Estimate Parameters from Measured Data

About This Tutorial

- Objectives
- About the Model

Objectives

This tutorial shows how to estimate parameters of a single-input single-output (SISO) Simulink® model from measured input and output (I/O) data.

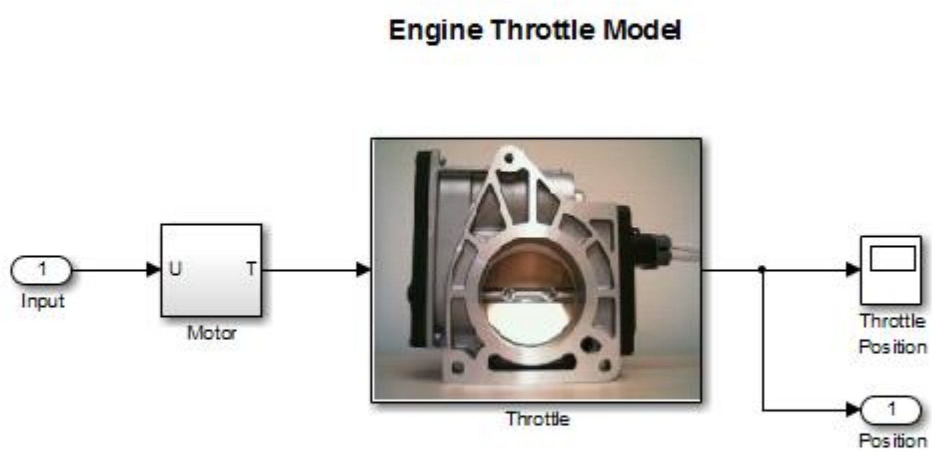
Note: Simulink Design Optimization™ software estimates parameters from real, time-domain data only.

You can perform the following tasks using the Parameter Estimation tool:

- Load a saved session containing data
- Estimate model parameters using default settings
- Validate the model, and refine the estimation results

About the Model

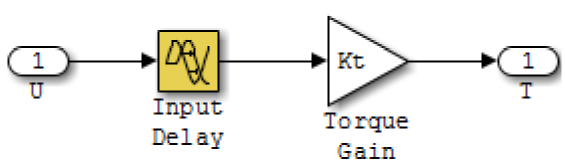
This tutorial uses the `spe_engine_throttle1` Simulink model, which represents an engine throttle system.



The throttle system controls the flow of air and fuel mixture to the engine cylinders. The throttle body contains a butterfly valve that opens when a driver presses the accelerator pedal. Opening this valve increases the amount of fuel mixture entering the cylinders, which increases the engine speed. A DC motor controls the opening angle of the butterfly valve in the throttle system. The models for these components are described in Motor Subsystem and Throttle Subsystem.

The input to the throttle system is the motor current (in amperes), and the output is the angular position of the butterfly valve (in degrees).

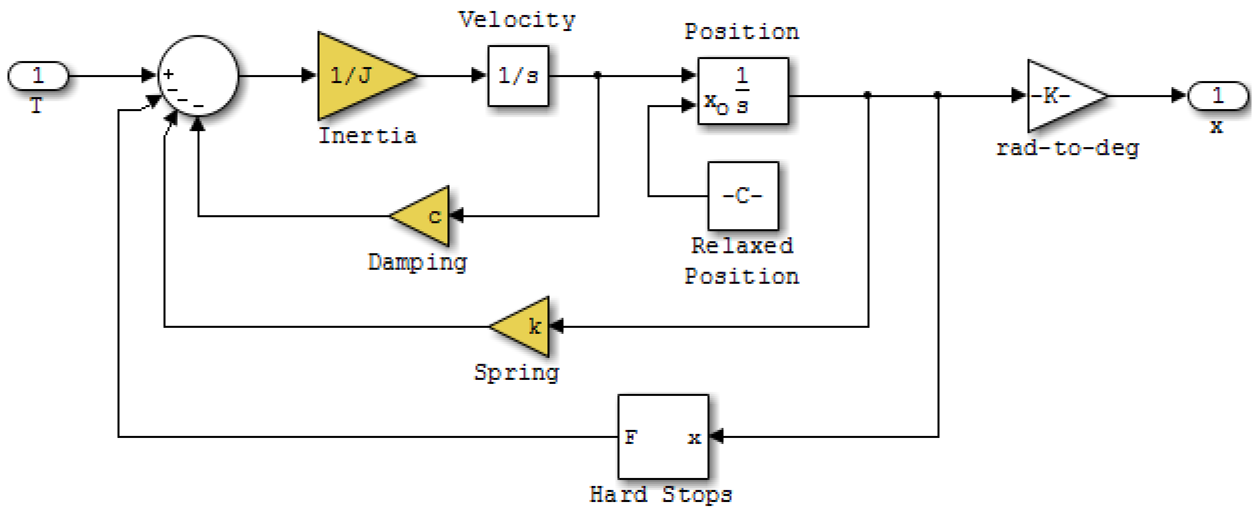
Motor Subsystem. The `Motor` subsystem contains the DC motor model. To open the model, double-click the corresponding block.



