Virtual Engine Calibration: DPF Regeneration Example

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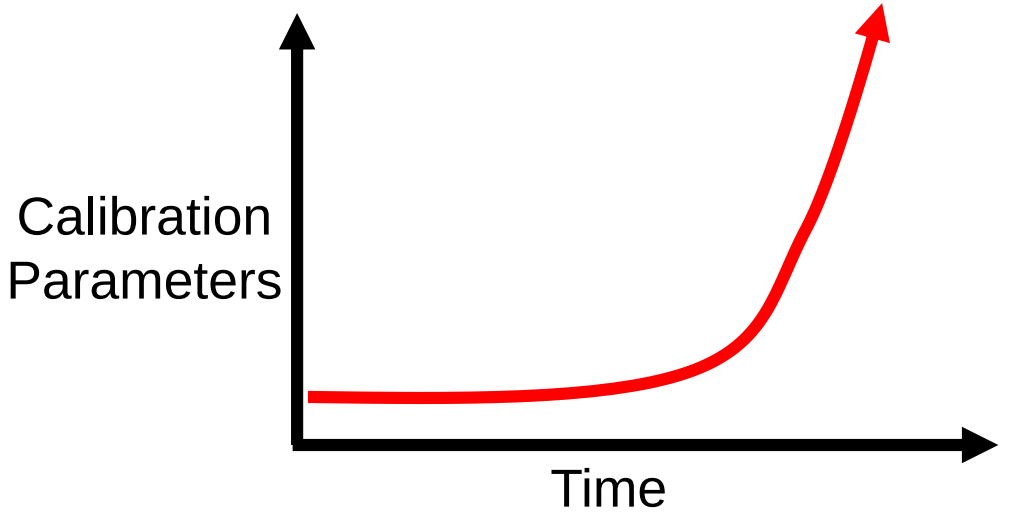
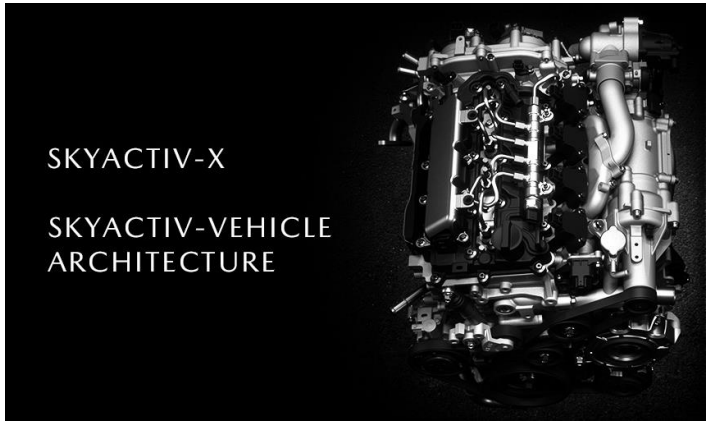
Outline

- Market drivers increasing calibration workload
- Building blocks for virtual calibration
  - Surrogate controller and plant models
  - Calibration support tools
  - Calibration Automation
- Example:
  - Automatically calibrate a diesel engine controller and plant
  - Assess DPF regeneration impact on fuel economy

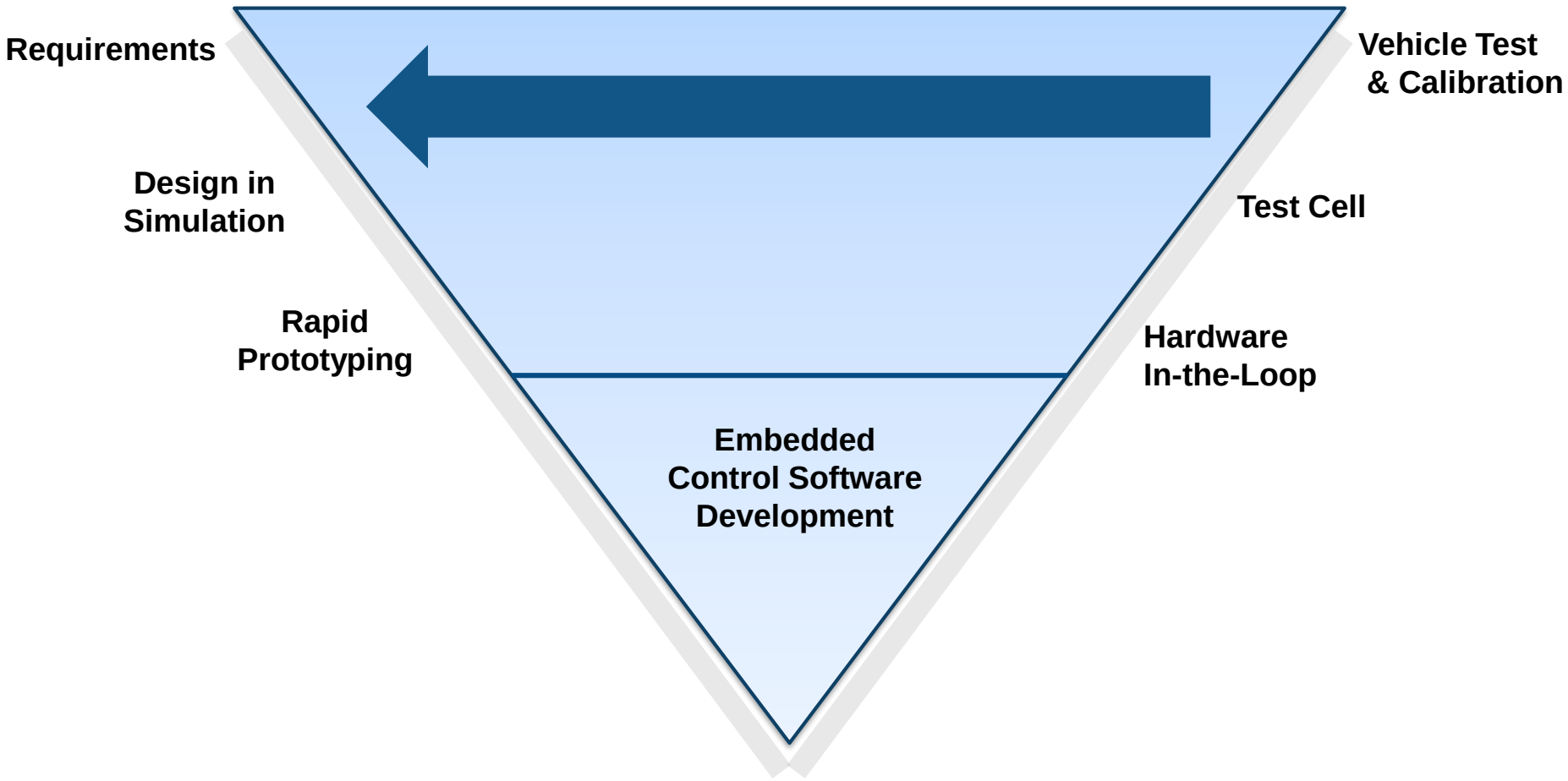
Market Drivers Increasing Calibration Workload

