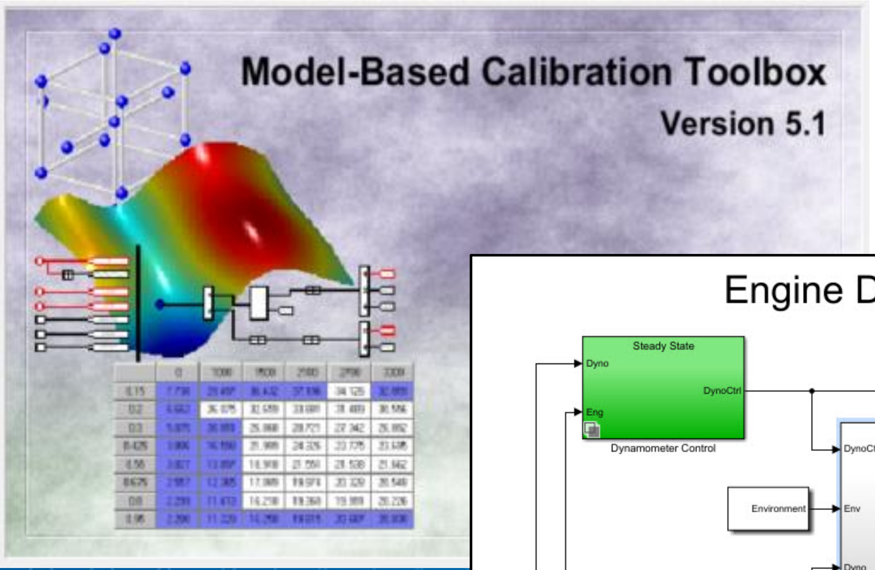
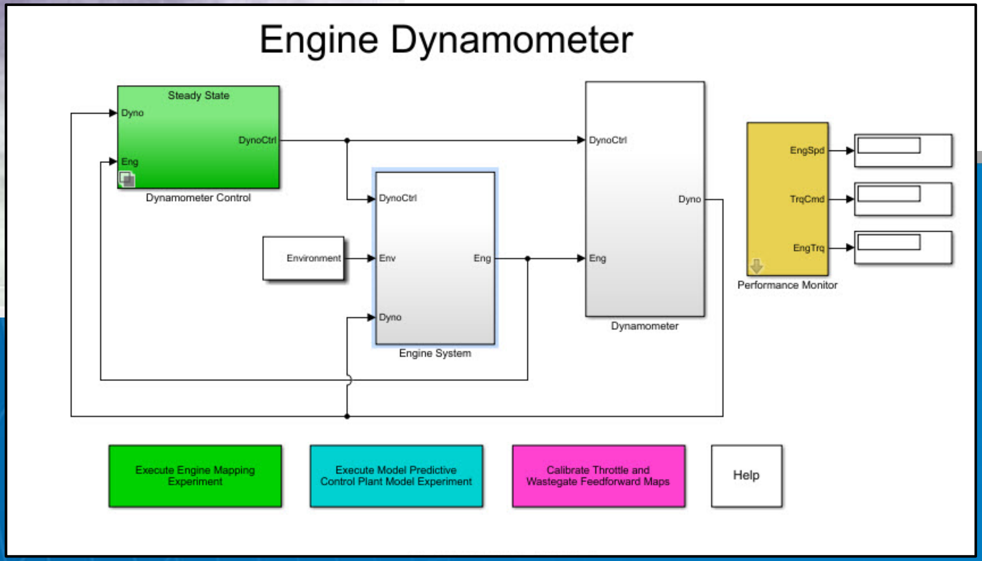
Engine Plant Model Development and Controller Calibration using Powertrain Blockset^{TM}

Brad Hieb — Application Engineering
Scott Furry — Consulting Services





Key Take-Away's

- Engine model parameterization is a very non-trivial task
- Engine controller calibration is a very non-trivial task
- **MathWorks has tools to help make these two tasks more manageable**

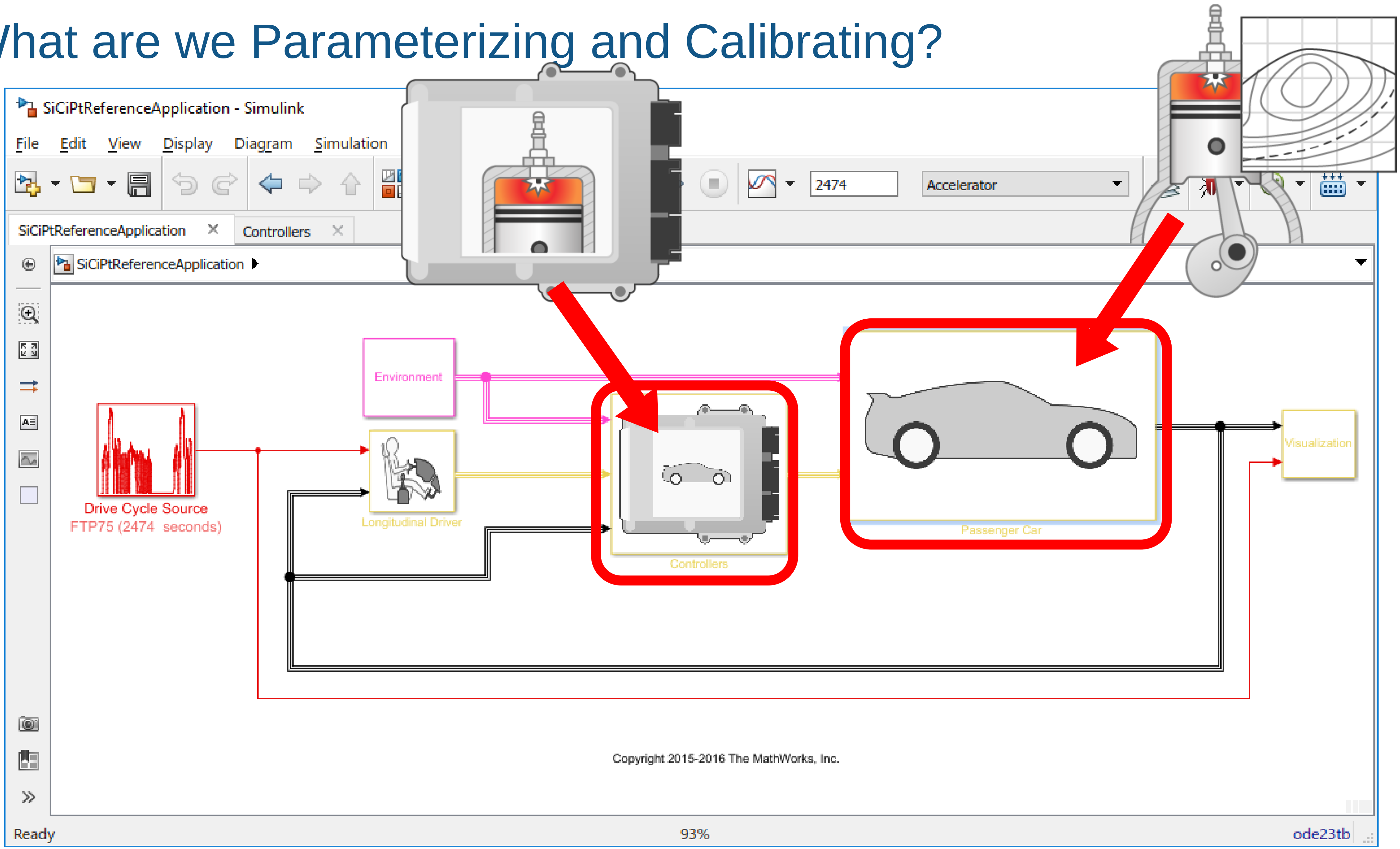
Problem Statement

- How do I use the Powertrain Blockset engine and controller models for my application so I can:
  - Design engine controls?
  - Perform fuel economy and emissions studies?
  - Create and validate dynamometer test plans?

What we'll Cover Today

- Parameterizing a Powertrain Blockset engine model
  - Workflow
  - Example: parameterizing a mapped engine model
- Calibrating a Powertrain Blockset engine controller
  - Workflow
  - Example: calibrating an engine controller

What are we Parameterizing and Calibrating?



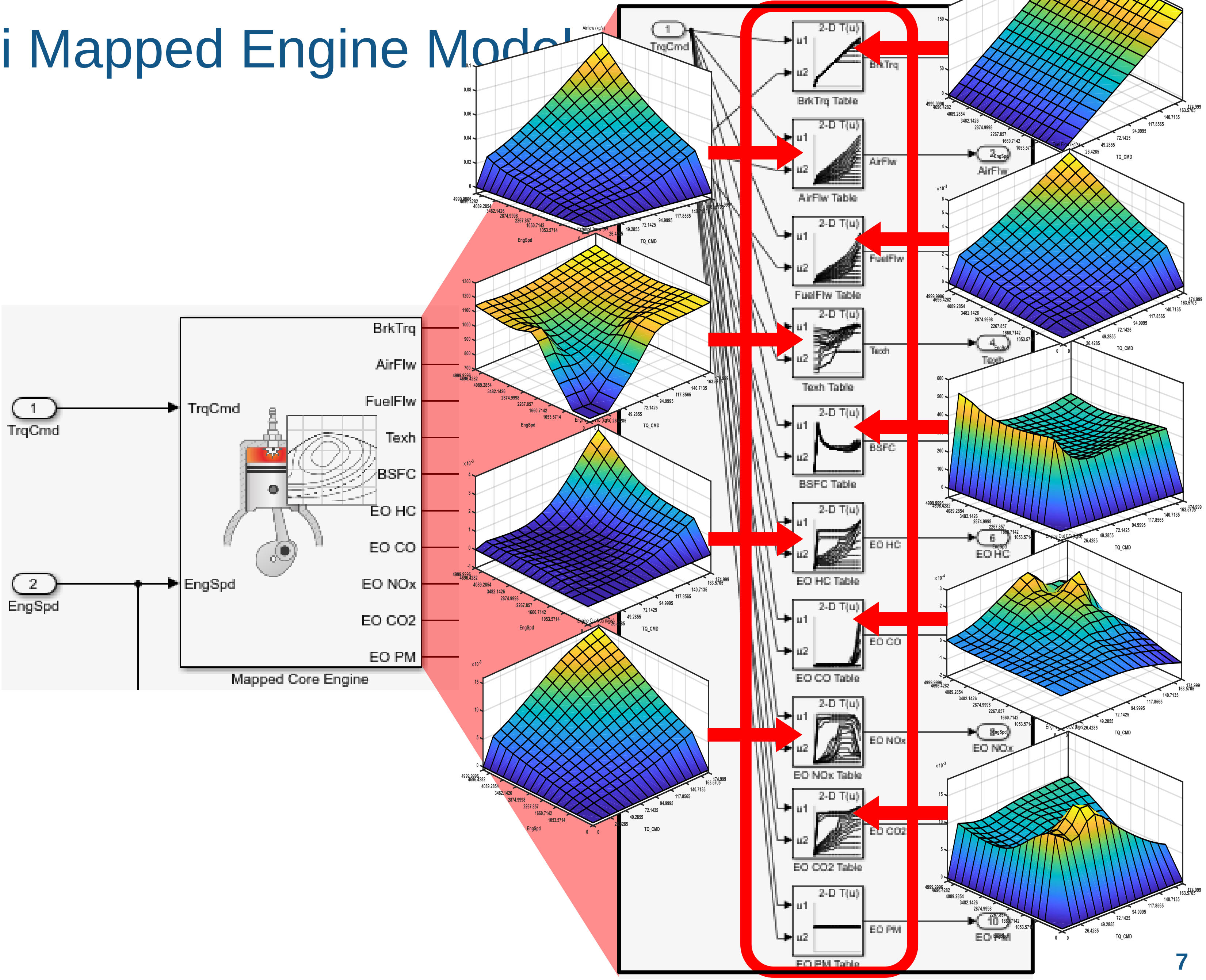
What we'll Cover Today

- **Parameterizing a Powertrain Blockset engine model**
  - **Workflow**
  - **Example: parameterizing a mapped engine model**

- Calibrating a Powertrain Blockset engine controller
  - Workflow
  - Example: calibrating an engine controller

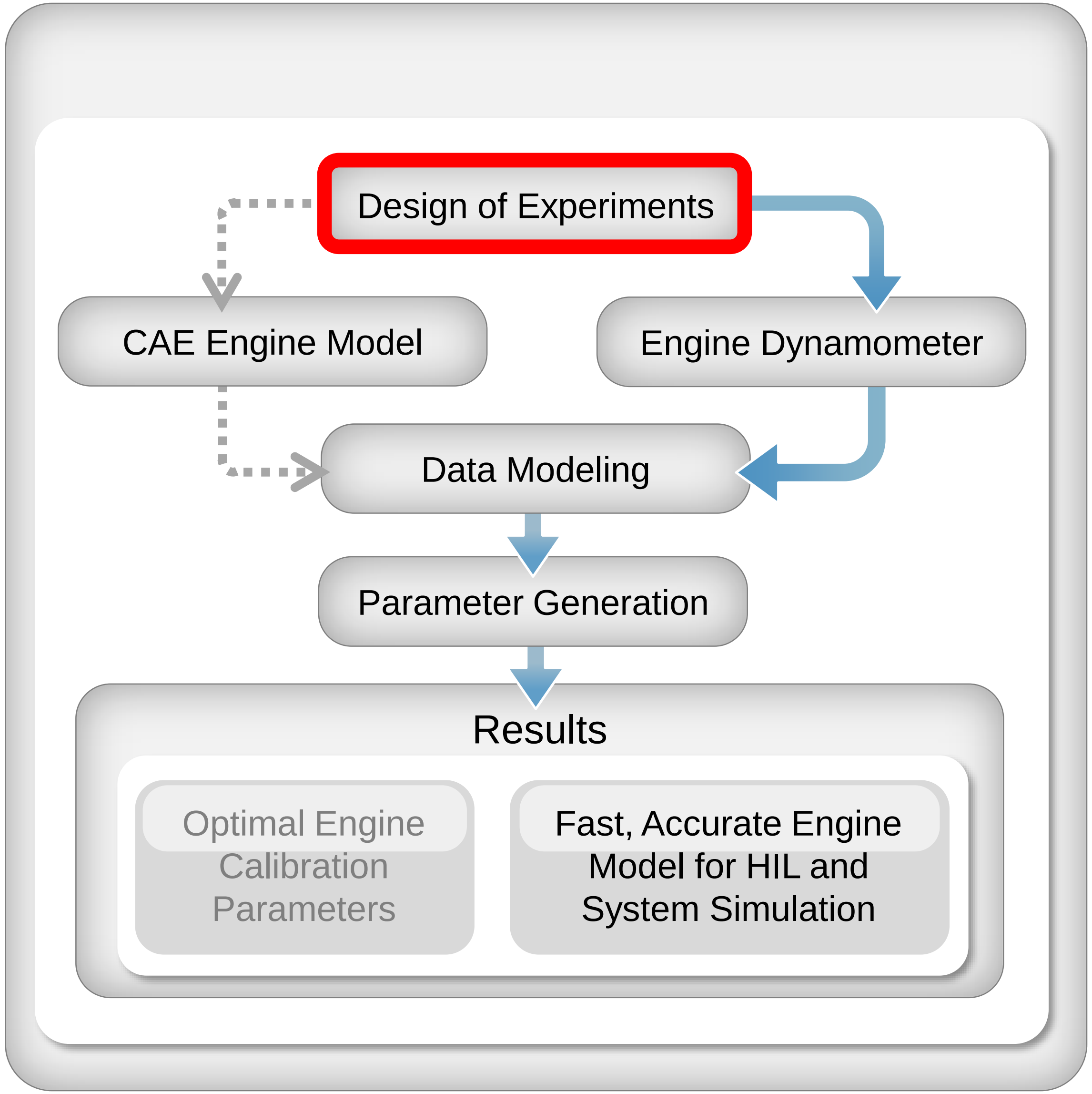
Powertrain Blockset Si Mapped Engine Model

- Contains 2D LUT’s for each model output
- Easy to parameterize
- Great for system level design and development



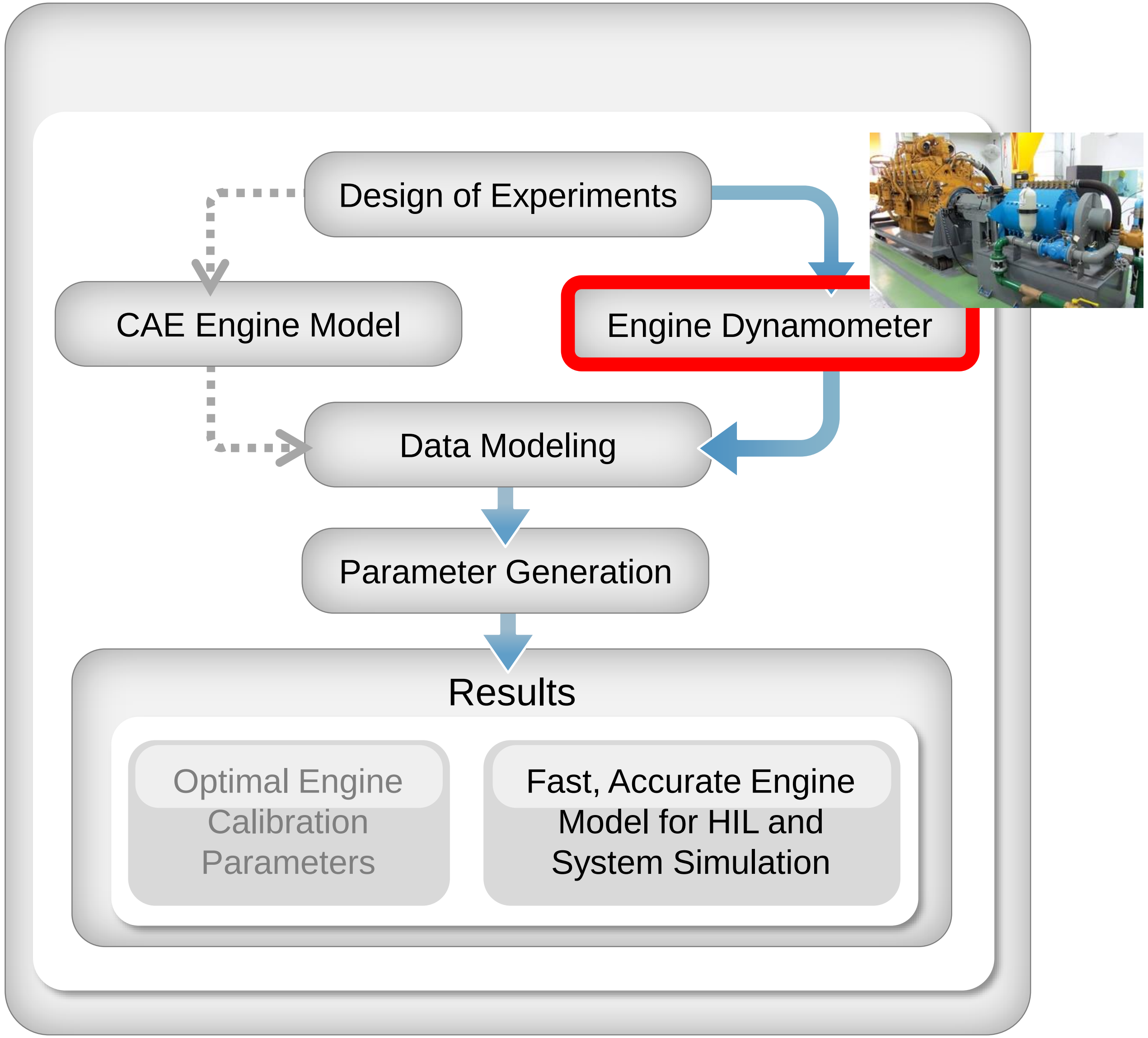
Parameterizing an Engine Model
- Workflow

- Model-Based Calibration Toolbox provides tools for the process:
  - **Creating the Design of Experiments**



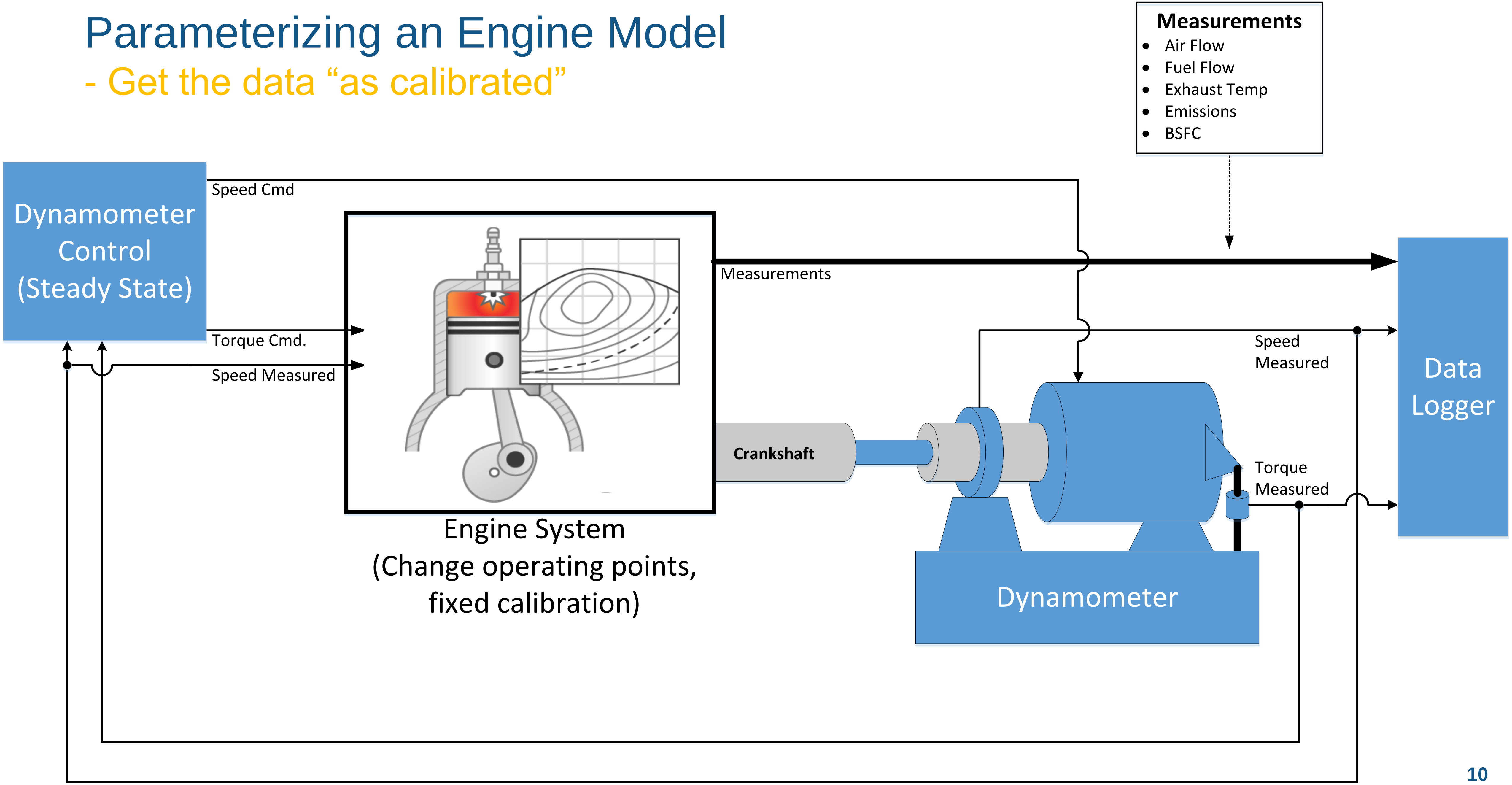
Parameterizing an Engine Model
- Workflow

- Model-Based Calibration Toolbox provides tools for the process:
  - Creating the Design of Experiments
  - **Gather the data**



