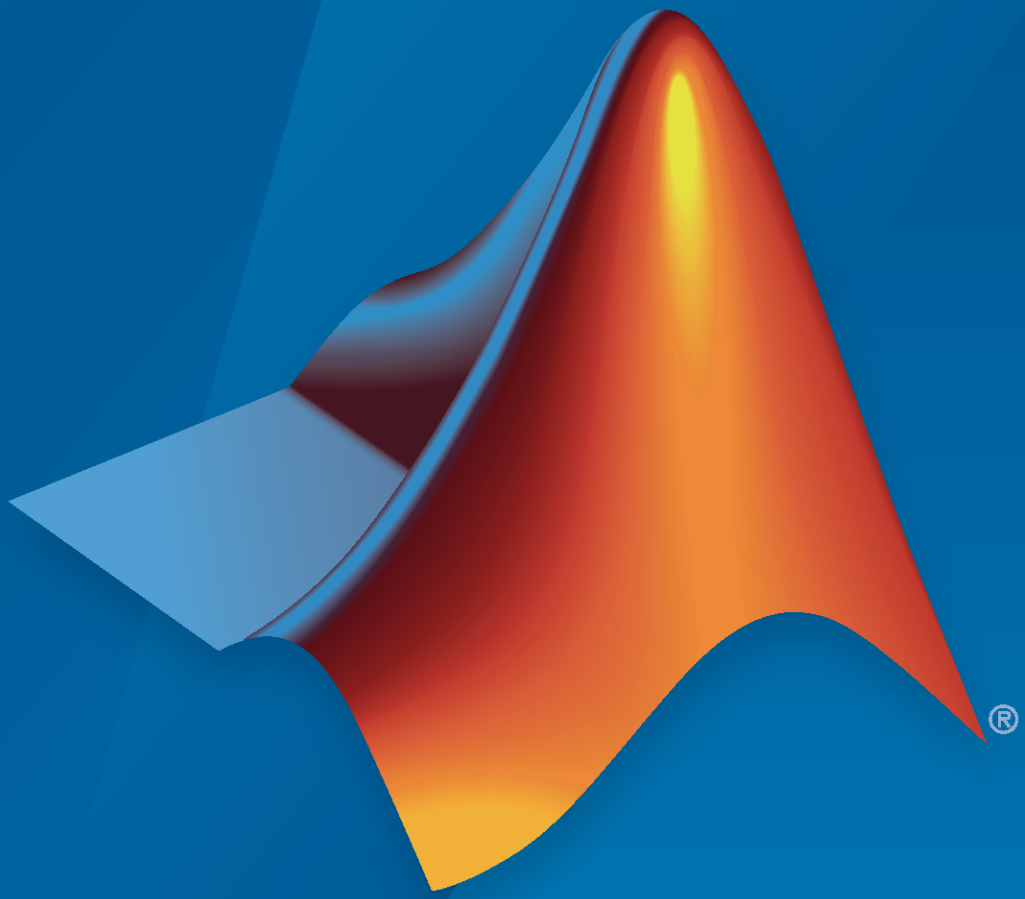
Model-Based Calibration Toolbox™ Release Notes



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Model-Based Calibration Toolbox™ Release Notes

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R2021a

Version: 5.10

New Features

Bug Fixes

Transient Calibration: Optimize calibrations of dynamic systems like DPF and NOx controllers and OBD estimators

Use CAGE to optimize calibrations with transient controllers, which enables calibration of dynamic systems like diesel particulate filter (DPF) and nitric oxide and nitrogen dioxide (NOx) emission controllers, and on-board diagnostics (OBD) estimators. Specifically, CAGE can optimize calibrations for features that:

- Include delays, discrete integrators and filters, and feedback loops.
- Contain many (> 50) lookup tables that require estimation.
- Have multiple test data files to tune the feature.
- Require analytic derivatives to perform large-scale optimizations.

For more information, see “Optimize Calibrations with Transient Controllers”.

Automatic Differentiation in Feature Fills: Use analytic derivatives to provide faster, more reliable optimizations

Feature fills use automatic differentiation (AD) to automatically calculate gradients of objective expressions. These automatic gradients can provide faster, more reliable optimizations than the previous default, finite-difference, approximations. When it is possible to determine the analytic derivatives, CAGE uses AD for all feature fills.

- Large-scale optimization methods introduced in R2021a for transient calibration require AD.
- When it is not possible to determine an analytic derivative, for example, when differentiating a non-smooth expression, the feature fills revert to a finite-difference approach to determine the approximate derivative.

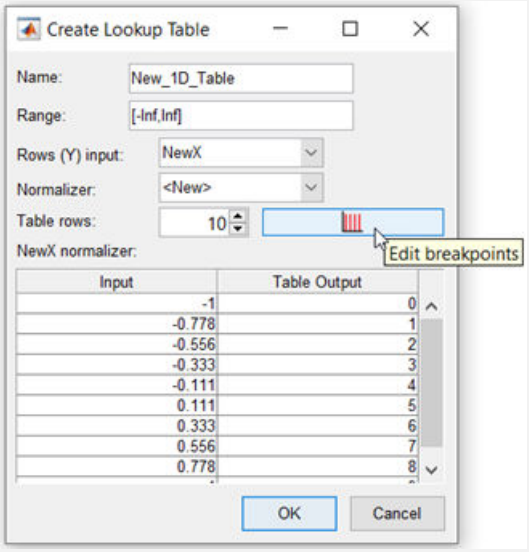
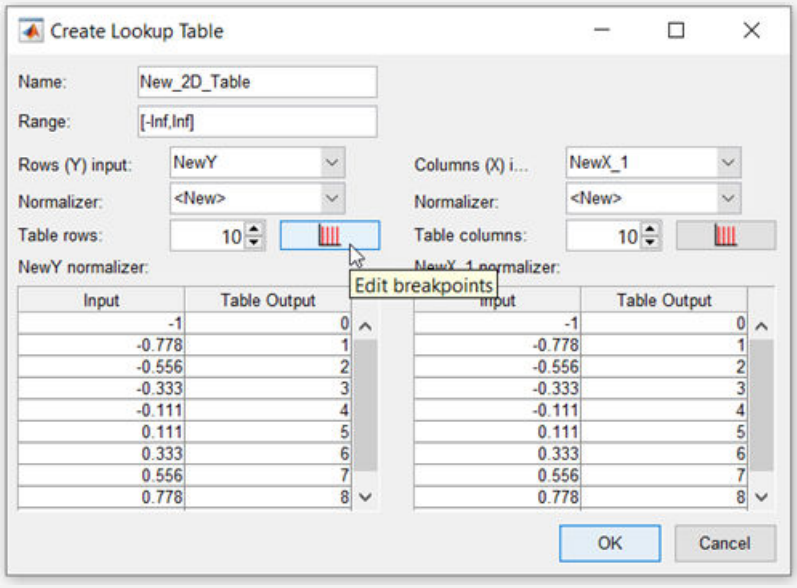
For AD details, see “Automatic Differentiation Background”.

Lookup Tables: Simplified workflow for setting breakpoints and viewing 1D optimization results

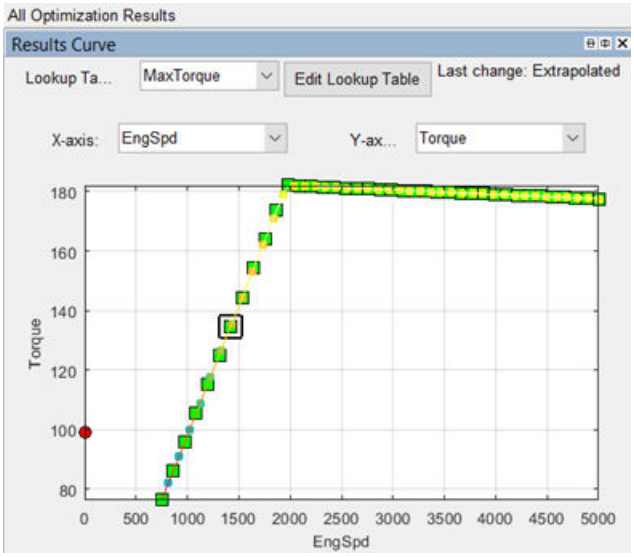
To simplify the workflow for creating lookup tables, CAGE allows you to set breakpoints and normalizers when you create the table. Previously, to set the breakpoints, you had to create the table and then use the **Breakpoint Fill** option.

Select **File > New > File > 1D Lookup Table** or **2D Lookup Table**. Use the Create Lookup Table dialog box to specify the following:

- Name
- Range
- Rows
- Normalizer
- Breakpoints with the **Edit breakpoints** option

File > New Option	Description
1D Lookup Table	
2D Lookup Table	

When you view optimization results for a 1D lookup table, the Optimization Results view shows a 1D plot. Previously, the view showed a surface view.



For more information, see “Viewing Your Optimization Results”.

Feature Fill: Performance improvements when filling a single lookup table

CAGE uses automatic differentiation to calculate the analytic derivatives during feature fill, resulting in performance improvements when filling a single table. The automatic differentiation applies during transient and non-transient feature fills. For more information, see “Fill Feature Lookup Tables”.

Feature Fill: View, edit, and optimize calibration constants

To streamline feature filling, the CAGE browser view allows control of the calibration constants. Previously, you could only view, edit, and optimize calibration constants in the Calibration Manager. To edit the calibration constants, in the CAGE Feature Filling view, select the **Calibration Constants** tab. You can review and edit the calibration constants for the feature.

Lookup Table Preview | Calibration Constants | Validation

Name	Value
Constant6	40
EO_NOx_ppm_delay_param	21.375
Exhaust_flow_min	10
Ka_AFR_max	60
Ka_AFR_min	2
Ka_EGR_max	1
Ka_EGR_min	0
Ka_RP_max	600
Ka_RP_min	120
Ka_SOI_max	30
Ka_SOI_min	-18
One	1
OneTenth	0.1
Two	2

For more information, see “Feature Calibration”.

R2020b

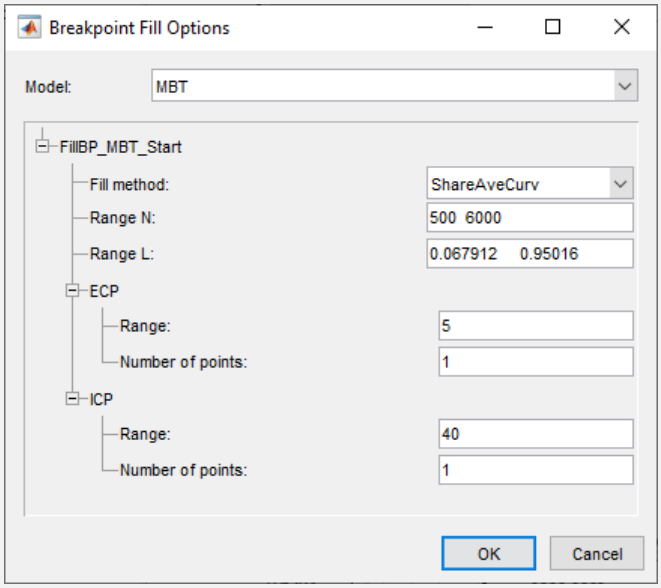
Version: 5.9

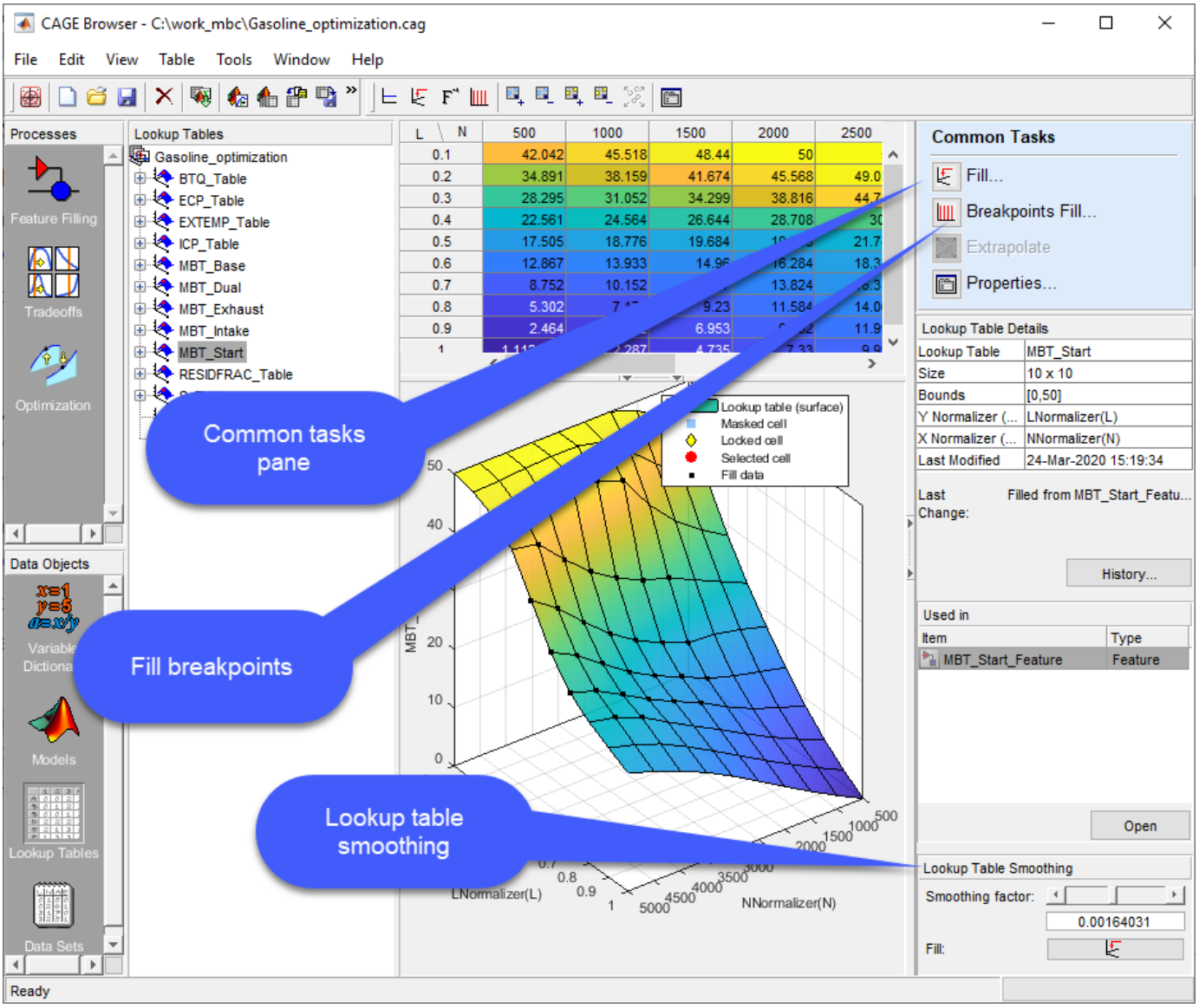
New Features

Bug Fixes

Lookup Tables: Simplified workflows for filling breakpoints, smoothing data, and accessing common tasks

Model-Based Calibration Toolbox now includes simplified workflows for filling lookup table breakpoints, smoothing data, and accessing common tasks in CAGE.

Goal	Workflow
Optimize the lookup table breakpoints.	On the Lookup Table view **Common Tasks** pane, select **Breakpoints Fill**. On Breakpoint Fill Options dialog box, specify the fill options. Click **OK**.  The Update Lookup Tables dialog opens, allowing you to update the lookup tables with the new breakpoints. Previously, you had to use initialize a feature and optimize the normalizer breakpoints to optimize the table breakpoints.
Interactively change the smoothing factor when you fill lookup tables with models or data.	On the CAGE Lookup Tables view, use the **Lookup Table Smoothing** interactive control to adjust the smoothing factor.
Quickly perform common actions, including table filling.	On the CAGE Lookup Tables view, on the Common Tasks pane, select the corresponding option.



For more information, see Edit Lookup Tables.

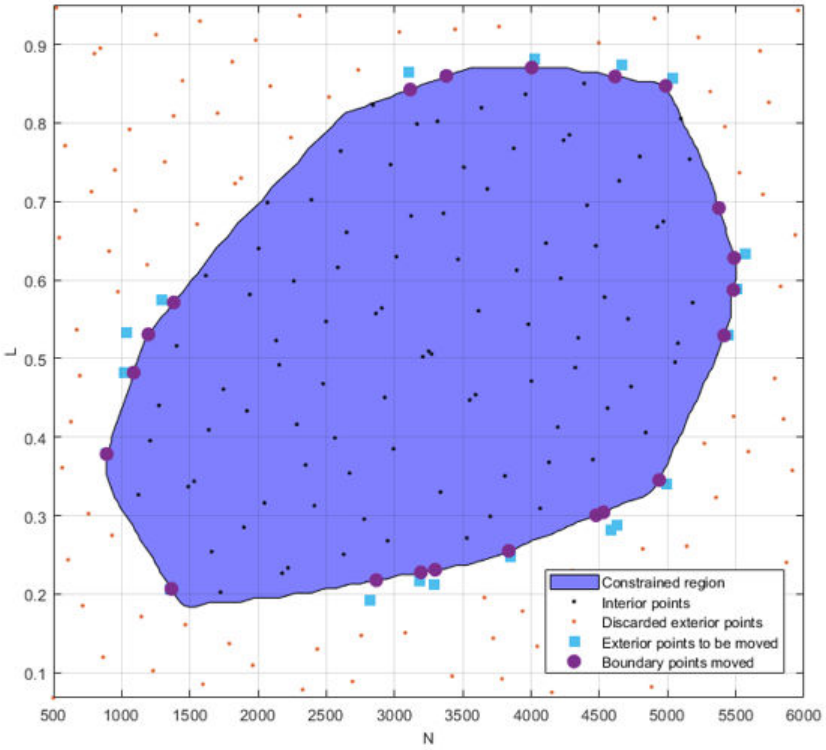
Models: Use CAGE to import and optimize Statistics and Machine Learning Toolbox regression models

Use CAGE to import and optimize Statistics and Machine Learning Toolbox™ regression models. For more information, see Regression Models.