Pollutant	Euro 5 Light-Duty		Euro 6 Light-Duty	
	Gasoline	Diesel	Gasoline	Diesel
CO	1.0	0.5	1.0	0.5
HC	0.1[a]		0.1[e]	
$HC+NO_x$		0.23		0.17
NO_x	0.06	0.18	0.06	0.08
PM	0.005[c]	0.005	0.005[c]	0.005
PN (#/km)		6.0×10^{11}	6.0×10^{11} [d]	6.0×10^{11}





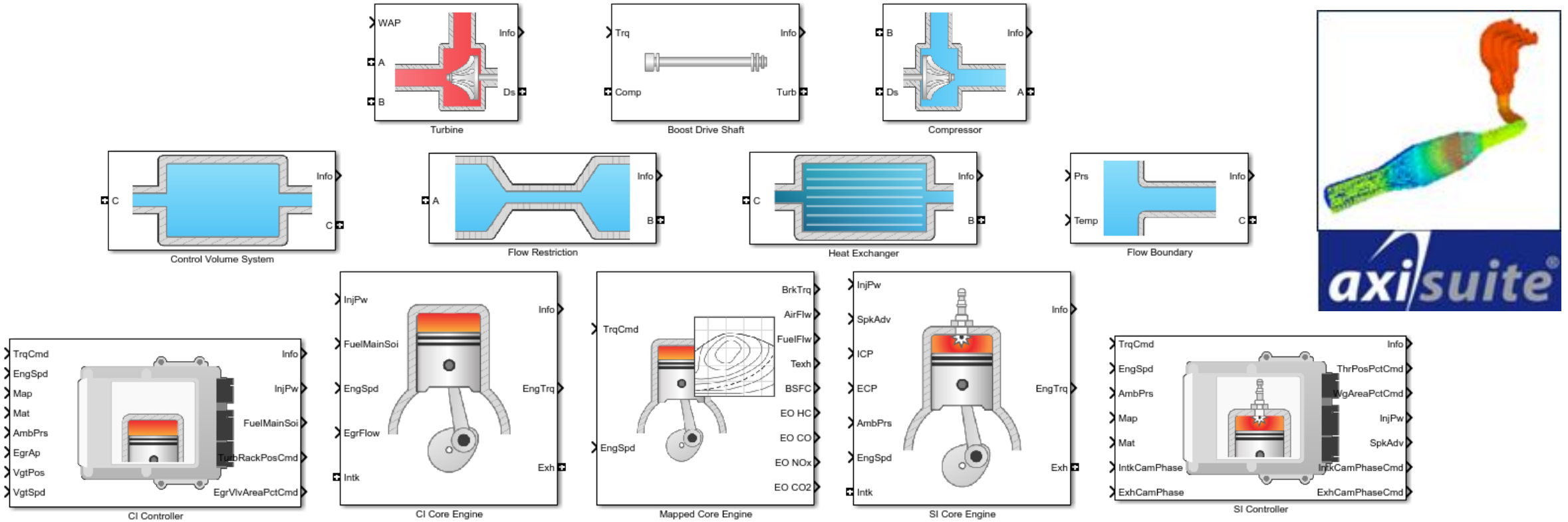
Virtual Calibration: Goal and Challenges



Need To Move Calibration Activities, Retain Measured Data Basis, Decrease Workload