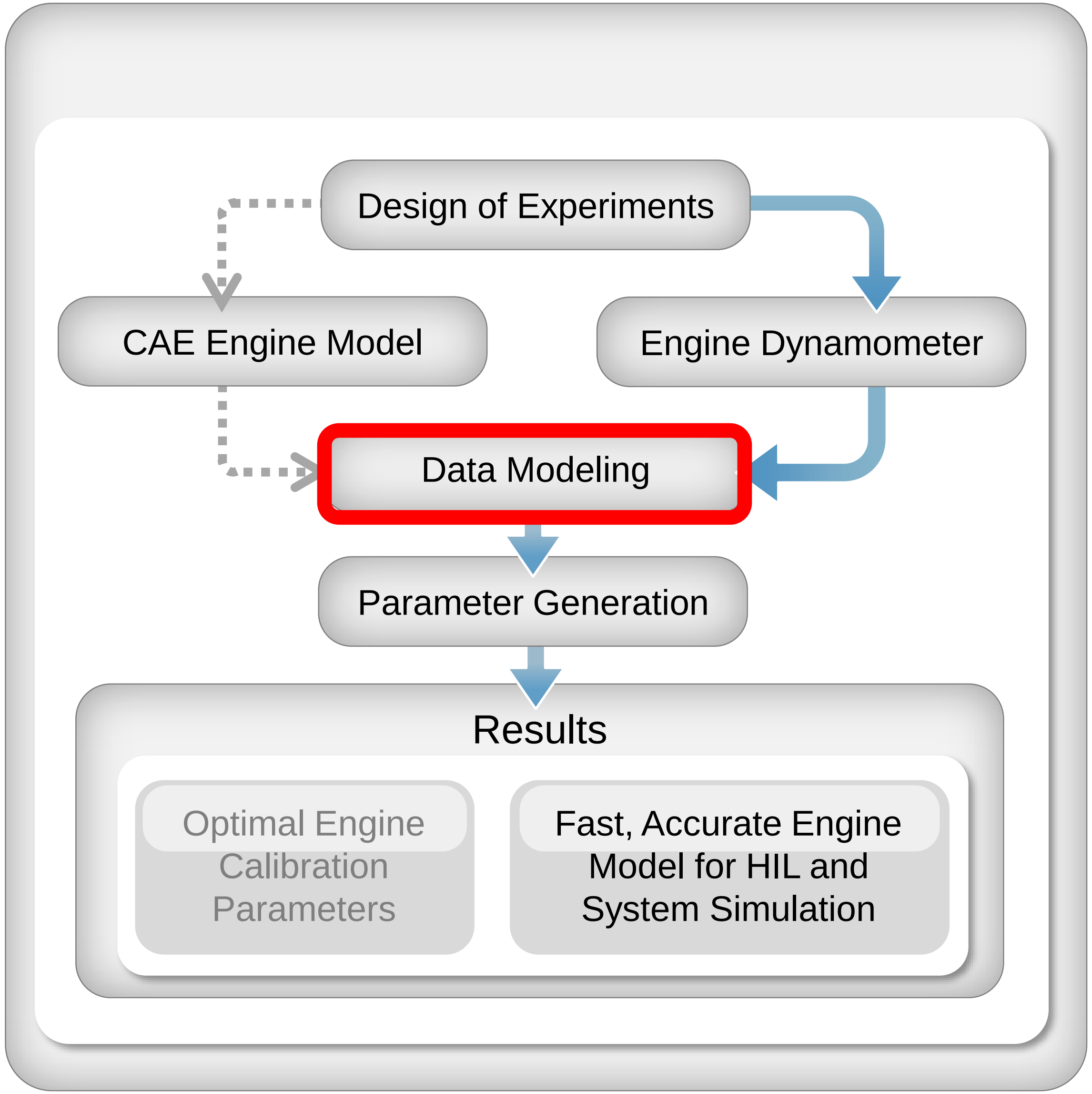
Parameterizing an Engine Model

- Get the data "as calibrated"



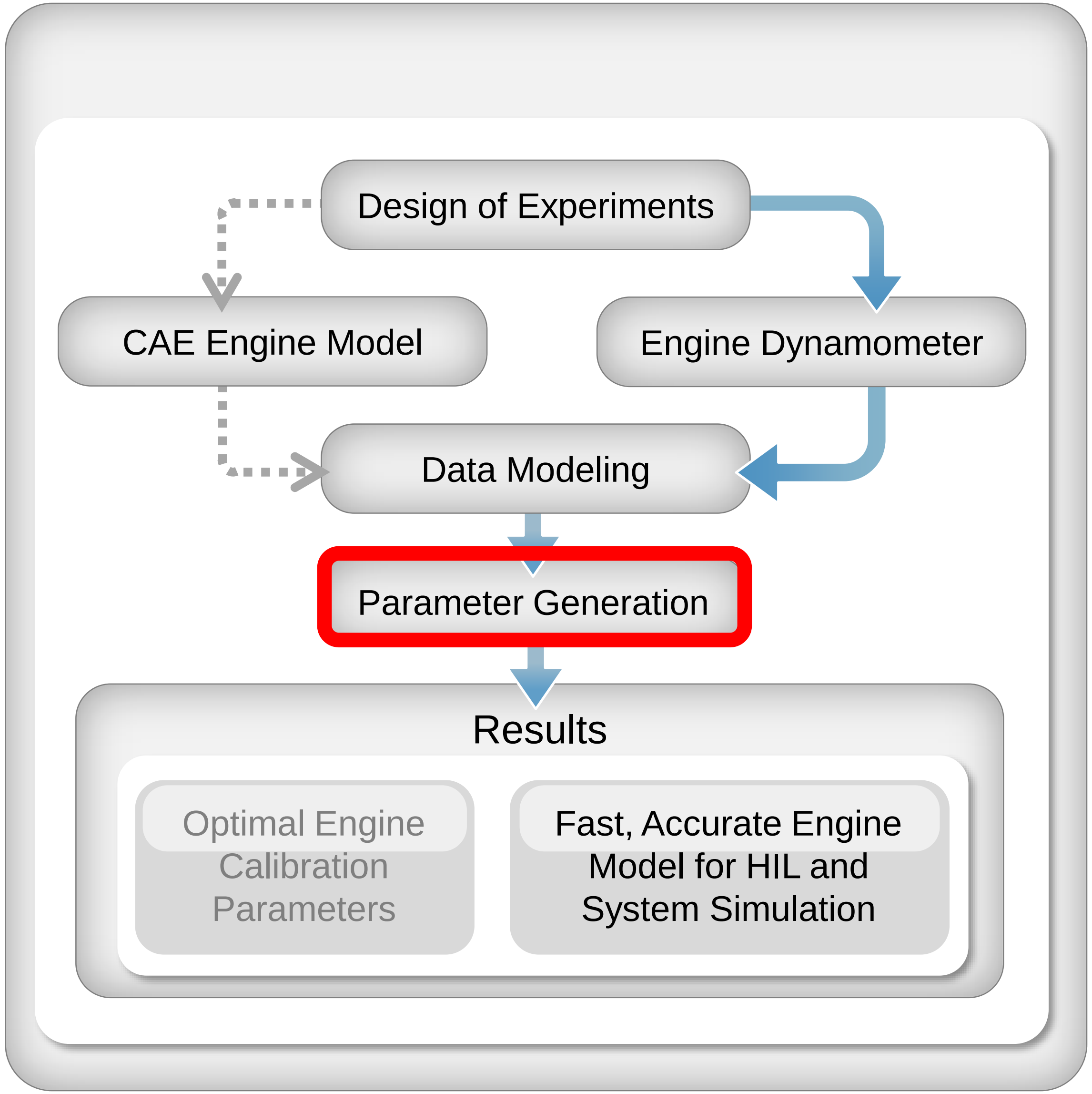
Parameterizing an Engine Model
- Workflow

- Model-Based Calibration Toolbox provides tools for the process:
  - Creating the Design of Experiments
  - Gather the data
  - **Fitting response surface models (RSM, statistical) to the data**



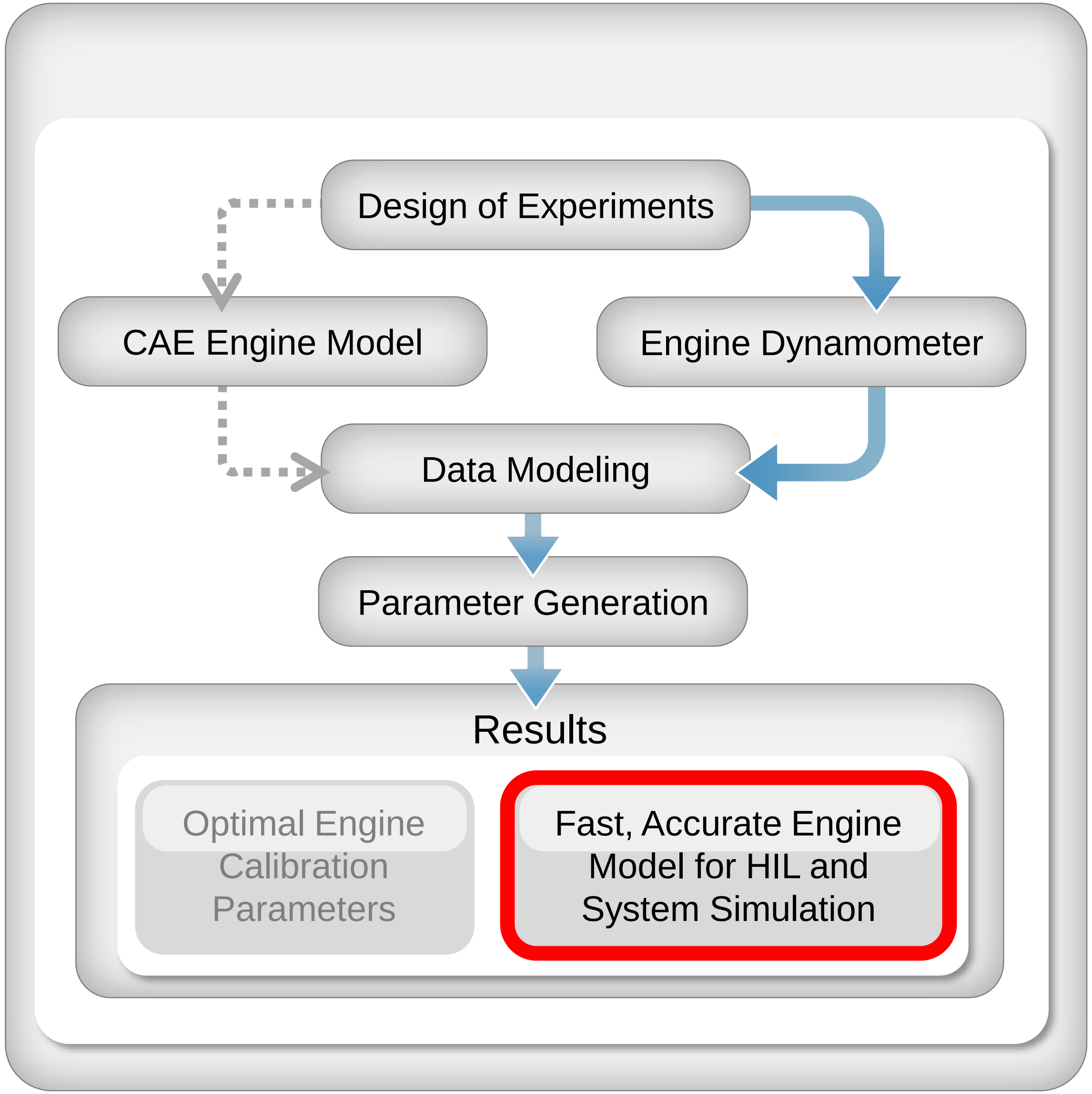
Parameterizing an Engine Model
- Workflow

- Model-Based Calibration Toolbox provides tools for the process:
  - Creating the Design of Experiments
  - Gather the data
  - Fitting response surface models
  - **Developing engine performance maps from RSM’s**



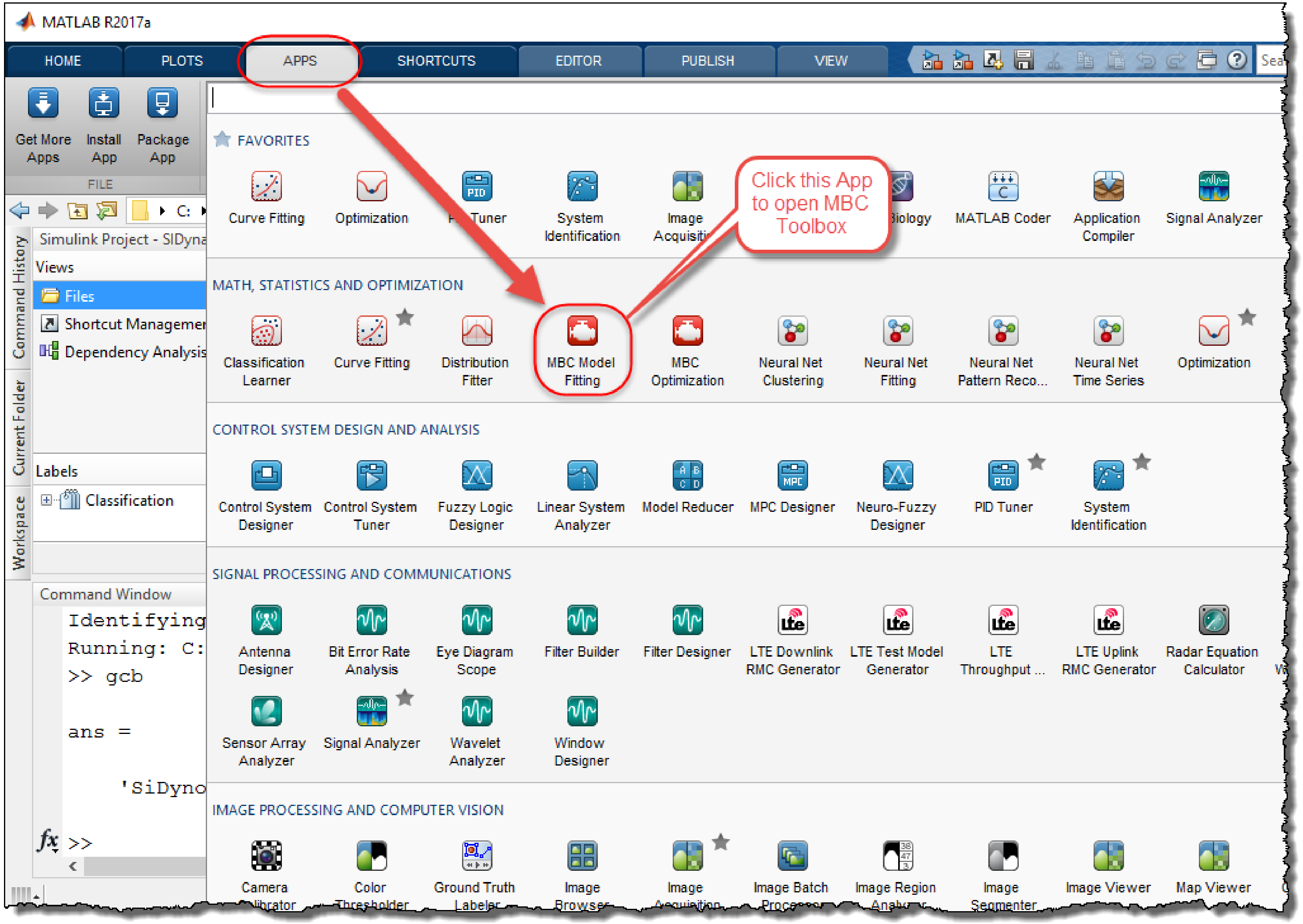
Parameterizing an Engine Model
- Workflow

- Model-Based Calibration Toolbox provides tools for the process:
  - Creating the Design of Experiments
  - Gather the data
  - Fitting response surface models
  - Developing engine performance maps
  - **Validate the result**

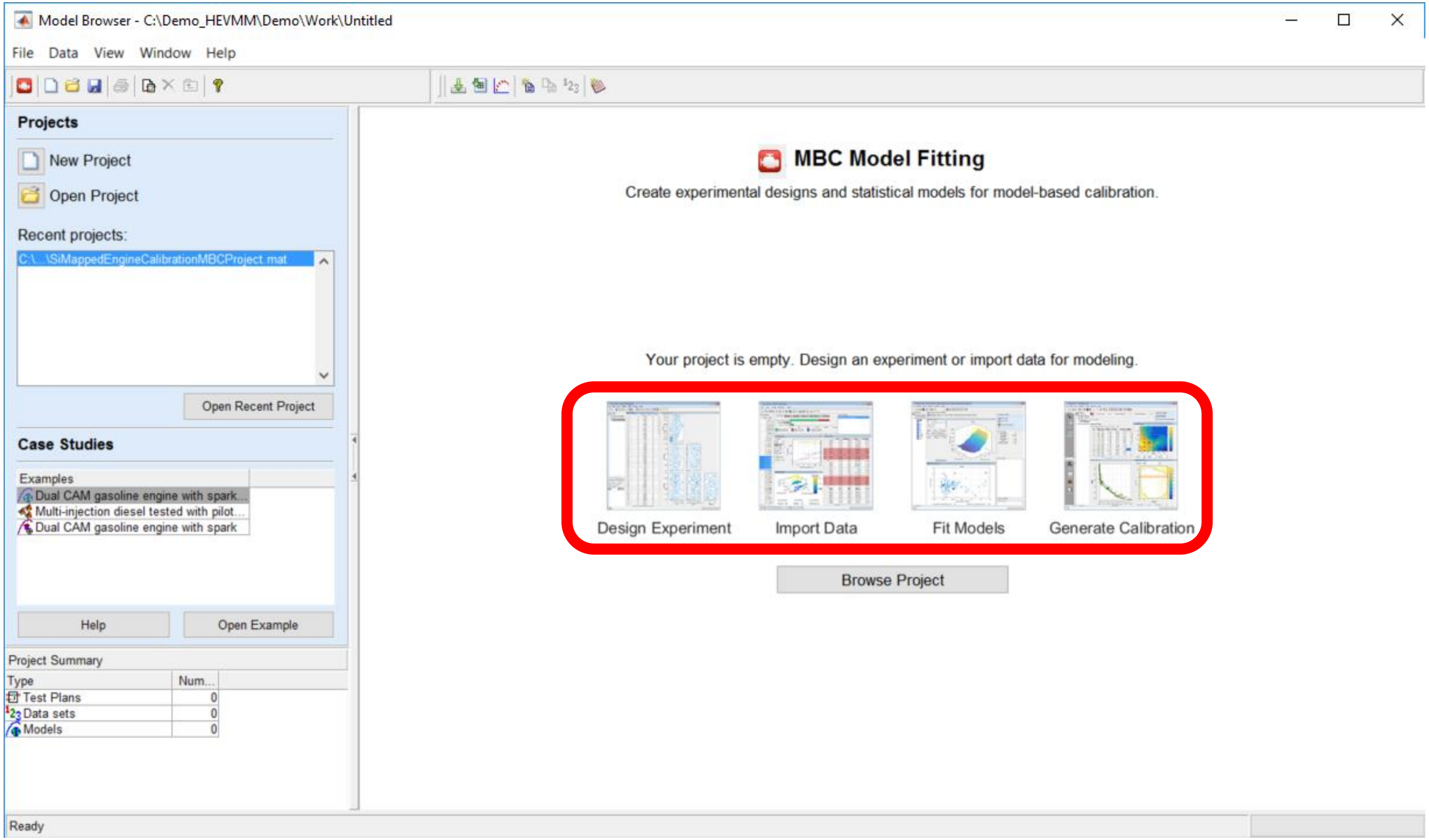


Launch MBC Toolbox

- From Apps tab
- From command line
  >> mbcmodel



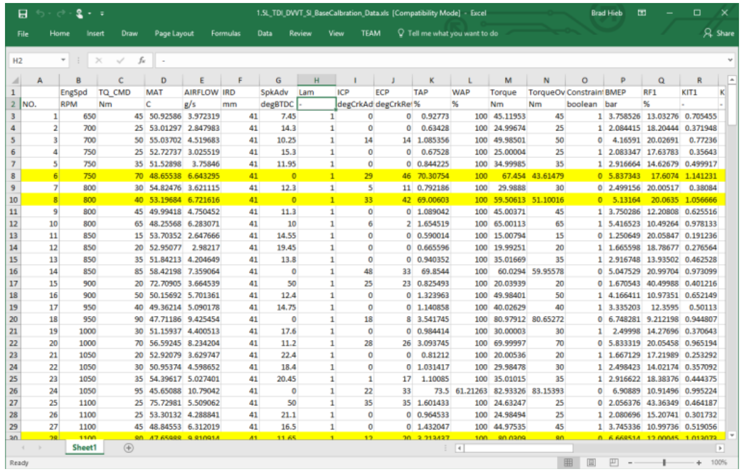
Launch MBC Toolbox

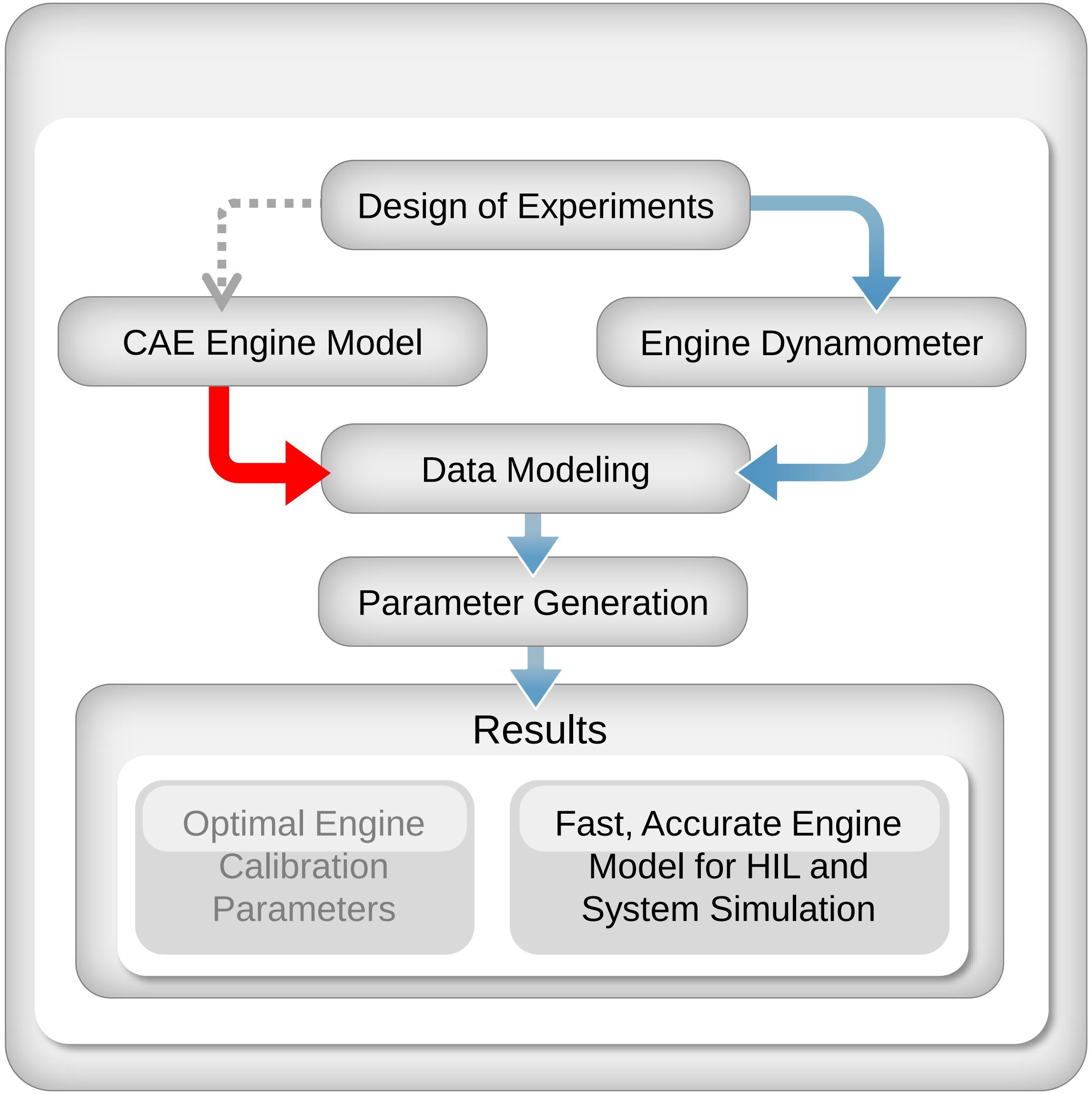


Parameterizing a Mapped Engine Model

- Importing existing data

- Mapped engine model workflow:
  - **Importing existing data**

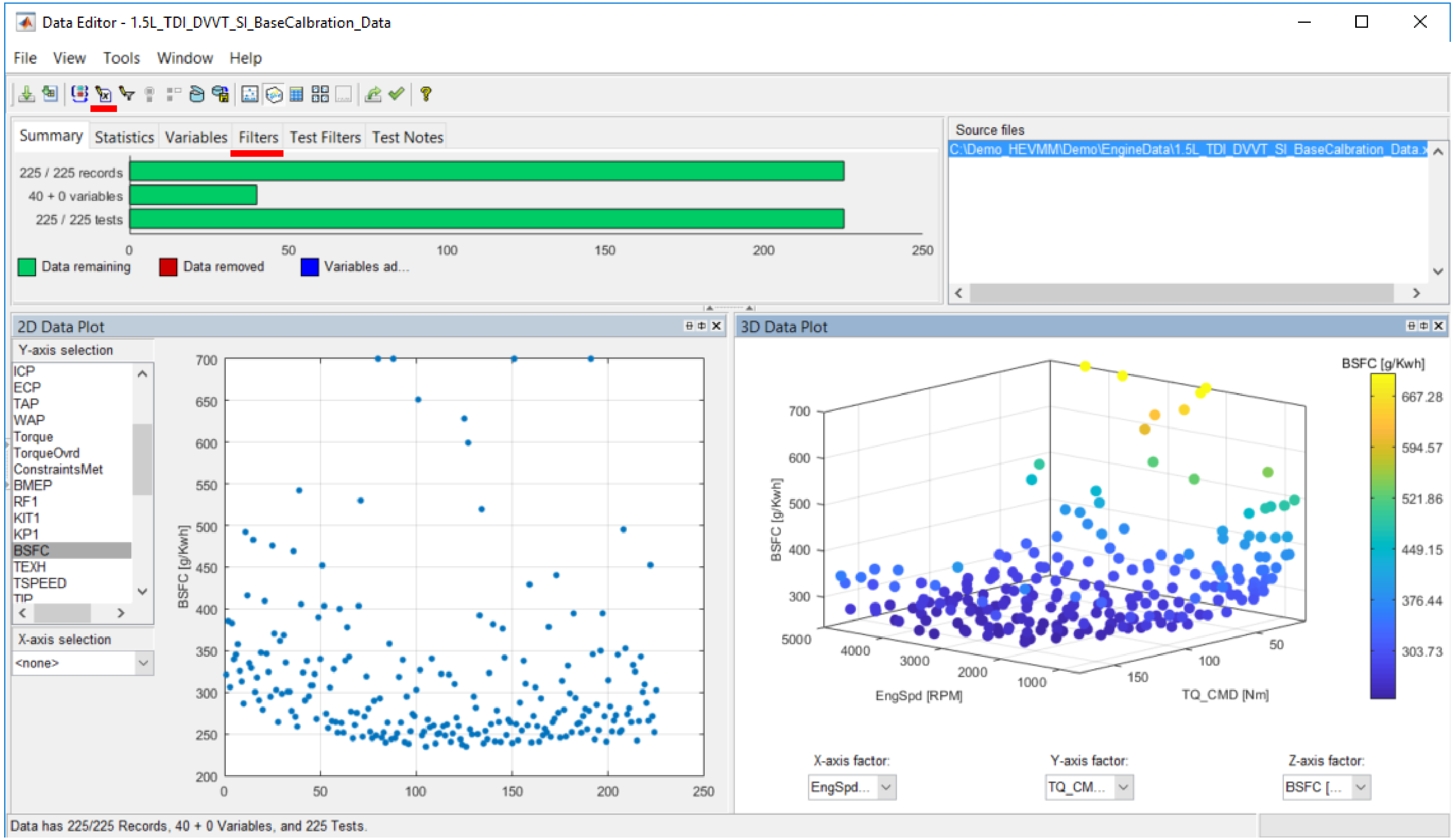




Import Data

- Inspect the data

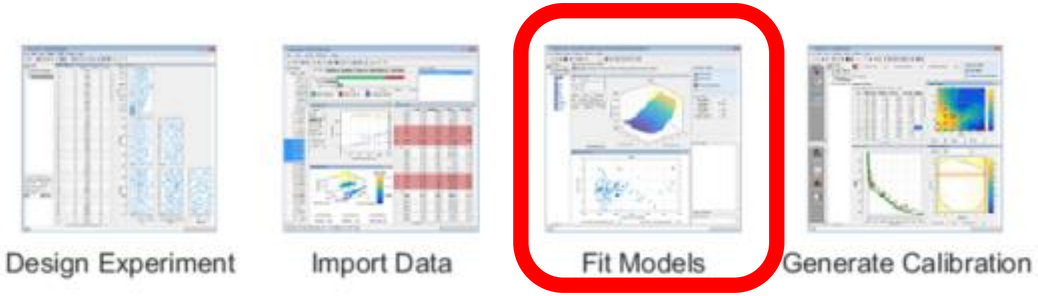
- Look for anomalies or gaps
- Filter data to remove anomalies
- Add derived quantities and unit conversions
- Graphical views speed inspection