Design of Experiments: Add points for engine calibrations at operating boundary

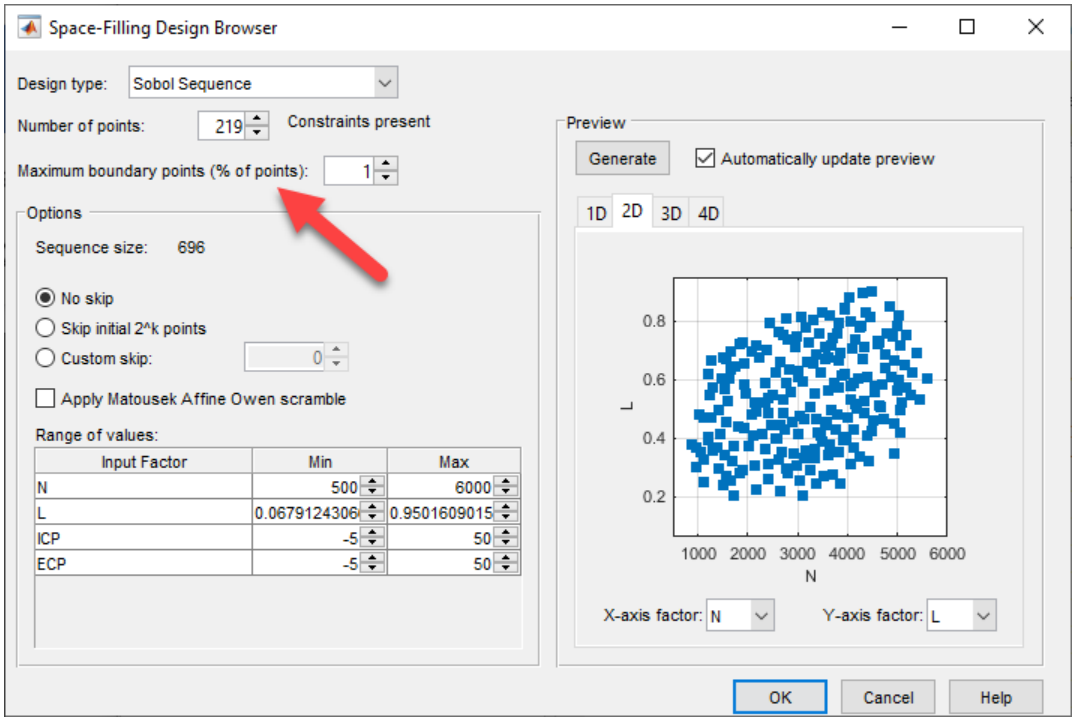
The Space-Filling Design browser has an option to add points at engine operating boundaries, creating more accurate engine calibrations. In the browser, when you specify a value for **Maximum**

boundary points (% of points), Model-Based Calibration Toolbox identifies operating points that are near the constraint boundary and exterior to the constrained operating region. In the illustration, the *Exterior points to be moved* are light blue. The software moves the identified points to the constraint boundary and includes them in the constrained region. In the illustration, the *Boundary points moved* are purple.



The **Maximum boundary points (% of points)** option limits the maximum number of boundary points as a percentage of the total number of design of experiment (DoE) points. The total number of DoE points is equal to the number of interior points plus boundary points. For example:

- If you set **Maximum boundary points (% of points)** to 100, Model-Based Calibration Toolbox projects all *Discarded exterior points* onto the constraint boundary.
- If you set **Maximum boundary points (% of points)** to 10 and the total number of DoE points is 100, the DoE will have 90 interior points and 10 boundary points. The exact number of boundary points might be less than 10% if the software finds a sufficient number of interior points.



For more information, see Create a Space-Filling Design.

Model-Based Calibration Toolbox Examples: Live Scripts for engine calibration, design of experiment, and engine modeling examples

Model-Based Calibration Toolbox includes live scripts for these engine calibration, design of experiment, and engine modeling examples:

- https://www.mathworks.com/help/releases/R2020b/mbc/mbc_gs/use-constraints.html
- https://www.mathworks.com/help/releases/R2020b/mbc/mbc_gs/local-design.html
- https://www.mathworks.com/help/releases/R2020b/mbc/mbc_gs/optimal-design.html
- https://www.mathworks.com/help/releases/R2020b/mbc/mbc_gs/gasoline-case-study.html
- https://www.mathworks.com/help/releases/R2020b/mbc/mbc_gs/gasoline-case-study-doe.html
- https://www.mathworks.com/help/releases/R2020b/mbc/mbc_gs/load-and-modify-data.html
- https://www.mathworks.com/help/releases/R2020b/mbc/mbc_gs/point-by-point-modeling-for-diesel.html

Previously, the examples were plain code scripts.

R2020a

Version: 5.8

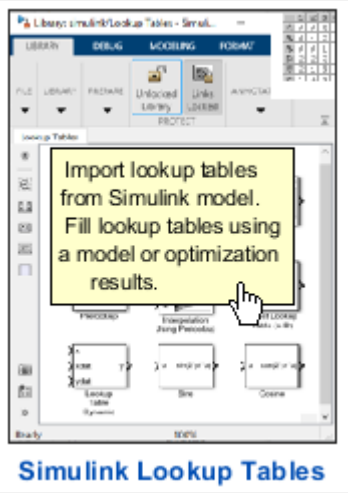
New Features

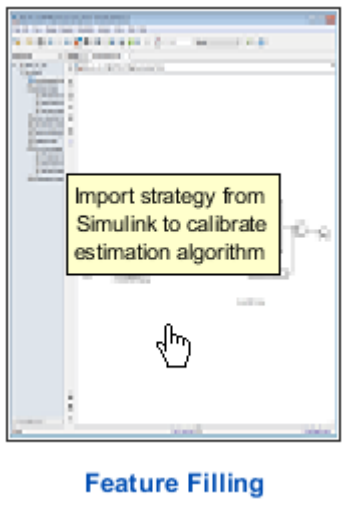
Bug Fixes

Compatibility Considerations

Simulink Integration: Simplified workflows for importing lookup tables and features and exporting data dictionaries

Model-Based Calibration Toolbox now includes these simplified workflows for importing lookup tables from Simulink® models into CAGE and exporting data dictionaries.

Goal	Using	Workflow
Fill Simulink lookup tables and export data to Simulink model workspace.	Statistical models or optimization results	**1** In the CAGE browser, select **Simulink Lookup Tables**.  Select the Simulink model. **2** Use the MBC Simulink Lookup Table Importer to preview and import all lookup tables in a subsystem. Click **Import Tables** to import tables into CAGE. **3** In CAGE, fill the lookup tables using statistical models or optimization results. **4** To export the calibration to a Simulink model workspace or data dictionary, select **File** > **Export** > **Calibration**. Set **Export to** to `Simulink Data`. For more information, see Import Lookup Tables from a Simulink Model.

Goal	Using	Workflow
	Feature calibration	1 In the CAGE browser, select **Feature Filling**.  Select the Simulink model. 2 Use the MBC Feature Importer to preview tables and import the features for the selected subsystems. Click **OK**. 3 In CAGE, fill the lookup tables using feature fill. 4 To export the calibration to a Simulink model workspace or data dictionary, select **File** > **Export** > **Calibration**. Set **Export to** to `Simulink Data`. For more information, see Set Up Feature and Strategy and Calibrate a Feature for an Estimator Subsystem in an ECU.

Compatibility Considerations

In R2020a, to export a calibration to a Simulink model workspace from CAGE, select **File** > **Export** > **Calibration** and set **Export to** to `Simulink Data`. This replaces the `Simulink Model Workspace` parameter setting for **Export to**.

R2019b

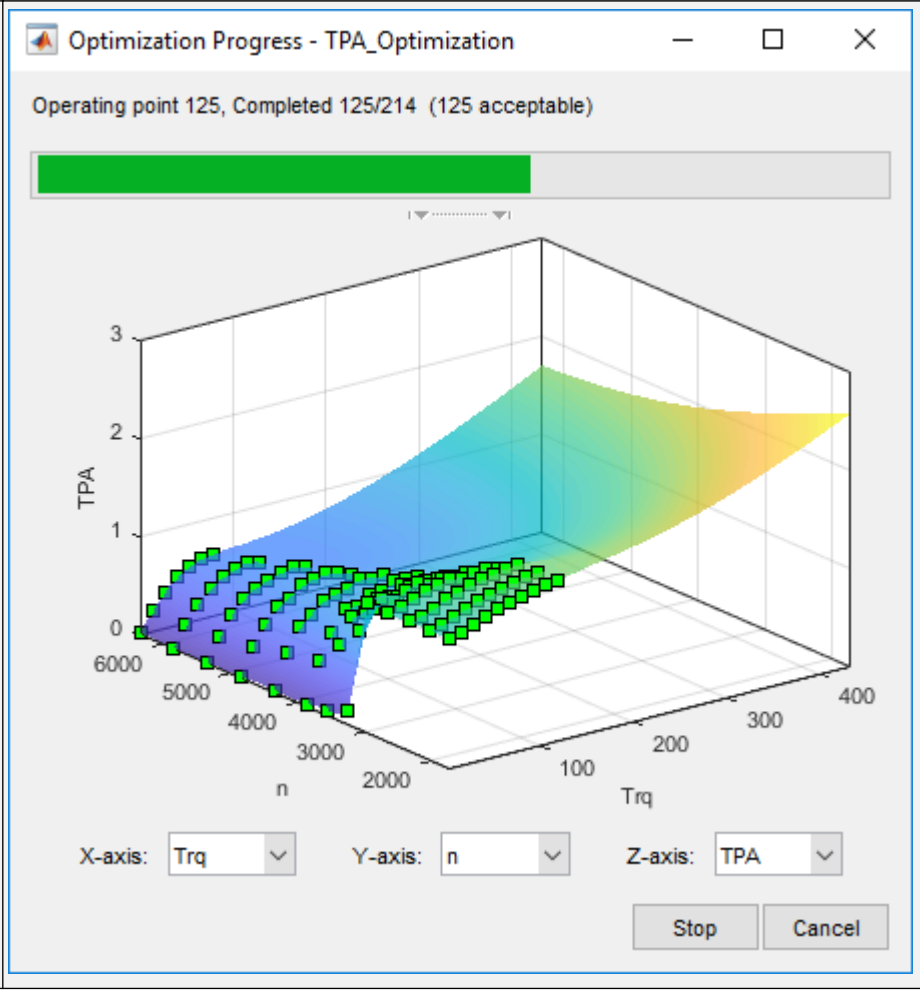
Version: 5.7

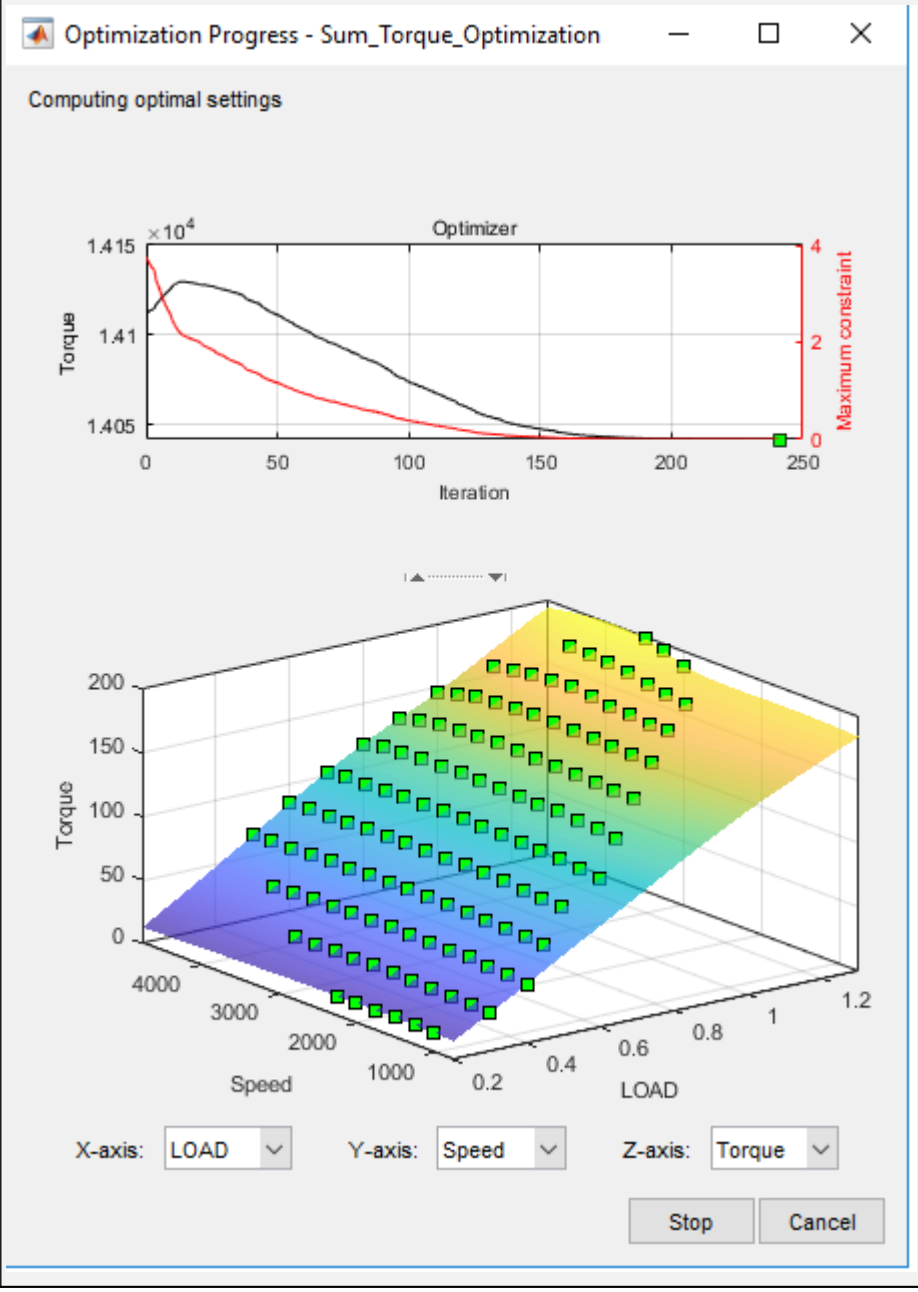
New Features

Bug Fixes

Optimization Progress: View result surface tables during optimization

The Optimization Progress dialog box provides the status of the optimization in progress, including the results surface tables.

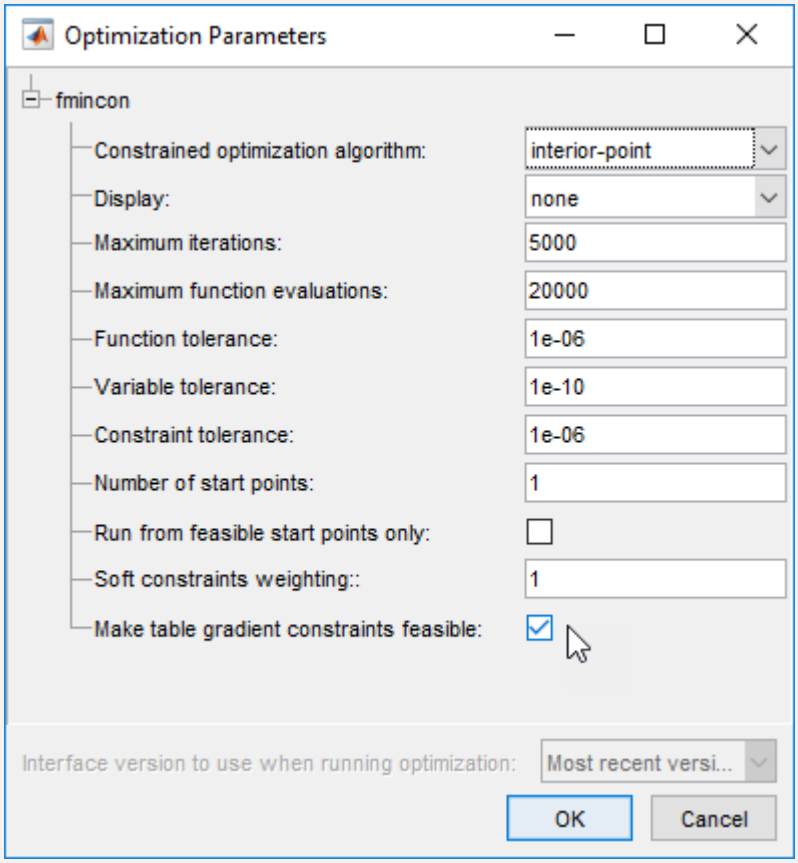
Optimization Objective	Progress Dialog Box
Point The dialog box provides the number of completed and acceptable operating point solutions. You can change the axes to view a specific result surface as the optimization runs.	

Optimization Objective	Progress Dialog Box
Sum In the dialog box, the trace lines provide this additional optimization information. **Trace Color** / **Description** Black / Objective Red / Maximum constraint violation You can change the axes to view a specific result surface as the optimization runs.	

Performance: Improved optimization performance with default settings and algorithms

To improve optimization performance, R2019b includes these updates.

Update	
Default settings	Default settings for these optimization algorithms. • `fmincon` • `modal` • `GA` • `patternsearch` • `gamultiobj` • `NBI` • `paretosearch` • `multistart`
	Default algorithms for point and sum optimizations. • `sqp` algorithm for point optimizations • `interior-point` algorithm for sum optimizations

Update	
	Setting for sum optimizations that use the `fmincon` algorithm. By default, the optimization option **Make table gradient constraints feasible** is enabled.  Model-Based Calibration Toolbox tries to satisfy the table gradient constraints before the `fmincon` algorithm begins optimizing. For more information, see Edit Optimization Parameters.
Model-Based Calibration Toolbox sets advanced optimization options that depend on the number of optimization variables and constraints.	

Optimization Solutions: Use soft constraints to find feasible optimization solutions

When you specify a soft constraint, Model-Based Calibration Toolbox does not require that the optimization satisfies the constraint. Instead, Model-Based Calibration Toolbox allows for some slack around the constraint. During the optimization, the algorithm satisfies the soft constraint by minimizing the slack and optimizing the objective. Consider specifying soft constraints when the:

- Constraint bounds are not well understood.
- Optimization has difficulty finding feasible solutions with hard constraints.

To specify a soft constraint, in CAGE, on the **Constraints** pane, select **Soft Constraint**.