Components of the `Motor` subsystem	**Description**
Variables	*U* is the input current to the motor. *T* is the torque applied by the motor.

Components of the `Motor` subsystem	Description
Parameters	K_t is the torque gain of the motor, represented by `Kt` in the model. t_d is the input time delay of the motor, represented by `input_delay` in the model.
Equation	The torque applied by the motor is described in the following equation: $T(t)=K_t U(t-t_d)$ where t is time.
Input	U
Output	T

Throttle Subsystem. The `Throttle` subsystem contains the butterfly valve model. To open the model, right-click the corresponding block, and select **Mask** > **Look Under Mask**.



The `Hard Stops` block models the valve angular position limit of 15° to 90°.

The following table describes the variables, parameters, states, differential equations, inputs, and outputs of the .

Components of the `Throttle` subsystem	Description
Variables	T is the torque applied by the DC motor. θ is the angular position of the valve, represented by `x` in the model. $T_{hardstop}$ is the torque applied by the hard stop.
Parameters	`J` is the valve inertia. `c` is the valve viscous friction. `k` is the valve spring constant.
States	θ is the angular position. $\dot{\theta}$ is the angular velocity.
Equations	The mathematical system for the butterfly valve is described in the following equation: $J\ddot{\theta}+c\dot{\theta}+k\theta=T+T_{hardstop}$ where $15^\circ \le \theta \le 90^\circ$, with initial conditions $\theta_0=15^\circ$, and $\dot{\theta}_0=0$. The torque applied by the `Hard Stops` block is described in the following equation: $T_{hardstop}=\begin{cases} 0, & 15^\circ \le \theta \le 90^\circ \\ K(90^\circ-\theta), & \theta>90^\circ \\ K(15^\circ-\theta), & \theta<15^\circ \end{cases}$ where `K` is the gain of the `Hard Stops` block.
Input	T
Output	θ

Estimate Model Parameters Using Default Estimation Settings

- Overview of the Estimation Process
- Specify Estimation Data and Parameters

Overview of the Estimation Process

Simulink Design Optimization software uses optimization techniques to estimate model parameters. In each optimization iteration, it simulates the model with the current parameter values. It computes and minimizes the error between the simulated and measured output. The estimation is complete when the optimization method finds a local minimum.

To start the estimation process, first open the engine throttle system Simulink model by typing the following at the MATLAB® prompt:

```
spe_engine_throttle1
```

