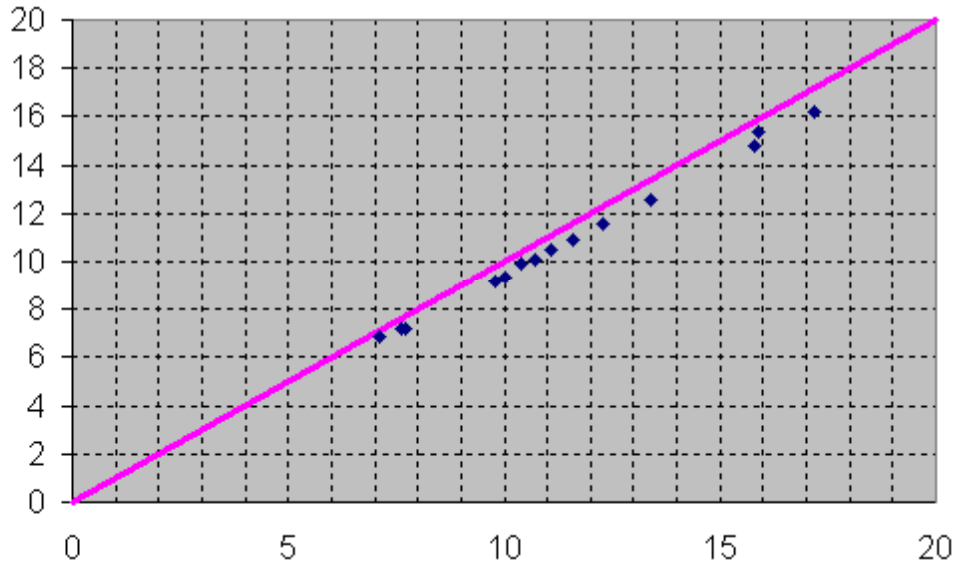
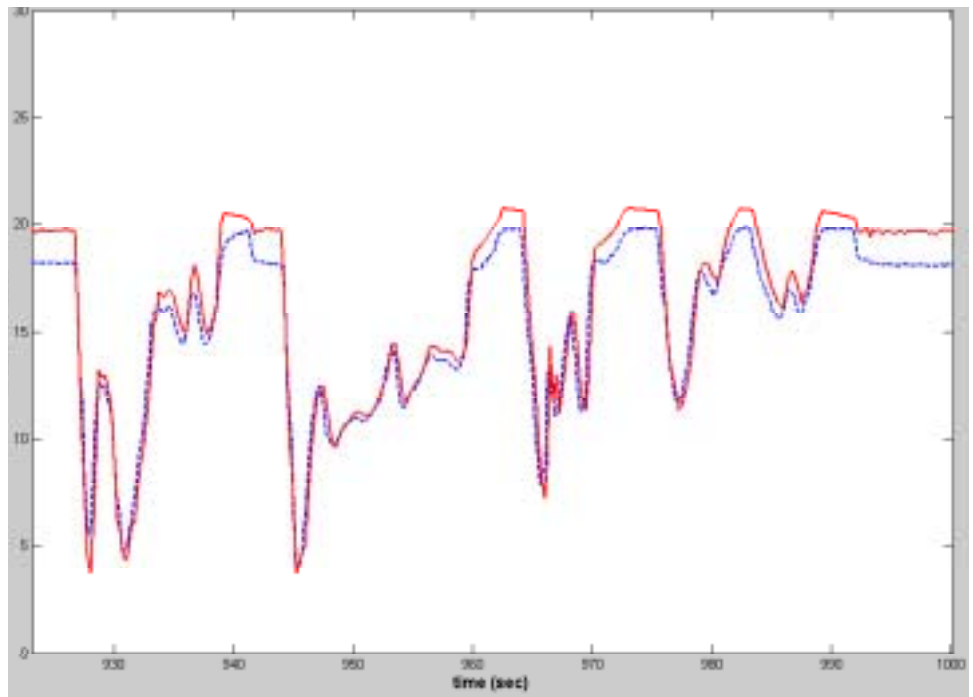
Dynamic Tracking of Exhaust Gas Species