Constraints

Name	Description	Type	Soft Constraint
Torque_Boundary	Boundary constraint of Torque(ECP, ICP...	Model	☐
KIT1	KIT1(ECP, ICP, LOAD, Speed) <= 2	Model	☐
RF1	RF1(ECP, ICP, LOAD, Speed) <= 25	Model	☐
TSPEED	TSPEED(ECP, ICP, LOAD, Speed) <= 20...	Model	☐
TEXH	TEXH(ECP, ICP, LOAD, Speed) <= 860	Model	☐
GradECP	Gradient constraint of ECP over (LOAD,...	Table Gradient	☑
GradICP	Gradient constraint of ICP over (LOAD,...	Table Gradient	☑

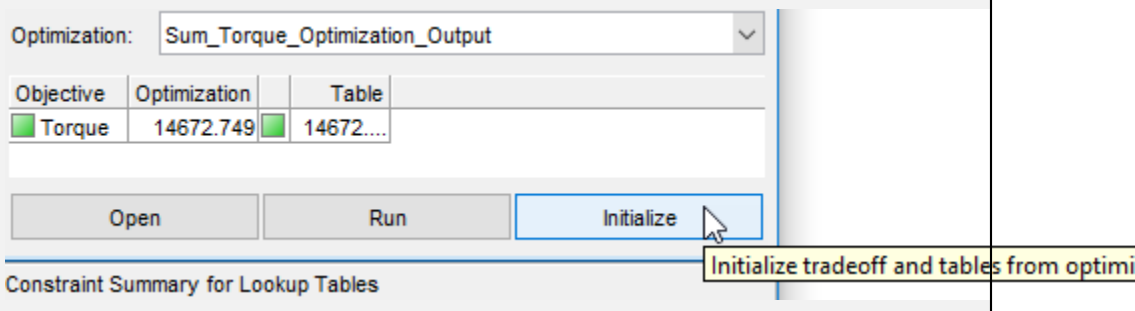
For more information about using soft constraints, see Soft Constraints.

Optimization Tradeoffs: Simplified workflow for viewing and assessing optimization tradeoffs

R2019b simplifies viewing and assessing optimization tradeoffs in the CAGE browser. For more information, see Tradeoff Calibration.

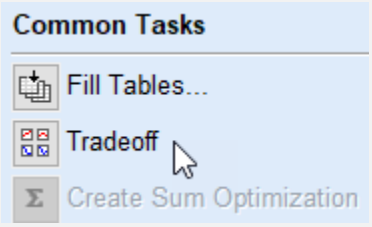
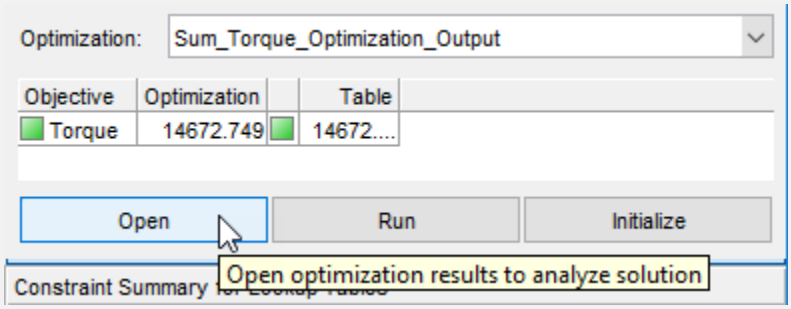
Initialization

You can initialize the entire tradeoff to set the tradeoff points for all operating points. In the CAGE tradeoffs view, after you select a tradeoff table, use these settings.

Goal	Option
Set all tradeoff points to the table values	**Inputs > Initialize from Tables**
Set all tradeoff points to the optimization solution	Either: • In the toolbar, select **Inputs > Initialize from Optimization** • In the right-hand pane, select **Initialize**  In the optimization view, you can select **Fill Tables**.
Clear tradeoff points	**Inputs > Clear tradeoff**

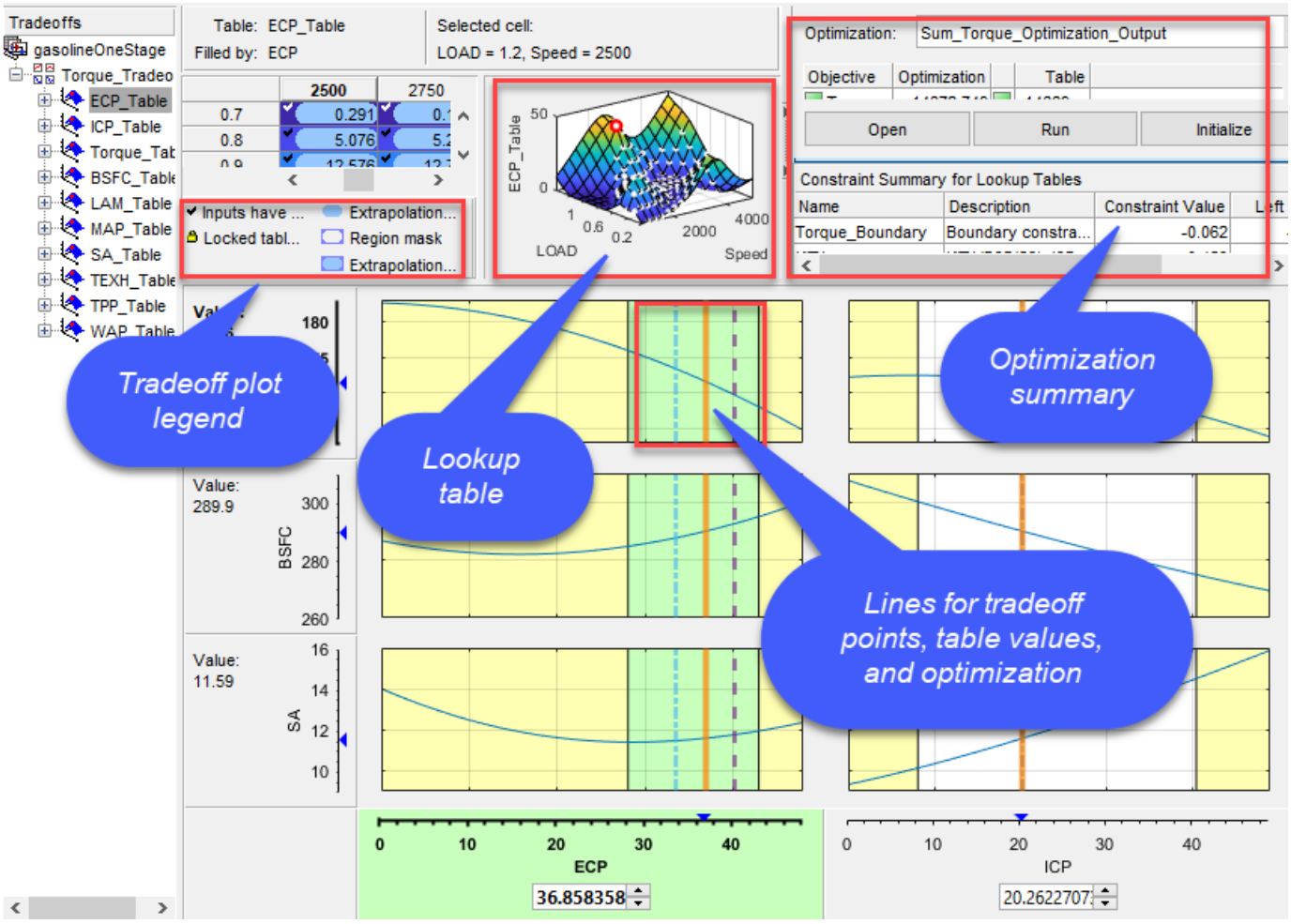
Navigation

In CAGE, you can navigate between the tradeoff plots and the optimization results.

Goal	Option
Navigate from optimization results to tradeoff plots.	In the Common Tasks, select **Tradeoff**. 
Navigate from tradeoff plots to optimization results.	In the right-hand-pane, select **Open**. 

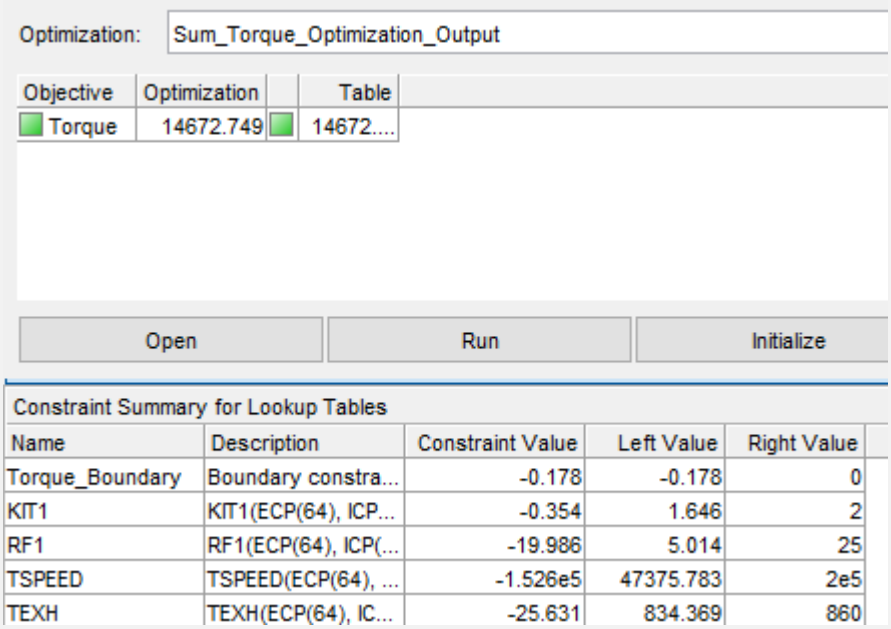
Tradeoff Plot View

The Tradeoff plot views include optimization information that allows you to quickly assess results.

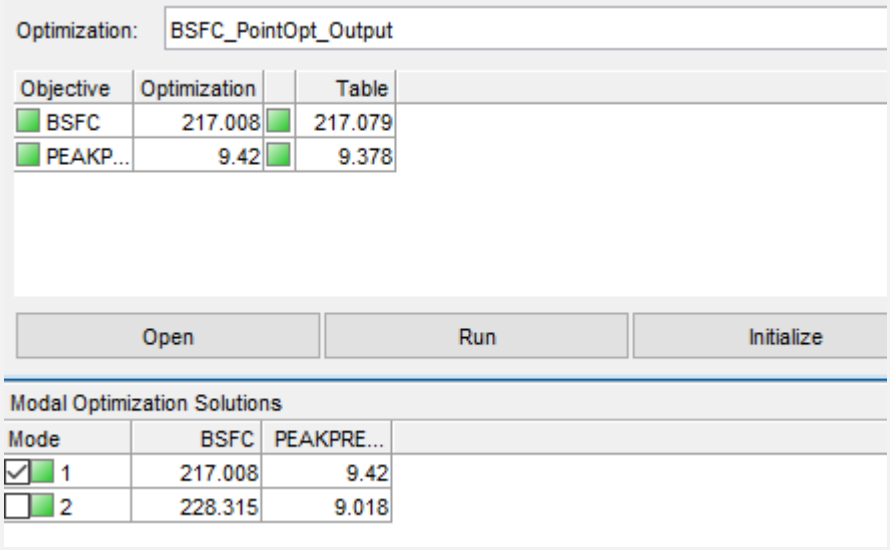
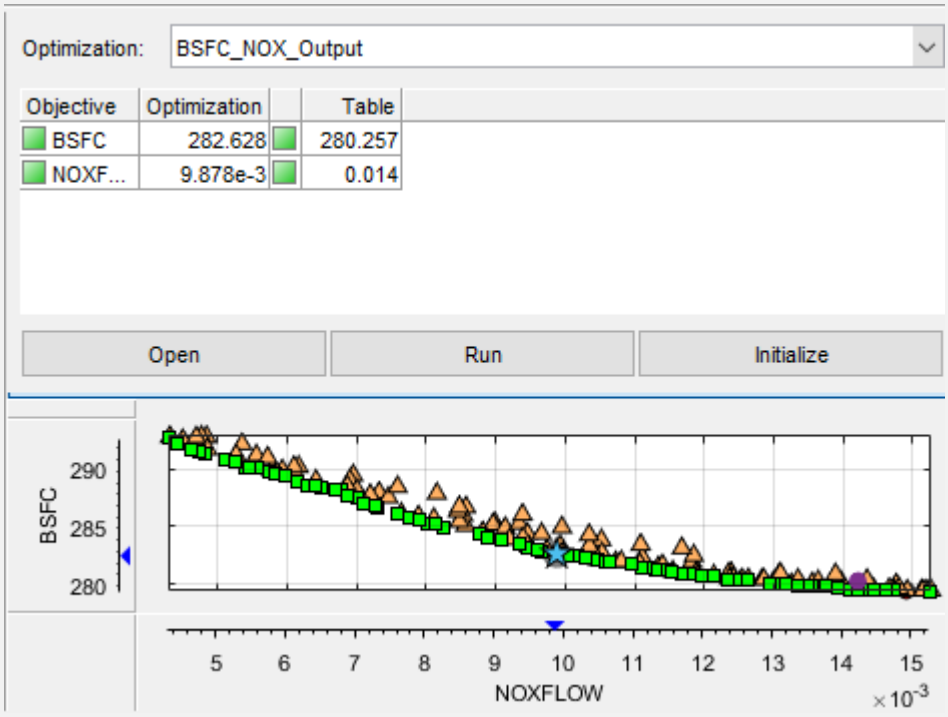

Tradeoffs
gasolineOneStage
Torque_Tradeo
ECP_Table
ICP_Table
Torque_Tab
BSFC_Table
LAM_Table
MAP_Table
SA_Table
TEXH_Table
TPP_Table
WAP_Table
Table: ECP_Table
Filled by: ECP
Selected cell:
LOAD = 1.2, Speed = 2500
2500
2750
0.7
0.8
0.291
5.076
Inputs have ...
Locked tabl...
Extrapolation...
Region mask
Extrapolation...
ECP_Table
LOAD
Speed
Optimization:
Sum_Torque_Optimization_Output
Objective
Optimization
Table
Open
Run
Initialize
Constraint Summary for Lookup Tables
Name
Description
Constraint Value
Torque_Boundary
Boundary constra...
-0.062
Tradeoff plot legend
Lookup table
Optimization summary
Lines for tradeoff points, table values, and optimization
Value:
289.9
BSFC
Value:
11.59
SA
ECP
36.858358
ICP
20.2622707

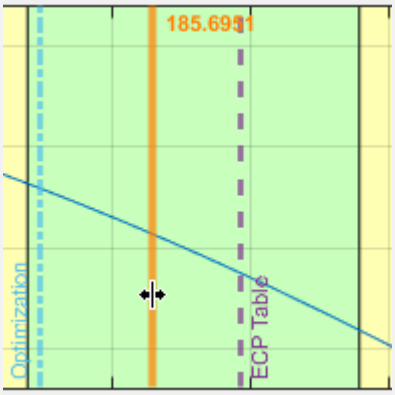
<table>
<tr><th>Enhancement</th><th>Description</th></tr>
<tr><td>Optimization summary</td><td>You can select an optimization for comparison with the current table values.
<table>
<tr><th>Goal</th><th>Option</th></tr>
<tr><td>Open the optimization results</td><td>Open</td></tr>
<tr><td>Set the initial values to the table values and rerun the optimization</td><td>Run</td></tr>
<tr><td>Set all tradeoff points to the optimization solution</td><td>Initialize</td></tr>
</table>

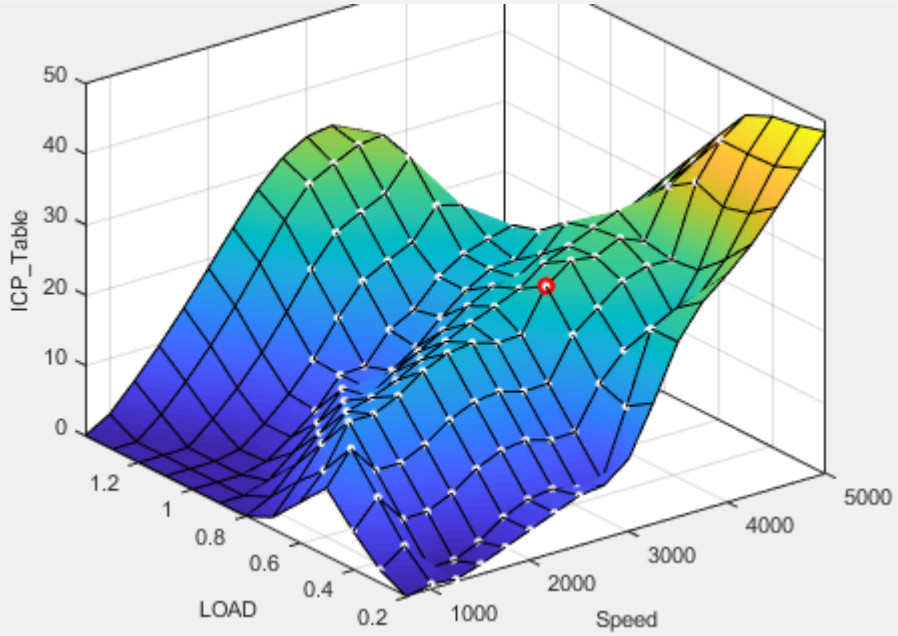
For single objective optimizations, the view includes a summary of constraints evaluated at the lookup table values for the current operating point.



For modal optimizations, you can select the mode.
</td></tr>
</table>

Enhancement	Description
	 • For multiobjective optimizations, the view includes the Pareto view. The blue start indicates the optimization result. 

Enhancement	Description
Lines for tradeoff points, table values, and optimization	The plots show lines for the tradeoff points, table values, and optimization. You can double-click on the lines to set the tables and tradeoff.  ff • Double-click the orange line to update tables to the tradeoff values. • Double-click the blue line to set the tradeoff value to the optimization solution at that operating point. • Double-click the purple line to set the tradeoff value to the table value at that operating point.
Tradeoff plot legend	The plots include tradeoff points, boundaries, responses, and values. For colors, refer to the legend.

Enhancement	Description
Lookup table surface view	The surface table view uses white dots to indicate the tradeoff points. You can select the white dots to change the table operating point. Right-click the table surface to edit or print to a figure. 