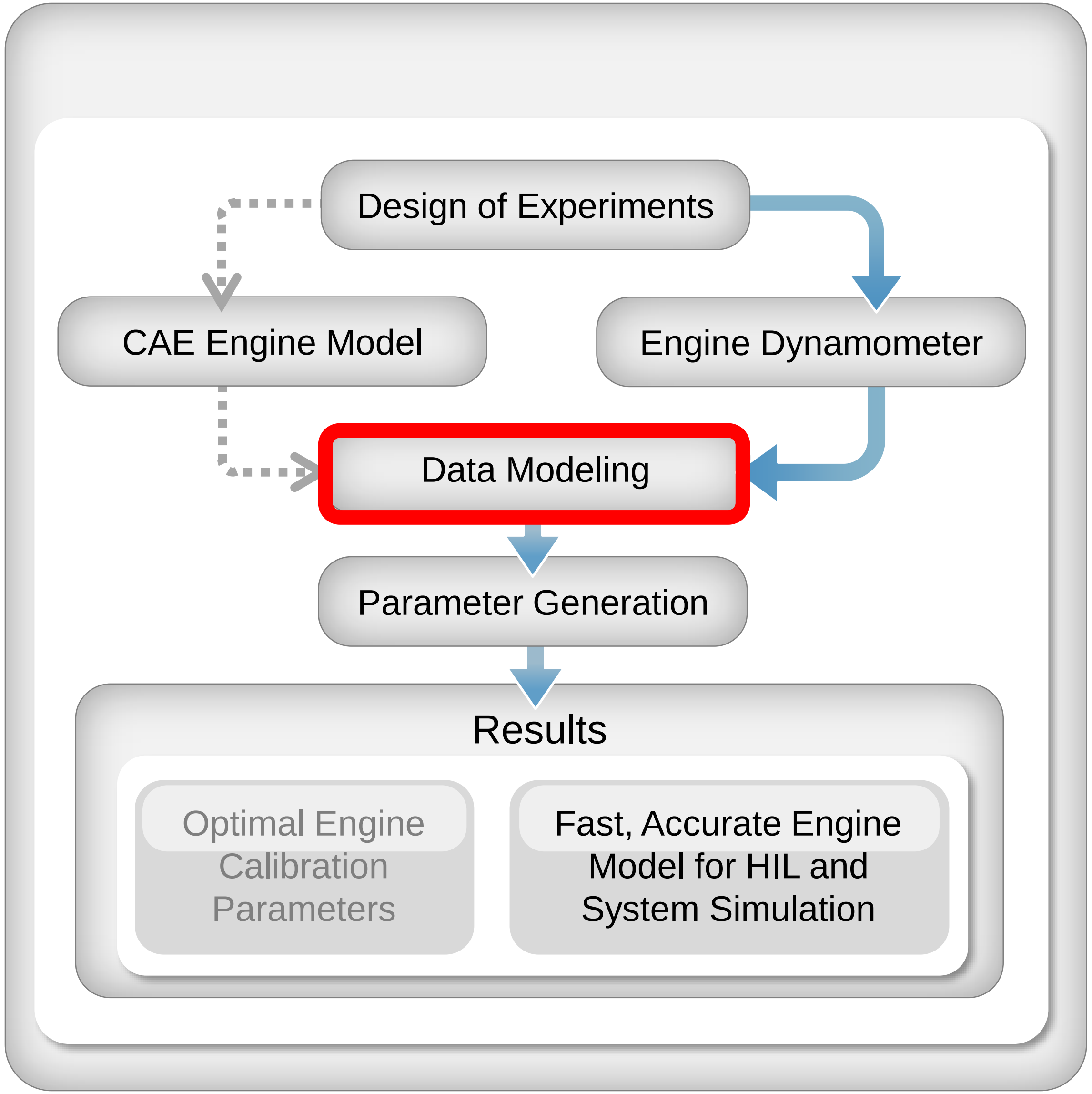


Parameterizing a Mapped Engine Model

- Fitting response surface models

- Mapped engine model workflow:
  - Importing existing data
  - **Fitting response surface models (RSM, statistical) to the data**

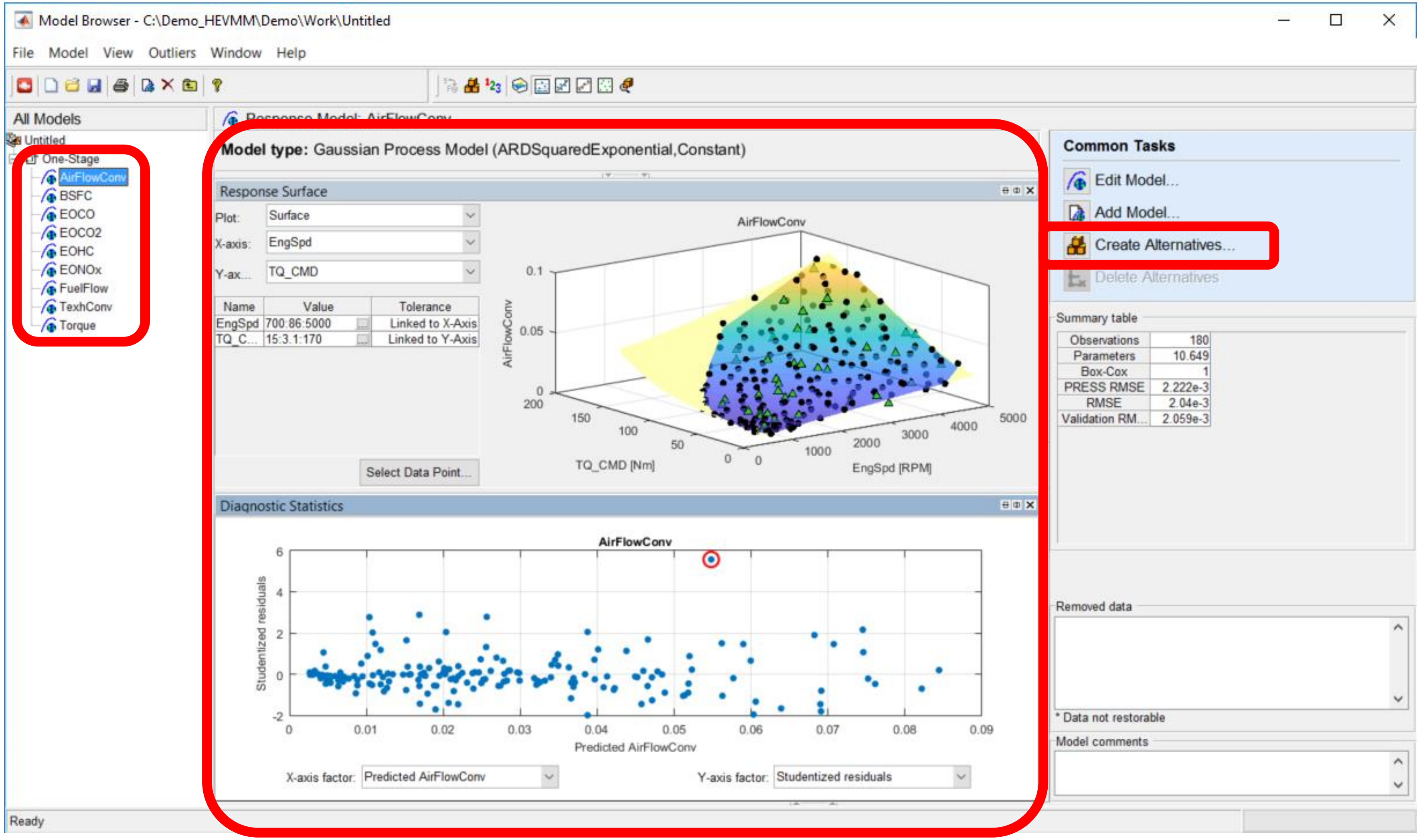




Fitting Models to the Data

- Generate response surface models

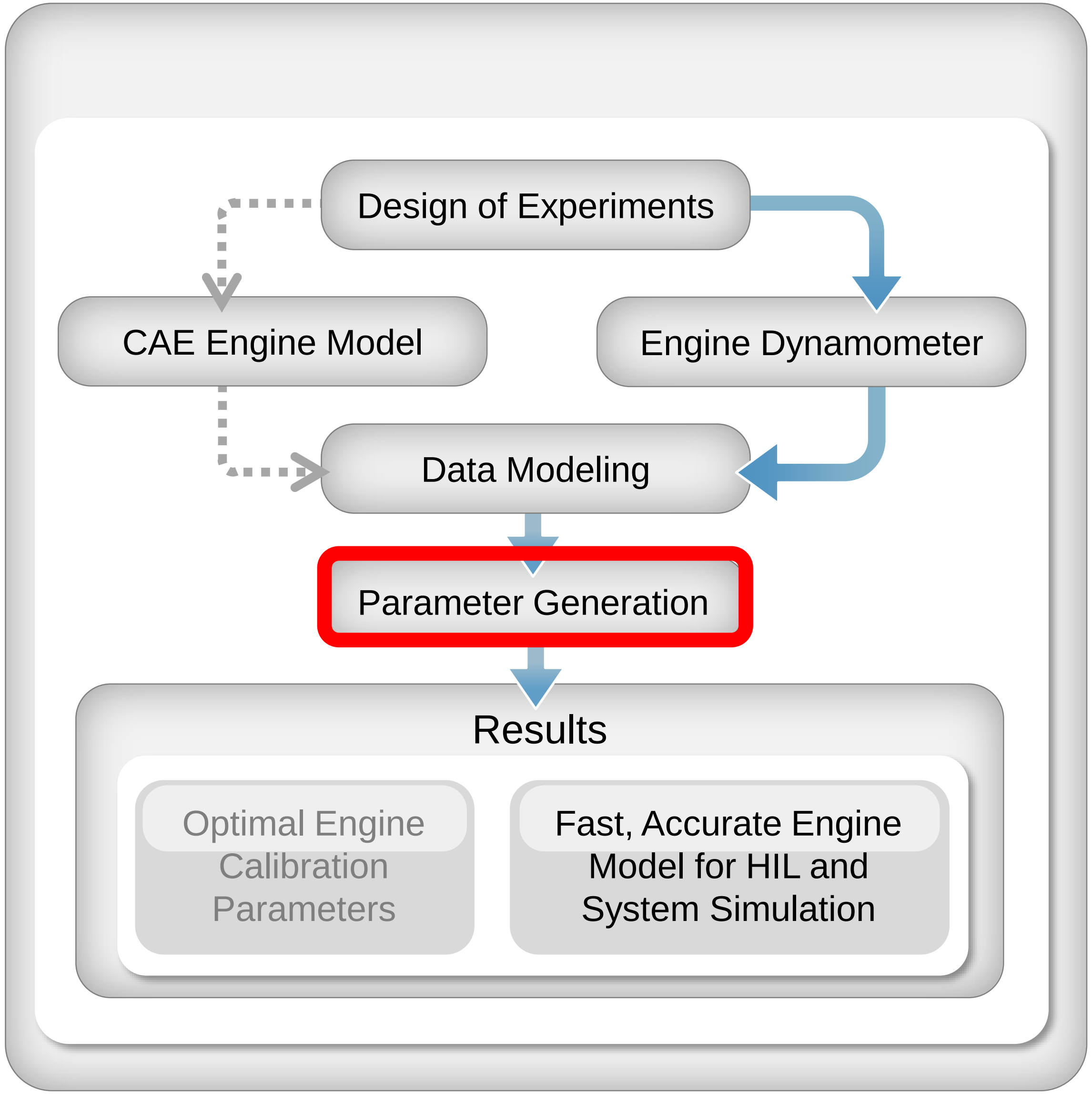
- Default models automatically fitted to all responses
- Inspect quality of fit
- Try out alternatives



Parameterizing a Mapped Engine Model

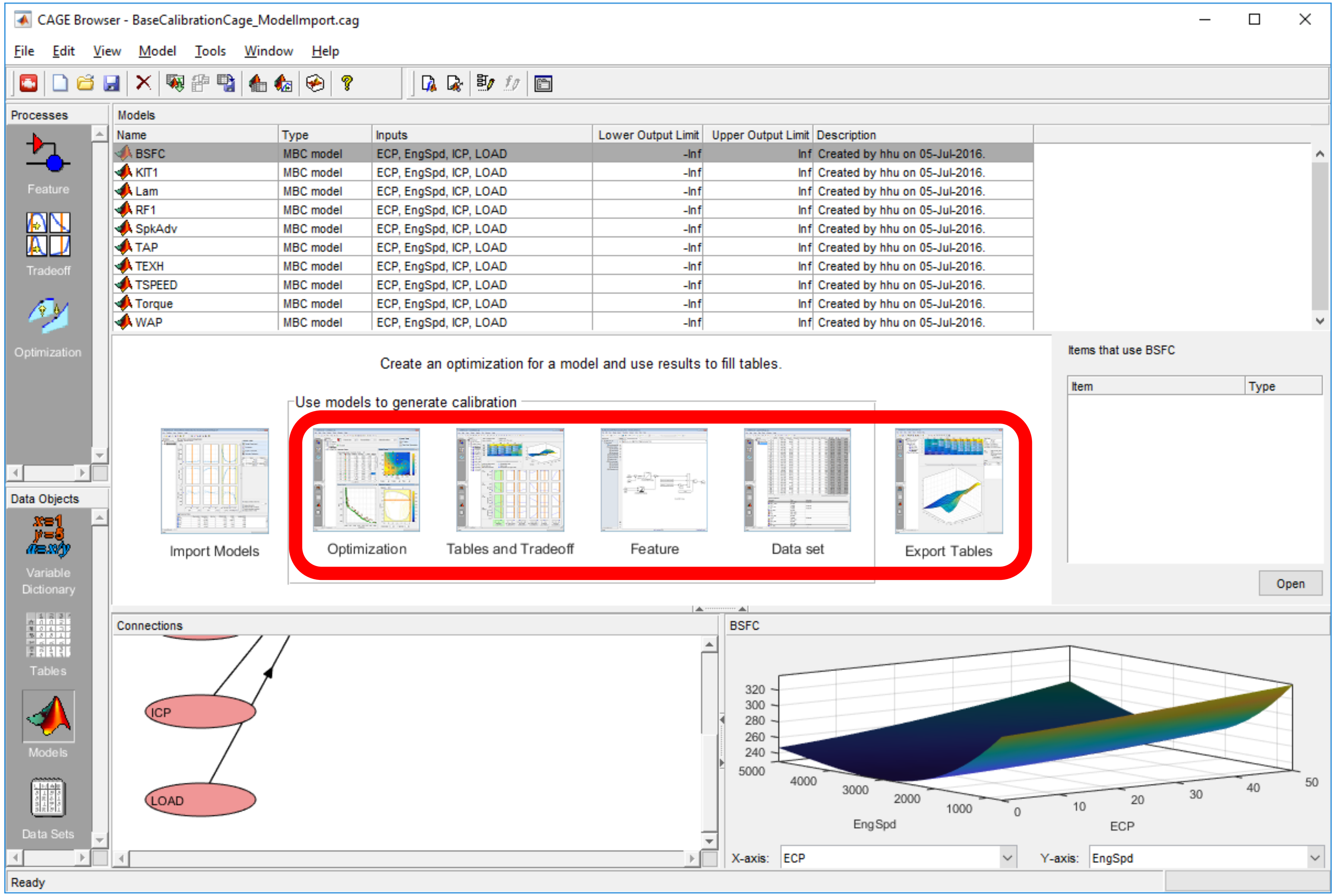
- Developing engine performance maps

- Mapped engine model workflow:
  - Importing existing data
  - Fitting response surface models
  - **Developing engine performance maps from RSM's**



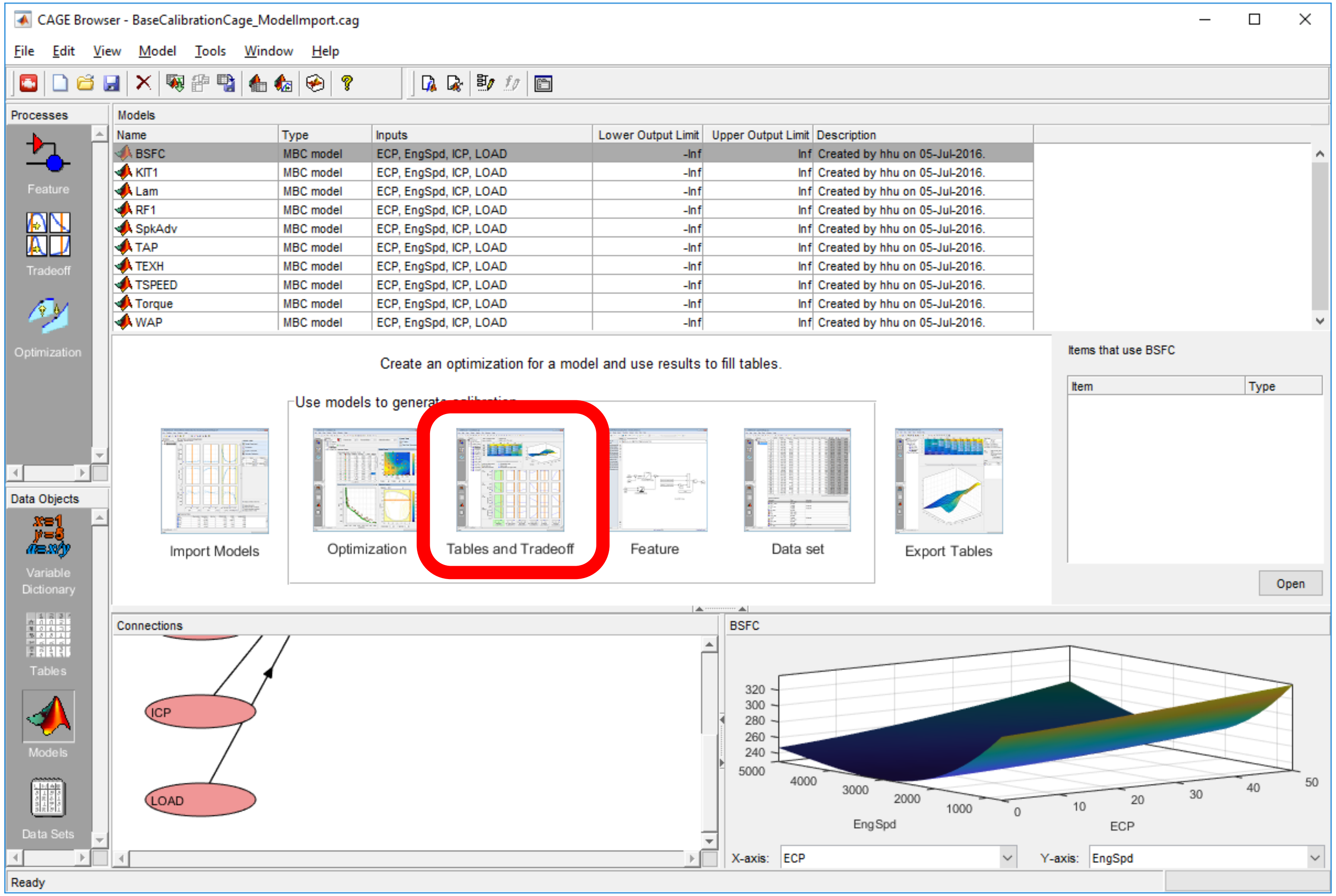
Calibration Generation Tool

- Fill tables
- Export cal tables



Calibration Generation Tool

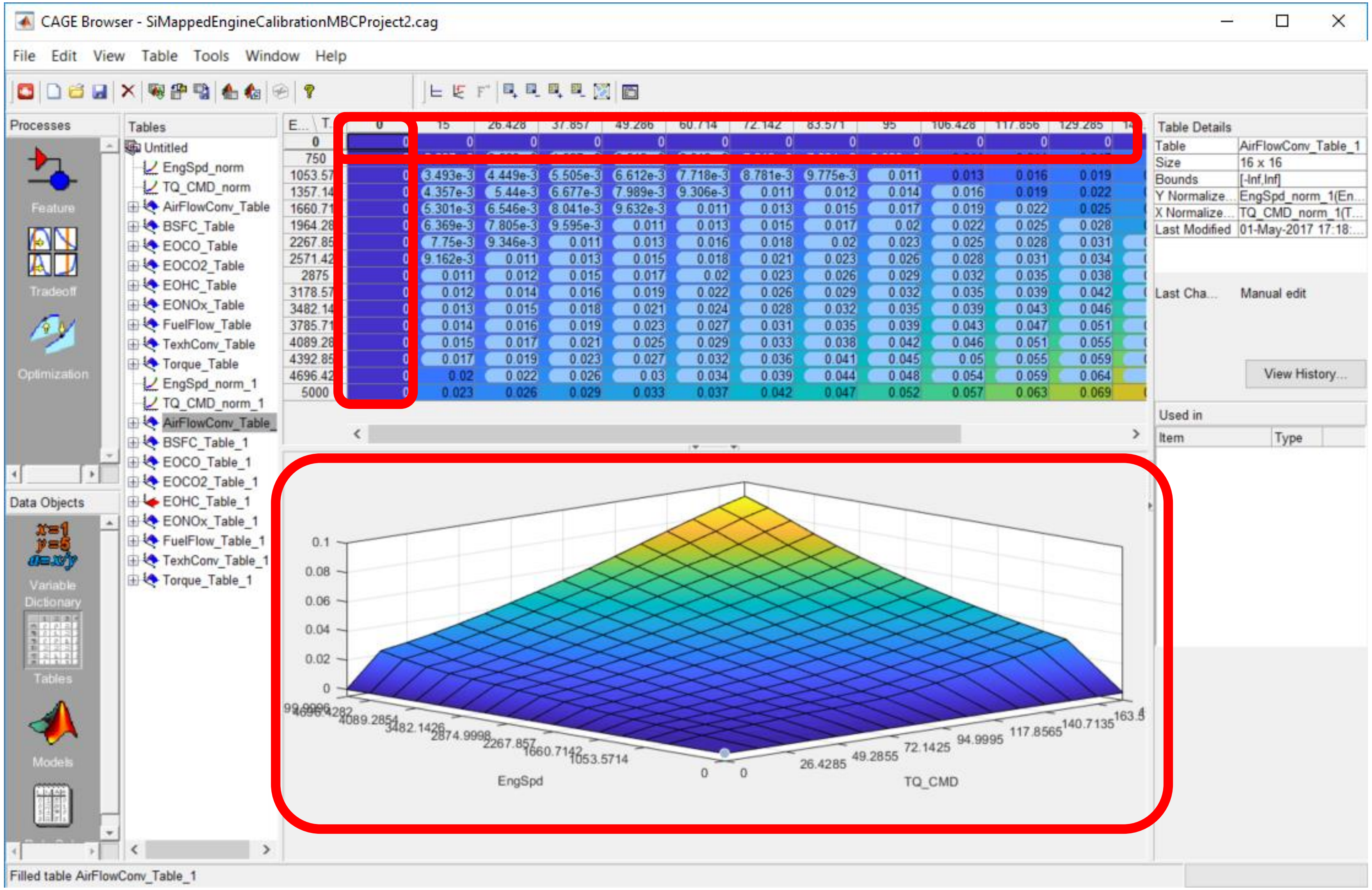
- Generating look up tables



Calibration Generation Tool

- Fill tables

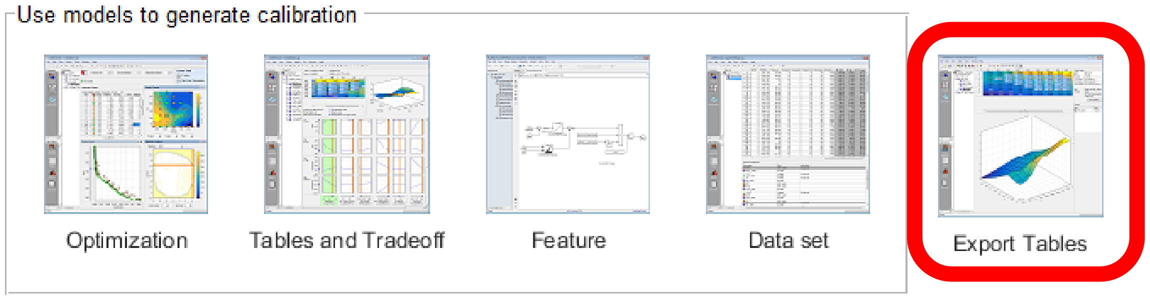
- Inspect surfaces
- Adjust table values in extrapolation areas
- Export to MATLAB, Excel or Cal tool