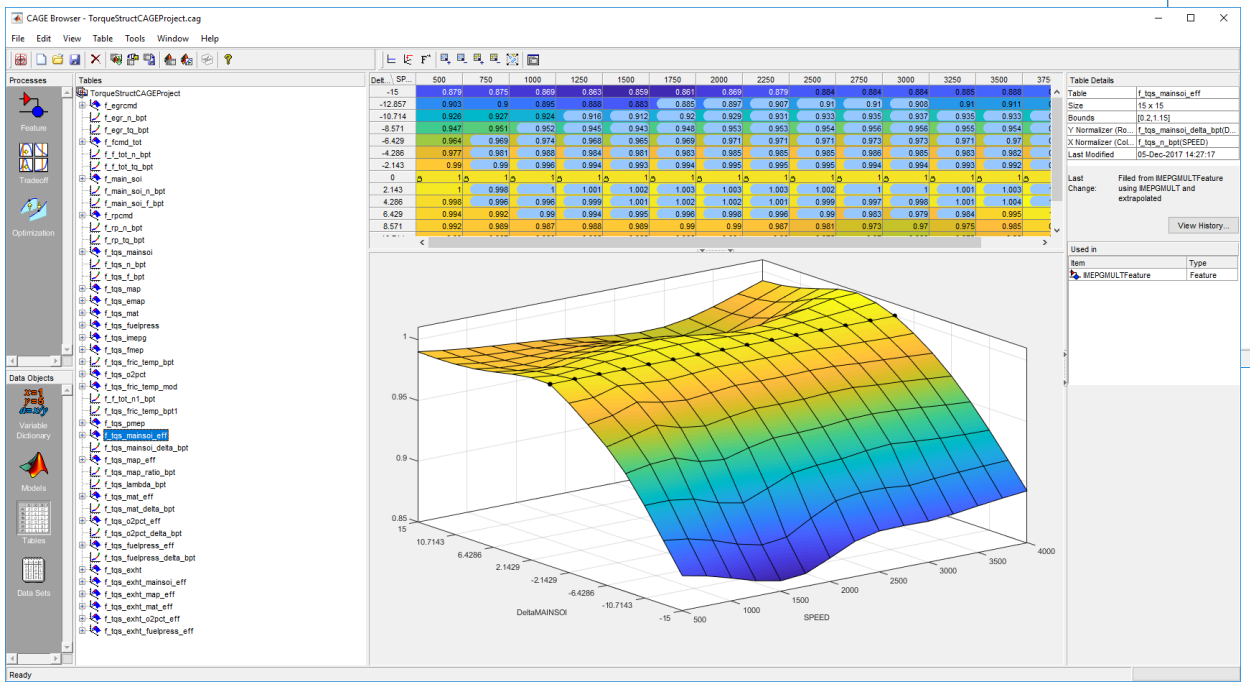
Surrogate Controller and Plant Models

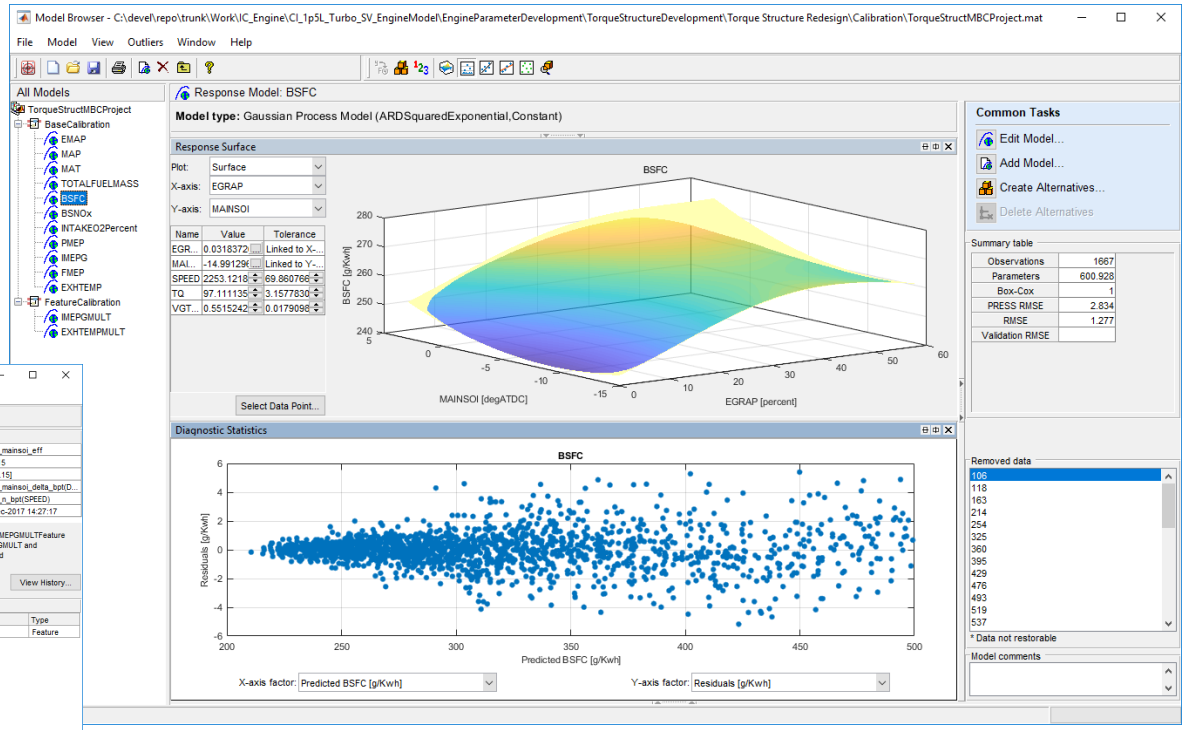
- Surrogate controller models
- Powertrain system models (aka plant models)



Calibration Support Tools: Model-Based Calibration Toolbox

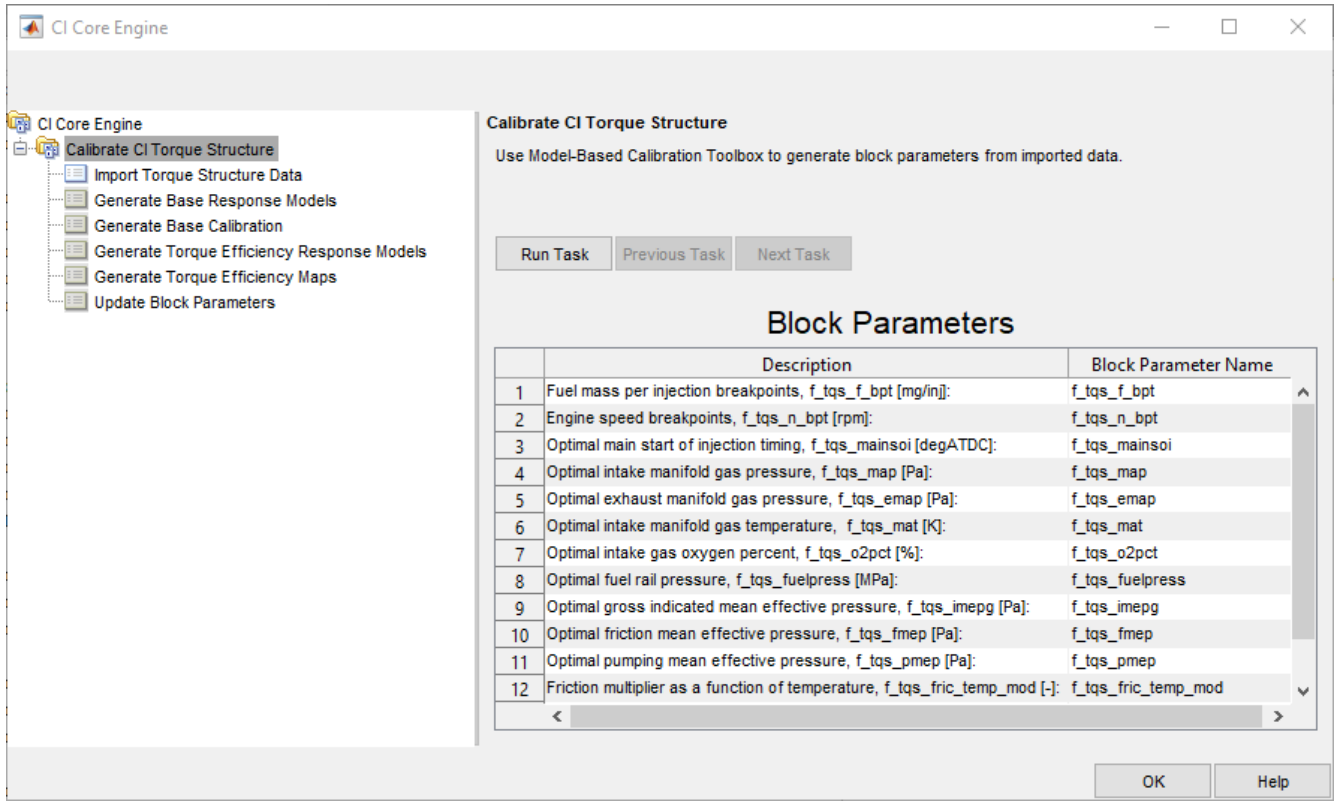
- Design of Experiments (DoE)
- Response Surface Modeling (RSM)
- Calibration Optimization





Calibration Automation

- Calibration automation tool
- Supports each step along the virtual calibration workflow



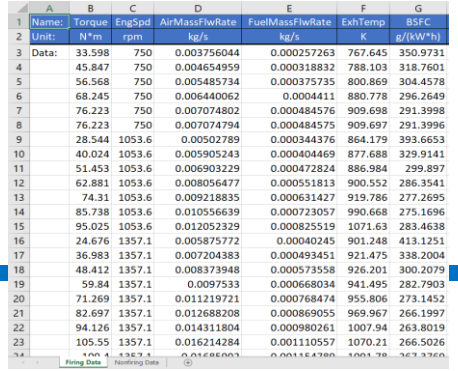
Calling other tools and accelerators in the background depending on the task