R2019a

Version: 5.6

New Features

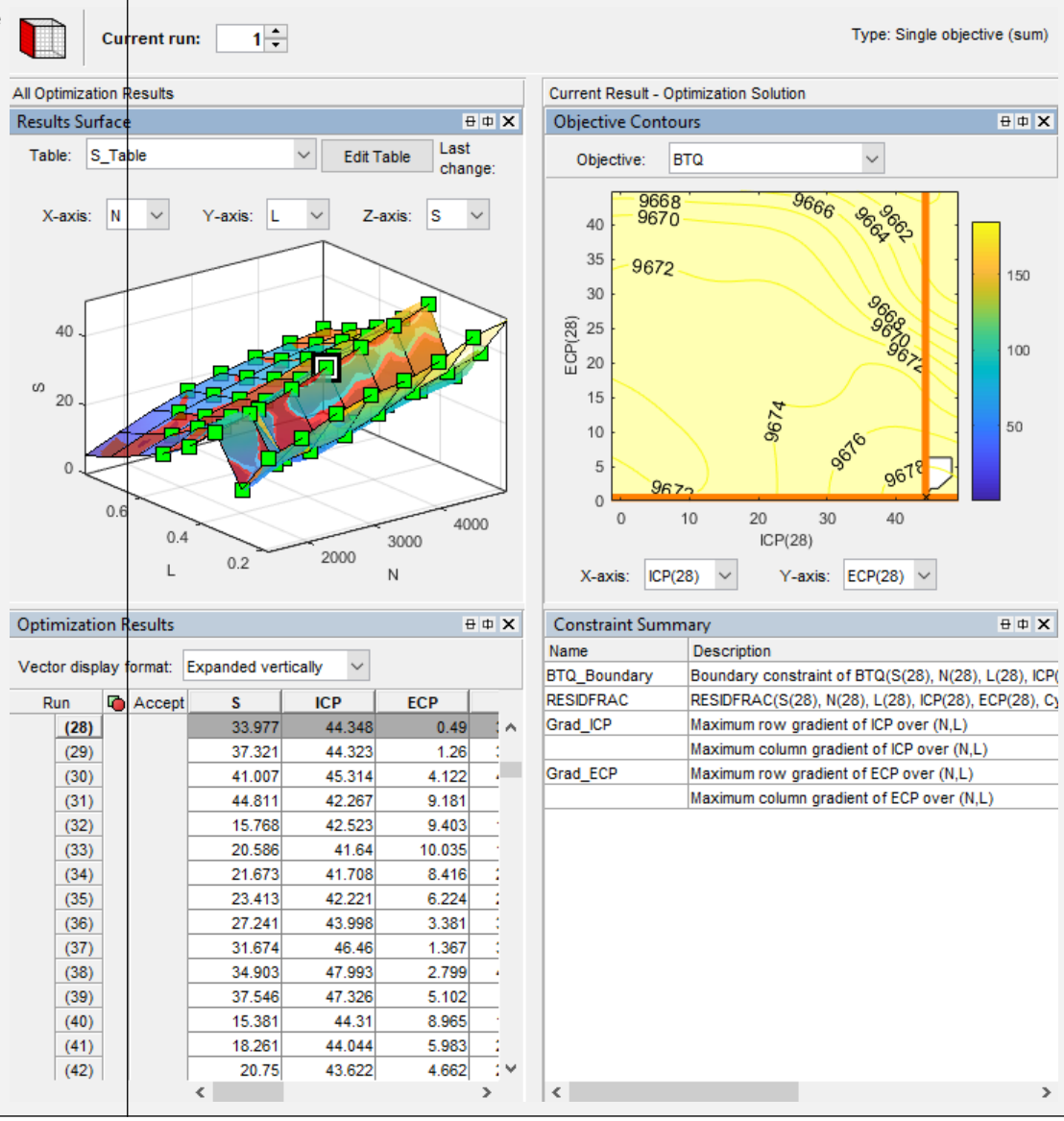
Bug Fixes

Compatibility Considerations

Optimization: Simplified workflow for assessing results, including lookup table comparison

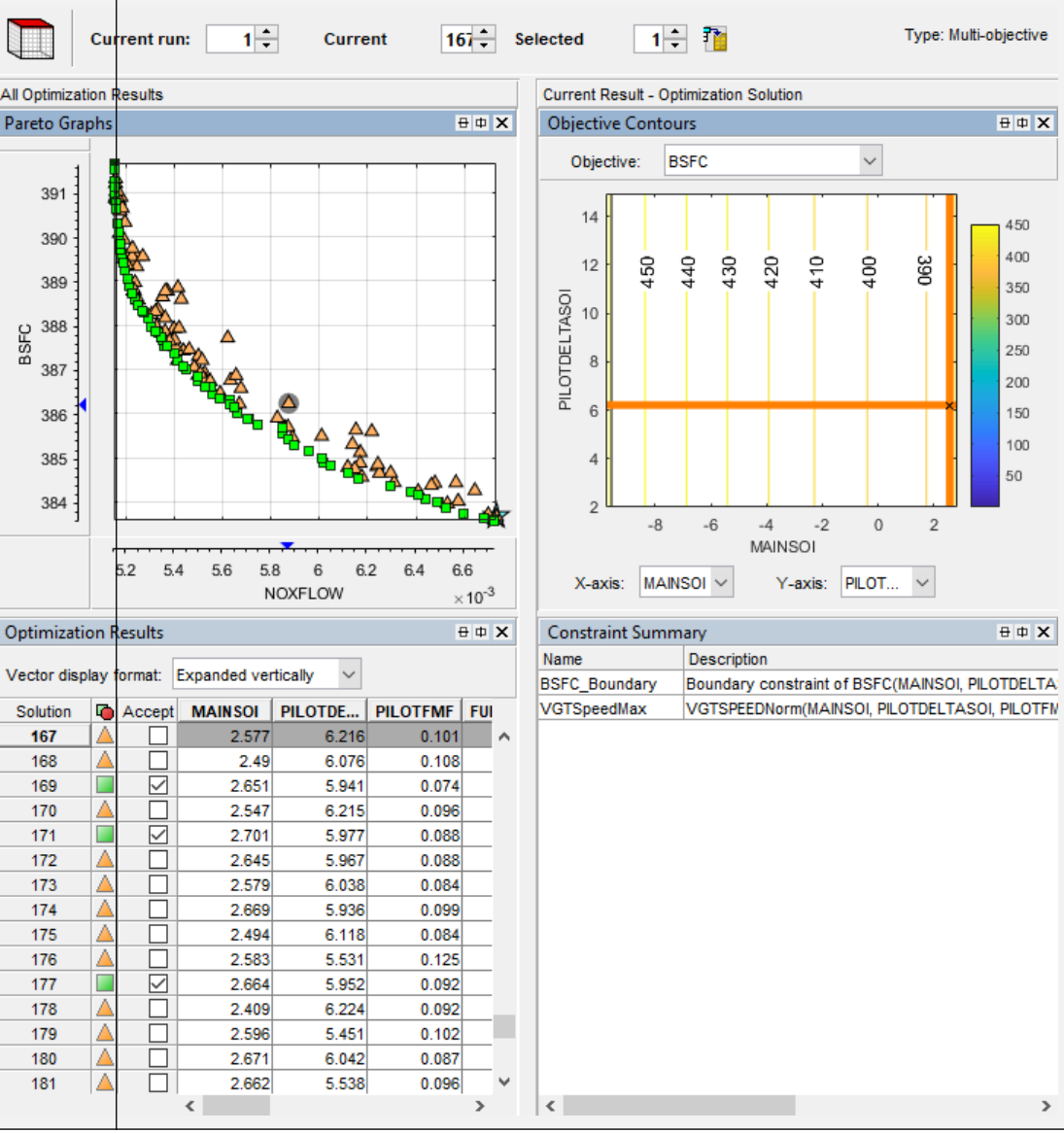
R2019a simplifies viewing and assessing optimization results in the CAGE browser. New capabilities include:

- Default configurations for single-objective, multiobjective, and modal optimizations that make it easier to assess optimization results.

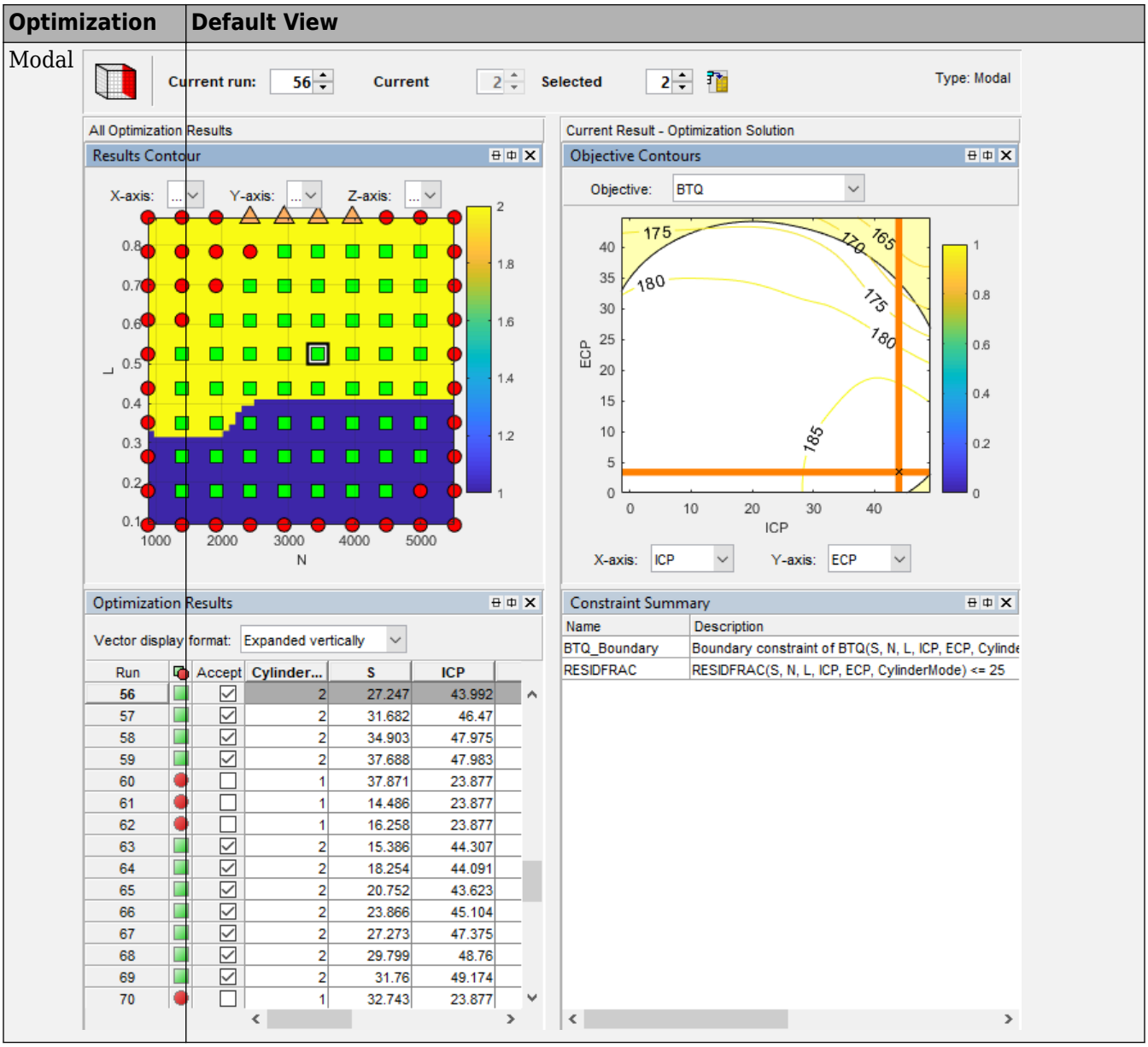
Optimization	Default View
Single	

Optimization | **Default View**

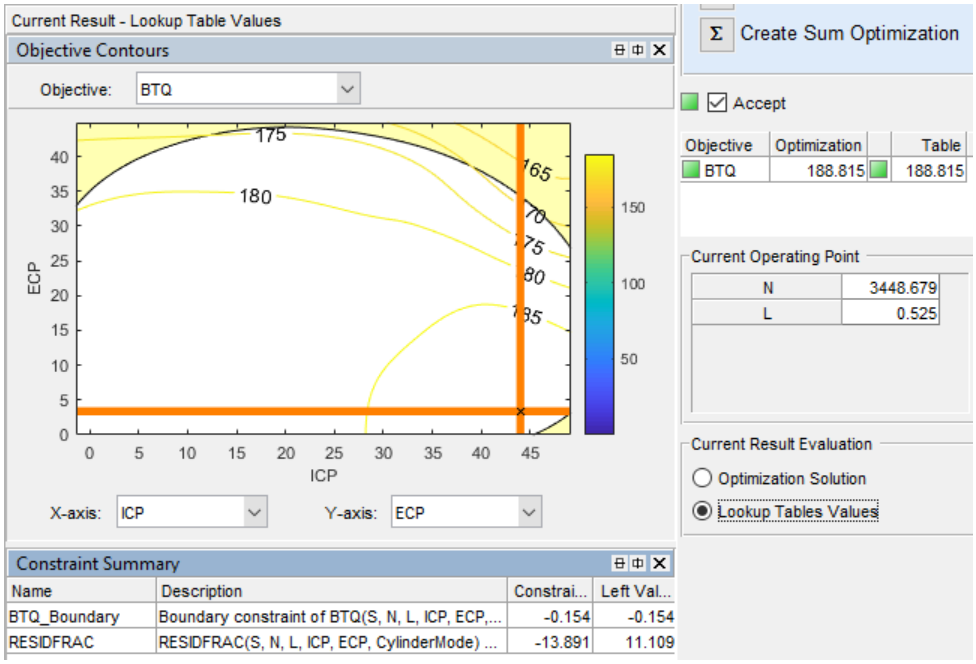
Multiol



Solution	Accept	MAINSOI	PILOTDE...	PILOTFMF	FUI
167	☐	2.577	6.216	0.101	
168	☐	2.49	6.076	0.108	
169	☑	2.651	5.941	0.074	
170	☐	2.547	6.215	0.096	
171	☑	2.701	5.977	0.088	
172	☐	2.645	5.967	0.088	
173	☐	2.579	6.038	0.084	
174	☐	2.669	5.936	0.099	
175	☐	2.494	6.118	0.084	
176	☐	2.583	5.531	0.125	
177	☑	2.664	5.952	0.092	
178	☐	2.409	6.224	0.092	
179	☐	2.596	5.451	0.102	
180	☐	2.671	6.042	0.087	
181	☐	2.662	5.538	0.096	



- A **Current Result Evaluation** toggle button that you can use to view the optimized solution or lookup table values for the current result.



For more information about analyzing optimization results, see Optimization Analysis.

Additionally, if you have Global Optimization Toolbox, you can use the Pareto search algorithm for multiobjective optimizations.

Automate Model Fits: Generate a MATLAB function that fits models with new data

You can generate a MATLAB® function that creates a new test plan from an existing test plan. The test plan contains the same data pre-processing rules, model types, and boundary models that are in the original test plan. Use the function to fit a model with new data.

To generate the function:

1. Select the model node.
2. Select **TestPlan > Generate Code**
3. Name and save the function.

For more information, see Automate Model Fits with MATLAB Function.

Gaussian Process Models: Quickly Assess Box-Cox Transformations

For Gaussian process models (GPMs), you can use the Box-Cox Transformation dialog box to adjust the transformation. In the Model Browser, select the model. To open the dialog box, select **Model > Box-Cox Transform**. Previously, you could only use the Box-Cox Transformation dialog box to adjust the transformation for linear models.

For more information, see Box-Cox Transformation.

Data and Model Fit APIs: Additional support for importing, exporting, and fitting table data

R2019a introduces command-line APIs and functions for importing, exporting, and fitting table data.

API	Enhancement
`CreateData`	Support for tables and structures when importing data to a project.

`ImportFromTable`
 	
`ExportToTable`
	New `mbcmodel.data` methods for importing and exporting tables.

`ValidationRMSE`	New `mbcmodel.model` method to calculate the root-mean-square error (RMSE) of a validation set.
`fit`	New `mbcmodel.fit` function to fit a model to data without creating a model object. Supports numeric, table, and data objects.

Compatibility Considerations

The `fit` method replaces `Fit`. Both methods fit model to data. However, the output order is different. Existing scripts are not affected.