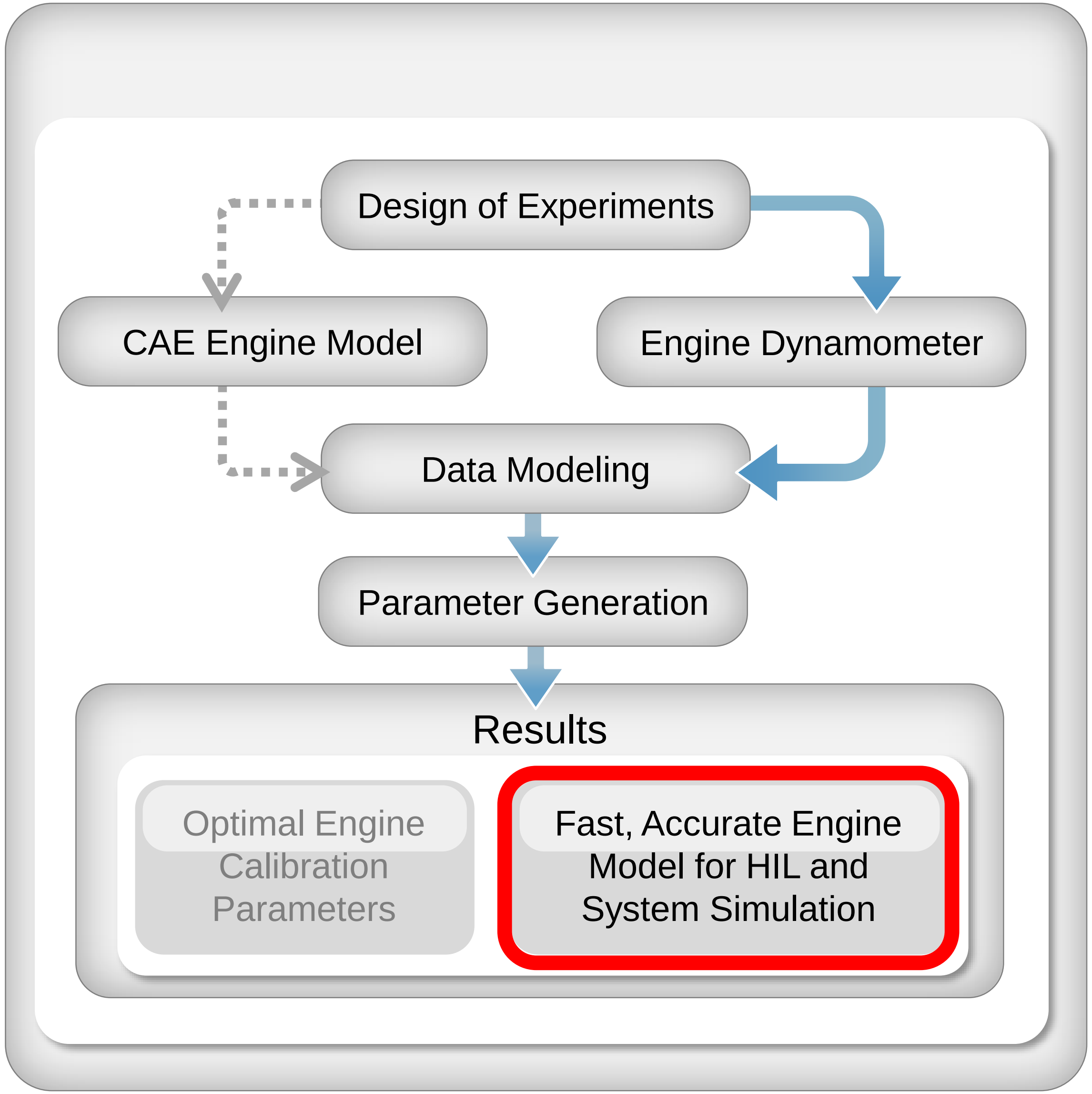


Parameterizing a Mapped Engine Model

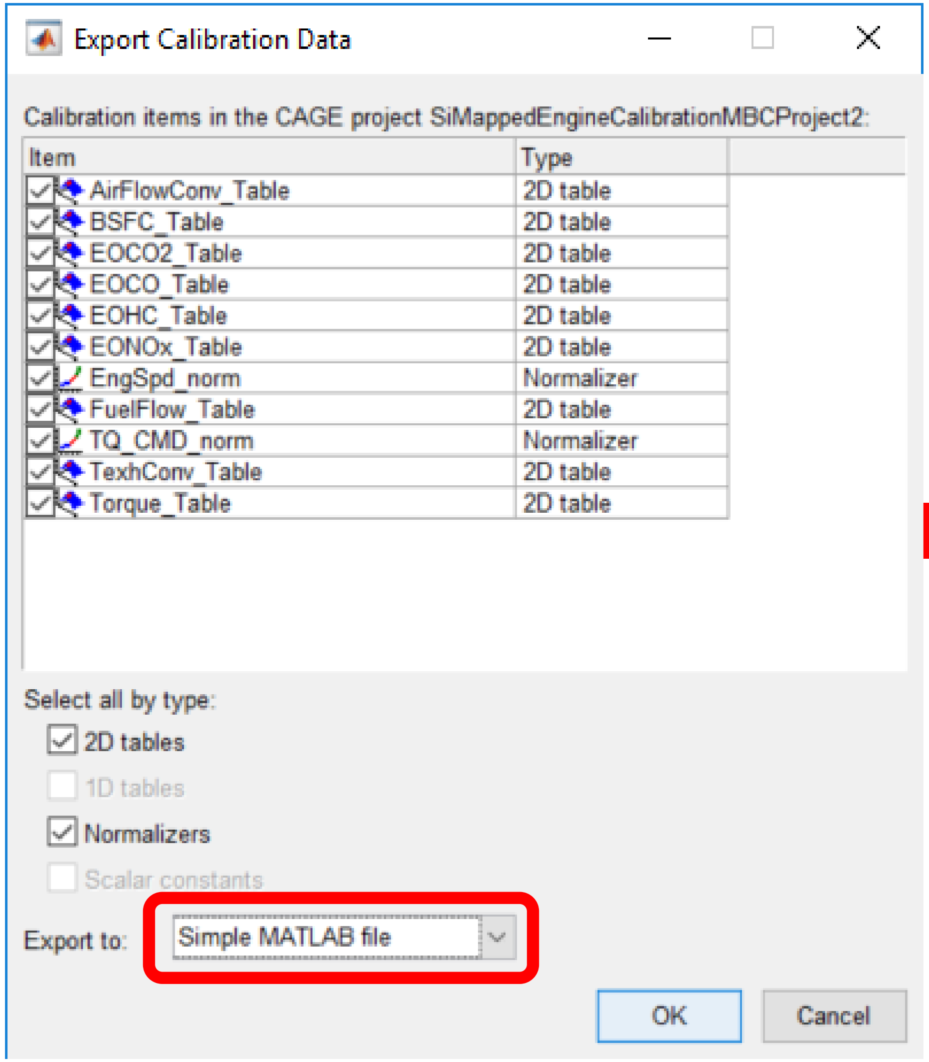
- Export and validate result

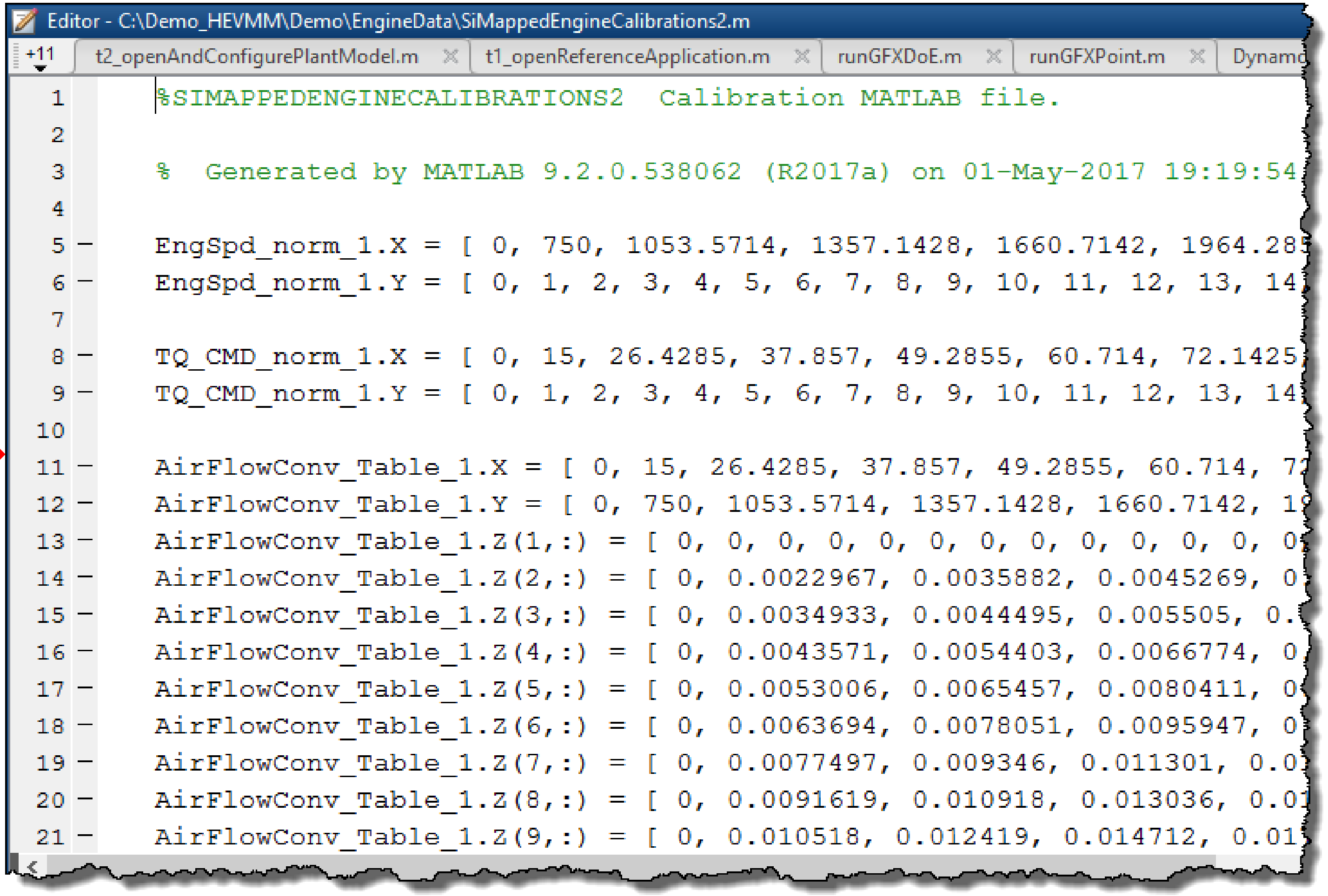
- Mapped engine model workflow:
  - Importing existing data
  - Fitting response surface models
  - Developing engine performance maps
  - **Export and validate the result**



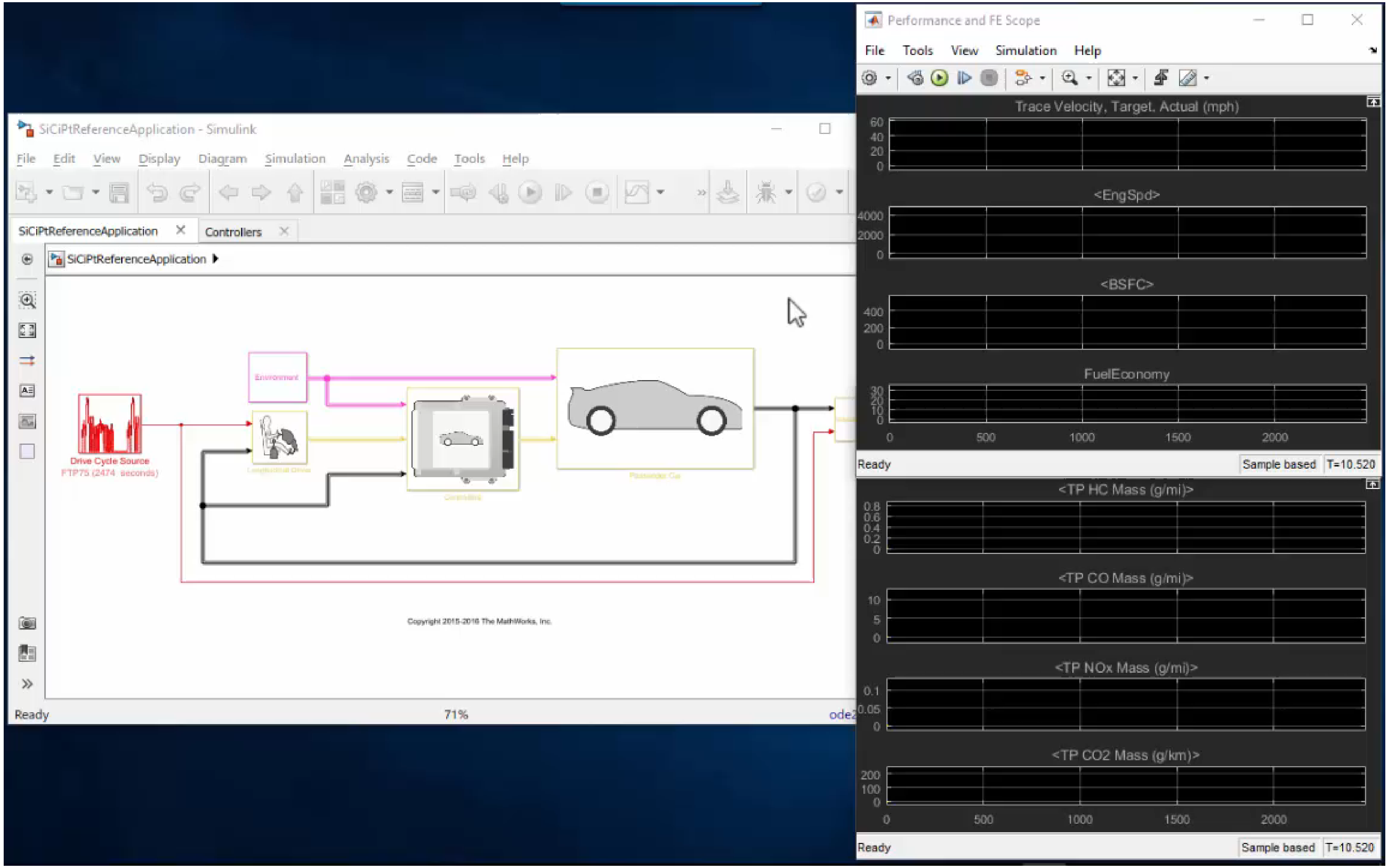


Export Tables to MATLAB



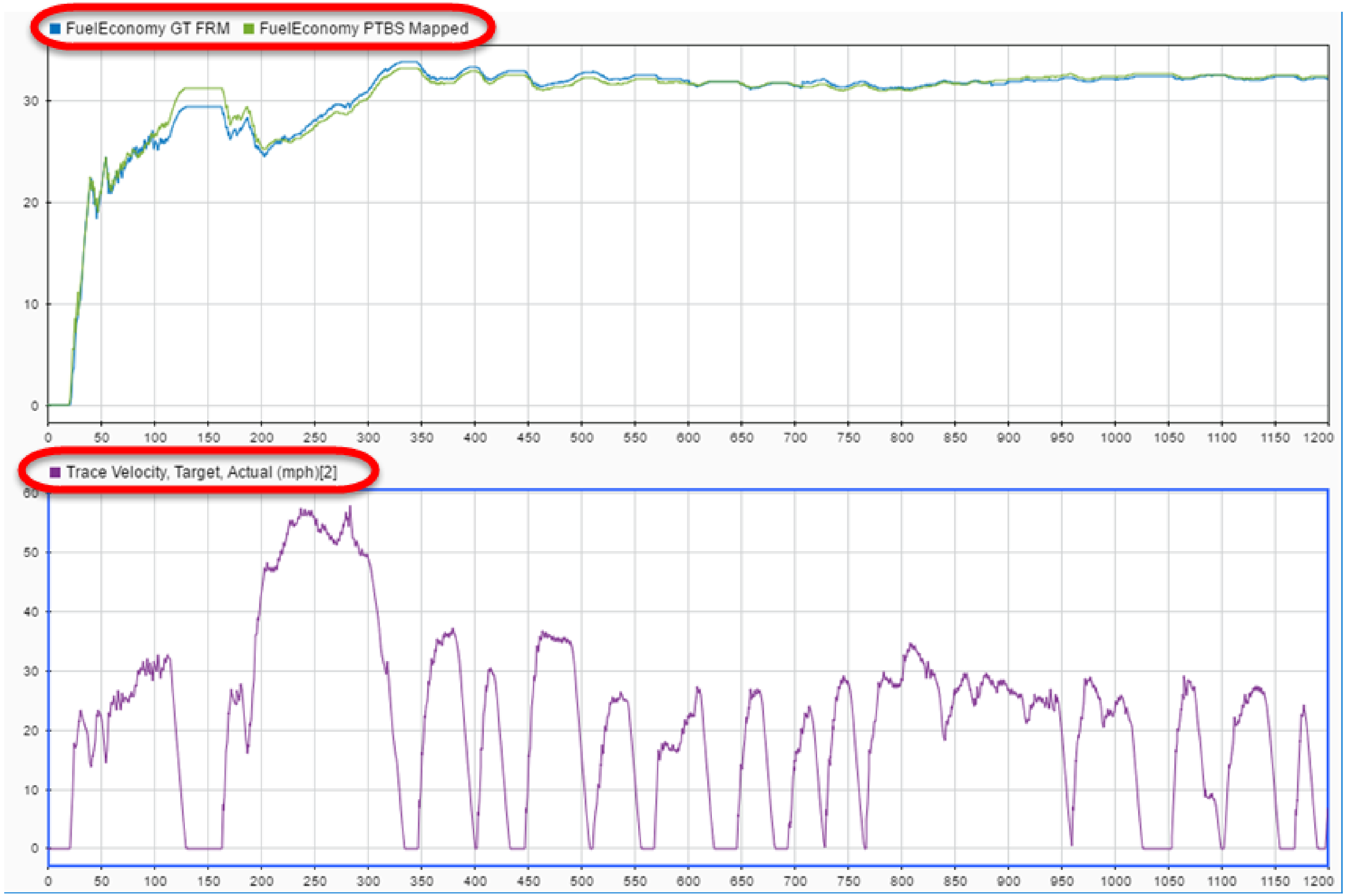


Validate the Result



Validate the Result

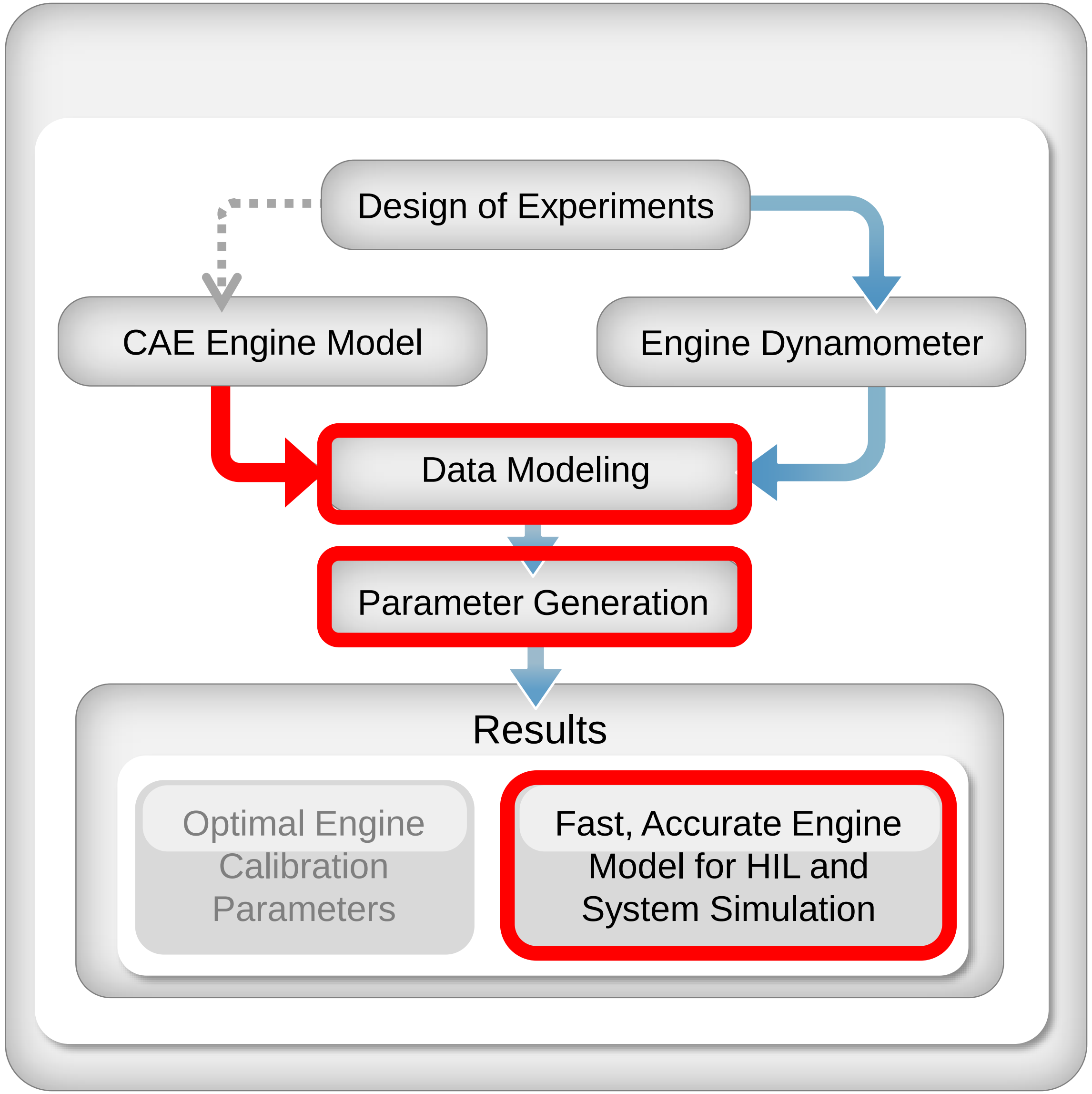
- Accuracy for 1200 sec of FTP75 sim:
  - % diff in FE was 0.31%
- Run time for 1200 sec of FTP75 sim:
  - PTBS Mapped engine model 28.4 sec
  - GT Power FRM engine model 1449 sec
  - Mapped engine model sim ~51x faster



Parameterizing a Mapped Engine Model

- Summary

- Mapped engine model workflow:
  - Importing existing data
  - Fitting response surface models (RSM, statistical) to the data
  - Developing engine performance maps from RSM's
  - Validate the result