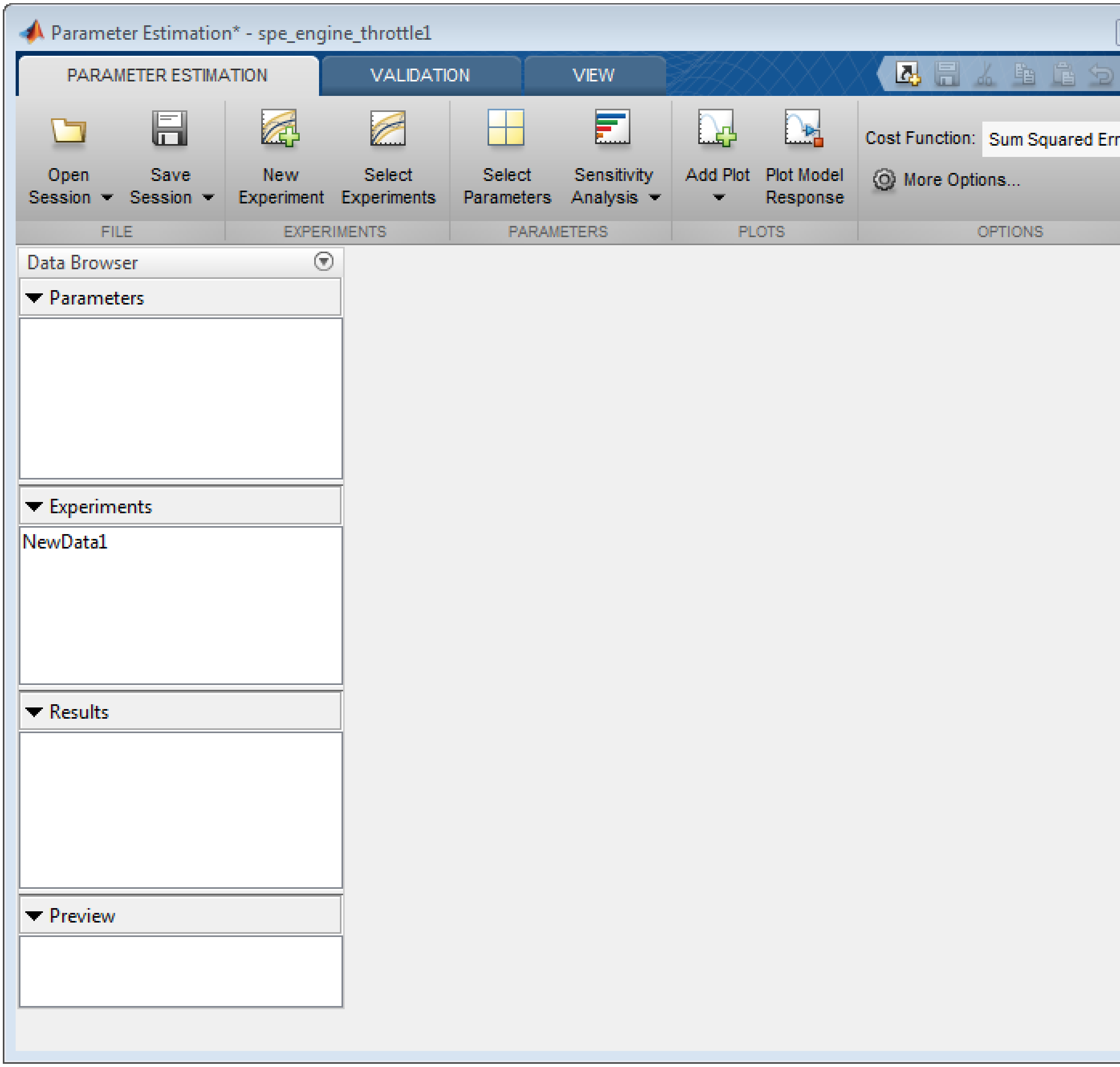
In the Simulink Editor, select **Analysis** > **Parameter Estimation**.

This action opens a new session with the name **Parameter Estimation - spe_engine_throttle1** in the Parameter Estimation tool.

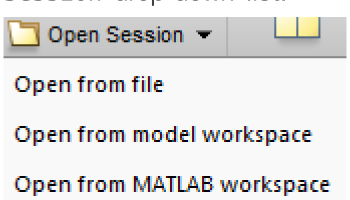
Note: The Simulink model must remain open to perform parameter estimation tasks.

Specify Estimation Data and Parameters

1. Load or import the estimation data.



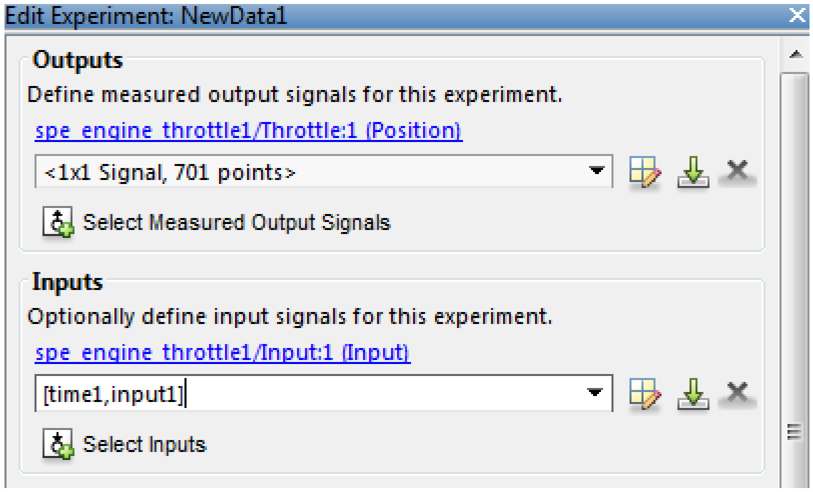
a. If you prepared data and saved your session as described in Prepare Data for Parameter Estimation, load the preconfigured session. On the **Parameter Estimation** tab, click the `Open Session` drop down list.