Function	Syntax
`fit`	`[model,statistics] = fit(model,X,Y)`
`Fit`	`[statistics,model] = Fit(model,X,Y)`

R2018b

Version: 5.5

New Features

Bug Fixes

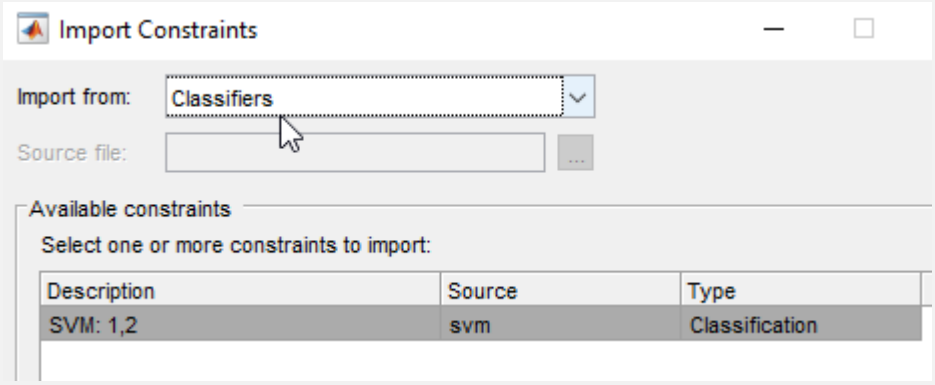
Classifiers: Represent engine operation boundaries with classification models, including support vector machines

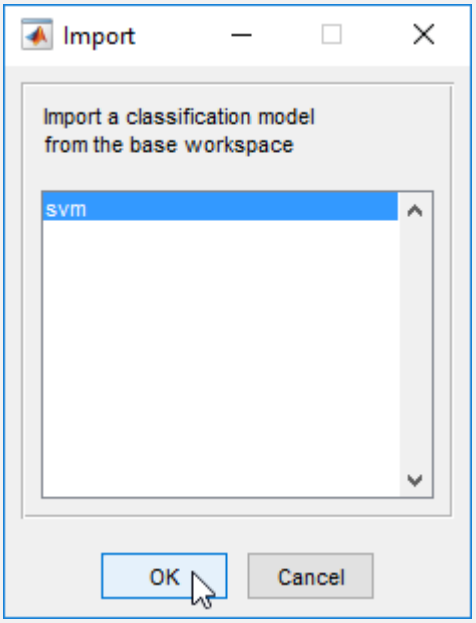
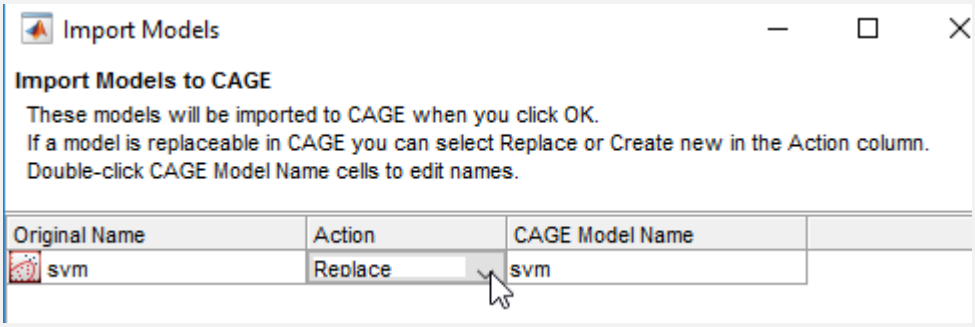
Using support vector machine (SVM) or discriminant classifiers, Model-Based Calibration Toolbox can differentiate between good and bad operating conditions when you specify boundary constraints for:

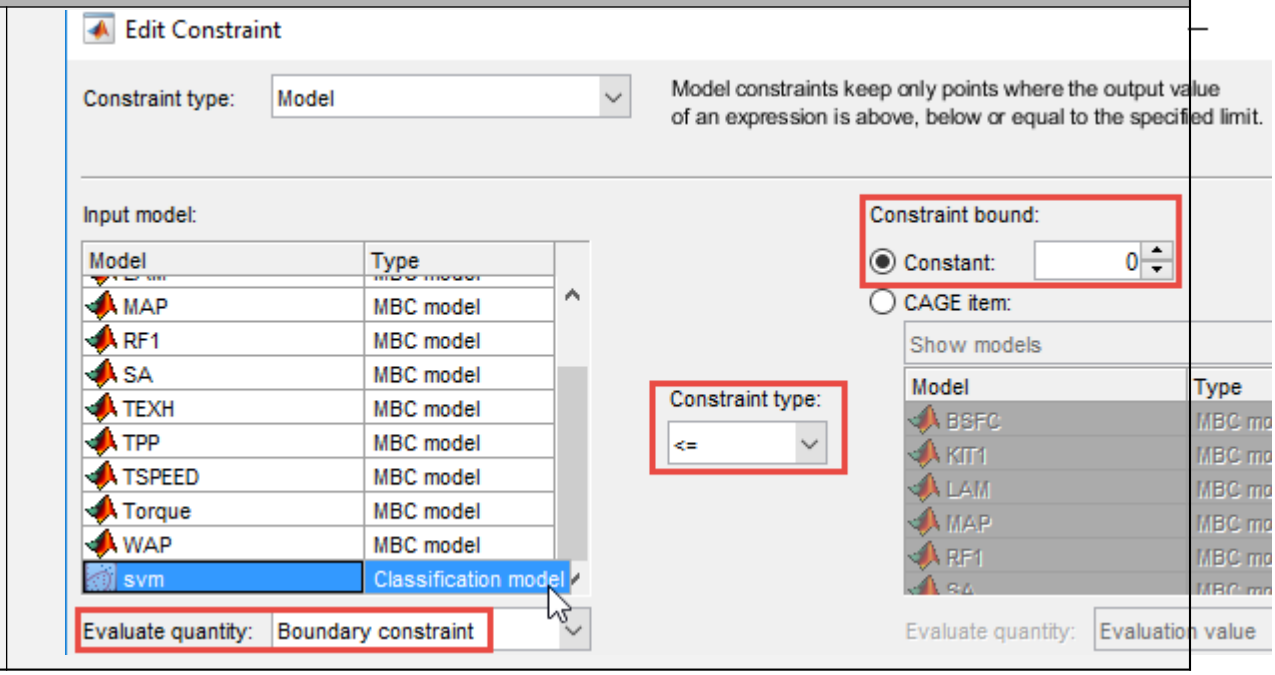
- Design of experiments (DoEs)
- Calibrations

To use SVM or discriminant classifiers for DoE and boundary constraints:

1. Use the Statistics and Machine Learning Toolbox to classify data using a discriminant or SVM classifier. For more information, see Support Vector Machine Classification (Statistics and Machine Learning Toolbox).
2. Use the Classification Learner App (Statistics and Machine Learning Toolbox) to export the classification model to the workspace.

To	
Use the SVM classification model as a DoE constraint	1. In the Model Browser, select **TestPlan > Design Experiment** to open the Design Editor. 2. In the Design Editor, select **Edit > Constraints**. 3. In the Constraint Manager, click **Import**. In the Import Constraints dialog box, set **Import from** to `Classifiers`. Import the SVM classification. 

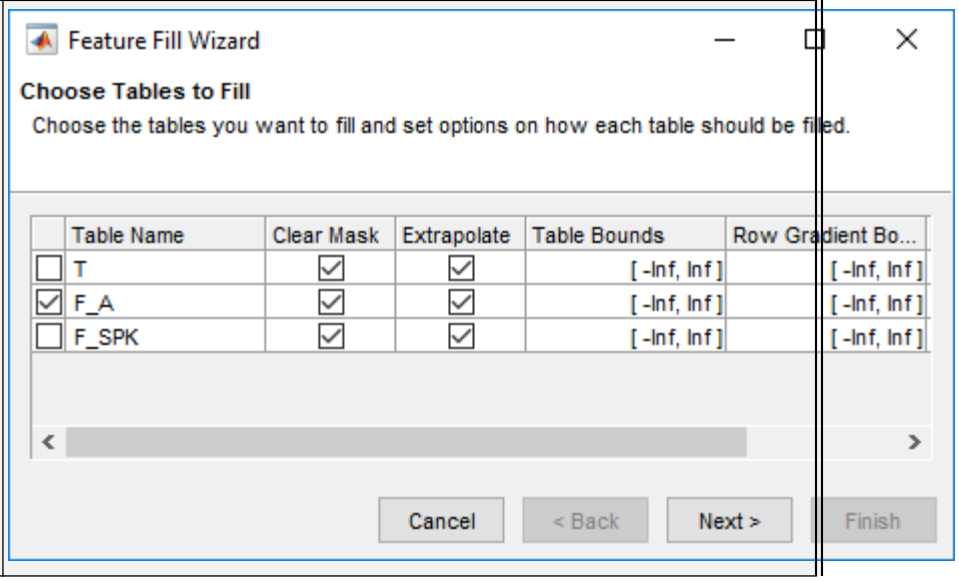
To	
Use the SVM classification model as a boundary constraint during calibration	**1** In CAGE, select **File** > **Import** > **Classification Model**. **2** In the Import dialog box, click **OK** to import the SVM classification.  **3** In the Import Models dialog box, accept the defaults and click **OK**.  **4** In CAGE, select **Optimization** > **Constraints** > **Edit Constraint**. For the svm input model: • Set **Evaluate quantity** to `Boundary constraint`. • Specify the **Constraint type** and **Constraint bound**.

To	
	

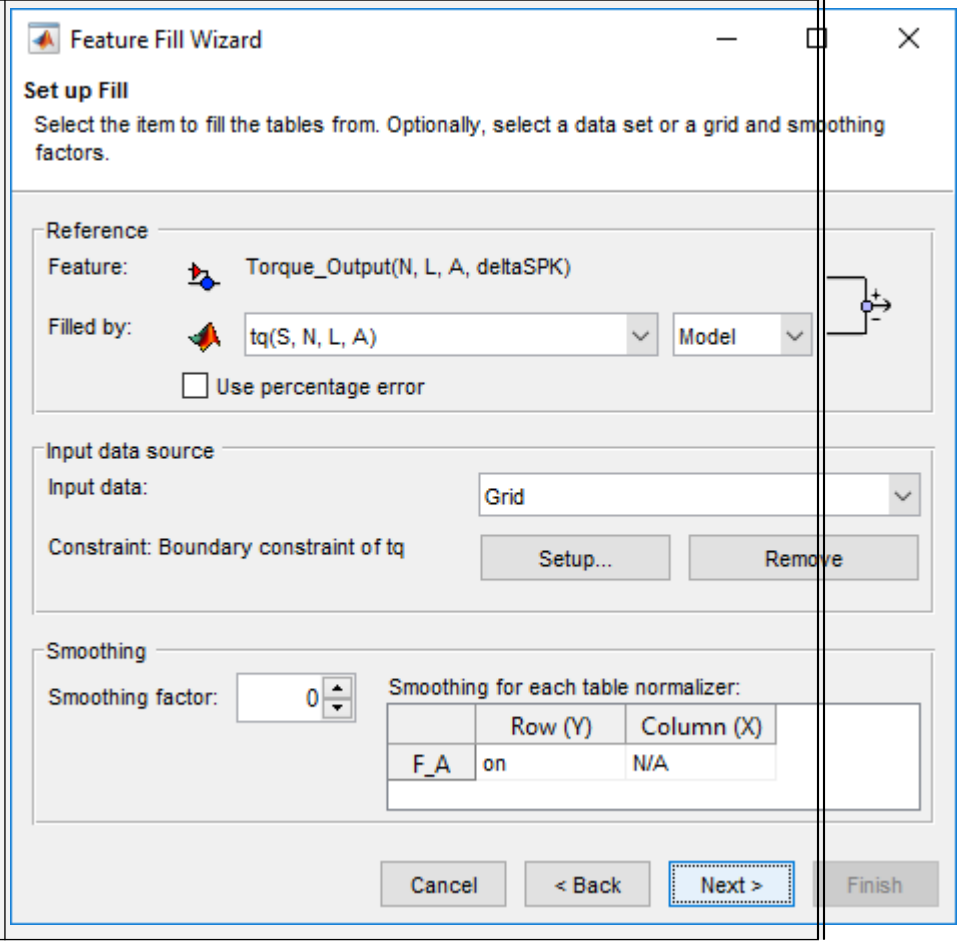
Feature Fills: Streamlined setup and validation

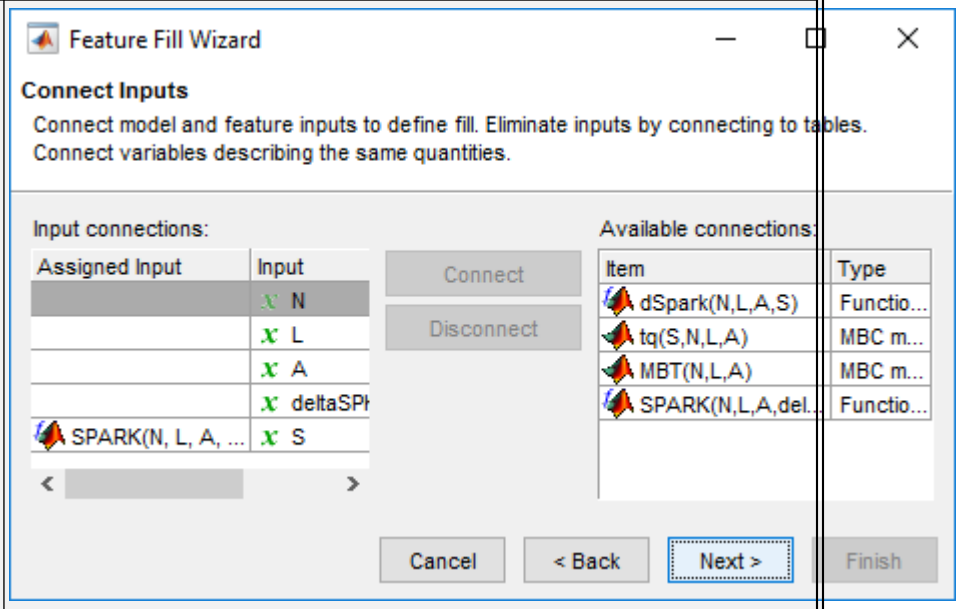
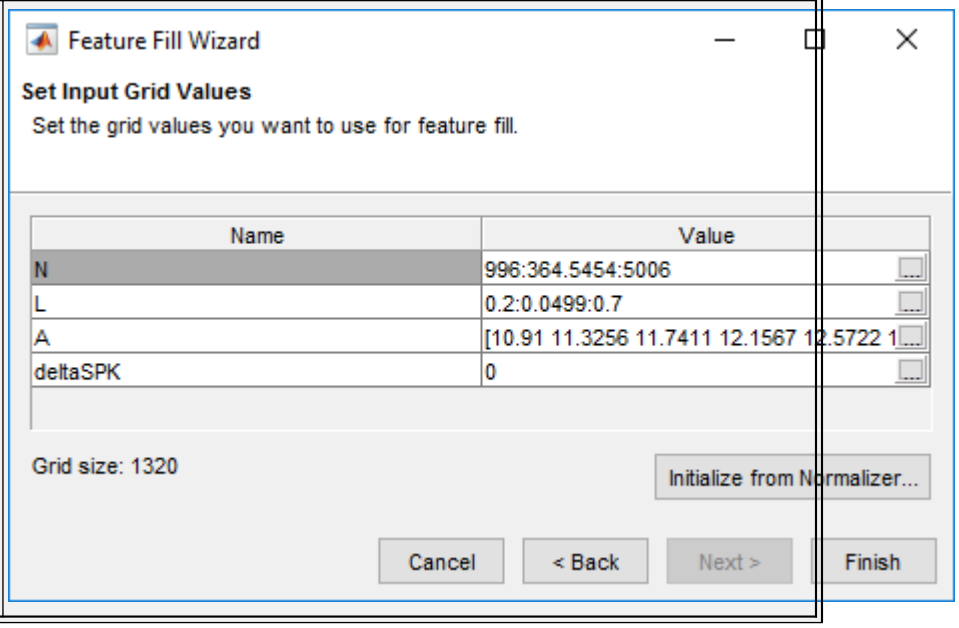
To streamline the feature fill setup and validation, the Model-Based Calibration Toolbox provides these workflow enhancements. For more information, see Feature Calibration.

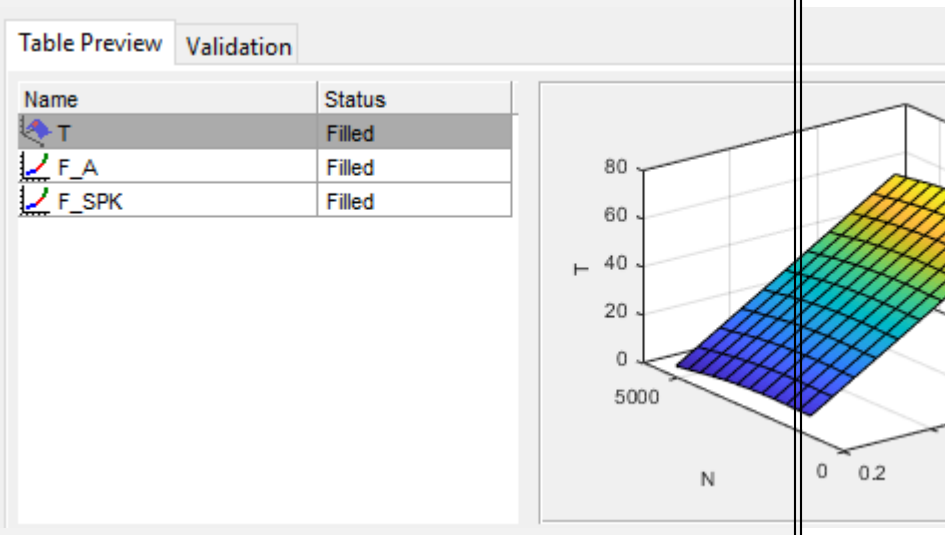
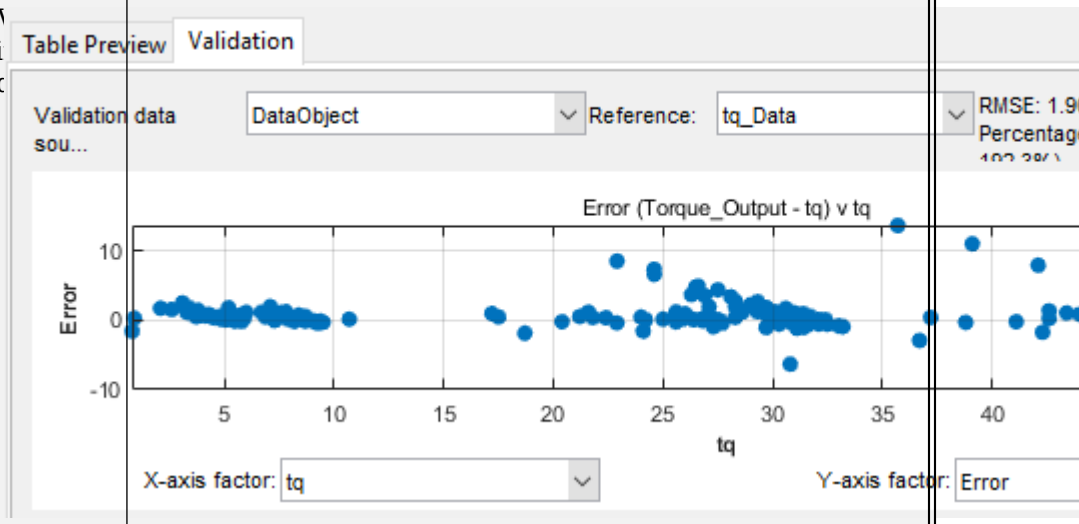
<table>
<tr><th>Workflow Step</th><th>Enhancement</th></tr>
<tr><td>Setup feature fills</td><td>After you import the strategy, the Feature Fill wizard has default settings that allow you to quickly set up the feature fill.
<table>
<tr><th>Feature Fill Wizard</th></tr>
<tr><td>Tables to fill</td></tr>
</table>
</td></tr>
</table>



Workflow Step	Enhancement
	Feature Fill Wizard
	Feature setup, including reference, input data source, and smoothing factor



Workflow Step	Enhancement
	Feature Fill Wizard
	Model inputs 
	Input grid 

<table>
<tr><th>Workflow Step</th><th>Enhancement</th></tr>
<tr><td>Validate feature fill</td><td>To help assess and validate the feature fill, the CAGE Browser feature view includes these tabs.
<table>
<tr><th>Tab</th><th>Description</th></tr>
<tr><td>Table Preview — Preview of table shape, with filled, uninitialized, or locked status</td><td> 
</td></tr>
<tr><td>Validation — V plots compari to validation d fit statistics</td><td> 
</td></tr>
</table></td></tr>
</table>

Response Models: Use parallel processing to fit data with one-stage and point-by-point models

By default, Model-Based Calibration Toolbox runs one-stage and point-by-point response model fits in parallel if you have Parallel Computing Toolbox™. Running the response model fits in parallel significantly reduces the computation time for large data sets.