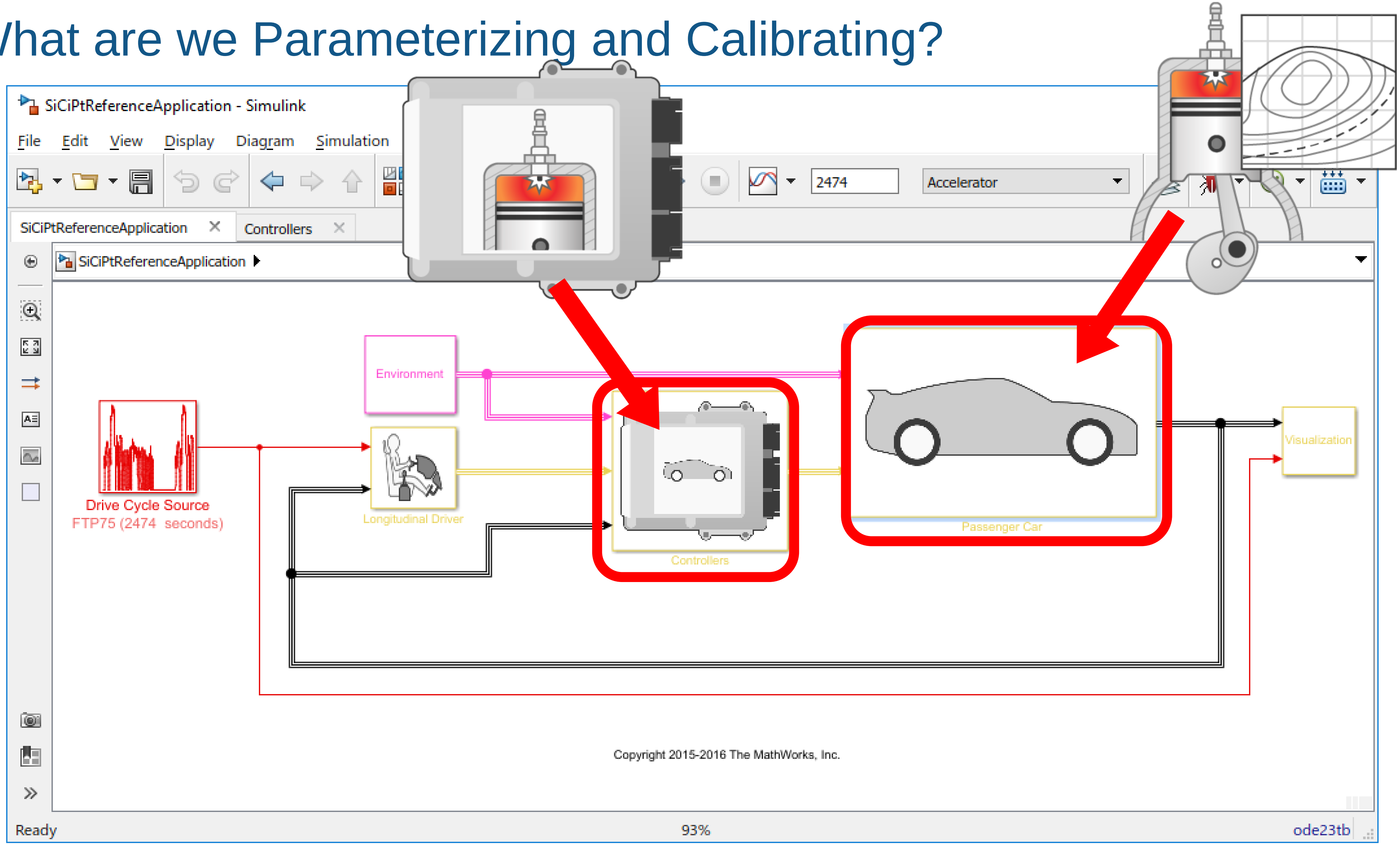


What we'll Cover Today

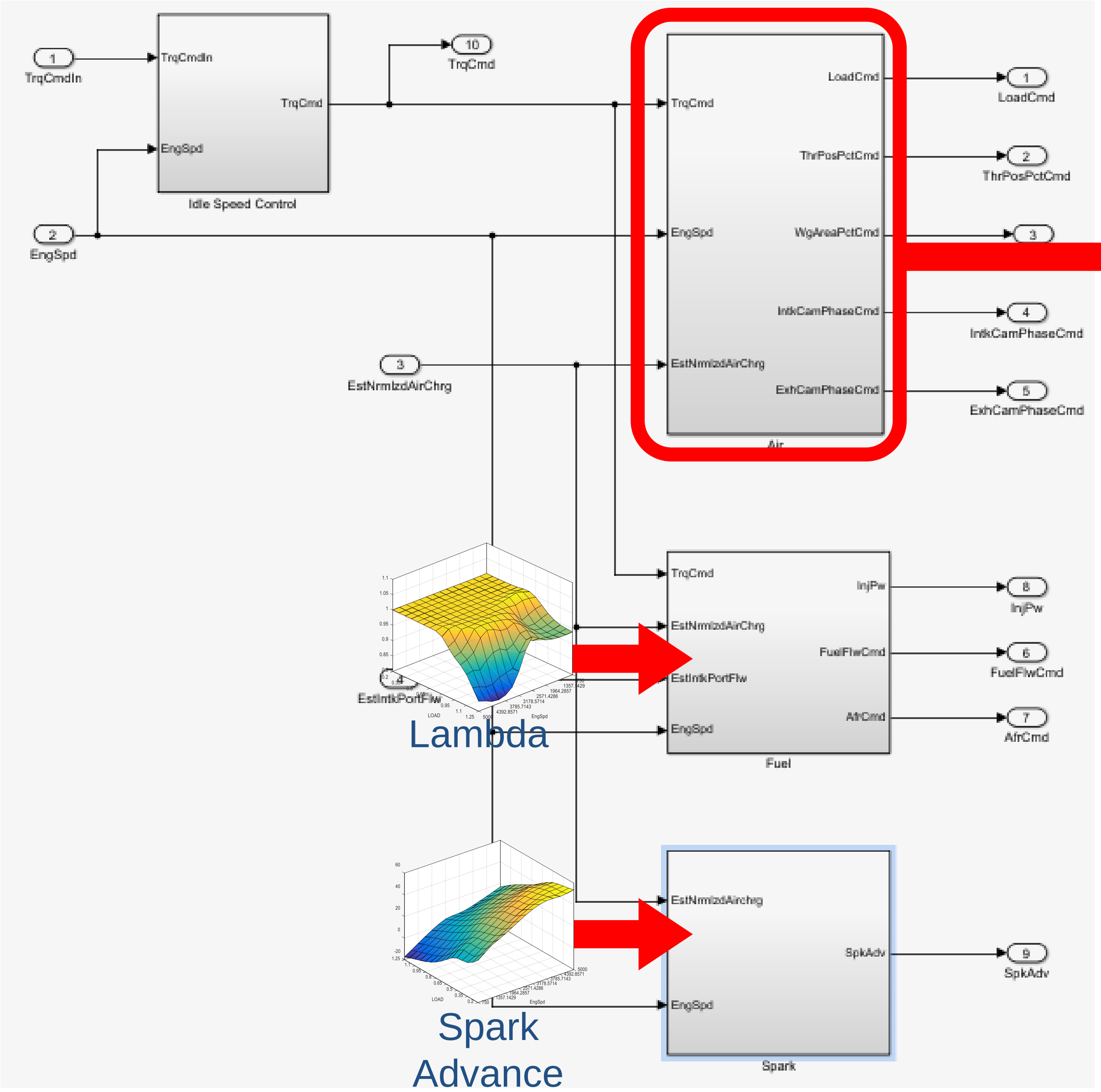
- Parameterizing a Powertrain Blockset engine model
  - Workflow
  - Example: parameterizing a mapped engine model

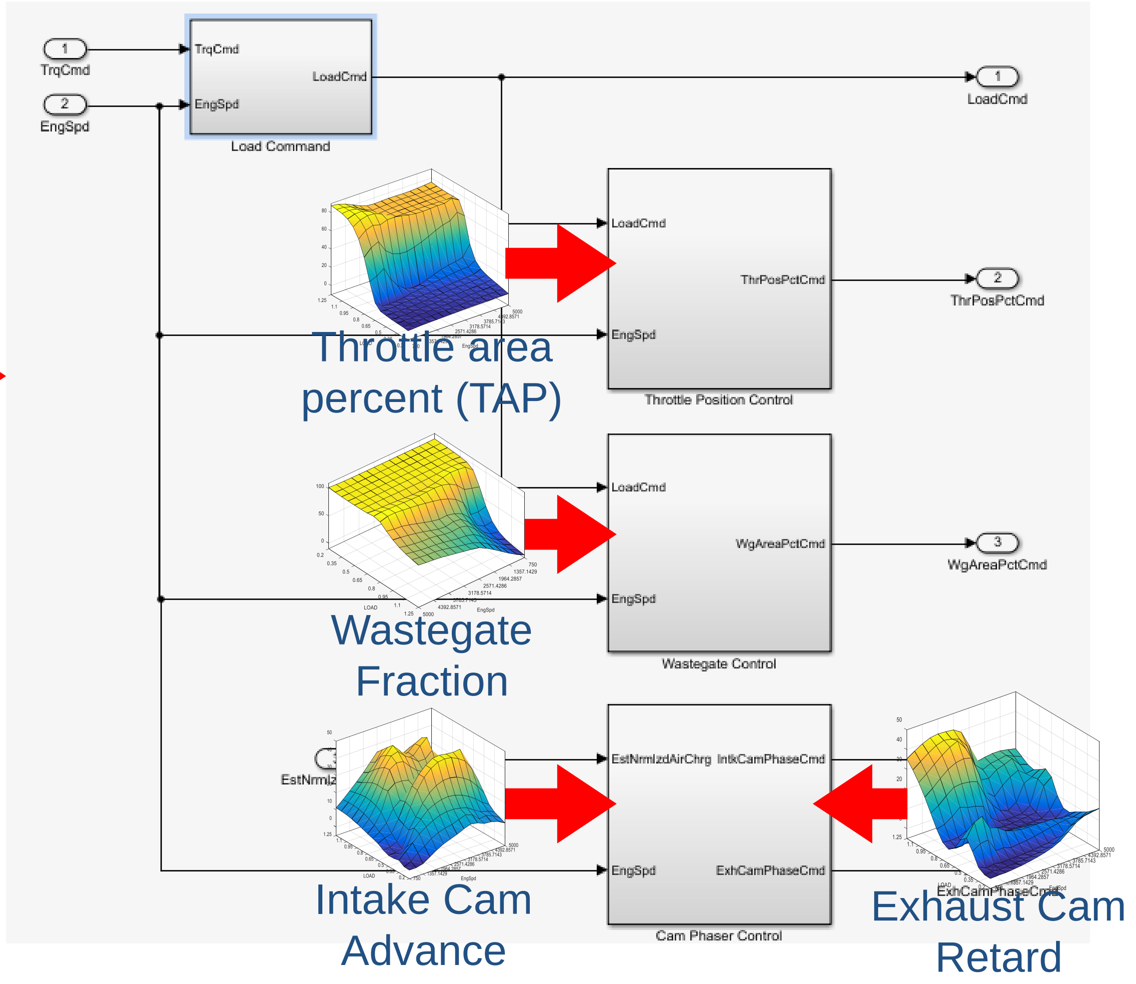
- **Calibrating a Powertrain Blockset engine controller**
  - **Workflow**
  - **Example: calibrating an engine controller**

What are we Parameterizing and Calibrating?



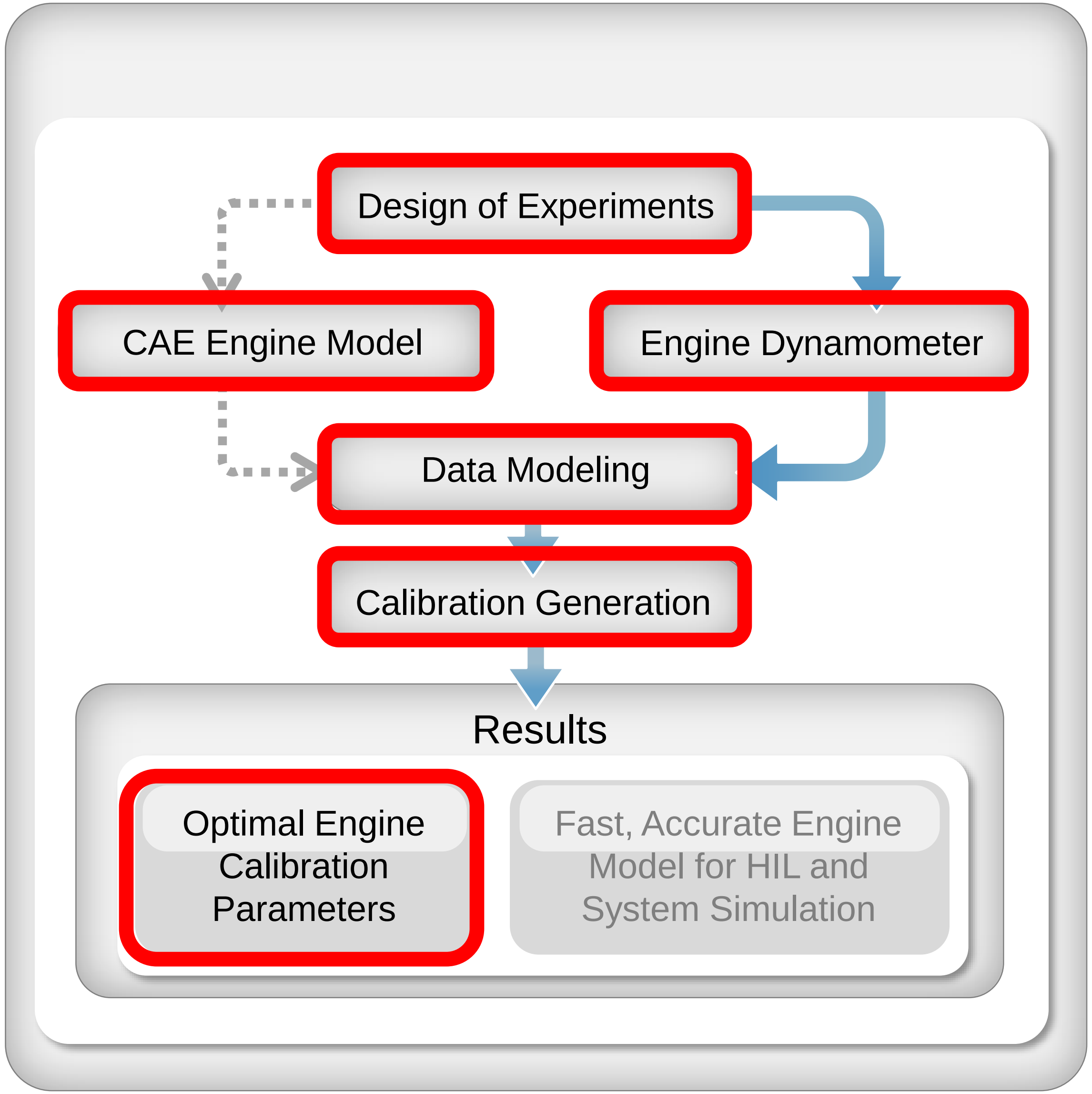
What are we Calibrating?





Calibrating Optimal Base Engine Control Tables
- Workflow

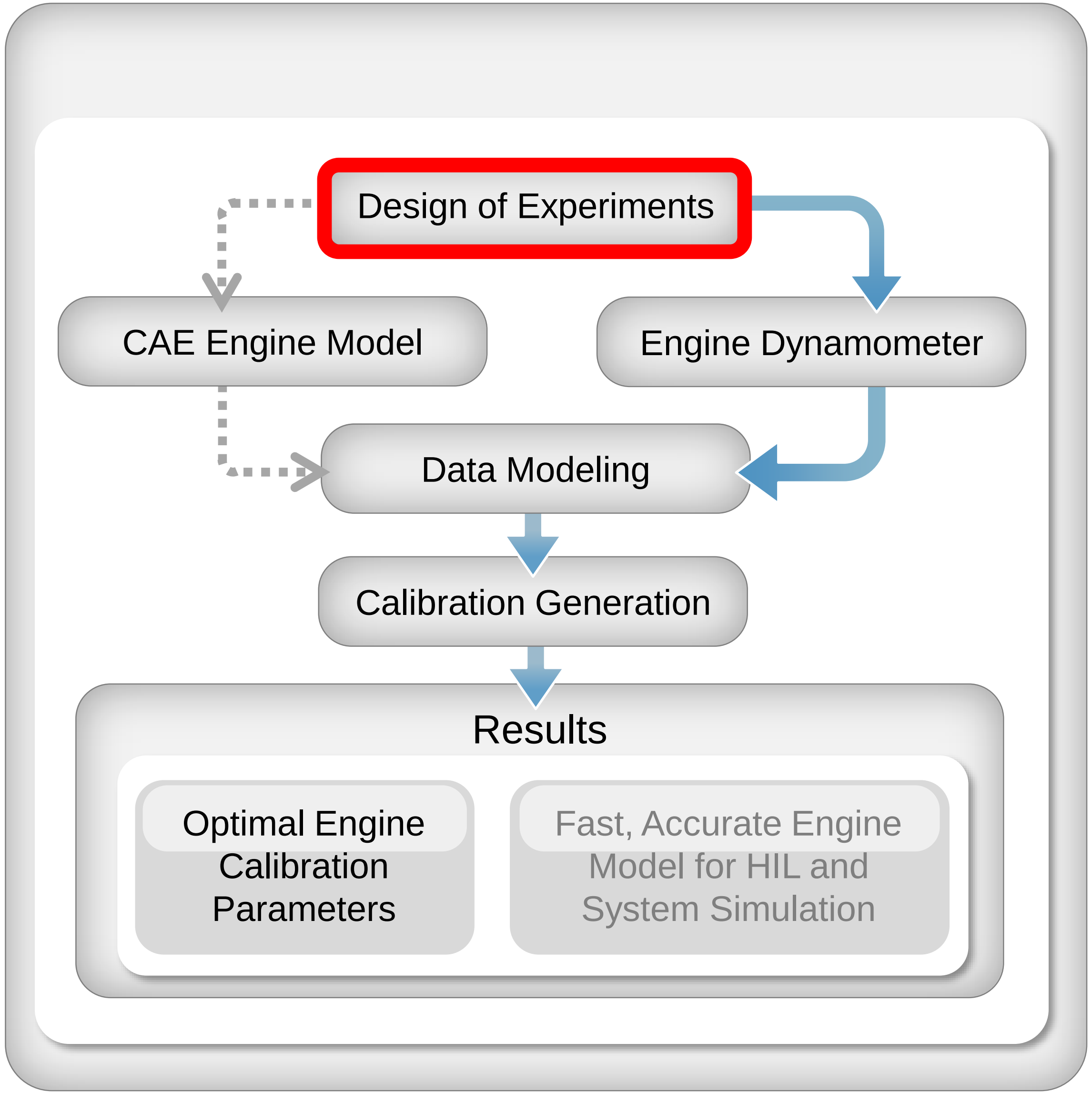
- Model-Based Calibration Toolbox provides tools for the process:
  - Creating the Design of Experiments
  - Gather the data
  - Fitting response surface models (RSM, statistical) to the data
  - Developing optimal base calibration tables
  - Export calibration to controller



Calibrating Optimal Base Engine Control Tables

- Creating the DoE

- Optimal base engine control calibration workflow:
  - **Creating the Design of Experiments**



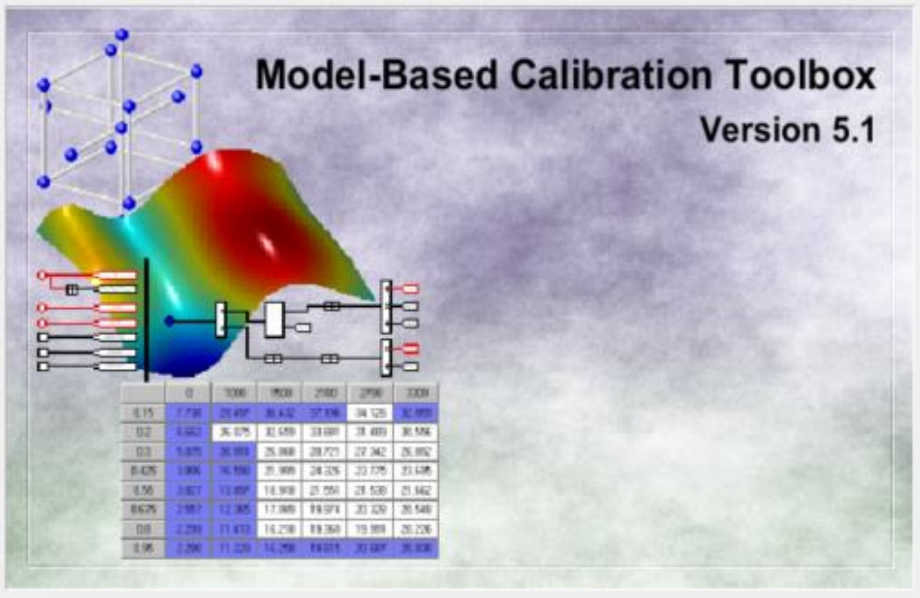
Calibrating Optimal Base Engine Control Tables

- Creating the DoE

I/O of Turbocharged Direct-Injection 1.5L DOHC Engine Model with Dual-Independent Continuously Variable Cam Phasing

Table Breakpoints
- RPM
- Load

Optimal Tables
- ICP
- ECP



- **Minimum BSFC** *Objective*
- Exhaust Temperature
- Turbocharger Speed
- Knock limit
- Residual Fraction