Select the correct option to browse to the location of your saved session, for example, `Open from file`. Then select the MAT-file.

b. If you do not have a previously saved session, create a new experiment. on the **Parameter Estimation** tab, click **New Experiment** . In the **Experiments** list on the left pane. You can rename it by right-clicking and selecting **Rename** from the list. For example, call it `NewData1`.

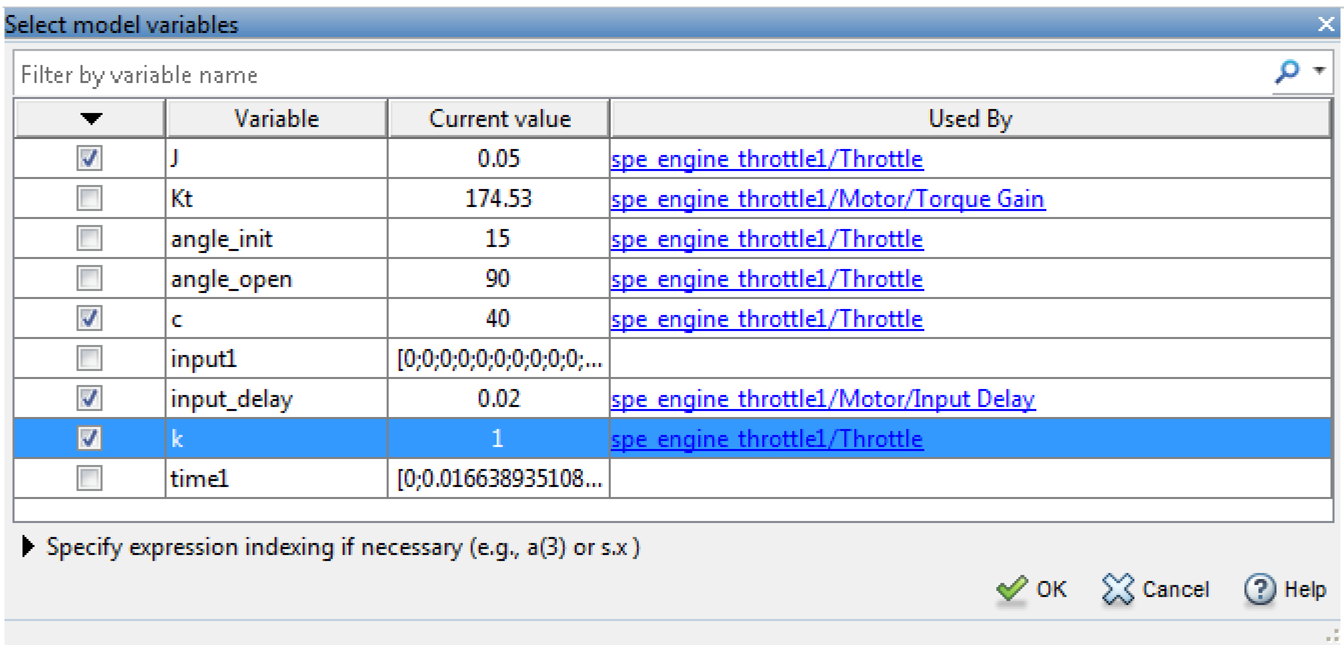
To import data into the experiment, right-click and select **Edit...** to launch the experiment editor. Import the output data by typing in the dialog box in the **Outputs** panel, for example `[time1,position1]`. Import the input data by typing in the dialog box in the **Inputs** panel, for example `[time1,input1]`.