When you fit the model with the data, Model-Based Calibration Toolbox calls `parpool` to open the parallel pool, if necessary. You see progress messages until the fitting completes. For more

information about parallel processing, see Specify Your Parallel Preferences (Parallel Computing Toolbox).

Data Outliers: Save time when you remove and restore data outliers from all response models

After you fit your data with a statistical model, you can quickly remove and restore data outliers from all response models. In the Model Browser, after you select a response model, select **Outliers > Apply to All Response Models**. After you select the option, these actions apply to all response models:

- **Remove Outliers**
- **Restore Removed Data**

Model-Based Calibration Toolbox updates the response and boundary model fits with the updated data. For more information, see Remove and Restore Outliers.

MATLAB String Support: Functions in Model-Based Calibration Toolbox accept MATLAB strings as input

You can use MATLAB strings for functions in the Model-Based Calibration Toolbox automation scripts. See Automation Scripting. For information on MATLAB strings, see Create String Arrays (MATLAB).

R2018a

Version: 5.4

New Features

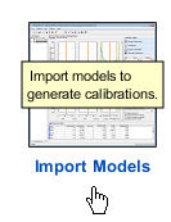
Bug Fixes

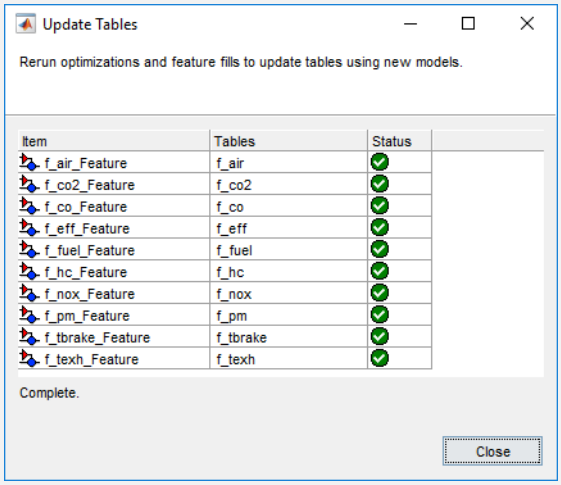
Compatibility Considerations

Calibration Templates: Automatically rerun calibration optimization and table fills when you update models

To streamline importing models and filling tables during optimization, Model-Based Calibration Toolbox now provides these workflow enhancements.

Workflow Step	Enhancements

Import models	• In CAGE, you can start the Import Models wizard using one of these methods:
	  • Toolbar
	
	  • **File > Import > Model**
	  • App home
	 
	
	To import projects, select **File > Import From Project**.
	• The Import Models wizard asks you if you want to replace existing models. If you do replace existing models, Model-Based Calibration Toolbox reruns the feature fills and optimizations that use the models.
	• Streamlined compatible model merge into composite models. During model import, Model-Based Calibration Toolbox checks to see if response models with the same name are in more than one test plan. If so, the Import Model wizard asks if you want to merge compatible models into composite models.

Workflow Step	Enhancements
Update tables with new models	After you import and replace the existing models, the Import Models wizard starts the Update Tables dialog box. You can use the Update Table dialog box to rerun optimizations and feature fills to update the tables with the new models. 
Fill lookup tables	Create Lookup Tables from Model wizard options: • **Optimization/Tradeoff** — Fill lookup tables using optimization results. Model-Based Calibration Toolbox also creates a tradeoff. • **Models** — Fill lookup tables using the standard feature fill at the table grid points, including any boundary model. Model-Based Calibration Toolbox uses the same feature fill configuration for subsequent table refills. • **None** — Create a table without a tradeoff.

Compatibility Considerations

In R2018a, models cannot be exported to an `.exm` model file. Instead, you can export your model to Simulink, the Simulink workspace, or CAGE.

Powertrain Blockset Integration: Use measured data to calibrate and generate tables for Powertrain Blockset mapped engines

You can use measured data to calibrate lookup tables for these Powertrain Blockset™ engine blocks:

- Mapped CI Engine — Implements a mapped compression-ignition (CI) engine model
- Mapped SI Engine — Implements a mapped spark-ignition (SI) engine model

To help you get started with the calibration, the CAGE browser and Model Explorer include these examples.

Example	Description	Lookup Tables
Mapped CI Lookup Tables as Functions of Fuel Mass and Engine Speed	Lookup tables as a function of fuel mass and engine speed	• Power • Air • Fuel • Temperature • Efficiency • Hydrocarbon (HC) emissions • Carbon monoxide (CO) emissions • Nitric oxide and nitrogen dioxide (NOx) emissions • Carbon dioxide (CO2) emissions • Particulate matter (PM) emissions
Mapped CI Lookup Tables as Functions of Engine Torque and Speed	Lookup tables as a function of engine torque and engine speed	
Mapped SI Lookup Tables as Functions of Engine Torque and Speed	Lookup tables as a function of engine torque and engine speed	

Simulink Integration: Export lookup tables to the Simulink model workspace

After you run an optimization and fill the calibration tables, you can export the results to the Simulink model workspace. You can use the calibration table data in Simulink models. To export the calibration lookup tables, select **File > Export > Calibration > All Items**. In the Export Calibration Data dialog box, for the **Export to** parameter, select `Simulink Model Workspace`.

This table summarizes the changes to the **Export to** parameter settings.

Setting	R2018a Change
`ATI Vision`	*Removed*
`ATI Vision MAT file`	*None*
`INCA DCM file`	*None*
`Matrix MAT file`	*New* —Saves table data as matrices and vectors in a MAT file
`Simulink Model Workspace`	*New*—Saves table data in Simulink model workspace
`Simple CSV file`	*None*
`Simple MAT file`	*Renamed to* `Structure MAT file`
`Structure MAT file`	*Renamed from* `Simple MAT file`
`Simple MATLAB file`	*None*

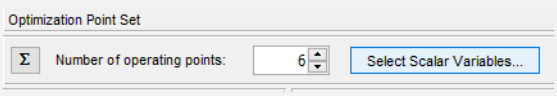
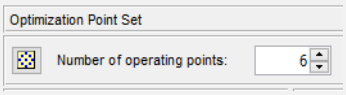
Compatibility Considerations

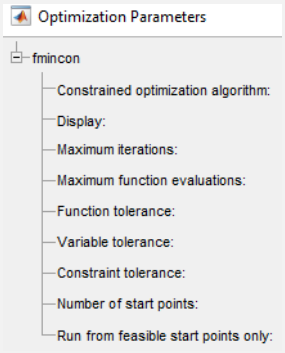
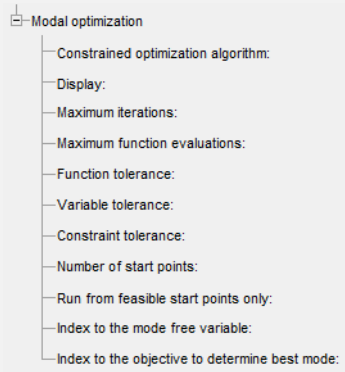
In R2018a, `ATI Vision` calibration data cannot be imported or exported. Instead, you can import or export calibration from `ATI Vision MAT` or `INCA DCM` files.

Optimization: Streamlined setup and improved modal optimization

To streamline the optimization setup, the Model-Based Calibration Toolbox provides these workflow enhancements.

Workflow Step	Enhancement
Create optimization from model	The Create Optimization from Model wizard has default settings for standard optimizations. To open the wizard, in CAGE, use one of these options: • **Tools > Create Optimization from Model** • **File > New > Optimization** If you have a user-defined optimization algorithm with advanced options, to create the optimization, select **File > New > Custom Optimization**. For more information about optimization algorithm advanced options, see User-Defined Optimizations.
Create constraints	The CAGE browser has default constraint settings for standard optimizations. The Model-Based Calibration Toolbox bases the default objective and constraint names on the model names. In the Range Constraint dialog box, you can specify bounds with lookup tables. To add or edit a constraint, in CAGE, select **Optimization > Constraints**.

Use sum or point optimization	To streamline sum and point optimizations, the Model-Based Calibration Toolbox includes these changes. In CAGE:
	• You can convert the optimization to a sum optimization. Select **Optimization > Convert to Sum Optimization**. CAGE converts the objectives to sum objectives.
	• You can convert the optimization to a point optimization. Select **Optimization > Convert to Point Optimization**.
	• If you rerun point optimizations that have associated sum optimizations, the Model-Based Calibration Toolbox can update and rerun the sum optimization with the point optimization results. The Model-Based Calibration Toolbox uses the existing sum optimization constraints when it reruns the optimization. Previously, the Model-Based Calibration Toolbox created a new sum optimization.
	• For sum optimizations:
	  • The **Number of operating points** is the number of points that the optimizer sums during the optimization.
	  • Use **Select Scalar Variables** to specify the scalar values that do not depend on the operating points.
	 
	• For point optimizations, the **Number of operating points** is the number of runs.
	 

Workflow Step	Enhancement
Select optimization options	The CAGE browser has default optimization settings for standard optimizations. By default, the optimization algorithm is `fmincon`.  For modal optimizations, the CAGE browser includes multistart options that help the optimizer find global solutions.  To view the optimization parameters, in CAGE, select **Optimization** > **Setup**. The dialog box lists the most commonly changed parameters first.
Select variables and algorithms	After you create the optimization, you can change the free variables, scalar variables, and algorithm. Previously, you could only select the variables and algorithm when you created the optimization. To select a variable or algorithm, in CAGE, select either **Optimization** > **Select Free Variables** or **Optimization** > **Select Algorithm**.

Compatibility Considerations

In a future release, Model-Based Calibration Toolbox will not run custom optimizations that have user-defined optimization algorithms with advanced options.

In R2018a, the optimization algorithm `foptcon` is renamed to `fmincon`. To streamline the optimization setup, these **Optimization** > **Setup** parameters are removed:

- **Minimum change in variables for gradient**
- **Maximum change in variables for gradient**

Model-Based Calibration Toolbox renames optimization scripts that use `foptcon` to `fmincon`.

Gaussian Process Model: Improved model fits for large data sets

To fit Gaussian process models (GPMs) for large data sets, Model-Based Calibration Toolbox uses a limited-memory Broyden-Fletcher-Goldfarb-Shanno (LBFGS) optimization algorithm from the Statistics and Machine Learning Toolbox. Previously, for large data sets, Model-Based Calibration Toolbox used the `fmincon` optimization algorithm. The LBFGS algorithm improves the optimization performance. For more information about GPMs, see Global Model Class: Gaussian Process Model.

R2017b

Version: 5.3

New Features

Bug Fixes

Getting Started Example: Generate Current Controller Calibration Tables for Flux-Based Motor Controllers

Use the getting started example to generate optimized calibration tables for flux-based motor controllers. The example shows how to import data, fit a model, and optimize the data based on objectives and constraints. See Generate Current Controller Calibration Tables for Flux-Based Motor Controllers.

R2017a

Version: 5.2.1

Bug Fixes

R2016b

Version: 5.2

New Features

Bug Fixes

Compatibility Considerations

MBC Model Fitting App and MBC Optimization App Home Pages: Get started or resume work faster by accessing frequent tasks, recent projects, and featured examples

In the home page, you can get started or resume work faster by accessing common tasks, examples, and recent projects.

For details, see Set Up Designs and Models, Resume Work, or Find Engine Modeling Examples and Set Up Calibrations, Resume Work, or Find Calibration Examples.

Compatibility Considerations

The home page offers the same tasks that were previously available in the Common Tasks pane, and previously you had to search the documentation to find examples.

R2016a

Version: 5.1

New Features

Bug Fixes

Compatibility Considerations

Import multiple data files: Simultaneously load data spread out across multiple files

In R2016a, you can import multiple data files at once. Previously you could only import a single data file at a time.

See Load and Edit Data and Merge Data.

Data merge with strict matching: Check variables and units and only merge when all match

Smarter merging helps you to avoid merging in the wrong data.

See Merge Data.

Data preprocessing reuse: Reuse filters, user-defined variables, and plot layouts from the current project or other project files

Import filters, user-defined variables, and plot layouts from other data sets in the same project, or import from other project files. You can reuse your previous definitions without needing to save them to a separate file.

See Import Variables, Filters, and Editor Layout.

Augment existing space-filling designs: Continue Sobol and Halton sequence to fill in the spaces when you want to collect more design points

When you want to collect more data, you can now add design points that continue the same space-filling sequence in your original design. This allows you to collect more data filling in the gaps between your previous design points.

Previously you could add more design points but only randomly or by manually specifying new points, which made it difficult to fill in spaces in the prior design points.

See Adding and Editing Design Points.

Simplified workflow for importing, merging, and manipulating data

Working with data for modeling is simplified in R2016a. New capabilities include:

- Filters and variables report success or failure
- Easier grouping and ungrouping of data
- Import or export to tables
- New default views to simplify plotting data

See Create Variables, Create Filters, and Define Test Groupings.

Simplified workflow for creating and constraining designs

Working with designs is simplified in R2016a. New capabilities include:

- Create a table constraint by importing from a CAGE table or normalizer
- When generating a space-filling design, the design editor now tries to provide points as close as possible to the number of points you specified. You no longer need to specify a larger number until you get the desired number of points within the constraints.
- When defining 2D constraints, you can now view a plot and table of points at the same time without needing to switch tabs.
- You can create and import constraints in a single dialog box instead of two.
- The Design Editor toolbar is simplified to show only frequent tasks.

See Define Design Constraints and Creating a Space-Filling Design.

R2015b

Version: 5.0

New Features

Bug Fixes

Compatibility Considerations

Gaussian process models for improved default fits

Gaussian process models (GPM) are popular nonparametric regression models used in model-based calibration. Gaussian process model is the new default model type for one-stage models and is now included in default point-by-point models. If you want to try all kernels and basis function options, use the new `Gaussian Process` model template to build a selection of Gaussian process models.

For details, see Global Model Class: Gaussian Process Model.

Tip To view example models, see Gasoline Engine Calibration.

Compatibility Considerations

Model Browser one-stage and point-by-point default models are a different type from previous releases.

To use the previous default model types, you can set up any model type from the test plan or the Edit Model common task in the model views.

Model Type	New Setting	Previous Setting
Default one-stage models	Gaussian process models	Hybrid radial-basis function (RBF)
Point-by-point models	Default model types: • Quadratic with Stepwise: Min PRESS • Cubic with Stepwise: Min PRESS • Hybrid RBF with nObs/3 • Gaussian process models (using defaults)	Default model types: • Poly2 with Stepwise: Min PRESS • Poly3 with Stepwise: Min PRESS • Hybrid RBF with nObs/4 • Hybrid RBF with nObs/3 • Hybrid RBF with nObs/2
	Point-by-point models selection criteria default: PRESS RMSE	AICc
Create Alternative Models	Selection criteria default: AICc if available, otherwise PRESS RMSE (for GPM)	AICc

Note For large data sets, the toolbox also uses new default models and boundary models. See “Faster Default Models for Large Data Sets” on page 12-4.

For information on all default model types, see Default Model Types.

Cross section and response surface views for assessing goodness of fit in MBC Model Fitting app

Improved model fitting and selection workflows for one-stage, two-stage and point-by-point models. Assess goodness of fit by viewing model trends and statistics in the main app.

- The new cross-section view provides a quick view of trends in all your response models at the same time.
- View the response surface as soon as you fit an initial model, to inspect model trends. You can view surfaces, multiline, contour and validation plots.
- View the RMSE for all tests at once to help identify and navigate to problem fits.
- New common tasks links provide access to the frequent tasks for each model view.

For details, see Model Assessment.

Tip To view example models, see Gasoline Engine Calibration.

Alternative model exploration and comparison in MBC Model Fitting app

- You can compare alternative models and select the best models in the Model Browser.
- You can select models by viewing useful plots all at once (for example, surfaces, contour, and RMSE plots). You no longer need to open additional windows such as the Model Selection window or RMSE Explorer plots.
- New common tasks links provide access to the frequent tasks for each model view.

For details, see Alternative Model Exploration.

Tip To view example models, see Gasoline Engine Calibration.

Simplified workflow for point-by-point models

Point-by-point model views now show alternative models. You can compare and select the best model for each operating point with no need to open the additional Model Selection window. You can use surface plots, data plots, and other plots to assess and compare models. You can use the RMSE plot to identify and navigate to problem tests.

Alternative model fits are now saved so it is faster to switch models and select a different model as best. If you open existing projects, you are prompted to refit the alternative models to store.

Point-by-point models are now immediately below the test plan node in the model tree, instead of reusing the local model node.

For details, see Assess Point-by-Point Models.

Automatic parallel execution of optimizations using Parallel Computing Toolbox

Optimizations automatically use Parallel Computing Toolbox when it is available. Previously you had to manually select parallel optimization.

For details, see Parallel Computing in Optimization.

Improved performance for parallel optimizations

Optimization speed when using Parallel Computing Toolbox is significantly faster because of improved transfer of data to the workers.

Changed Optimization Default Algorithm

New optimizations use the `interior-point` algorithm for `fmincon`. This is the default in Optimization Toolbox™.

Compatibility Considerations

Existing projects are not affected by the change in algorithm. New optimizations will use the new default algorithm. Usually, the new algorithm is faster and more robust. You can still select the previous default algorithm (`active-set`) if desired. This change affects: `foptcon`, `NBI`, and `Modal` optimizations.