Constraints

- AFR
- Spark Advance
- Waste-gate area
- TAP

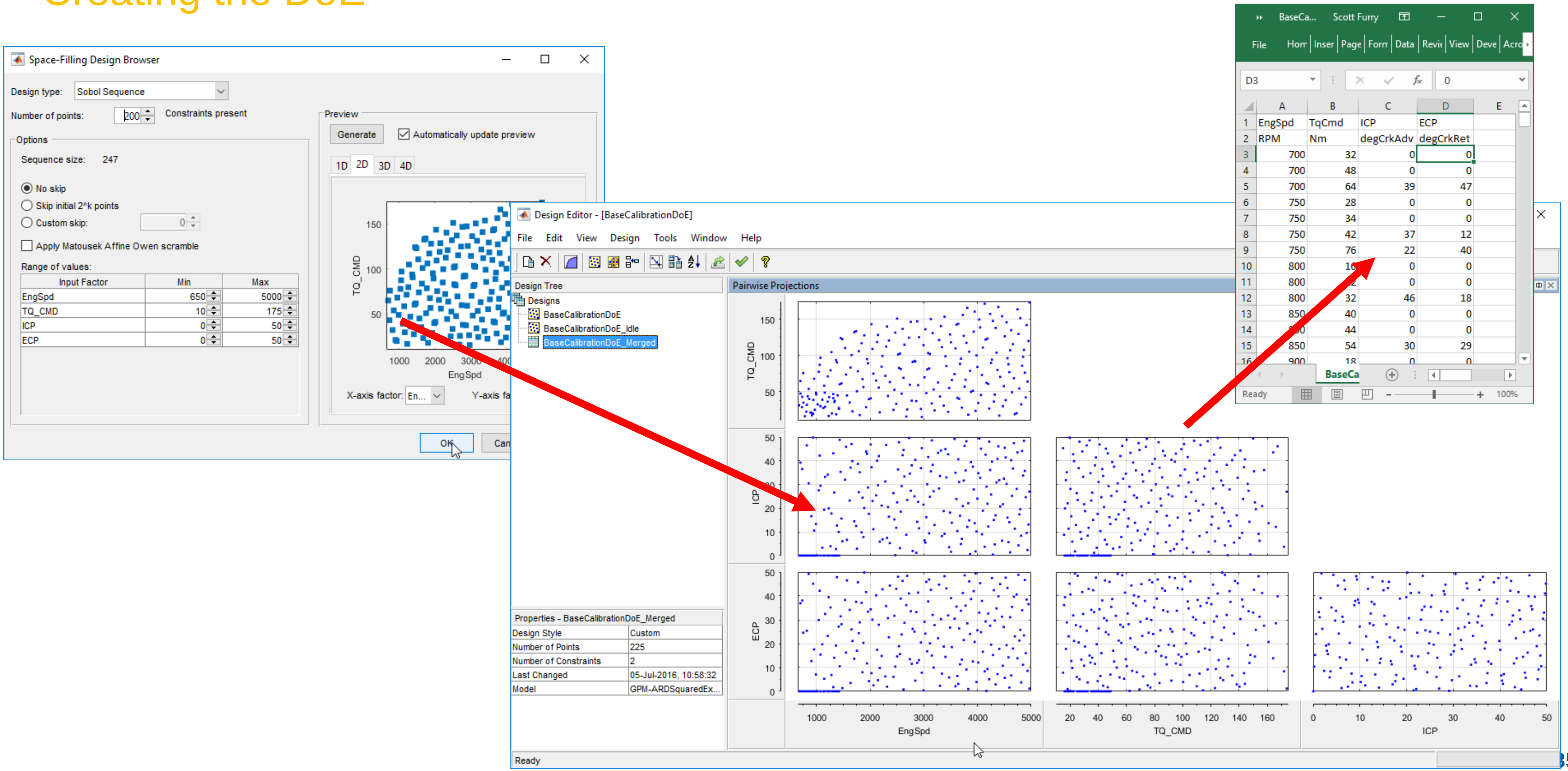
Optimal Tables

- Intake Manifold Pressure

Auxiliary Table

Calibrating Optimal Base Engine Control Tables

- Creating the DoE

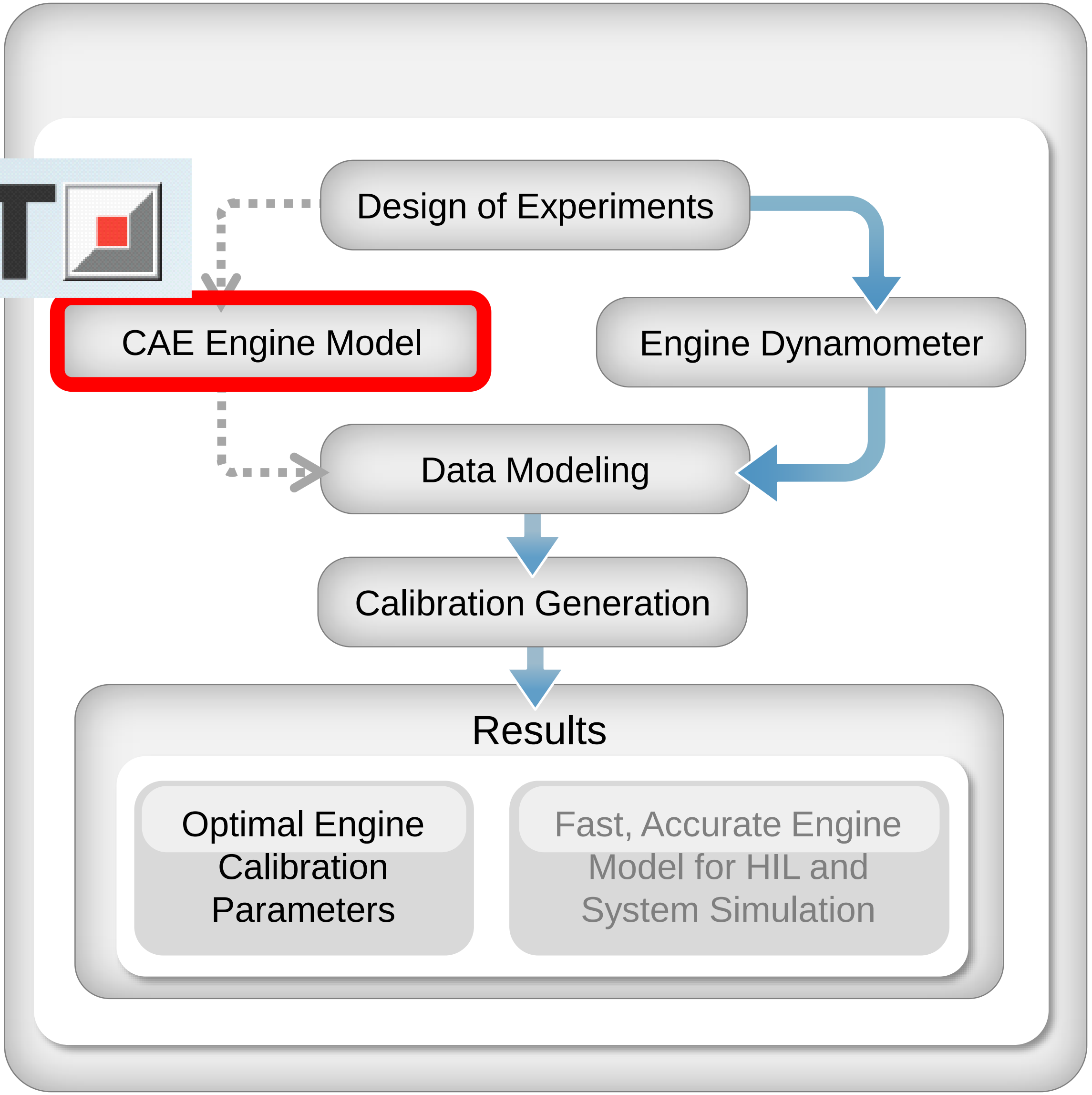


Calibrating Optimal Base Engine Control Tables

- Gather the data

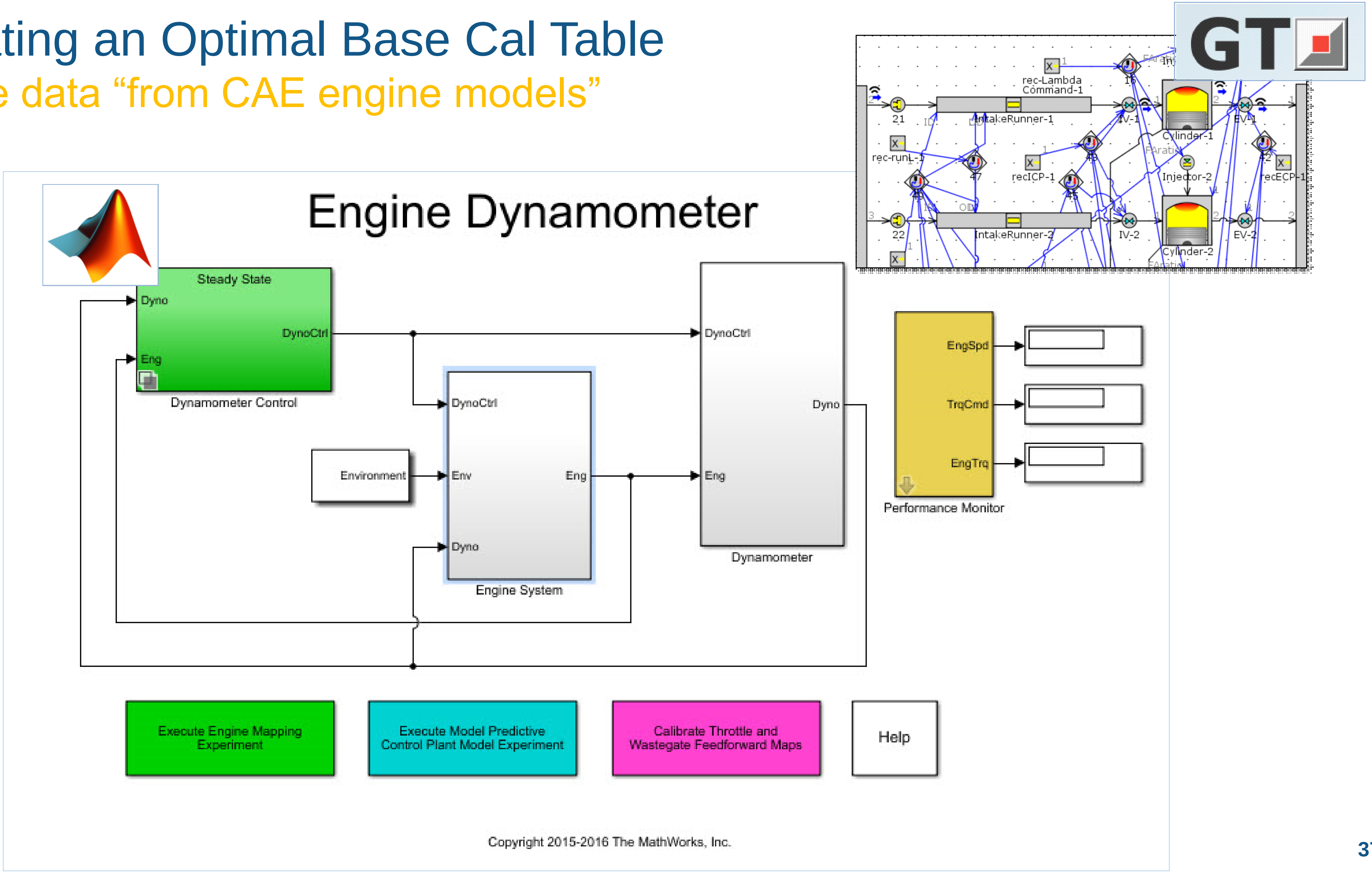
- Optimal base engine control calibration workflow:
  - Creating the Design of Experiments
  - **Gather the data**

Design Experiment   Import Data   Fit Models   Generate Calibration



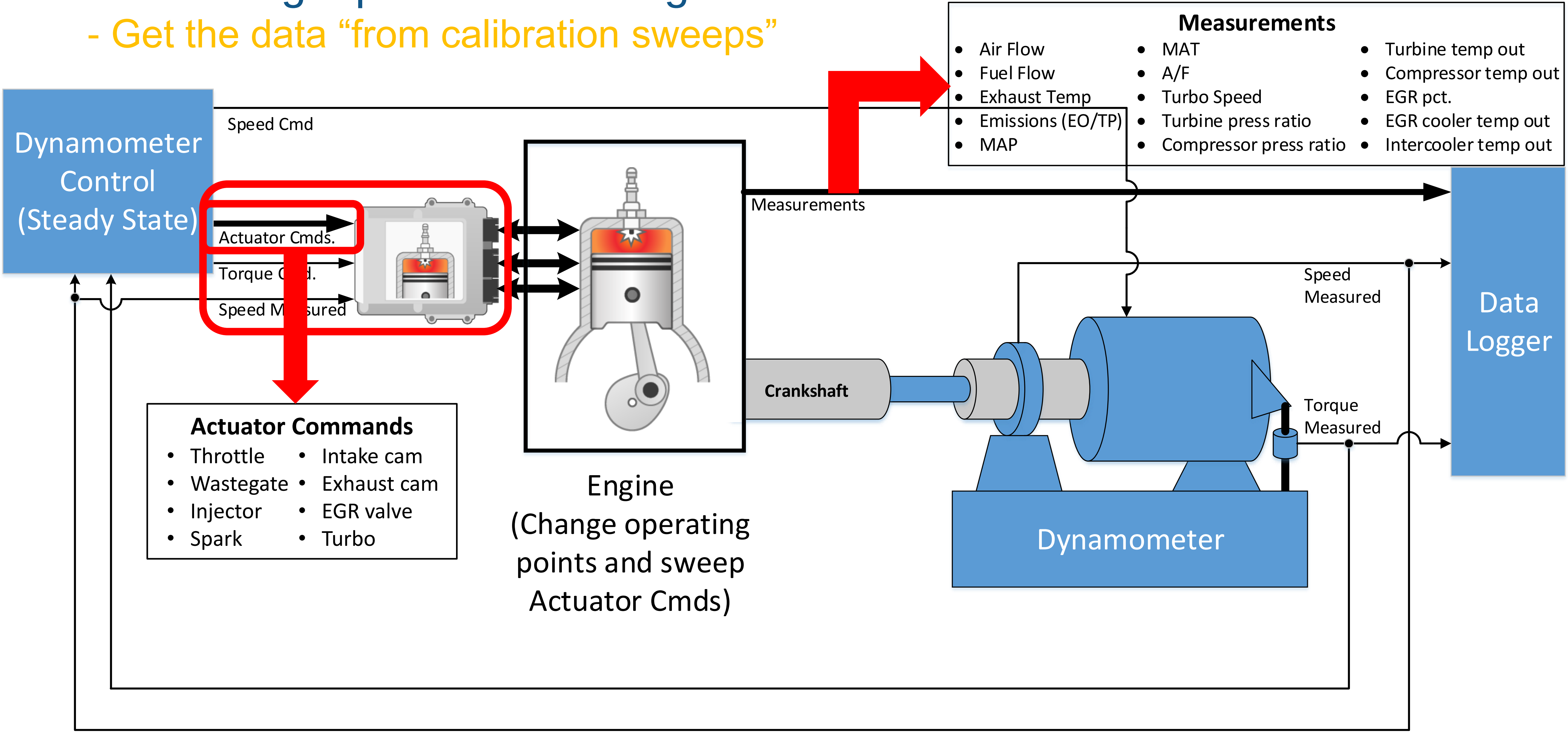
Calibrating an Optimal Base Cal Table

- Get the data “from CAE engine models”



Calibrating Optimal Base Engine Control Tables

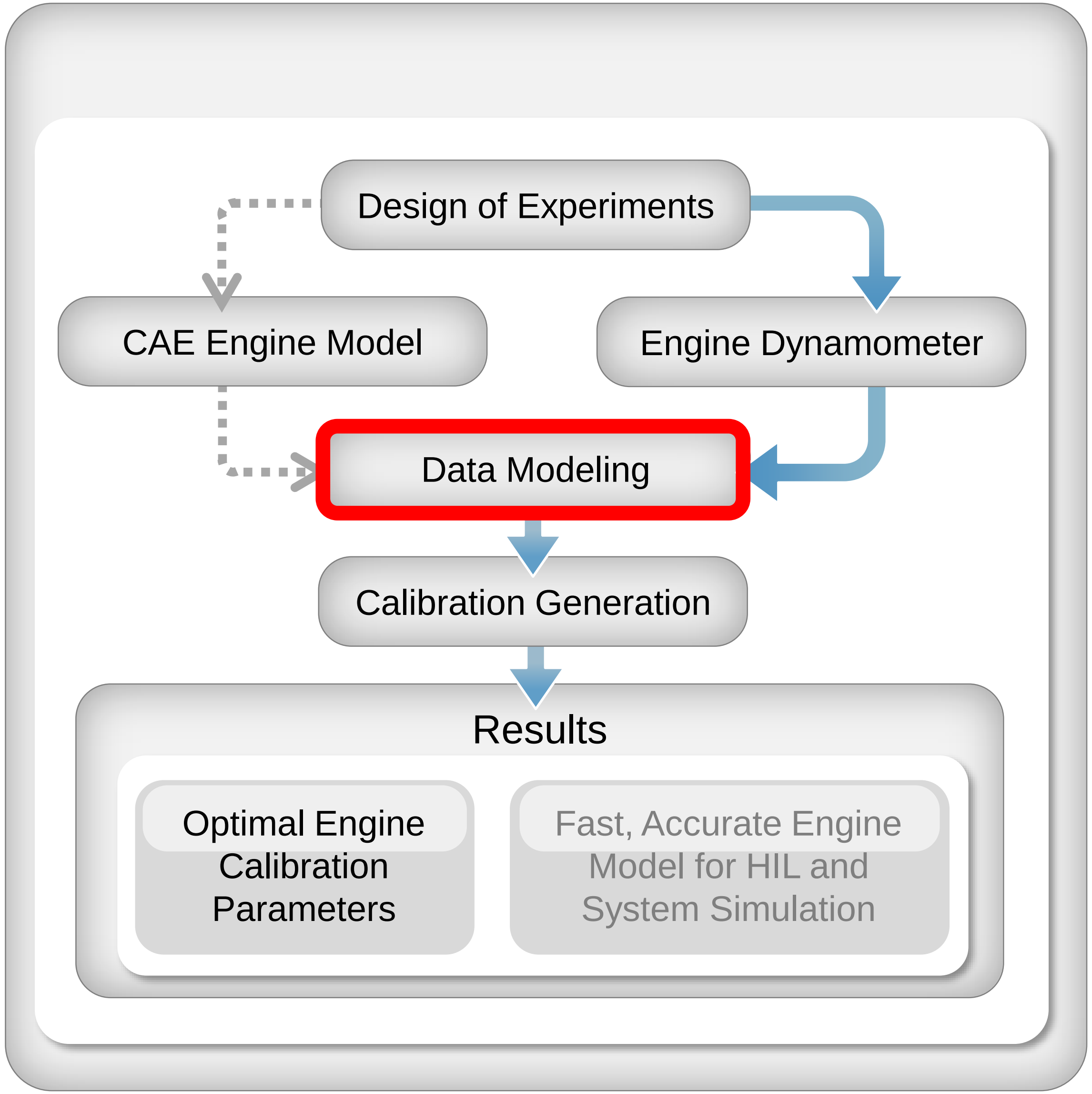
- Get the data “from calibration sweeps”



Calibrating Optimal Base Engine Control Tables

- Fitting response surface models

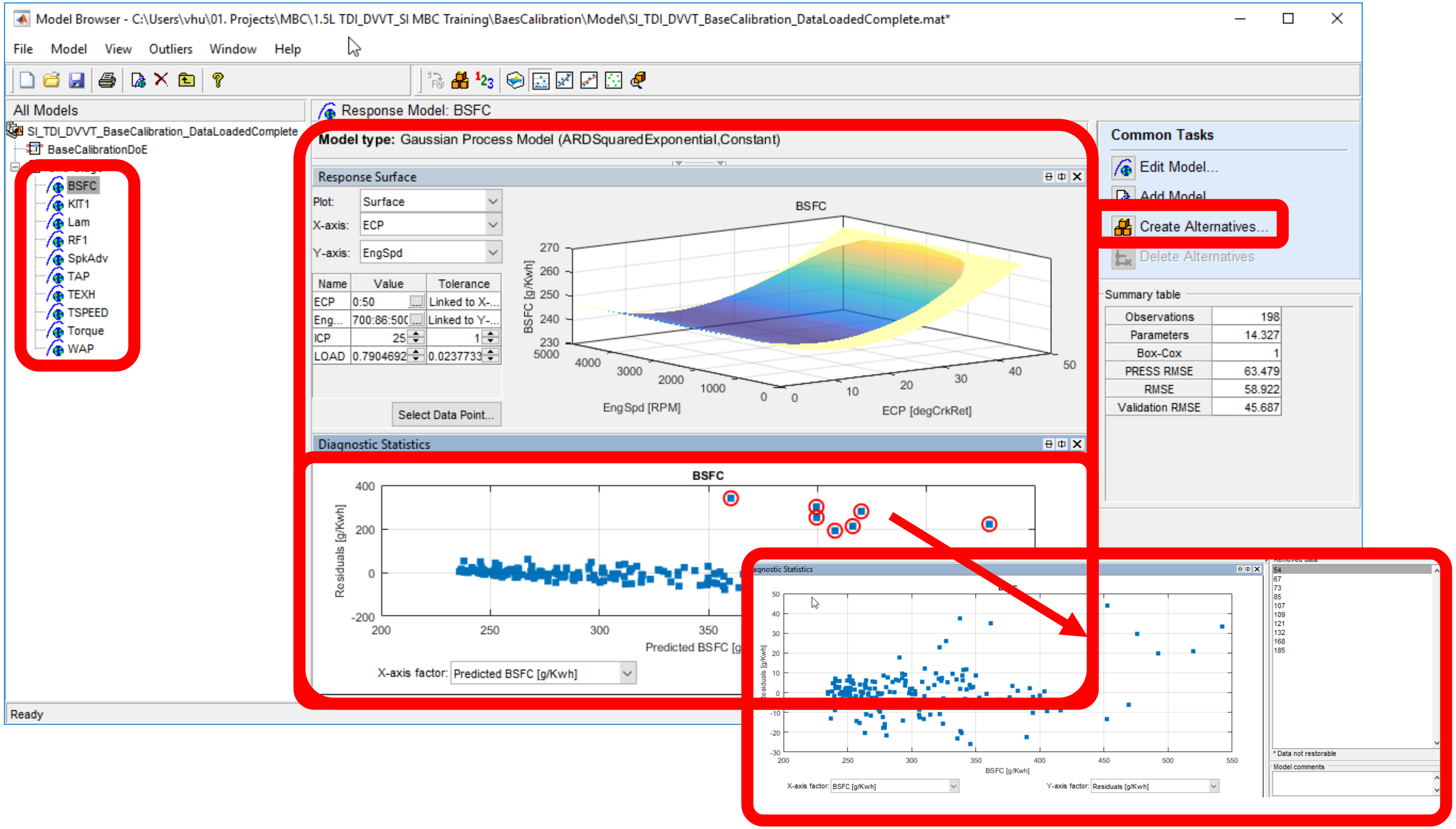
- Optimal base engine control calibration workflow:
  - Creating the Design of Experiments
  - Gather the data
  - **Fitting response surface models (RSM, statistical) to the data**



Calibrating Optimal Base Engine Control Tables

- Generate response surface models from data

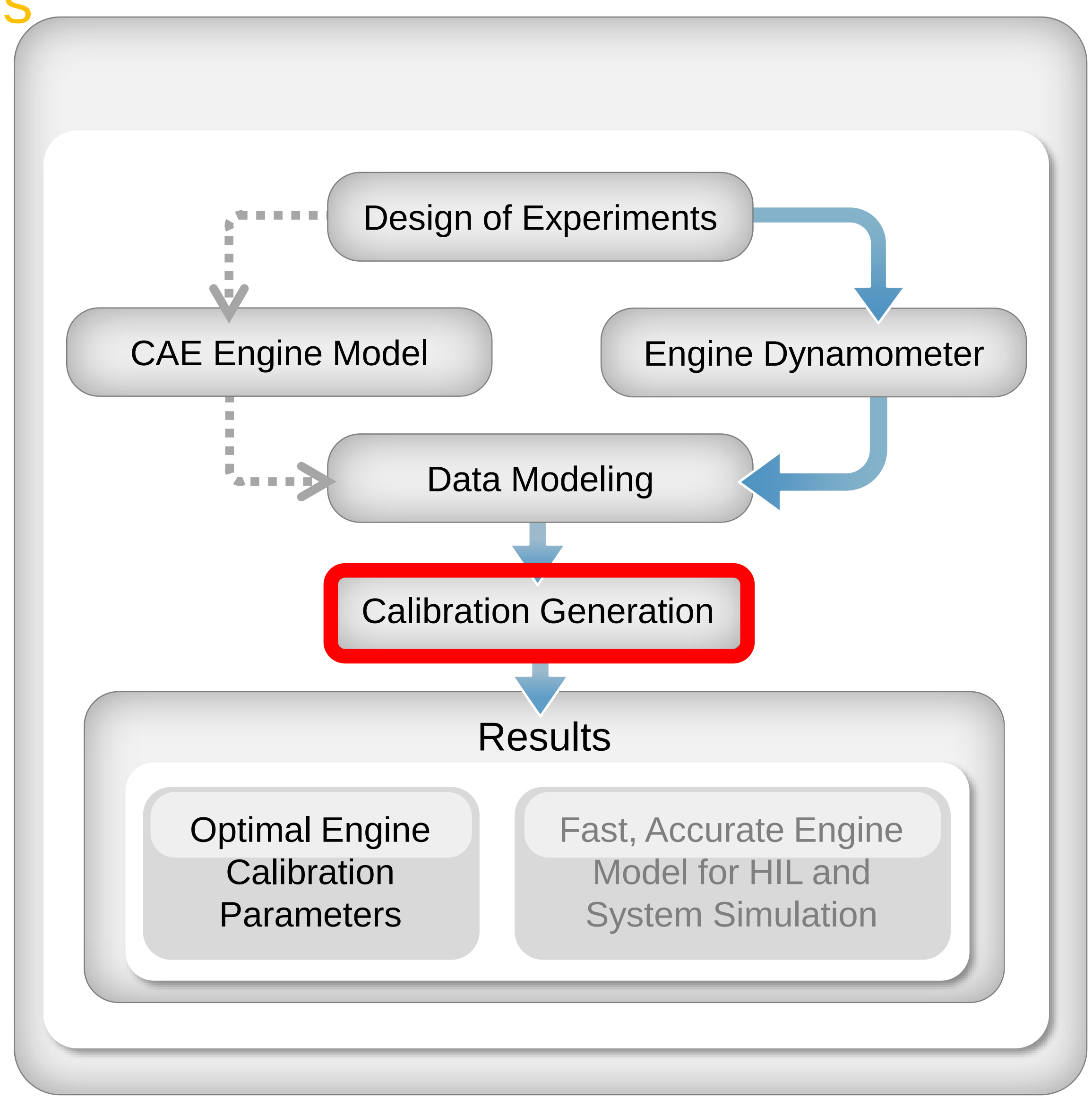
- Default models automatically fitted to all responses
- Inspect quality of fit
- Try out alternatives



Calibrating Optimal Base Engine Control Tables

- Develop optimal base calibration tables

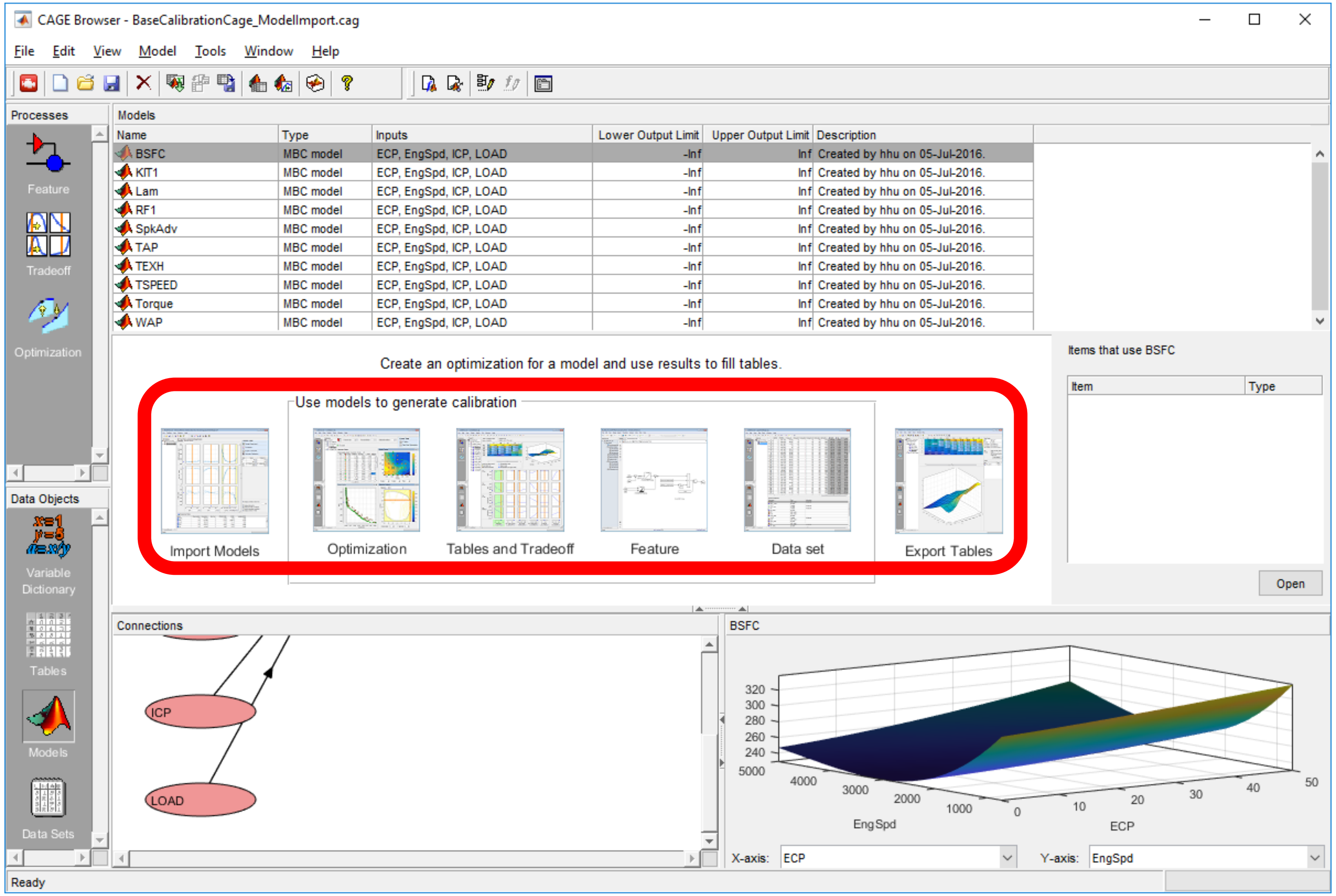
- Optimal base engine control calibration workflow:
  - Creating the Design of Experiments
  - Gather the data
  - Fitting response surface models
  - **Developing optimal base calibration tables from RSMs**