- Parallel Computing
- Statistics and Machine Learning
- Integration With Off-Shelf Blocks
- Calibration Report Generation

Building Blocks for Virtual Calibration

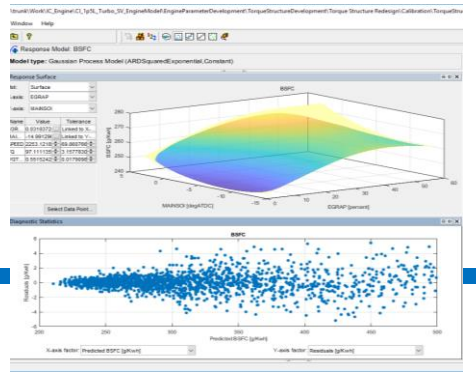
- Integration with existing data collection tool and measurement data
- Measurement data is essential to achieving high model quality

Set Up Hardware

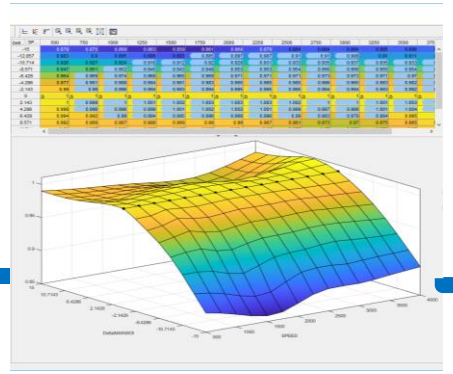


	A	B	C	D	E	F	G
1	Name:	Torque	EngSpd	AirMassFlwRate	FuelMassFlwRate	ExhTemp	BSFC
2	Unit:	N*m	rpm	kg/s	kg/s	K	g/(kW*h)
3	Data:	33.598	750	0.003756044	0.000257263	767.645	350.9731
4		45.847	750	0.004654959	0.000318832	788.103	318.7601
5		56.568	750	0.005485734	0.000375735	800.869	304.4578
6		68.245	750	0.006440062	0.0004411	880.778	296.2649
7		76.223	750	0.007074802	0.000484576	909.698	291.3998
8		76.223	750	0.007074794	0.000484575	909.697	291.3996
9		28.544	1053.6	0.00502789	0.000344376	864.179	393.6653
10		40.024	1053.6	0.005905243	0.000404469	877.688	329.9141
11		51.453	1053.6	0.006903229	0.000472824	886.984	299.897
12		62.881	1053.6	0.008056477	0.000551813	900.552	286.3541
13		74.31	1053.6	0.009218835	0.000631427	919.786	277.2695
14		85.738	1053.6	0.010556639	0.000723057	990.668	275.1696
15		95.025	1053.6	0.012052329	0.000825519	1071.63	283.4638
16		24.676	1357.1	0.005875772	0.00040245	901.248	413.1251
17		36.983	1357.1	0.007204383	0.000493451	921.475	338.2004
18		48.412	1357.1	0.008373948	0.000573558	926.201	300.2079
19		59.84	1357.1	0.0097533	0.000668034	941.495	282.7903
20		71.269	1357.1	0.011219721	0.000768474	955.806	273.1452
21		82.697	1357.1	0.012688208	0.000869055	969.967	266.1997
22		94.126	1357.1	0.014311804	0.000980261	1007.94	263.8019
23		105.55	1357.1	0.016214284	0.001110557	1070.21	266.5026

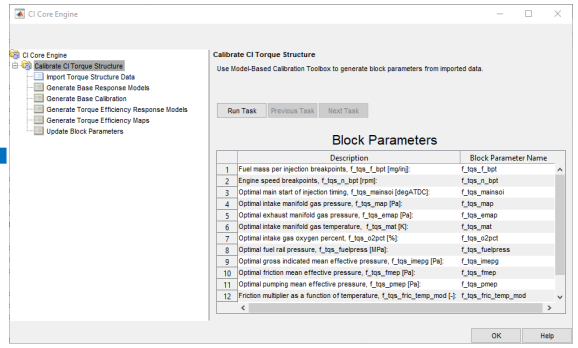
Measure



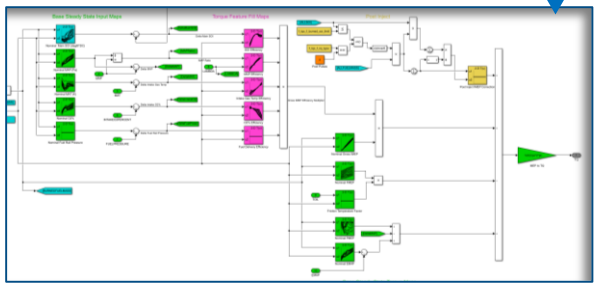
Model Response



Optimize Control



Orchestrate With Calibration Automation



Embed

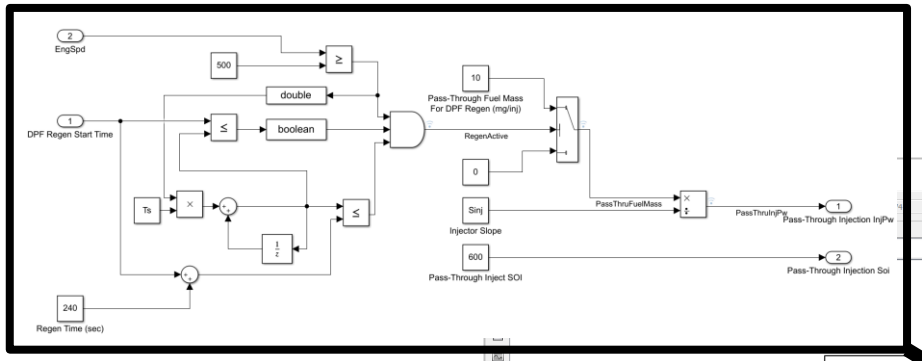
Virtual Calibration Example

- Problem statement:

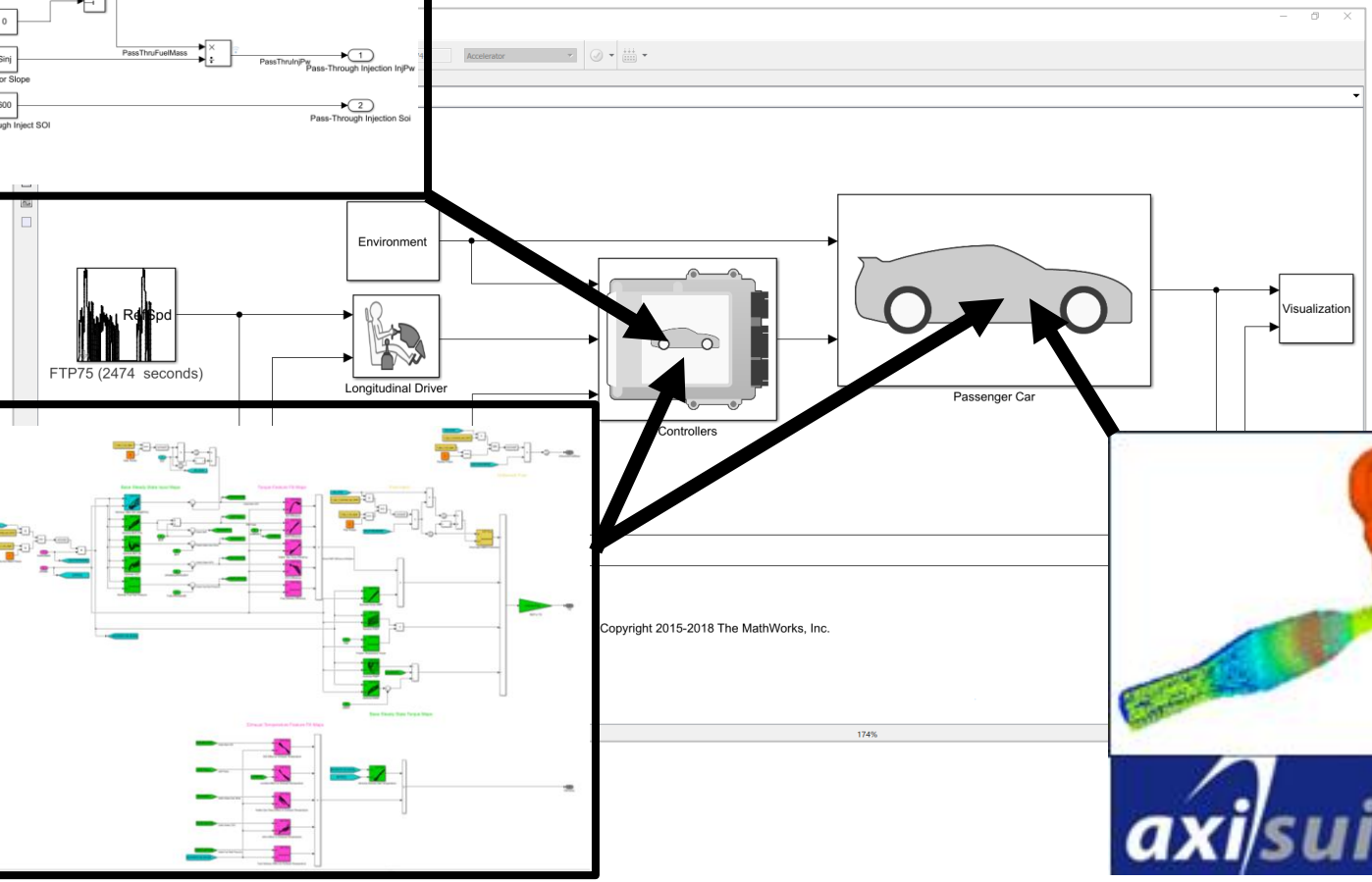
  Design diesel particulate filter (DPF) regeneration post-fueling logic and assess fuel economy impact of regeneration event.

- Solution
  - Use Powertrain Blockset as starting point for system model
  - Use calibration automation tool for plant and controller torque structure model
    - Model-Based Calibration Toolbox
  - Add DPF regeneration post-inject fueling logic and DPF plant
  - Assess fuel economy impact at vehicle level on US-FTP75 drive-cycle