Faster Default Models for Large Data Sets

When you fit models to data and the data set is larger than a threshold, the toolbox uses new default models and boundary models.

Model Type	Data Set Size	Boundary Model	Large Data Settings
One-stage	>2000 points	Switches to pairwise convex hull. Switch when >10 inputs even when <2000 points.	Uses the large data behavior for Gaussian process models from Statistics and Machine Learning Toolbox.
Two stage	>2000 tests	Global boundary model switches to pairwise convex hull. Switch when >10 inputs even when <2000 points.	Global model switches to quadratic.

Model Type	Data Set Size	Boundary Model	Large Data Settings
Point-by-point	If any test >2000 points, or >100 operating points	If any operating point has >2000 points, then point-by-point boundary model switches to pairwise convex hull. Switch when >10 inputs even when <2000 points.	Switches to fitting a single GPM per operating point (no Hybrid RBF or polynomial).

For information on all default model types, see Default Model Types.

Compatibility Considerations

Existing projects are not affected. New model fitting will use the new default settings. You can still select any other model types after fitting models to data.

Changes to Feature Filling Algorithm

Feature-filling projects switch to `interior-point` algorithm for `fmincon` if you have table gradient constraints.

Compatibility Considerations

Existing projects switch to `interior-point` algorithm if you refill lookup tables.

New Gasoline Case Study Example

The gasoline case study shows how to systematically develop a set of optimal steady-state engine calibration tables using the Model-Based Calibration Toolbox. The engine to calibrate is a direct-injected 1.5L spark ignition turbocharged engine with dual camphasers and turbocharger wastegate. The toolbox provides example files to show each stage of the model-based calibration process: design of experiment, empirical engine modeling, and optimization.

For details, see Gasoline Engine Calibration.

R2015a

Version: 4.8.1

Bug Fixes

R2014b

Version: 4.8

New Features

Bug Fixes

Compatibility Considerations

Common Tasks pane for fitting statistical models to data

If you want to load data and fit models, the Model Browser provides new tools to create models quickly. When you open the Model Browser, you can click common tasks to import data or fit models.

Importing data is simplified. You can click the common task to load data from a file or the workspace before opening the Data Editor. You can now import table objects from the workspace. You can also load data during the model fitting task.

When you click the Fit Models task, new dialog boxes help you select data and responses to model. The toolbox fits responses using the new default model type, Hybrid radial basis functions. Input names and ranges are taken from the data set. The toolbox also fits boundary models for you. Optionally, you can select a subset of your data for validation, and the Model Browser plots validation data with your model plots.

After fitting models, the Model Browser shows the next common tasks in the test plan view, to guide you on the next step in the workflow. You can click the common tasks list to generate a calibration or export models to Simulink.

The workflow is simplified compared to previous releases, when creating test plans was the first step for both fitting data and creating designs. Separating these workflows helps you get started with fewer options to choose. If you only want to load data and fit models, many fewer steps are required and the toolbox creates models using better defaults. You no longer have to interact with the test plan diagram to set up your models. You no longer need to match signal names, decide to copy data ranges, or choose model settings unless you want to.

For details, see Modeling Workflows.

Design Experiment dialog box for specifying input factors

To create a design when you open the Model Browser, click the Design Experiment task. A new dialog box guides you through specifying inputs and ranges for your design.

The workflow is simplified compared to previous releases. You no longer have to interact with the test plan diagram to set up your inputs. After you create your design and collect data, the Model Browser common task options Import Data and Fit Models guide you through the next steps. The new default model type, Hybrid radial basis functions, can produce better fits.

For details, see Set Up Design Inputs and Fit Models to Collected Design Data.

Genetic algorithm for global optimization of multiobjective drive cycle problems

You can use the new `gamultiobj` optimization algorithm in the CAGE browser. This algorithm is only available if you have Global Optimization Toolbox installed.

The `gamultiobj` algorithm is good for multiobjective optimizations with more than two objectives or those that are not smooth. Such problems can work better with `gamultiobj` than with the previous option for multiobjective optimizations, the `NBI` algorithm.

Analyzing results from these problems is easier with improved Pareto plots. The Pareto plot displays solution status highlighting of successful and unsuccessful solutions (Pareto, dominated, or

infeasible). Pairs of objectives are plotted against each other, so you see three plots for three objectives. Repeated axes and empty diagonal plots have been removed.

For details, see Set Up Multiobjective Optimizations and Analyzing Multiobjective Optimization Results.

Code generation of exported models with Simulink Coder, by exporting using MATLAB Function blocks

All model types are exported to Simulink using MATLAB Function blocks. This enables code generation for deploying, sharing, and executing Model-Based Calibration statistical models using C code.

In R2014a, only polynomial models could be deployed. In previous releases, exported models contained S-functions instead of MATLAB Function blocks.

To deploy a model, ensure the **Inline parameters** option is on. The option is on by default when you export to Simulink. If you copy a block to another system, then set the option before building the exported block into an S-function.

For details, see Export Models to Simulink.

Changed model defaults and automatic boundary model creation can produce better fits

The Model Browser new default models are Hybrid radial-basis functions (RBFs), which can usually produce a good fit the first time. The Model Browser also automatically creates boundary models for your global inputs using the convex hull type.

Hybrid RBF and RBF models have some new defaults and new parameters to produce better fits. These new settings work better for larger data sets, to choose more centers in a better distribution. The fitting algorithm selects up to 50% of the data as centers. Limits start to apply to data sets with >2000 observations. New parameters improve regularization and center selection to reduce overfitting.

You no longer need to interact with the test plan diagram to set up model types or open the Boundary Editor to create boundary models.

For details, see Modeling Workflows.

Compatibility Considerations

Model Browser default models are a different type from previous releases.

To use the previous default model types, you can set up any model type by interacting with the test plan diagram or the Boundary Editor.

Model Type	New Setting	Previous Setting
Default response models	Hybrid radial-basis function (RBF)	Quadratic

Model Type	New Setting	Previous Setting
Default boundary models	Convex hull for global inputs, automatically created	Star-shaped, manual setup, and you had to choose local or global inputs
Hybrid RBF and RBF models	Maximum number of centers, default min(nObs/3,1000)	min(nObs/4,25)
	Candidate centers, default min(100,(2000/nObs)*100)	min(100,(200/nObs)*100)
	Center tolerance, default 0.01, to avoid centers too close together.	N/A. To replicate old behavior, set to 0.
	Number of terms to update between updating regularization parameter, default 10.	N/A. To replicate old behavior, set to 1.
	Stepwise defaults: Prune, AICc	Minimize PRESS
Multiple models	Default model types: • Poly2 with Stepwise: Min PRESS • Poly3 with Stepwise: Min PRESS • Hybrid RBF with nObs/4 • Hybrid RBF with nObs/3 • Hybrid RBF with nObs/2	Default model types: • Poly2 with Stepwise: None • Poly3 with Stepwise: None • Old default RBF • Old default Hybrid RBF
	Multiple models selection criteria default: AICc	RMSE
Build Models feature	Selection criteria default: AICc	RMSE

Import of table objects from the MATLAB workspace

In R2014b, the Model Browser provides the following improvements to data handling:

- You can import table objects from the MATLAB workspace.
- You can select **Data > Import Data from Workspace** in the project view when you open the Model Browser. This simplifies importing data, because you no longer need to open the Data Editor before loading data.
- You can create test filters for records within tests as well as whole tests. For example, `abs(SPK-mean(SPK))<10` keeps all records where `SPK` is within 10 of the test mean.
- You no longer need to reconfigure Data Editor views because it remembers layouts for each data set.

In CAGE, you can import and export between the workspace and CAGE data sets, including table objects. Export creates a table object.

For details, see Loading Data from the Workspace.

R2014a

Version: 4.7

New Features

Bug Fixes

Table editing options to copy, convert, and preserve extrapolation masks and lock table values

CAGE provides new tools for easier locking and extrapolation from desired table values:

- Copy masks and locks from other tables
- Convert masks to locks and vice versa
- Extrapolate using masks and locks rather than just locks
- Smoother extrapolation to locked table cell values
- Revert to previous table version without losing extrapolation mask
- Simplified table inversion

For details, see Filling a Table by Extrapolation and Locking Table Values.

Mask generation from predictive error variance and boundary models

You can generate masks from PEV and Boundary models for any table in CAGE. In previous versions this was only possible if the table was part of a feature calibration.

For details, see Filling a Table by Extrapolation.

Lookup table shading for relating table values to surface plots

CAGE provides new tools for visually exploring tables. Table cells background color now matches the corresponding 3D surface plot color.

Surface plots of tables are transposed to match the numerical table axes and other calibration tools.

Table and plot are now stacked vertically for better use of screen space.

For details, see Viewing and Editing a Table.

Summary information for lookup table size, bounds, normalizers, inputs, and history

Table information now displays size, bounds, normalizers, inputs and history in a single place. The Table Information pane provides easier access to the table history to revert to previous values.

For details, see Viewing and Editing a Table.

Tradeoff plots that zoom inside constraint boundaries

Improved zoom capability in tradeoff plots allows you to set the axes limits to the constraint boundary. This zooms the tradeoff plots inside the constraint boundaries to explore competing objectives in valid regions only. Select **View > Zoom Inside Constraints**. This reduces the y axis scale as the plots do not include regions where the model is extrapolating.

See Choosing a Table Value at a Specific Operating Point.

Polynomial model deployment

Polynomial models exported to Simulink are now implemented as MATLAB Function blocks. This enables code generation for deploying, sharing, and executing Model-Based Calibration statistical models using C code.

See Export Models to Simulink.

R2013b

Version: 4.6.1

Bug Fixes

R2013a

Version: 4.6

Bug Fixes

Compatibility Considerations

Import of more Math Operation Simulink blocks and subsystem hierarchy, enabling more complex calibration strategies

In R2013a, the CAGE Browser includes new and improved features for importing Simulink models into CAGE for feature calibration with reference to statistical models. New features include:

- Import strategies with multiple out ports.
- Import a strategy hierarchy by creating subfeatures for each subsystem. This makes it easier to understand how the model strategy corresponds to the features in CAGE.
- Reuse tables when importing strategies. CAGE reuses existing tables if they have the same inputs. If tables with the same name use different inputs, CAGE asks what you want.
- Switch blocks now support all operators. Previously CAGE could only parse >=.

See Import a Strategy from Simulink.

Compatibility Considerations

2D tables now use Y (rows), X (columns) input order to be consistent with Simulink. Previously, CAGE parsed the first input as columns and the second as rows. You can use a backward compatibility mode if needed for previously saved strategies.

The Graphical Strategy Editor provides a left to right flow, consistent with Simulink. Previously, the single output was on the left with the strategy on the right.

See Importing Older Strategies.

Import and export of table values and breakpoints in Simulink model strategies

When you import strategies into the CAGE Browser, you can import lookup table values from Simulink into CAGE tables, so you can get table and normalizer data.

See Import a Strategy from Simulink.

Configuration and storage of multiple fill settings for feature filling processes

In the CAGE Browser Feature view, new information panes display all the tables in a feature and any filling factors already set up. You can store, view, and reuse feature filling settings for any of the tables from the top Feature view.

See Saving and Reusing Feature Fill Settings.

Case study example showing calibrating a multi-injection diesel engine

R2013a includes new example files showing how to systematically develop a set of optimal steady-state calibration tables for a diesel multi-injection engine using Model-Based Calibration Toolbox.

The engine to be calibrated is a 3.1L multi-injection combustion ignition engine with common rail, variable-geometry turbocharger (VGT), and cooled exhaust gas recirculation (EGR).

The aim of the calibration is to minimize Brake Specific Fuel Consumption (BSFC) at specific speed/load operating points across the engine's operating range, and meet the following constraints:

- Limit total NOx emissions.
- Limit maximum turbocharger speed.
- Limit calibration table gradients for smoothness.

The analysis produces optimal calibration tables in speed and torque for:

- Best main start of injection timing
- Best total injected fuel mass per cylinder per cycle
- Best pilot injection timing relative to main timing
- Best pilot injection fuel mass fraction of total injection mass
- Best exhaust gas recirculation (EGR) position
- Best variable geometry turbocharger (VGT) vane position
- Best fuel rail pressure relative to nominal pressure vs. engine speed

See Multi-Injection Diesel Calibration.

Use model ranges from point-by-point models as optimization bounds

In R2013a, the CAGE Browser uses model ranges from point-by-point models instead of data variable ranges. Providing more precise bounds can help optimizations to converge quicker. For point-by-point models, the variable ranges can be much larger than the bounds for a particular operating point.

In previous releases, CAGE used data variable ranges instead of model ranges. If the data ranges for operating points differ widely across model operating points, this could cause optimizations to run more slowly or fail to converge. The data range often contains large infeasible parts of the space between the bounds that are outside the boundary model constraint. Using more precise model ranges can help the optimization find a feasible result.

R2012b

Version: 4.5

New Features

Table filling from optimization results, when optimization operating point inputs are different from table inputs

For some optimization problems, you want to optimize at operating points in different variables to the tables you want to fill, and use response models as normalizer inputs to tables. For example, if your problem requires running an optimization at torque and speed operating points, but you want to fill lookup tables on axes of `mainfuel` (a response model) and speed.

Previously, it required many manual steps to create and fill such tables from your optimization results. The toolbox now provides tools to quickly create tables with response models as normalizer inputs, and select such tables to fill with your optimization results. Now you can use your optimization results to fill lookup tables with different inputs to your optimization operating point inputs.

See Creating Tables From a Model and Table Filling When Optimization Operating Point Inputs are Different From Table Inputs.

Overlay of validation data on boundary model plot views

You can now choose to plot validation data on boundary model plots. This is useful for investigating where validation data lies in the operating envelope compared to the original points used to fit the model.

See Plotting Boundary Models.

R2012a

Version: 4.4

New Features

Bug Fixes

Smaller Project File Sizes

CAGE and Model Browser file sizes are reduced by up to 95% for point-by-point projects, enabling easier file sharing.

More Efficient Boundary Modeling

More efficient boundary modeling contributes to reducing file sizes. Identical boundaries are shared between response model fits instead of duplicated.

The convex hull model is simplified for more efficient boundary modeling. In a typical example, using 8 factors and 70 points results in a convex hull with around 35,000 faces. By default, the boundary model now keeps only the most useful facets and can discard around 30% of the facets because they contribute only a small amount to the boundary. The new method is more efficient and includes all data points within the boundary, with the total volume increasing by around 1%. If you want the minimal volume at the expense of a much larger number of facets, you can select a new option, **Keep All Facets**.

See Boundary Model Setup in the Model Browser documentation.

Stored Feature Filling Settings

CAGE projects now store last-used settings for tables, models, data, and optimizations for feature filling. The Feature Filling Wizard can require many steps to set up and you might need to repeat this process many times. Stored settings can save time when using the Feature Filling Wizard repeatedly with slightly different settings.

You can remove saved fill settings using a new menu item, **Feature > Reset Fill Settings**.

See Performing Feature Calibrations in the CAGE documentation.

R2011b

Version: 4.3

New Features

Bug Fixes

Improved Design Creation

The design creation process is improved to help you save time and choose good settings for generating efficient candidate sets. The toolbox now warns you if you try to generate a large candidate set of points that will take a long time. Previously, you could try to generate candidate sets that were so large that you could run out of memory. The toolbox now warns and gives you the option to stop and change settings to create a better design more quickly. The toolbox also provides suggestions for better alternative settings.

Support for the Windows 64-Bit Platform

A 64-bit version of Model-Based Calibration Toolbox software is now available for users of 64-bit Windows® and the 64-bit version of MATLAB.

Note the 32-bit version of Model-Based Calibration Toolbox also works on a 64-bit version of Windows, but requires a 32-bit version of MATLAB.

64-bit support required some changes to the appearance of trees in CAGE. Projects in CAGE have a new root project node in the tree. There is no functionality at this project node.

R2011a

Version: 4.2

New Features

Bug Fixes

Extra Objectives for Modal Optimization Analysis

You can now specify more than one objective for graphical comparison in modal optimization. You can optimize with one objective, and use the other objectives to explore the results. You can optionally choose a different objective to use to select the best mode.

See Adding Extra Objectives to Modal Optimizations and Analyzing Modal Optimization Results in the CAGE documentation.

New MultiStart Algorithm to Find Local Optima and Create Smoother Tables

If you have Global Optimization Toolbox you can now use the MultiStart algorithm in CAGE. This algorithm tries to identify local optima to help you create smoother tables. Multiple local optimal solutions are often found because of the flat nature of engine responses. The difference in performance between these different solutions can be small and result in tables that are not smooth enough. The new MultiStart algorithm tries to identify multiple optimal solutions for each operating point. You can select the solutions that meet your table smoothness constraints based on the entire table.

See Set Up MultiStart Optimizations and Analyzing MultiStart Optimization Results in the CAGE documentation.

Tradeoff Tool Plots Local Model Ranges

The Tradeoff tool in CAGE now automatically scales plot axes to the local range when switching between different point-by-point models. This avoids having to manually zoom on each graph from the global range to the range of interest.

See Point-by-Point Model Tradeoffs in the CAGE documentation.

Defer Fit Updates

In the Model Browser, you can now delay lengthy updates of dependent fits when leaving the local node. This can be useful when you want to examine a particular global model after removing an outlier at the local level. Defer updates to avoid waiting while updating all other dependent fits.

See Updating Fits in the Model Browser documentation.

Simplified Parallel Model Building

To use parallel processing with model building, you no longer have to use the `mbcmatlabpool` function as well as the `matlabpool` function. The removal of `mbcmatlabpool` simplifies parallel model building by reducing the number of setup steps.

See Parallel Model Building in the Model Browser documentation.

R2010b

Version: 4.1

New Features

Bug Fixes

Equality Constraints

Version 4.1 provides the ability to define equality constraints on models. The feature enables you to optimize performance while meeting demanded operating conditions. See Model Constraints in the CAGE Optimization Setup documentation.

For an example, see Setting Up Constraints in the Getting Started Diesel Case Study.

Feature Filling with Data

You can now fill features directly from experimental data using the Feature Fill wizard. This wizard now enables you to fill feature tables without a model.

You can use data sets in the Feature Fill wizard to fill features over irregular data sets, without gridded data.

See Filling and Optimizing Table Values in the CAGE Feature Calibration documentation.