Calibrating Optimal Base Engine Control Tables

- Developing calibration tables

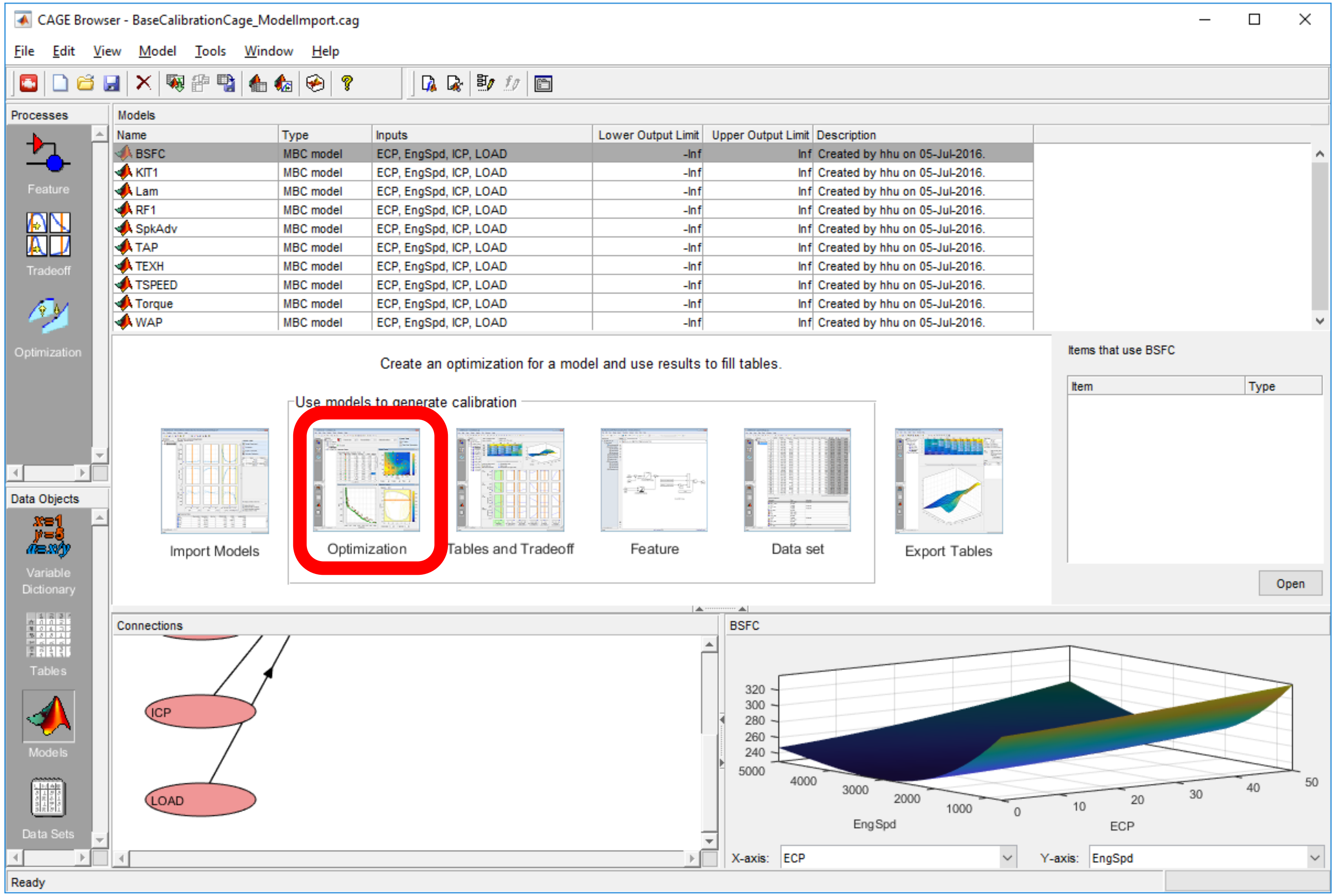
- Import response surface models
- Run optimizations
- Analyze tradeoffs and sensitivity
- Fill tables
- Export cal tables



Calibrating Optimal Base Engine Control Tables

- Developing calibrations from response surface models

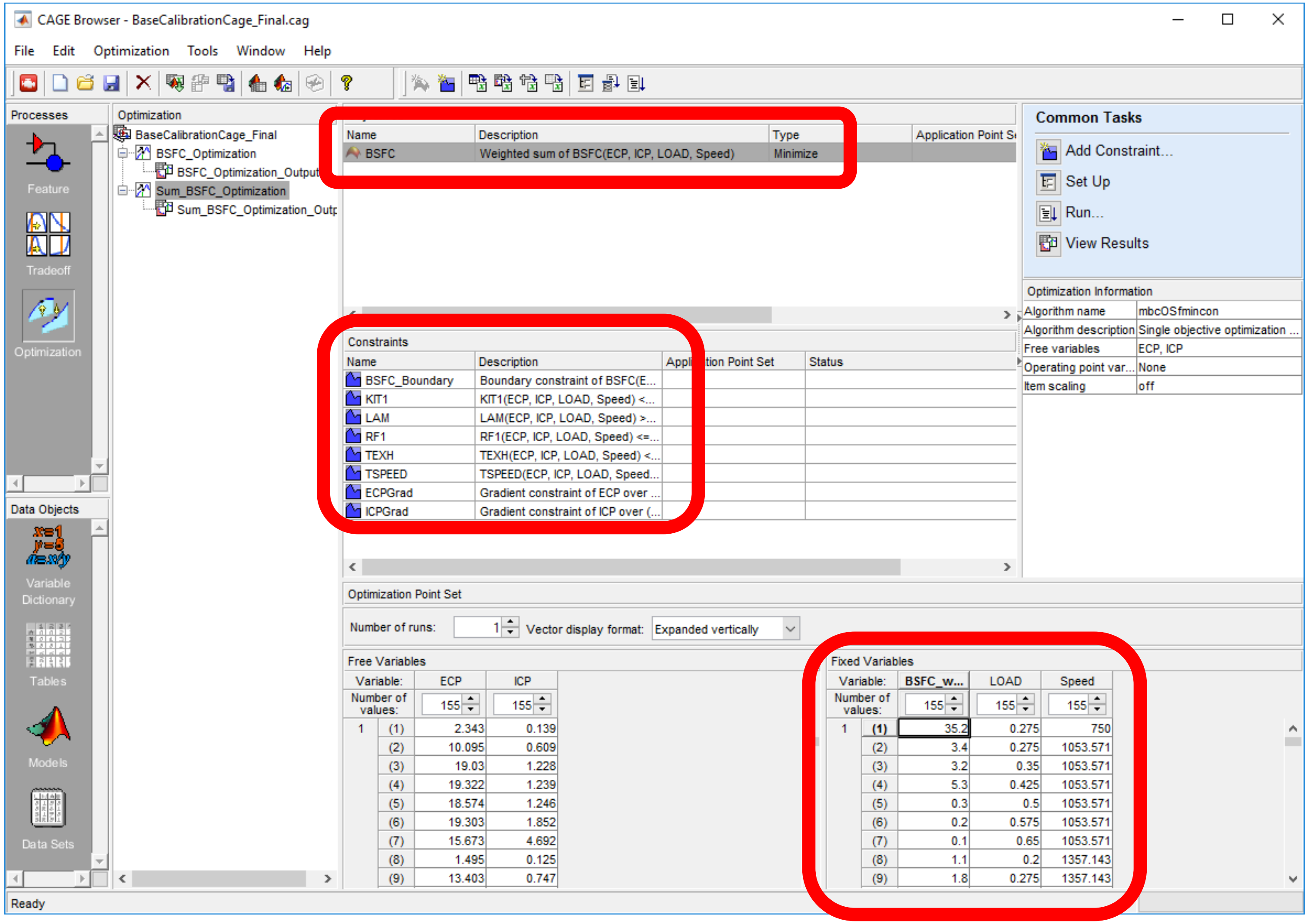
- Import response surface models
- **Run optimizations**
- Analyze tradeoffs and sensitivity
- Fill tables
- Export cal tables



Calibrating Optimal Base Engine Control Tables

- Run optimizations

- Define objective
- Define constraints
- Determine operating point weights

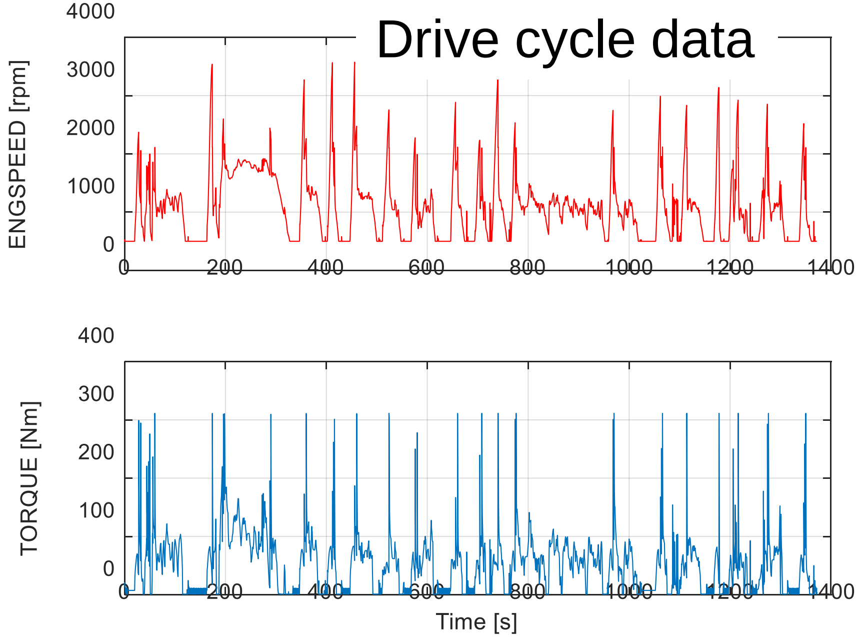


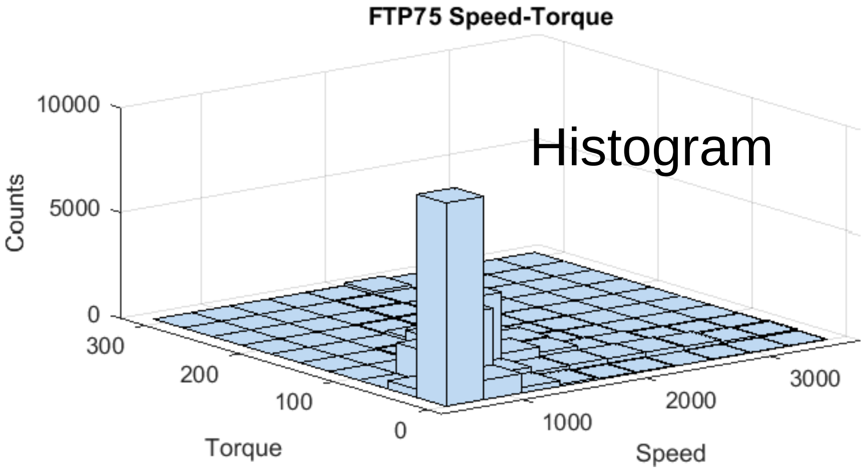
How to calculate the weights for a sum optimization

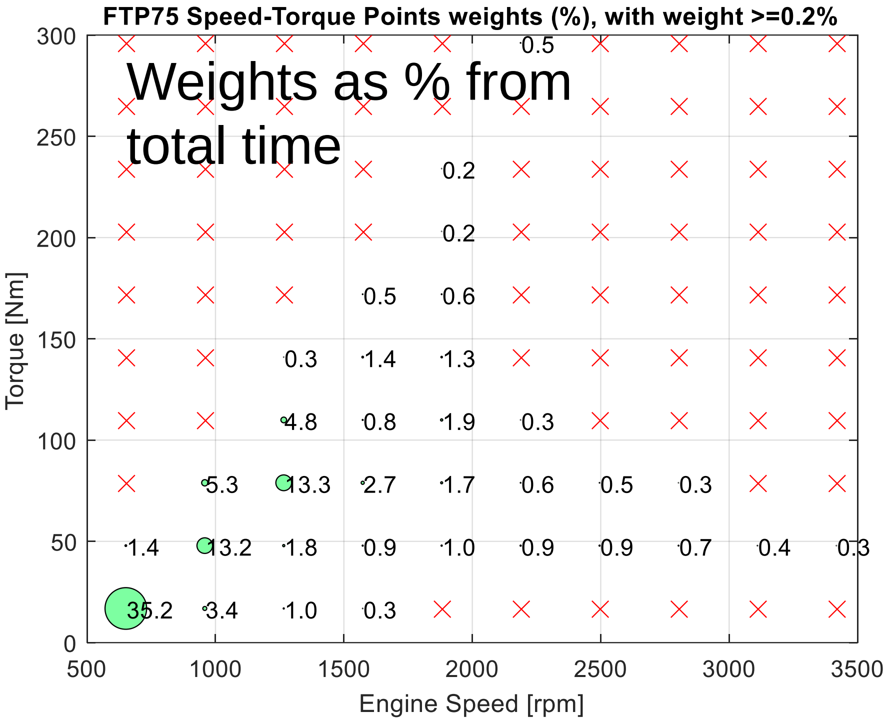
Use MATLAB to calculate weights for a drive cycle

```
AnalyzeDriveCycle.m
%% 総合モード解析の例
% MathWorks Japan, Florin Nae, 20160626

%% DriveCycleの生データを読込 (乗用車のFTP75の例)

[num,txt,raw] = xlsread('DriveCycleData.xlsx');

time = num(:,1);
ENGSPEED = num(:,2);
TORQUE = num(:,3);

% データの可視化
figure
subplot(2,1,1)
plot(time,ENGSPEED,'-r'),grid on
ylabel('ENGSPEED [rpm]')
subplot(2,1,2)
plot(time,TORQUE),grid on
ylabel('TORQUE [Nm]')
xlabel('Time [s]')
```

MATLAB program reads measurements from Excel measurement file and calculate weights automatically