Powertrain Blockset as a framework for the solution



DPF Regen Logic

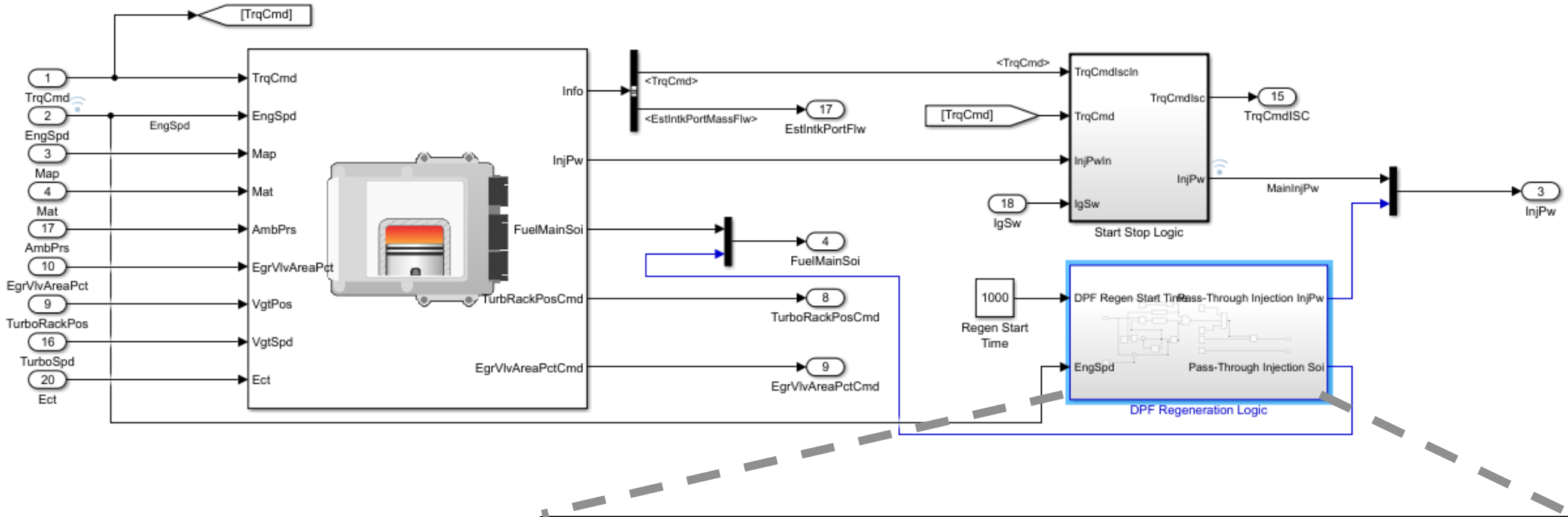


22 coupled calibration tables

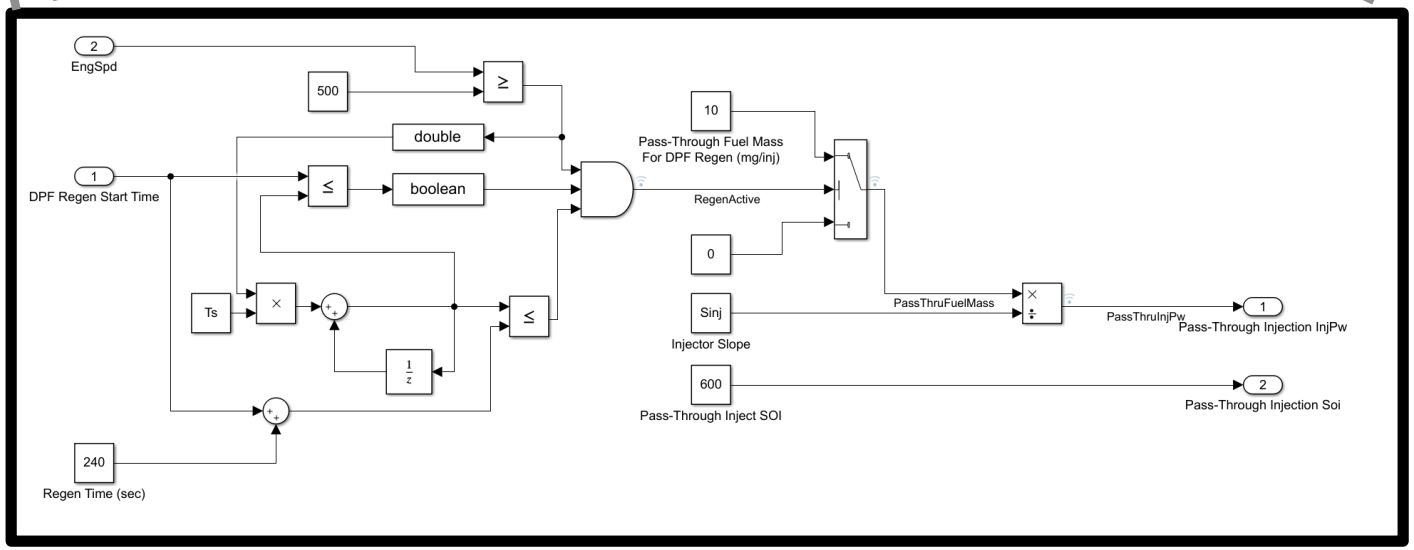
Torque Structure Used As Estimator and Plant

Exothermia Aftertreatment Plant

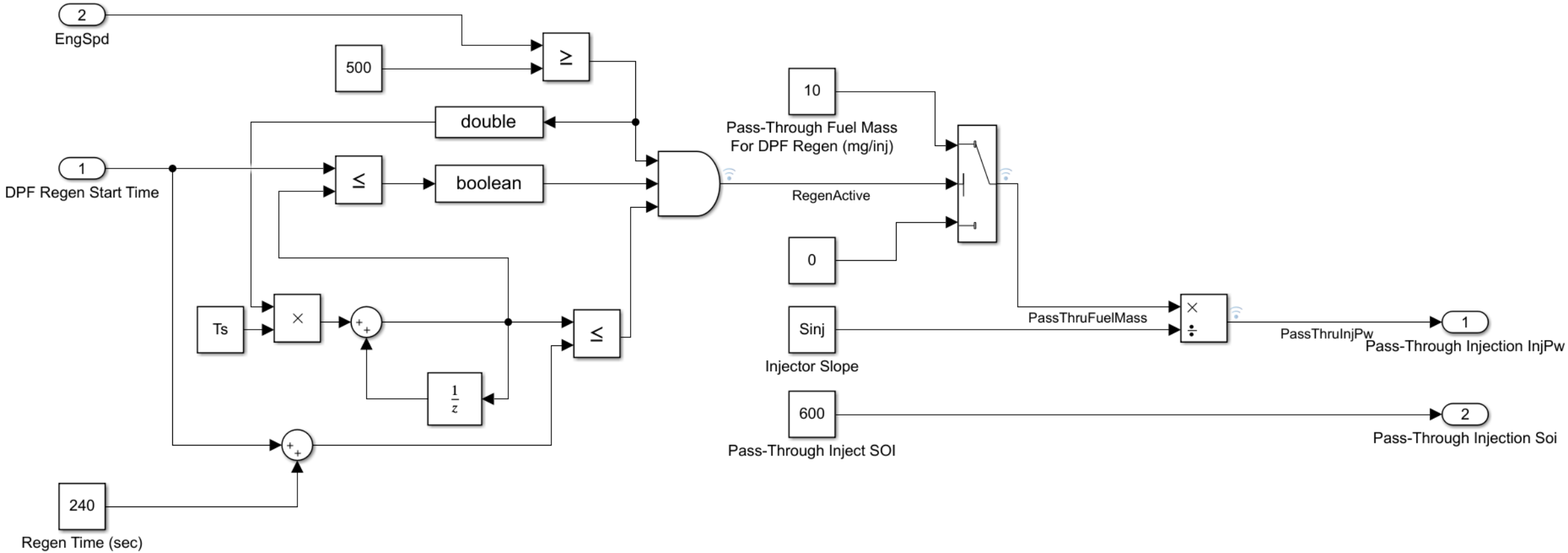
Powertrain Blockset as a framework for the solution