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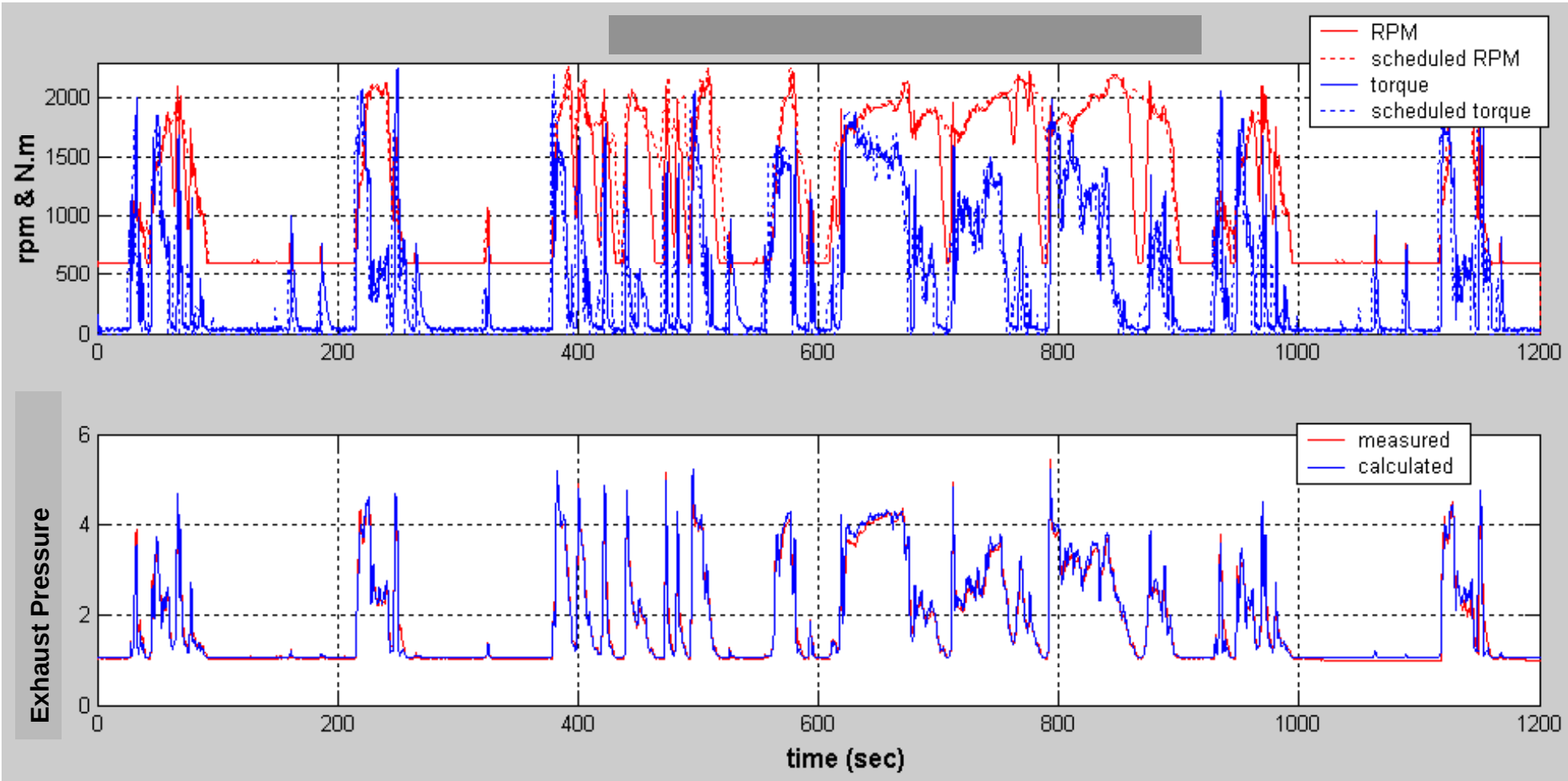
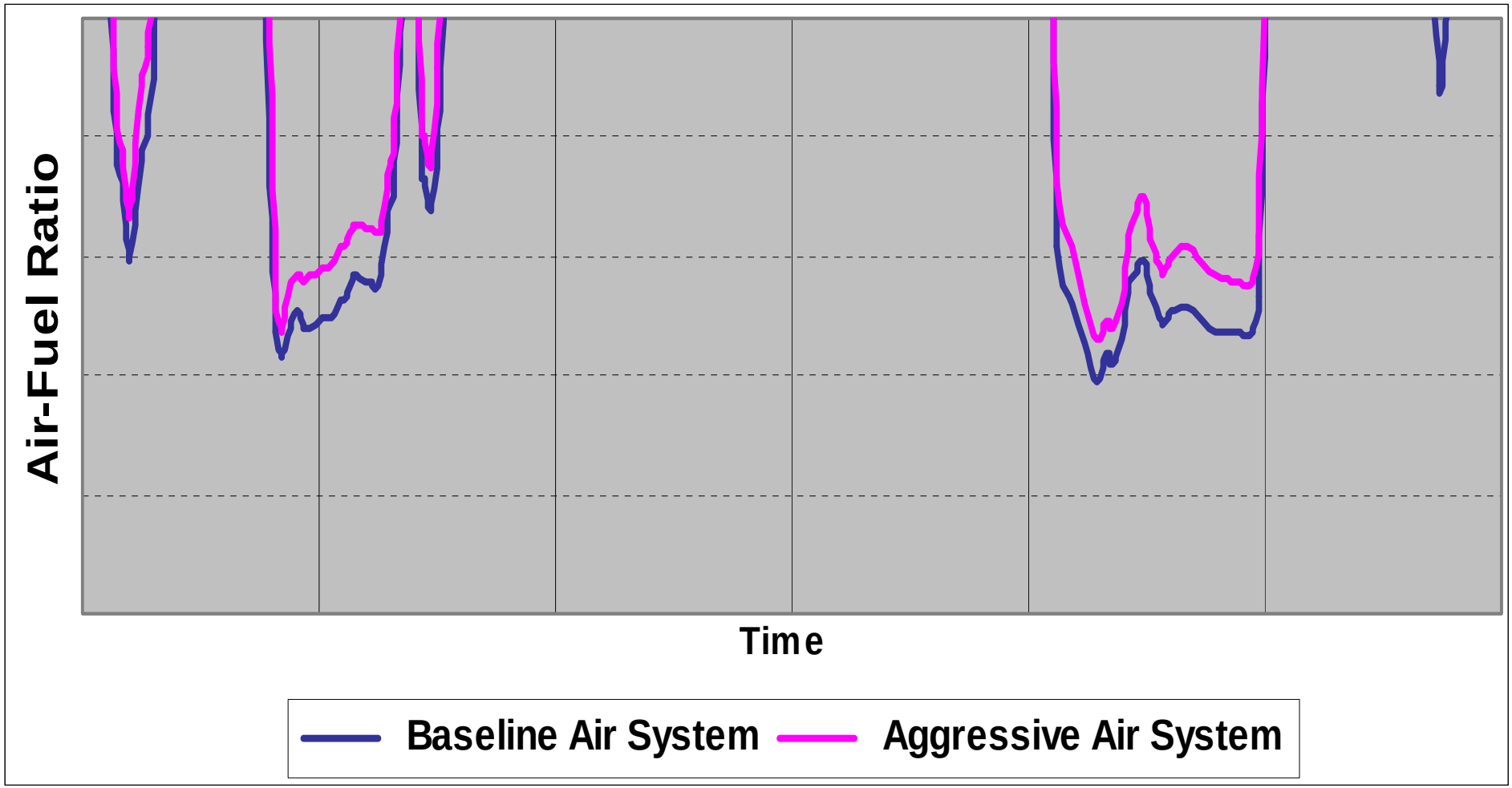
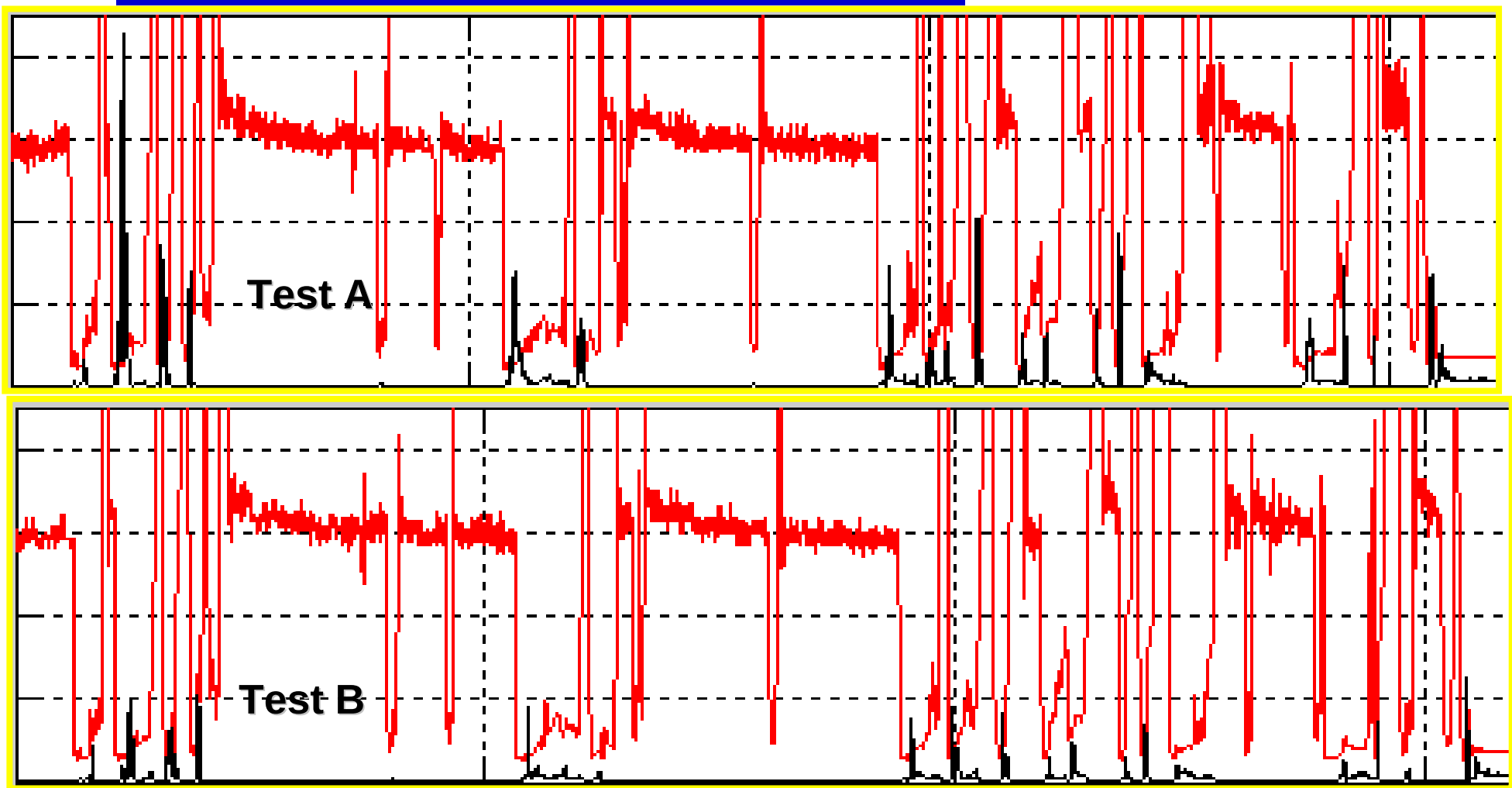
Intermediate Exhaust State Variable Sensing



Off-Line Transient Response to Design Revision



Experimentally Demonstrated Smoke Reduction During the FTP Test



What and When is It Appropriate to Develop, Then Implement ?

- » Gain Scheduling
- » Predictive Models
- » Self Learning / Optimizing
- » Nonlinear Compensating
- » Fuzzy Logic
- » Neural Nets
- » Chaos

Intelligent or Smart ?

Intelligent	Smart
As Originally Conceived	Learning by Experience
Inherent to the Family	Unique to the Individual
Focused on Local Influence	Focused on Global Impact
Intensive Calculations	Streamlined Estimations
Off-Line	On Board
Major Effort to Revise	Adaptable to Revision