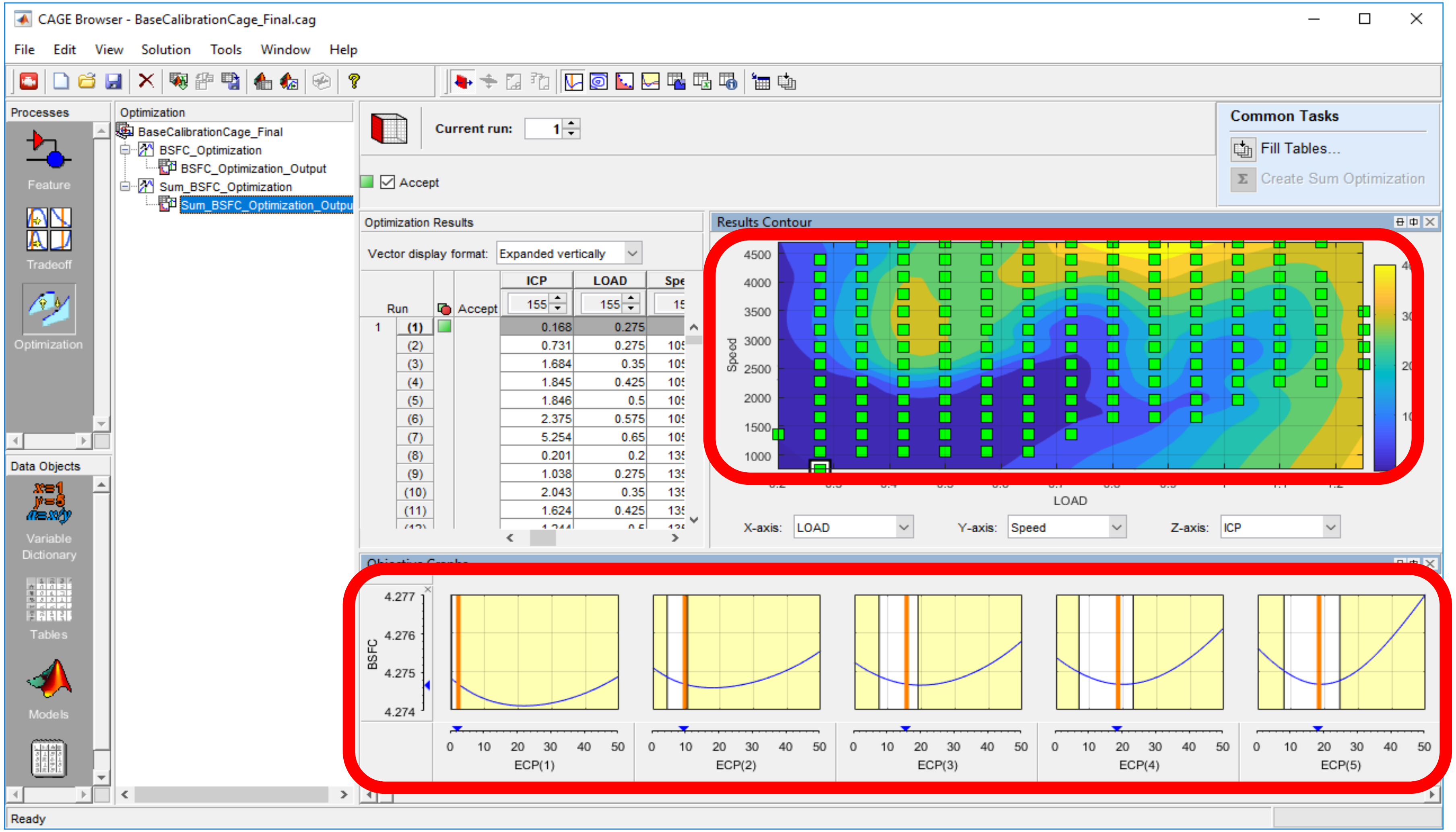




Calibrating Optimal Base Engine Control Tables

- Run optimizations

- Evaluate optimization results
- Diagnose optimization convergence issues

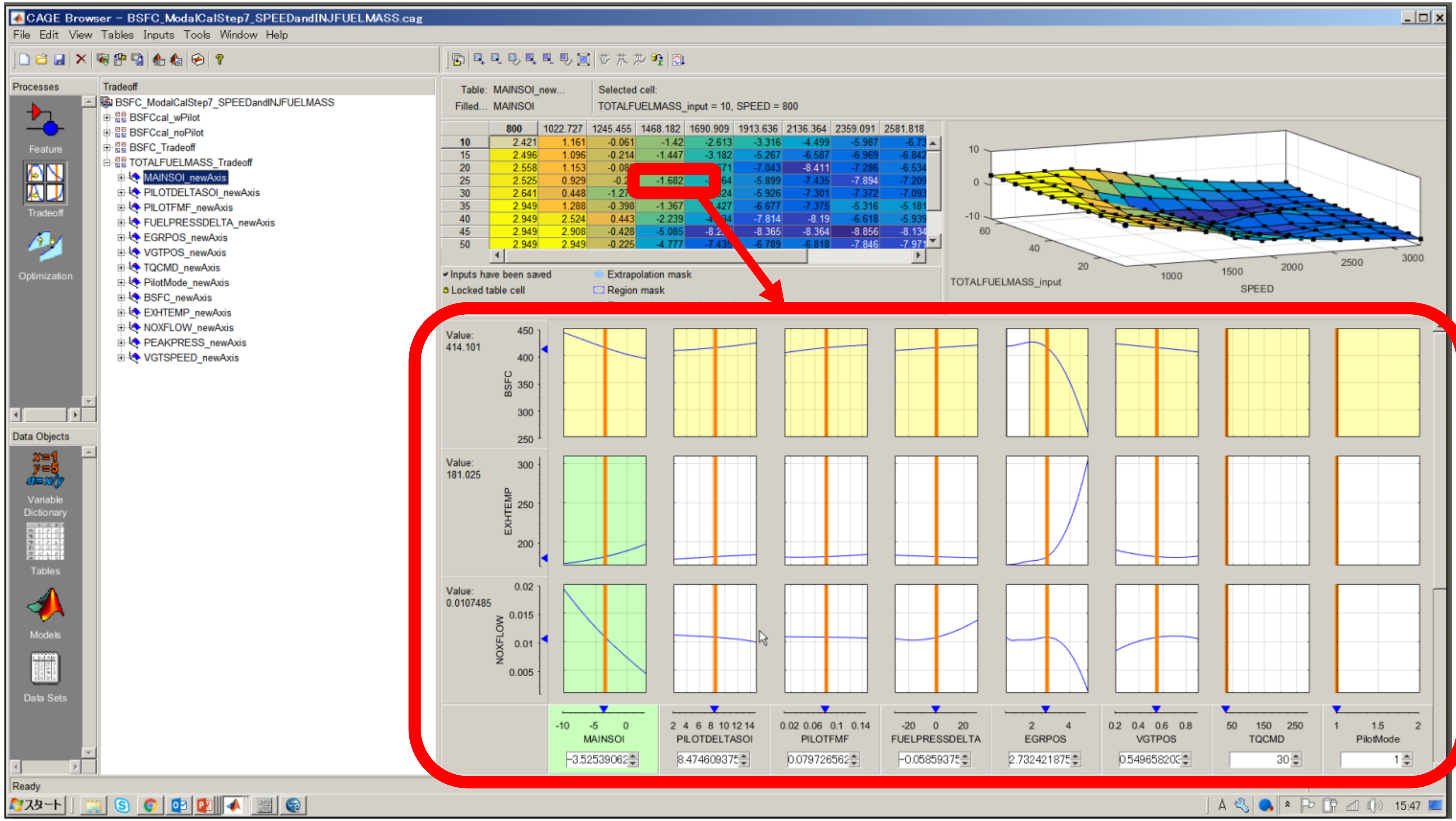


Calibrating Optimal Base Engine Control Tables

- Analyze tradeoffs and sensitivity

- Evaluate local sensitivity

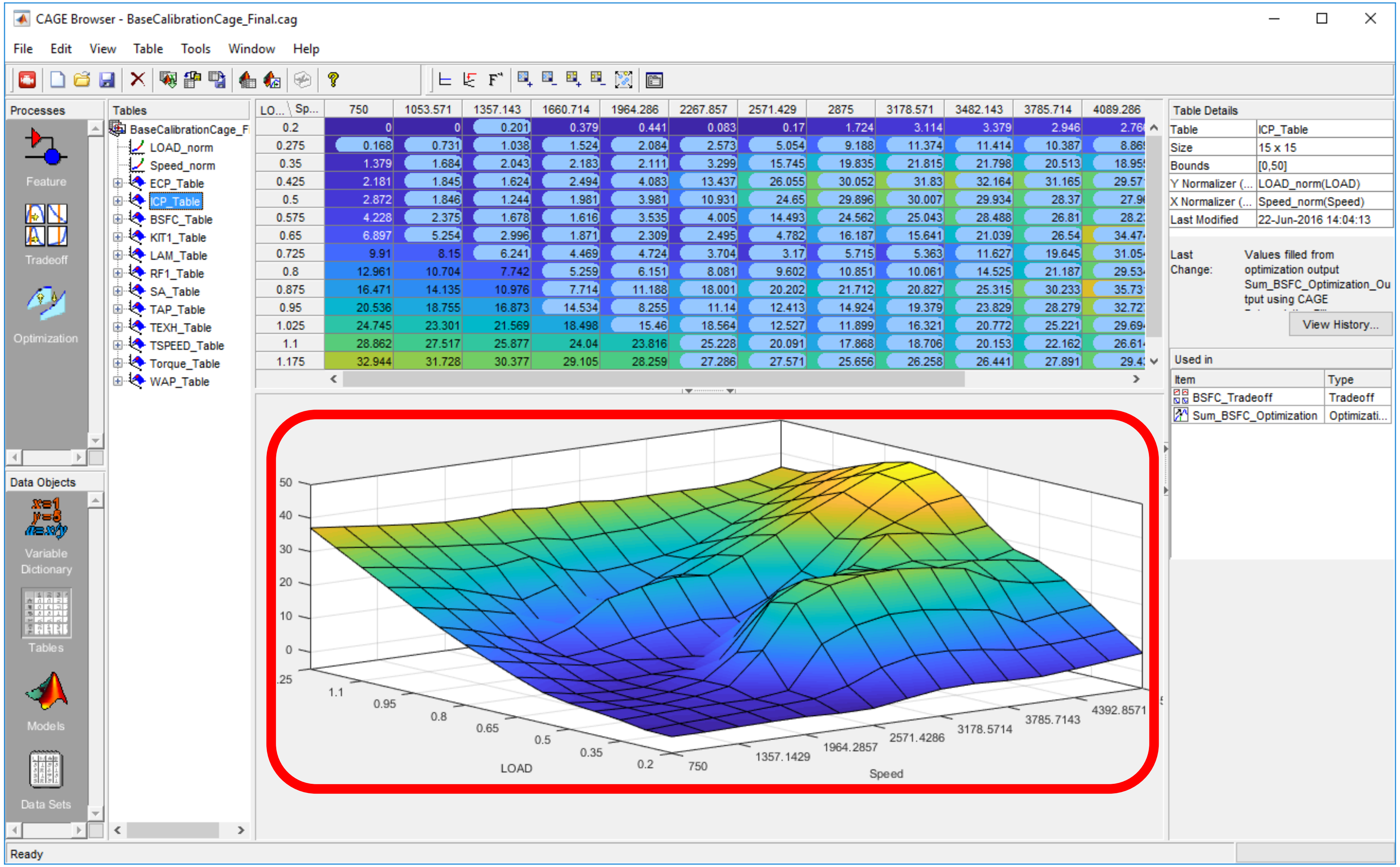
- Determine if tradeoffs are needed



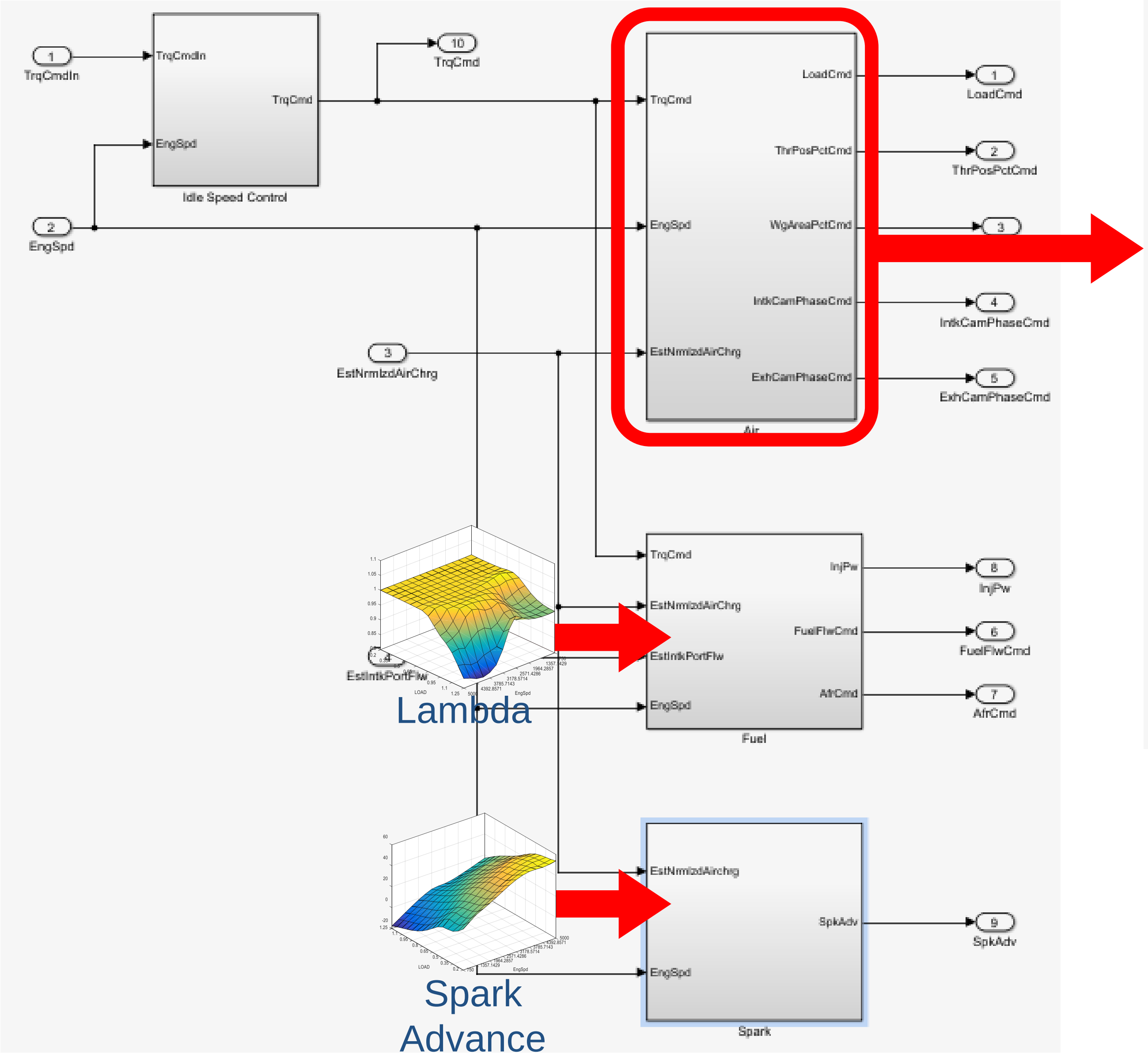
Calibration Generation Tool

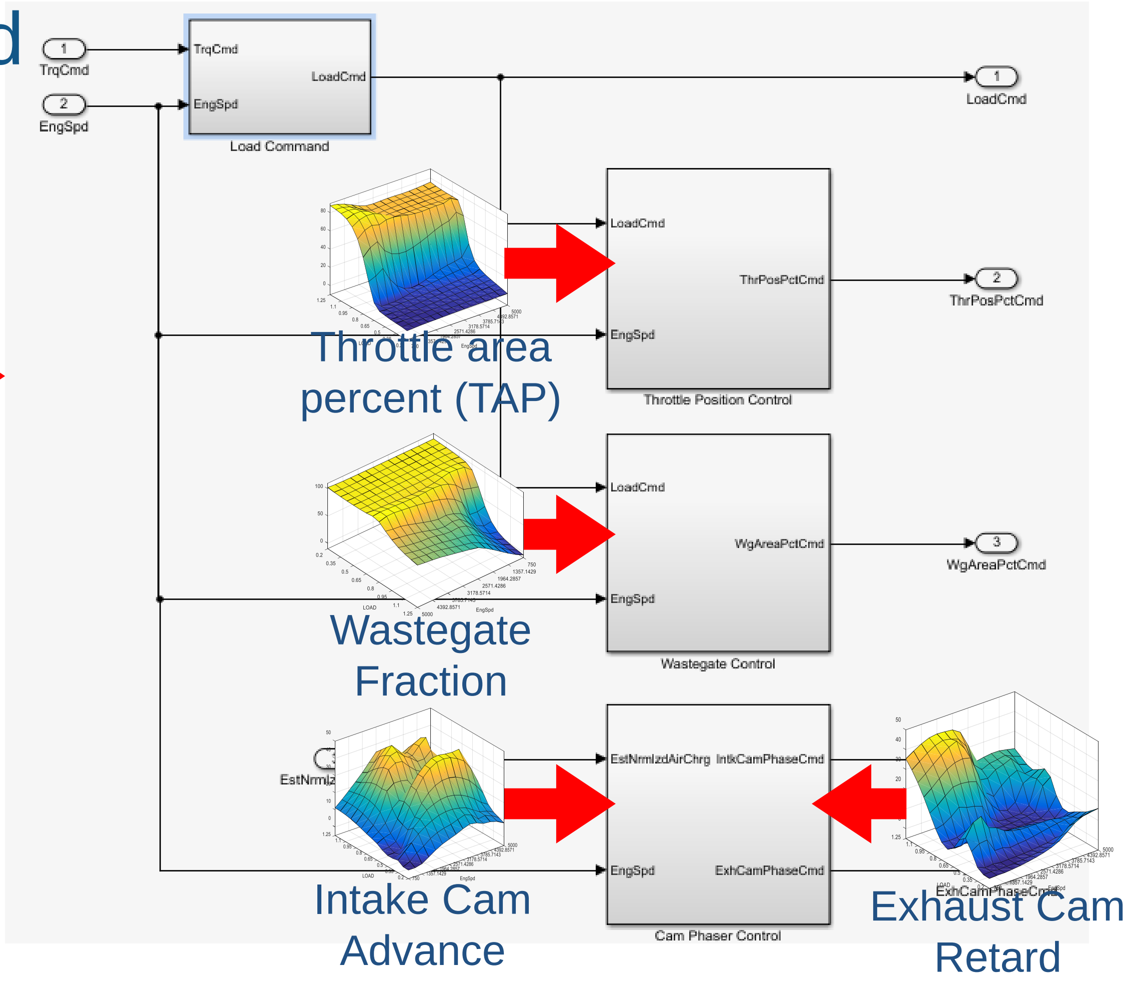
- Fill tables

- Inspect surfaces
- Export to MATLAB, Excel or Cal tool



Optimal Base Calibrations Completed

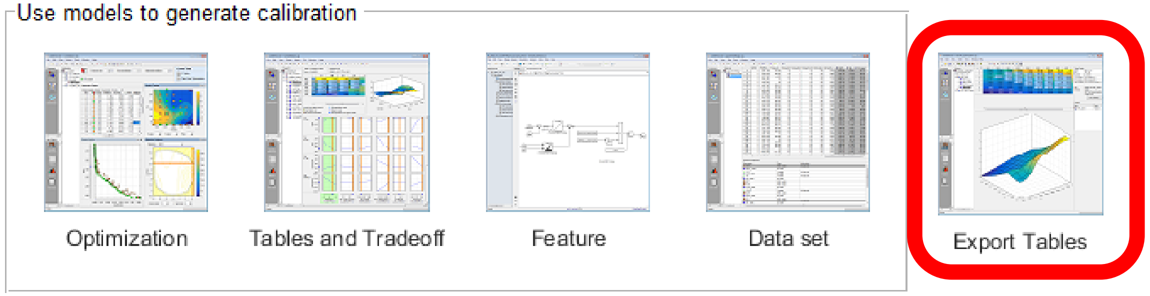


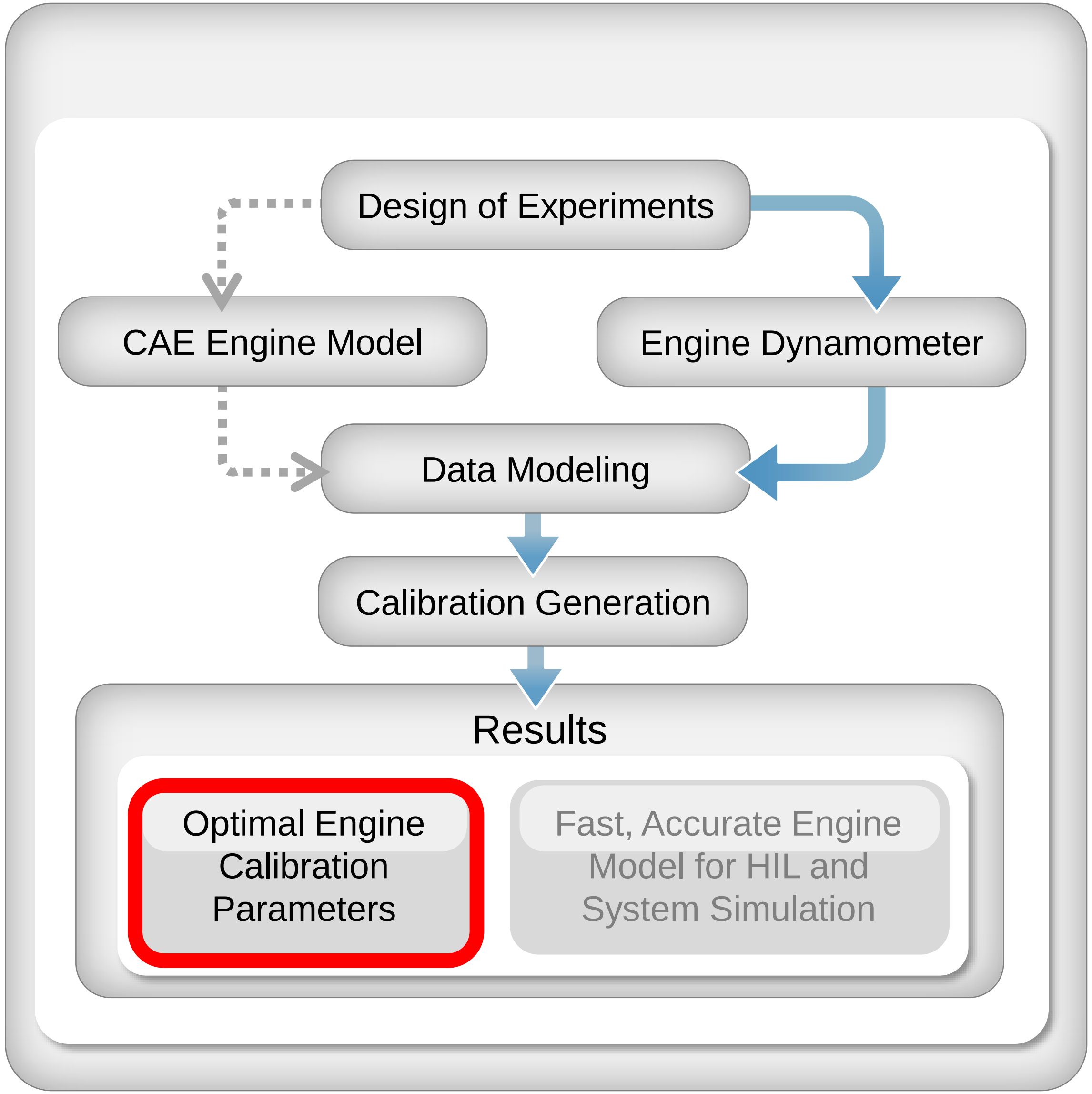


Calibrating Optimal Base Engine Control Tables

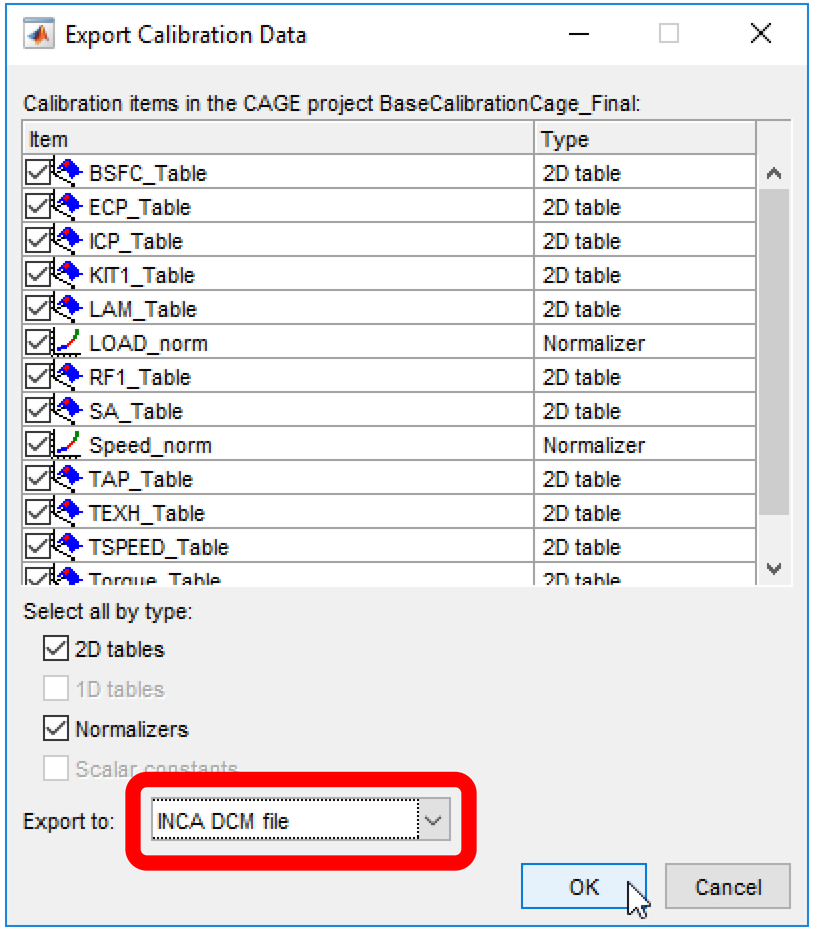
- Export and validate the result

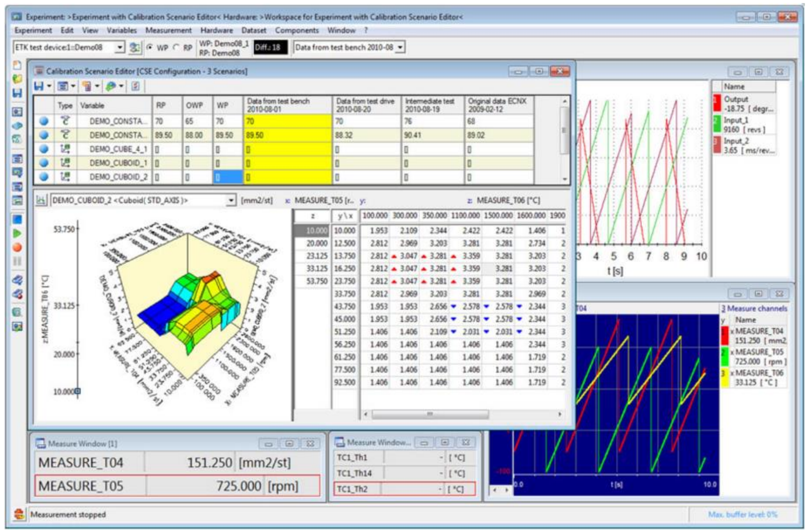
- Optimal base engine control calibration workflow:
  - Creating the Design of Experiments
  - Gather the data
  - Fitting response surface models
  - Developing optimal base calibrations
  - **Export calibration to controller**



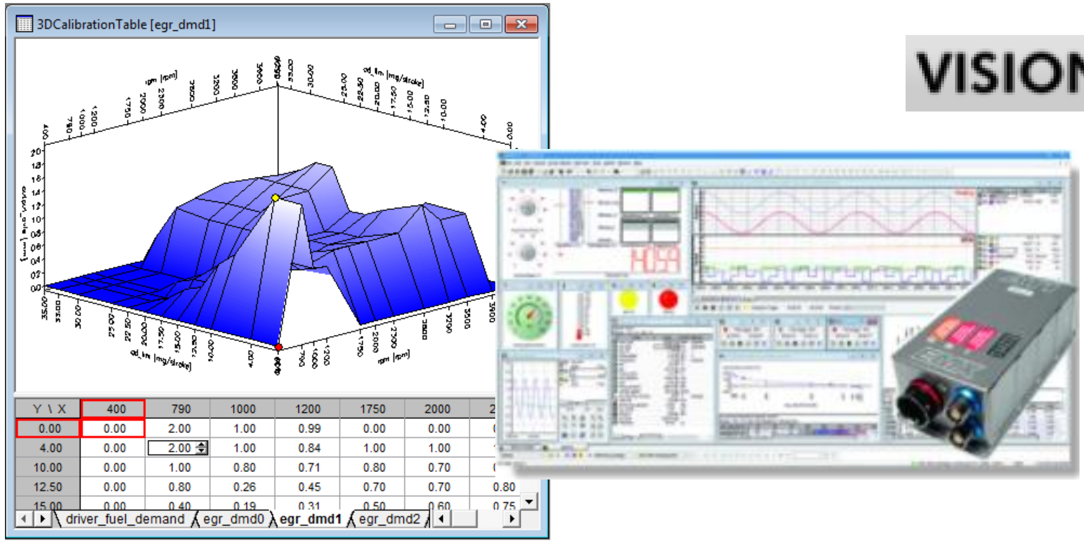


Export Tables to Calibration Tool





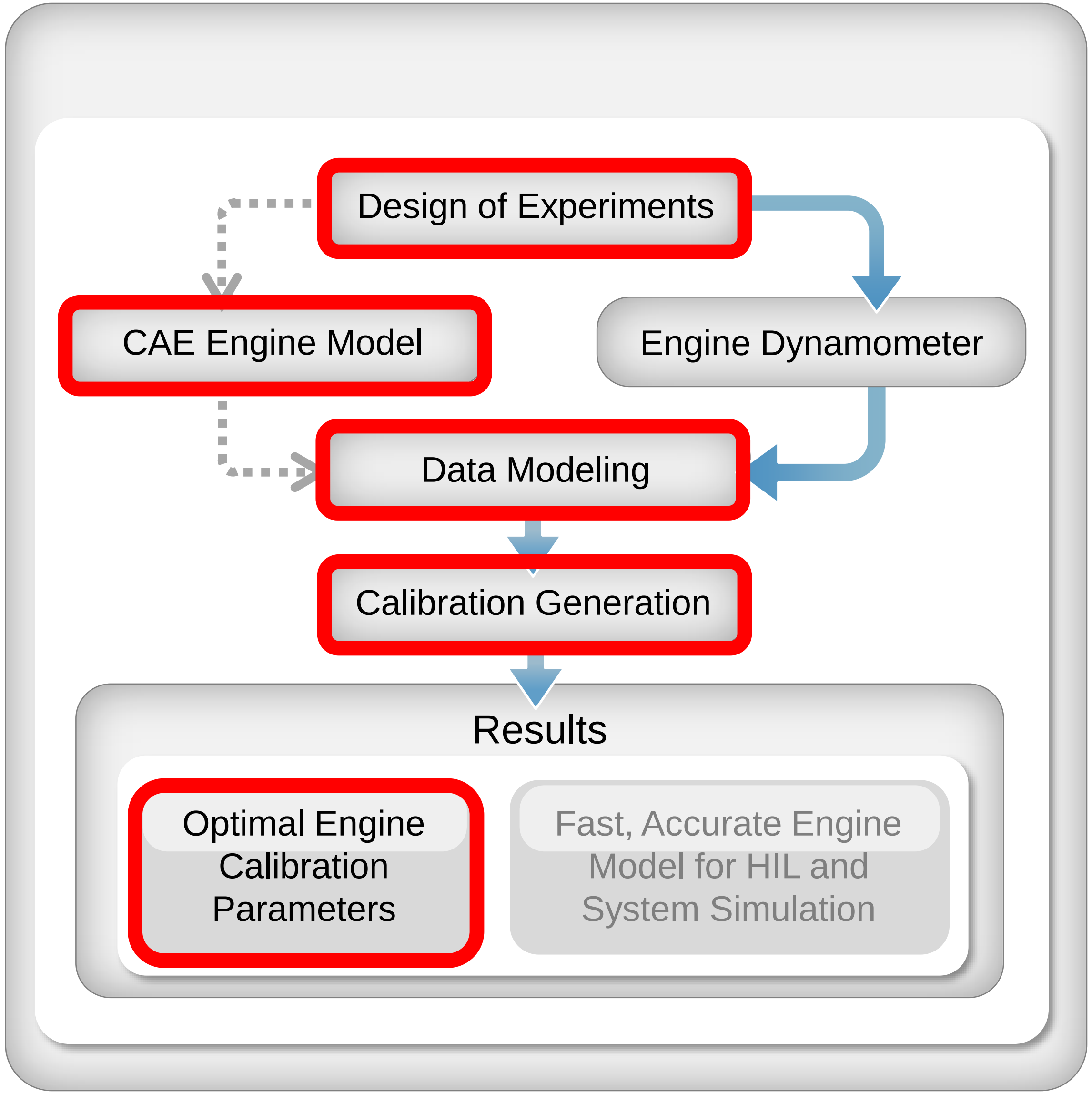
INCA



VISION

Calibrating Optimal Base Engine Control Tables
- Summary

- Optimal base engine control calibration workflow:
  - Creating the Design of Experiments
  - Gather the data
  - Fitting response surface models
  - Developing optimal base calibrations
  - Export calibration to controller



Key Take-Away's

- Engine model parameterization is a very non-trivial task

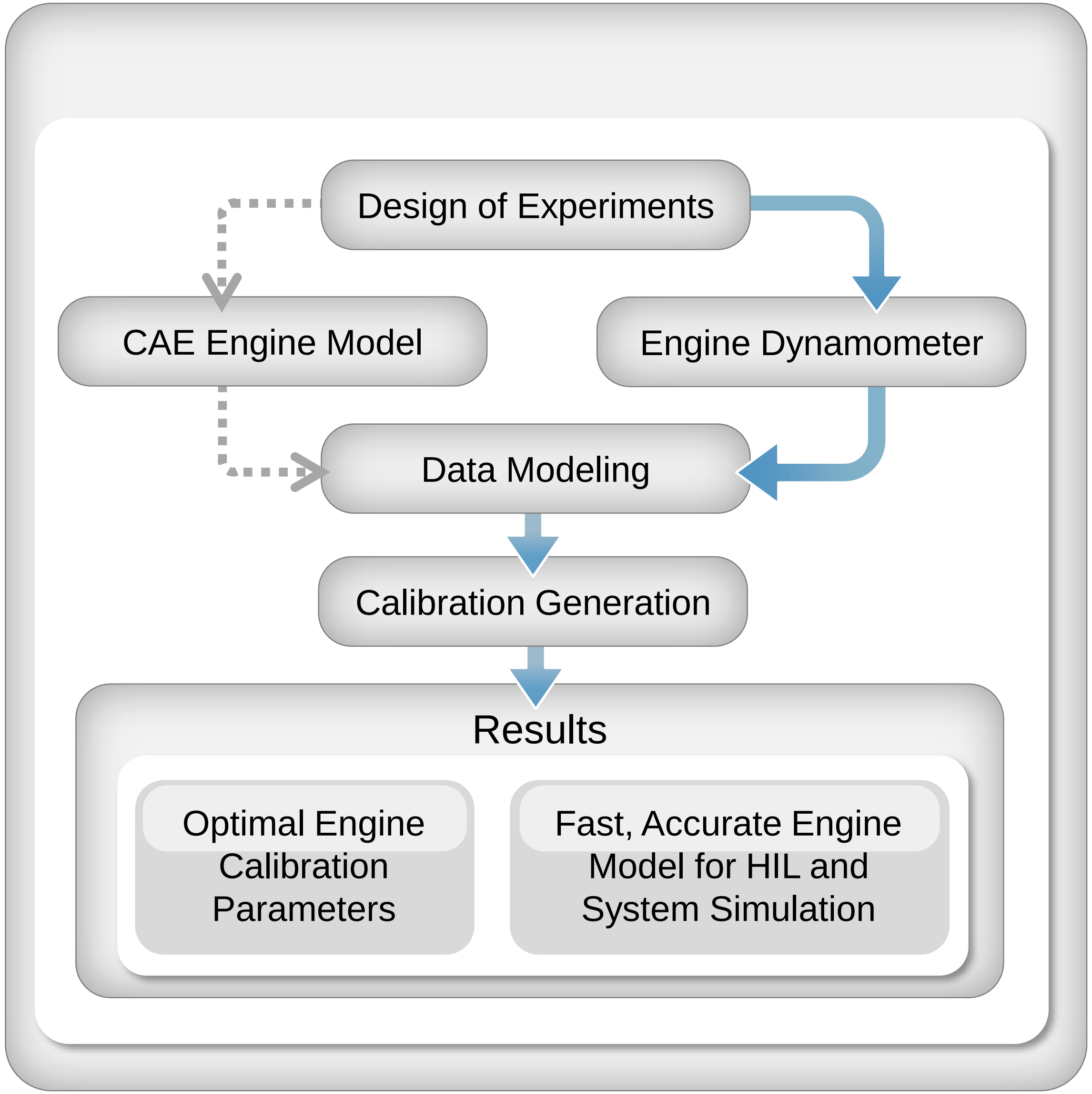
- Engine controller calibration is a very non-trivial task

- **MathWorks has tools to help make these two tasks more manageable**

Contact us to Learn More

- Scott Furry
(scott.furry@mathworks.com)

- Brad Hieb
(brad.hieb@mathworks.com)



Q & A