Controller Modification for DPF Regeneration



Powertrain Blockset as a framework for the solution



Controller Modification for DPF Regeneration

Calibration Automation Tool

Import Data

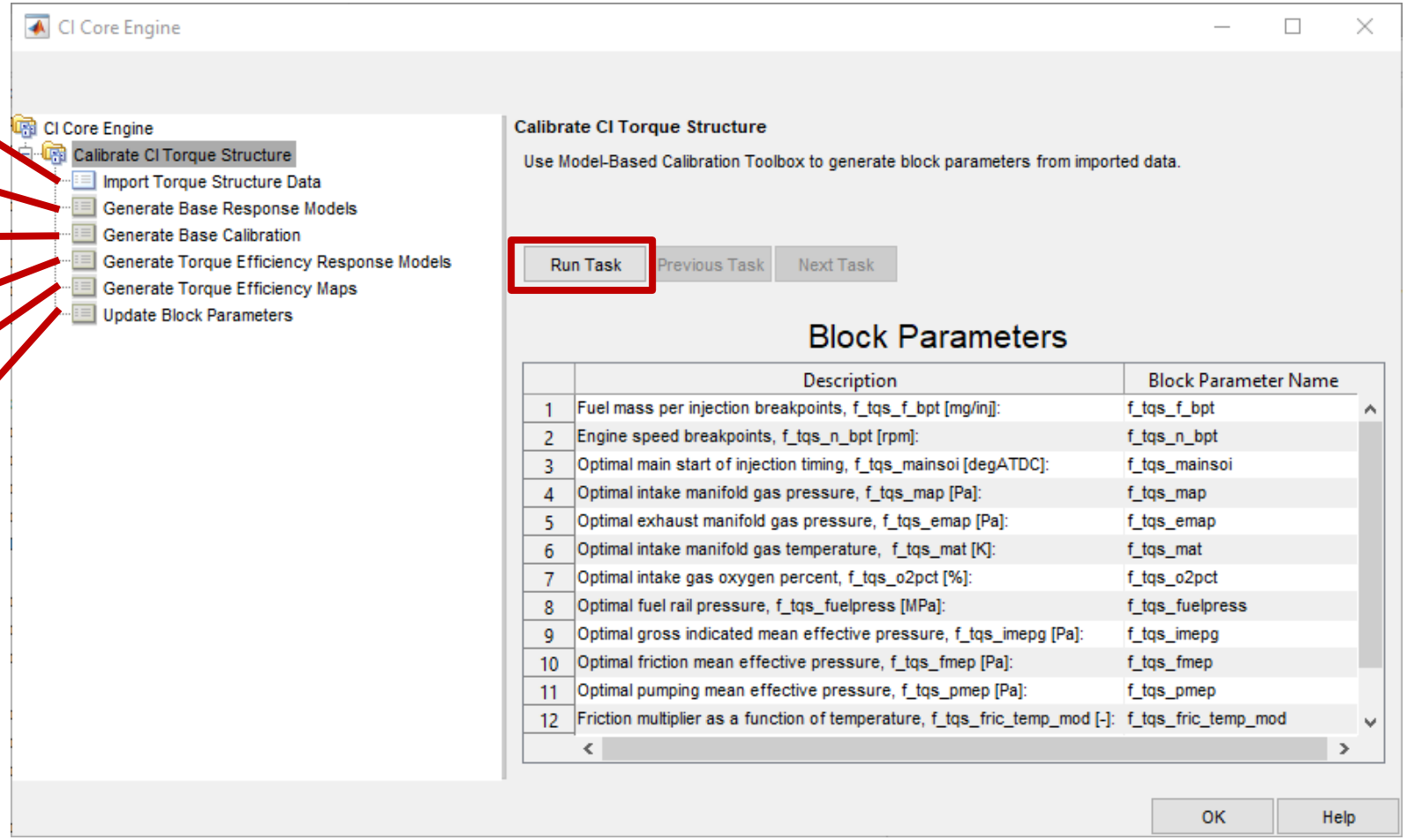
Base Calibration Model Fit

Base Calibration Map Generation

Torque Efficiency Model Fit

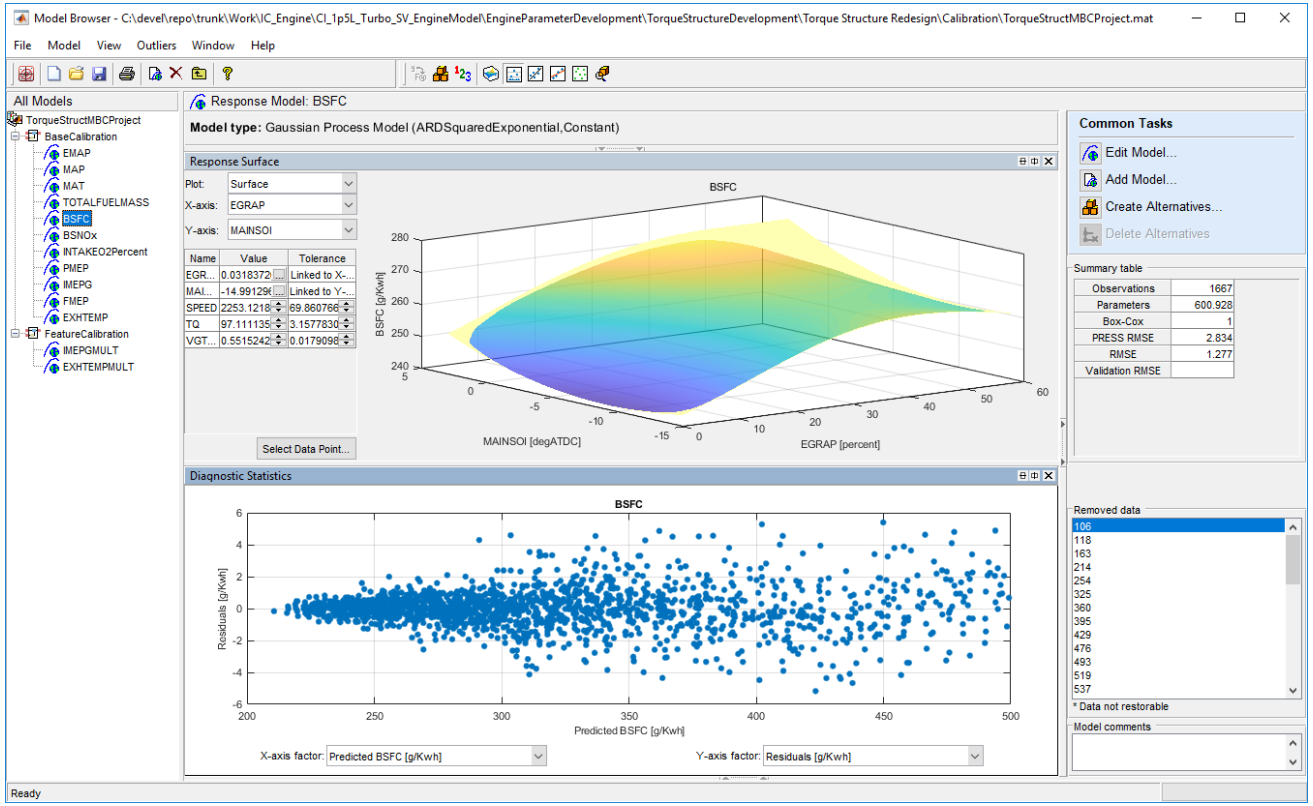
Torque Efficiency Map Generation

Update Lookup Table Maps in Simulink



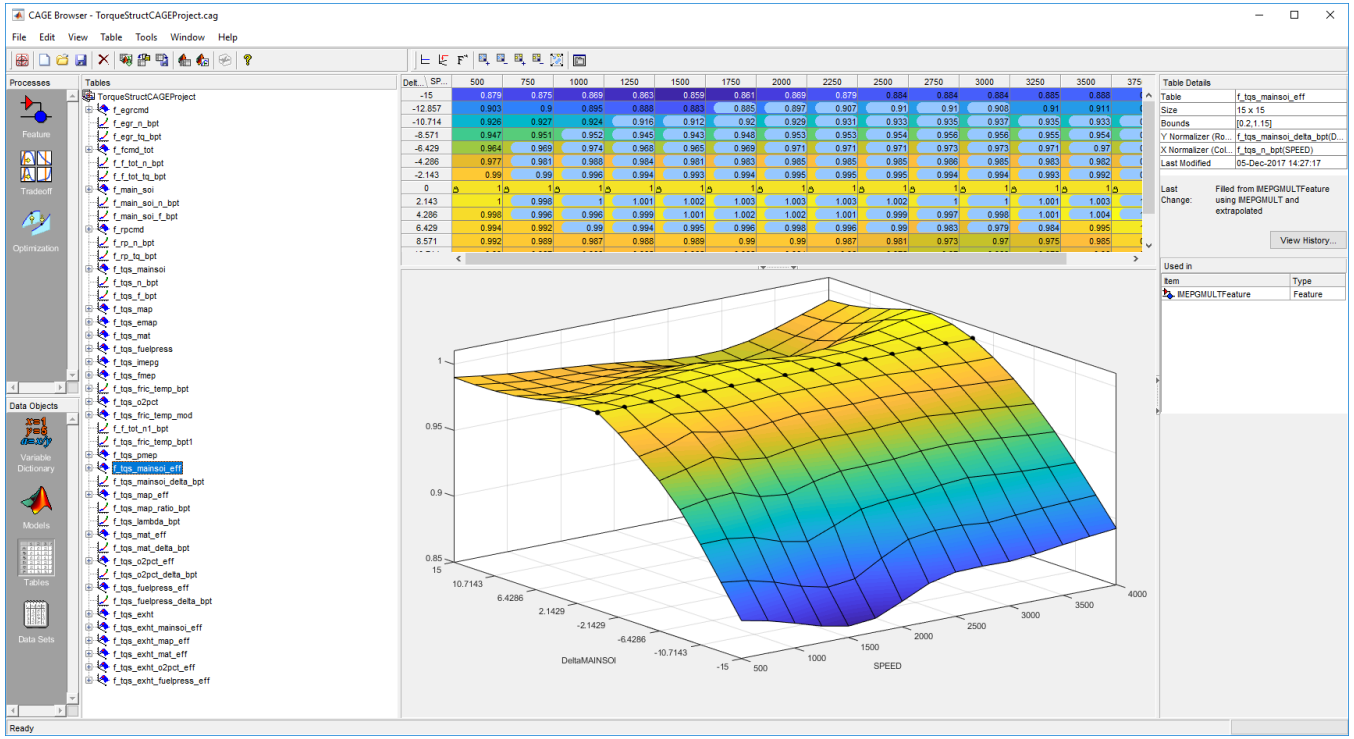
Calibration Support: Model-Based Calibration Toolbox Template

- User provides spreadsheet data
  - Torque
  - Fuel
  - BSFC
  - Etc.
- MBC builds model automatically
  - Engines
  - Turbochargers
- MBC/CAGE writes calibrations to model
- User can open MBC to inspect and modify results

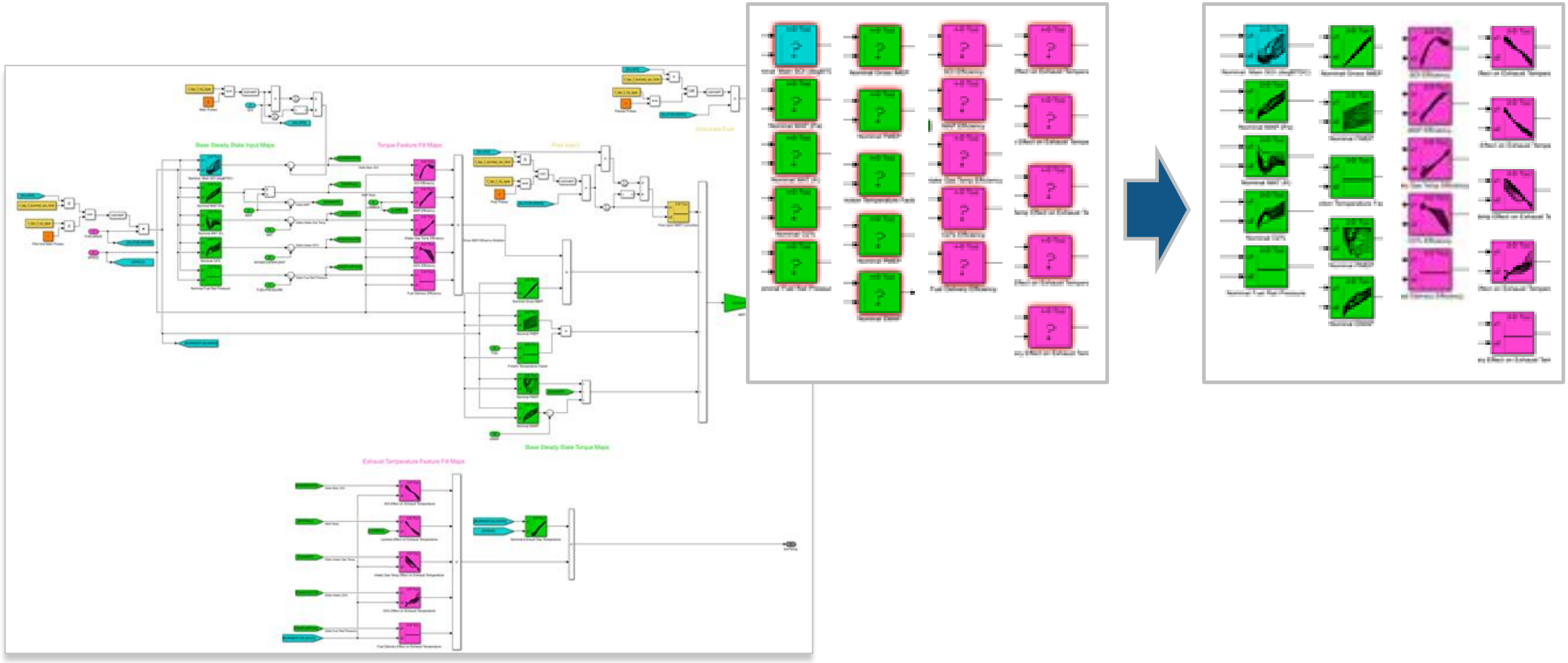


Calibration Support: Model-Based Calibration Toolbox Template

- Increase productivity
  - Less hands-on interaction
  - Uniform data
- Leverage the power of MBC
  - Statistics
  - Optimization



Result: Automated Filling of Calibration Tables in the Torque Structure



Result: Determined Active DPF Regen Fuel Economy Impact

8.7% Increase in fuel consumption due to DPF Regen on USFTP75

Summary

- Market drivers increasing calibration workload
- MathWorks provides building blocks for virtual calibration
  - Surrogate controller and plant models : open and useful for new and advanced users
  - Calibration support tools
  - Calibration Automation
- We look forward to supporting you and taking the tooling for virtual calibration to the next level

Questions?