Data Transfer Between CAGE and the Model Browser

In Version 4.1, you can directly transfer data between Model Browser and CAGE without saving an intermediate file. In CAGE, you can now import data directly from the Model Browser, and export data to the Model Browser.

See Importing Data from the Model Browser and Exporting Data to the Model Browser in the CAGE Data Sets documentation.

R2010a

Version: 4.0

New Features

Bug Fixes

Modeling Enhancements

- “New Composite Models for Multiple Operating Modes” on page 23-2
- “Update Models with Additional Data” on page 23-2
- “Improved API for Export Models” on page 23-3

New Composite Models for Multiple Operating Modes

Version 4 of Model-Based Calibration Toolbox enables you to produce optimal calibrations for engines with multiple operating modes. You can use the new *composite* model type to combine a number of models to represent engine responses under different operating modes. You can use the composite model in CAGE to produce optimal calibrations for engines with multiple operating modes. Use for calibration problems where the goal is to fill a single table for all modes or to fill a table for each mode.

You can create a composite model by either:

- Importing to CAGE from the Model Browser
- Combining existing models in CAGE

The composite model consists of a collection of models with an extra mode input. The mode input is an index into the list of models. The component models can have different sets of inputs.

See Creating and Viewing Composite Models in CAGE in the CAGE documentation.

New example projects are provided to illustrate using the new features to produce optimal calibrations for diesel and gasoline engines with multiple operating modes. See Example Composite Models and Modal Optimizations in the Getting Started documentation.

Update Models with Additional Data

You can now update test plans in the Model Browser with new data points while retaining boundary models and validation data.

Previously, when you updated test plan data, the toolbox deleted boundary models and validation data. The toolbox retained local fits, including your outlier selections, if their test data was unchanged after adding new test plan data.

In R2010a, when you update test plan data, the toolbox refits boundary models and retains validation data. Thus, you have less rework to do when fitting models as you collect more data.

The test plan data update functionality is particularly important for building two-stage or point-by-point models. You can load local models into the Model Browser as you collect the data. The update functionality ensures that you do not lose current work when you load data for new tests. The update functionality is also useful when you augment a one-stage design because you need more data to build an accurate model.

Input signal names need to match when update test plan data. The toolbox deletes boundary models and validation data if the input signal names change.

To update data for a test plan, use the Select Data toolbar button or the **TestPlan** menu item. See Use Test Plans to Set Up Designs, Data, and Models in the Model Browser documentation.

Improved API for Export Models

This release introduces improved command-line API support for exporting models. This support includes new methods for calculating confidence intervals and prediction error variance for models. See Export and xregstatsmodel in the Reference documentation.

Optimization Enhancements

- “New Optimization Algorithm for Multiple Operating Modes” on page 23-3
- “Table Gradient Constraints of Models” on page 23-3
- “Filter Rules for Table Filling” on page 23-4
- “Incremental Table Filling” on page 23-4
- “Support for New Version of ATI VISION” on page 23-5
- “New Optimization Parameters” on page 23-5

New Optimization Algorithm for Multiple Operating Modes

Version 4 of Model-Based Calibration Toolbox enables you to produce optimal calibrations for engines with multiple operating modes. You can use the new Modal optimization algorithm to select optimal operating modes for such calibrations. This algorithm helps you choose the best operating mode for each operating point. The algorithm can optimize an objective for each operating mode and select the best solution automatically. You must use a composite model for these optimizations.

This release also introduces enhanced optimization output views to help you view the solutions and decide which mode you want to use for each operating point. The enhanced views make it easier to see which solution is selected and to change the selection. These features are also useful for selecting solutions for multiple objective optimizations such as NBI.

You can only use modal optimization for point optimization problems. When you have selected the best mode for each operating point, you can create a sum optimization from your modal optimization results. The toolbox automatically creates a sum optimization for you with your selected best mode for each operating point. For more information see Set Up Modal Optimizations in the CAGE documentation.

New example projects are provided to illustrate using the new features to produce optimal calibrations for diesel and gasoline engines with multiple operating modes. See Example Composite Models and Modal Optimizations.

Table Gradient Constraints of Models

With R2010a you can apply table gradient constraints to models to restrict optimal solutions to smooth responses. Previously, you could only constrain the table gradients of variables. Optimal calibrations need constraints on both model responses and variables. You can now specify a maximum gradient for engine responses as well as control inputs.

Sometimes the inputs for testing differ from the inputs for tables. In such cases, engineers often use a model to derive the table input. To constrain the table gradient you need to define a gradient constraint for models. You can also define a constraint on the smoothness of the engine response for drivability.

You can define a table gradient constraint for any free variable in your optimization or any model that has a free variable as an input. The Edit Constraint dialog box for the table gradient constraint has been rearranged to simplify workflow.

You can only use table gradient constraints for sum optimizations because the toolbox needs multiple operating points to estimate the table. If you require filling rules to select part of the optimization results for filling, then use the table gradient constraints in combination with application point sets. In particular, if your goal is to fill different tables for each mode, then define application point sets for each mode. For an example, see

Composite Model Example with Separate Tables for Each Mode in the Getting Started documentation.

Filter Rules for Table Filling

You can now apply filter rules to select part of the optimization results for table filling. You can specify an operating mode or any valid expression as a filter when using the Table Filling wizard.

The filter rules are important for modal optimizations. Composite models can require the ability to select part of the optimization results to fill a particular table. For example, you need to discard solutions for other modes when filling a table with an input that is not used for all modes.

- Use filter rules when your goal is to fill a different table for each mode.
- Specify a filter rule with a logical expression using any input or model available for use in table filling.
- The Table Filling from Optimization Results wizard automatically sets up filter rules for you if some inputs are not used for all modes in your composite model.

For an example, see Filling Tables for Operating Modes in the CAGE documentation.

Incremental Table Filling

New settings in the table filling wizard enable you to incrementally fill lookup tables from the results of multiple optimizations with smooth interpolation through existing table values. CAGE can extrapolate the optimization results to pass smoothly through table masks and locked cells. Use these features when you want to use separate optimizations to fill different regions of a lookup table.

Use the new check boxes in the Table Filling from Optimization Results wizard to specify when you want to:

- Use locked table values in extrapolation.

  If your calibration tables have fixed values for some table cells, use locked cells for the table cells with fixed values. Such cells often appear on the edge of a table.

  Select this check box and CAGE smoothly fills the table between fixed table values and optimization results.
- Use existing extrapolation mask in fill.

  Select this check box when you want to fill the same table from multiple optimizations that provide solutions at different operating points. Complex calibration problems can require different optimizations for different regions of a table. The toolbox automatically adds filled cells to the table mask.

Select this check box for subsequent table filling. CAGE smoothly fills the table between the values in the mask (from previous table filling) and the current optimization results.

See Filling Tables from Optimization Results in the CAGE documentation.

Support for New Version of ATI VISION

The toolbox now supports ATI VISION Version 3.5.1.

You can import and export calibrations directly from/to ATI Vision (via a live link or .mat files). See Importing and Exporting Calibrations in the CAGE documentation.

New Optimization Parameters

A new setting in the Optimization Parameters dialog box for the `foptcon` algorithm allows you to choose one of the `fmincon` function algorithms: `active-set`, `sqp`, `interior-point`. First try the default, `active-set`, the only option in previous releases. If you have sum optimizations which are slow or have problems converging, you can try the new `sqp` or `interior-point` options. For details of `sqp` see New fmincon Algorithm in the Optimization Toolbox release notes.

To use the new options in CAGE, see the **Constraint optimization algorithm** setting described in Edit Optimization Parameters in the CAGE documentation.

New Example Projects for Calibrating Engines with Multiple Operating Modes

Version 4 of Model-Based Calibration Toolbox enables you to produce optimal calibrations for engines with multiple operating modes. Examples of applications include: multi-injection diesel engine; inclusion of startup conditions in drive cycles; rich and stoich regions for engines.

New example projects are provided to illustrate using the new features to produce optimal calibrations for diesel and gasoline engines with multiple operating modes. See Example Composite Models and Modal Optimizations in the Getting Started documentation.

R2009b

Version: 3.7

New Features

Bug Fixes

Optimization Tools

- New wizards to automate creating an optimization, tables, and tradeoff from a model. The wizards simplify common calibration workflows to create optimizations, and related tables to fill with optimization results, and tradeoffs for investigating results. These utilities make these workflows easier and faster by eliminating many manual steps. See:
  - Creating Optimizations from Models in the CAGE documentation.
  - Creating Tables From a Model in the CAGE documentation.
- Enable difficult diesel calibrations problems by evaluating optimization objectives and constraints over different drive cycles. See Using Application Point Sets in the CAGE documentation.
- Improved tools to analyze and export multi-objective optimization results: an exit flag per solution, improved exit messages, only successful solutions shown on pareto plots, and the ability to export all solutions. See Tools for Optimizations With Multiple Solutions in the CAGE documentation.
- Ability to duplicate and import optimization constraints. See Edit Objectives and Constraints in the CAGE documentation.
- New dialog box for selecting calibration items for export. See Exporting Calibrations in the CAGE documentation.

Modeling Tools

- New API for creating and evaluating boundary models, vital for constraining online Design of Experiments (DOE). See Boundary Model Scripting in the Getting Started documentation.
- Ability to negate design constraints, for example, if you want to constrain points to be *outside* a boundary model. See How to Apply Constraints in the Model Browser documentation.
- New model type: interpolating RBF to fit an interpolating surface that passes through every data point. See Global Model Class: Interpolating RBF in the Model Browser documentation.

Point-By-Point Case Study

- New case study demonstrating how to use the tools for a *point-by-point* diesel engine calibration project. The instructions and example files show you how to:

  1. Programmatically create designs, models, and boundary models at each operating point.
  2. Interactively create a multiregion sum optimization, with a constraint applied only at full load points, and a second drive cycle with different weights to evaluate the optimization results at intermediate points.

  For instructions see Point-by-Point Diesel Engine Calibration Case Study.

R2009a

Version: 3.6

New Features

Bug Fixes

Optimization Enhancements

- Usability improvements including:
  - The new Table Filling Wizard makes it easier to fill a single table from a model. The wizard automates this process and eliminates a number of manual steps. See Filling a Table From a Model in the CAGE Browser documentation.
  - Utility to automatically create a sum optimization from the results of a point optimization. A common workflow is to use a point-by-point optimization to find good initial values for a sum optimization. This utility makes this workflow easier and faster by eliminating a number of manual steps. See Create Sum Optimization from Point Optimization Output in the CAGE Browser documentation.
  - CAGE Surface Viewer snaps display automatically to point-by-point model operating points. When you are using point-by-point models, these are the points of interest you want to display. See Displaying Point-by-Point Models in the Surface Viewer in the CAGE Browser documentation.
- Support for ATI VISION 3.5. See Importing and Exporting Calibrations in the CAGE Browser documentation.

Modeling Enhancements

- Usability improvements including:
  - New navigation ability in RMSE explorer. You can double-click points to select the test in Model Browser views. This helps you investigate problem tests and avoids the need to enter the test number in the Model Browser. See Using the RMSE Explorer with Local Models in the Model Browser documentation.
  - Process for augmenting space-filling designs. These instructions explain how to augment your space-filling design by keeping your existing points and adding points with the same sequence parameters. See Augmenting Space-Filling Designs in the Model Browser documentation.
  - CAGE and the Model Browser open projects at last displayed node. This memory of your last project view avoids the need to remember where you were working and the Browsers automatically navigate there.

R2008b

Version: 3.5

New Features

Bug Fixes

Boundary and Point-By-Point Modeling

- Improved Boundary Editor workflow. Menus, dialog boxes, and the toolbar are simplified to streamline creation of boundary models. See Boundary Model Setup.
- Enhancements to point-by-point modeling tools that are useful for diesel engine modeling. You can use a new template for creating point-by-point test plans with local models at each engine operating point. You can now create boundary models for point-by-point test plans in the Boundary Editor. Boundary model constraints are now displayed for local models in the Model Selection window to help you evaluate your point-by-point models. Exporting your point-by-point models now automates creation of items for optimized calibration in CAGE. See Set Up a Point-by-Point Model.

R2008a+

Version: 3.4.1

Bug Fixes

R2008a

Version: 3.4

New Features

Bug Fixes

New Design Tools

- Create space-filling, optimal, classical, or custom designs interactively using new command-line functionality. See the toolbox examples, and design scripting documentation.
- New Sobol and Halton sequence space-filling design types can provide highly uniform experimental designs. See Halton Sequence and Sobol Sequence.

Optimization Multistart, Surface and Contour Views

- New optimization output contour and surface views that aid in the assessment and use of results for generating optimal lookup tables. See Solution Slice: Results Surface and Results Contour Views.
- Improved generation of multiple starting conditions to help detect global optima with gradient-based optimization algorithms. See Edit Optimization Parameters.

Parallel Model Building

Use parallel computing to speed up model building (requires Parallel Computing Toolbox license). See Parallel Model Building.

R2007b

Version: 3.3

New Features

Bug Fixes

Design Tools

- Command-line definition of inputs for test plans and models.

  See modelinput, and for examples see Scripting Demos.

- Extended command-line functionality for creating, editing, and fitting local models.

  See LocalModel Properties, and for examples, see Scripting Demos in the Model-Based Calibration Toolbox Getting Guide documentation.

- Enhanced defaults and previews for space-filling designs, including performance increases, design property improvements, and improved handling of constrained design points. The new defaults are faster to compute and provide symmetrical designs with better space-filling properties. The default **Selection criteria** is now `Minimize RMS variation from CDF`, and **Enforce Symmetrical Points** is now selected by default.

  The number of constrained design points are now displayed in the Design Browser preview, where you can iterate design generation until the desired number of constrained points is achieved. The preview design is now identical to the final design.

  See Setting Up a Space-Filling Design.

Optimization Setup and Analysis Tools

- Enhanced optimization set up and analysis, including support for boundary constraint definition in the optimization wizard, ability to rename objectives and constraints, and improved display of table gradient constraints.

  You can now use a right-click shortcut to convert an existing constraint to a boundary model constraint without opening the Constraint Editor. Table gradient constraint output is simplified in the Optimization Output Table and Constraint Summary table to aid analysis, and these constraints are faster to display.

  See Overview of Objectives and Constraints.

- New process suggestions for analyzing optimization results, with advice for detecting problems and improving results.

  See Analyzing Point Optimization Output.

R2007a

Version: 3.2

New Features

Bug Fixes

Modeling API

Extended command-line API to setup models for use as standalone objects or as part of MBC projects. See DIVCP Example.

Accepting Optimization Solutions

New tools to assist in the assessment and use of optimization results for producing optimal lookup tables. See Choosing Acceptable Solutions.

Parallel and Global Optimizations

- Use distributed computing to speed up multiple run optimizations (requires Distributed Computing Toolbox™). See Parallel Computing in Optimization.
- Use Genetic Algorithms and Pattern Search to find globally optimal solutions (requires Global Optimization Toolbox). See Choose Optimization Algorithm.

R2006b

Version: 3.1

New Features

Bug Fixes

Optimization Enhancements

- Gradient constraints for controlling table smoothness in optimization-based and feature-based table filling
- Contour plot view for optimization results
- Point-by-point variable bounds for finer control of optimization problems
- Ability to enable and disable optimization constraints for “what if” studies
- Support for starting optimizations from the results of a previous run
  - Solve related “what if” problems faster
  - Refine calibration results by tweaking algorithm settings
- Enhanced user interface for comparing the results of different calibration optimization problems

Modeling Enhancements

- Improved integration of validation metrics within the model selection process
- Enhanced local modeling at each operating point (a complementary approach to building a single, global model)
- Ability to alter variable ranges and refit models automatically

R2006a

Version: 3.0.1

No New Features or Changes

R14SP3+

Version: 3.0

New Features

Compatibility Considerations

Command-Line Interface to the Model-Based Calibration Toolbox Software

The command-line interface to the Model-Based Calibration Toolbox software enables the modeling process to be automated using MATLAB commands. In this way, you can simplify the modeling process for technicians and engineers who might not have extensive background and training in this area. You can also access modeling functionality from test bed automation tools.

Improved CAGE Setup

The CAGE Import Tool allows easier reusability of CAGE sessions. You can use the CAGE Import Tool to import models, data sets, optimizations and features from any Model-Based Calibration Toolbox project file produced in CAGE or the Model Browser (`.mat` or `.cag`). This feature can greatly simplify the application of proven feature filling and optimization processes to new engine variants.

Optimization

Optimization in CAGE has had major updates:

- Significant speed improvements
- New optimization parameters that help avoid local minima by specifying multiple start points, and running only from feasible start points
- Automatic scaling of objective and constraint values improves numerical stability of algorithms
- Enhanced table filling from optimization results now allows more flexible filling methods: you can exclude infeasible solutions, choose whether to extrapolate, use selected solutions, and apply custom fill algorithms
- Enhanced API for user-defined optimization scripts
- Improved results visualization for drive-cycle optimizations and multiobjective optimizations
- Improved constraint display for non-model constraints (1–D and 2–D tables, ellipsoid, etc.)

Compatibility Considerations

Some existing user-defined optimization scripts may require a call to the function `setRunInterfaceVersion` to fix incompatibilities. You can also do this in the CAGE Browser GUI in the Optimization Parameters dialog box.

If you want to use the new `foptcon` optimization parameters (multiple start points and run only from feasible start points) with existing optimizations, you must use the menu item **Optimization > Reset Parameters**.

Calibration Tool Interface

New links to standard industry tools allow import and export of calibrations directly from/to ATI Vision (via a live link or `.mat` files) and ETAS INCA (via `.dcm` files).

Boundary Modeling

You can model boundaries using convex hulls. You can create boundary models for subsets of inputs, which simplifies the boundary identification process for complex engines. Improved visualization tools

in the Boundary Editor help you construct accurate constraints. Boundary constraints can now be imported into the Design Editor and exported to Simulink.

Feature Filling

The Feature Fill Wizard uses new algorithms to fill and optimize table values with reference to a model. You can fill multiple tables simultaneously using the wizard, extending the range of calibration problems that CAGE can solve. You can impose gradient and smoothing penalties, and fill lookup tables on a region-by-region basis.

Surface Viewer Movie

The Surface Viewer now has a movie mode that is faster and easier to use, with an interactive progress bar.