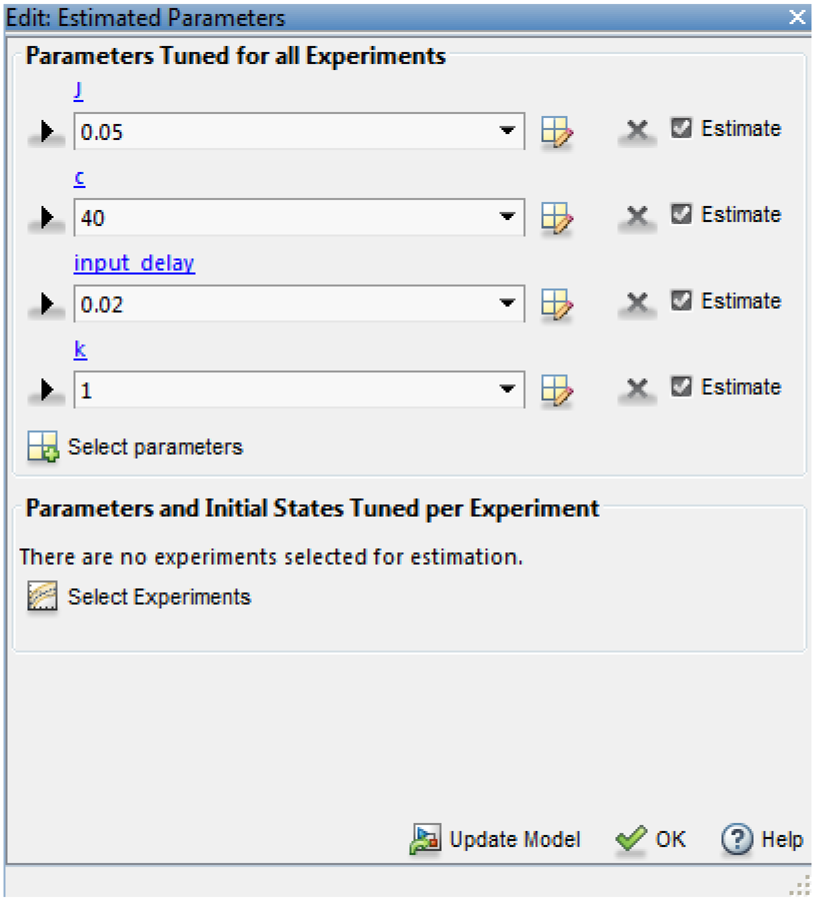
2. Specify parameters for estimation. On the **Parameter Estimation** tab, click the **Select Parameters** button to open the **Edit: Estimated Parameters** dialog box. In the **Parameters Tuned for all Experiments** panel, click the **Select parameters** button to launch the **Select Model Variables** dialog box.

   Select the parameters `J`, `c`, `input_delay`, and `k`, and click **OK**.

   Note: In your application, if the model parameters you want to estimate are not listed in the Select Model Variables dialog box, first specify these parameters as variables. See, Add Model Parameters as Variables for Estimation.



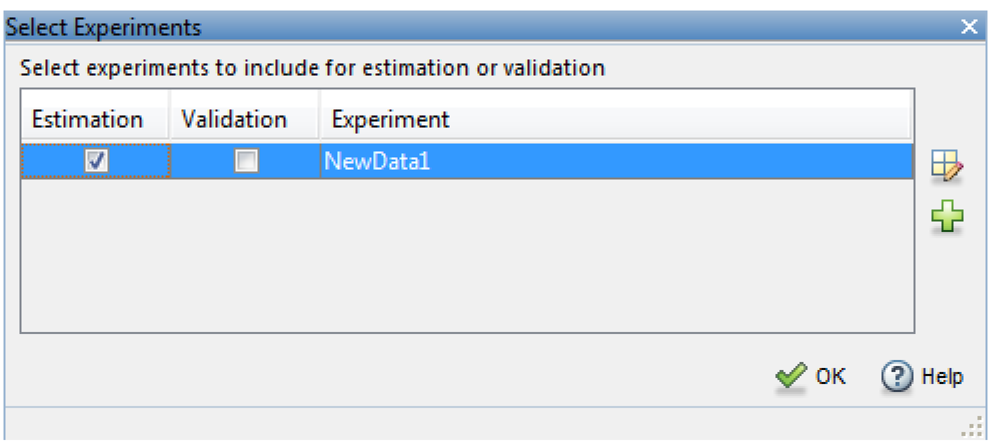
   The **Edit: Estimated Parameters** window now looks as follows.



The tool selects the parameters you add for estimation by default. When estimating a large number of parameters, you can first select a subset of parameters to estimate.

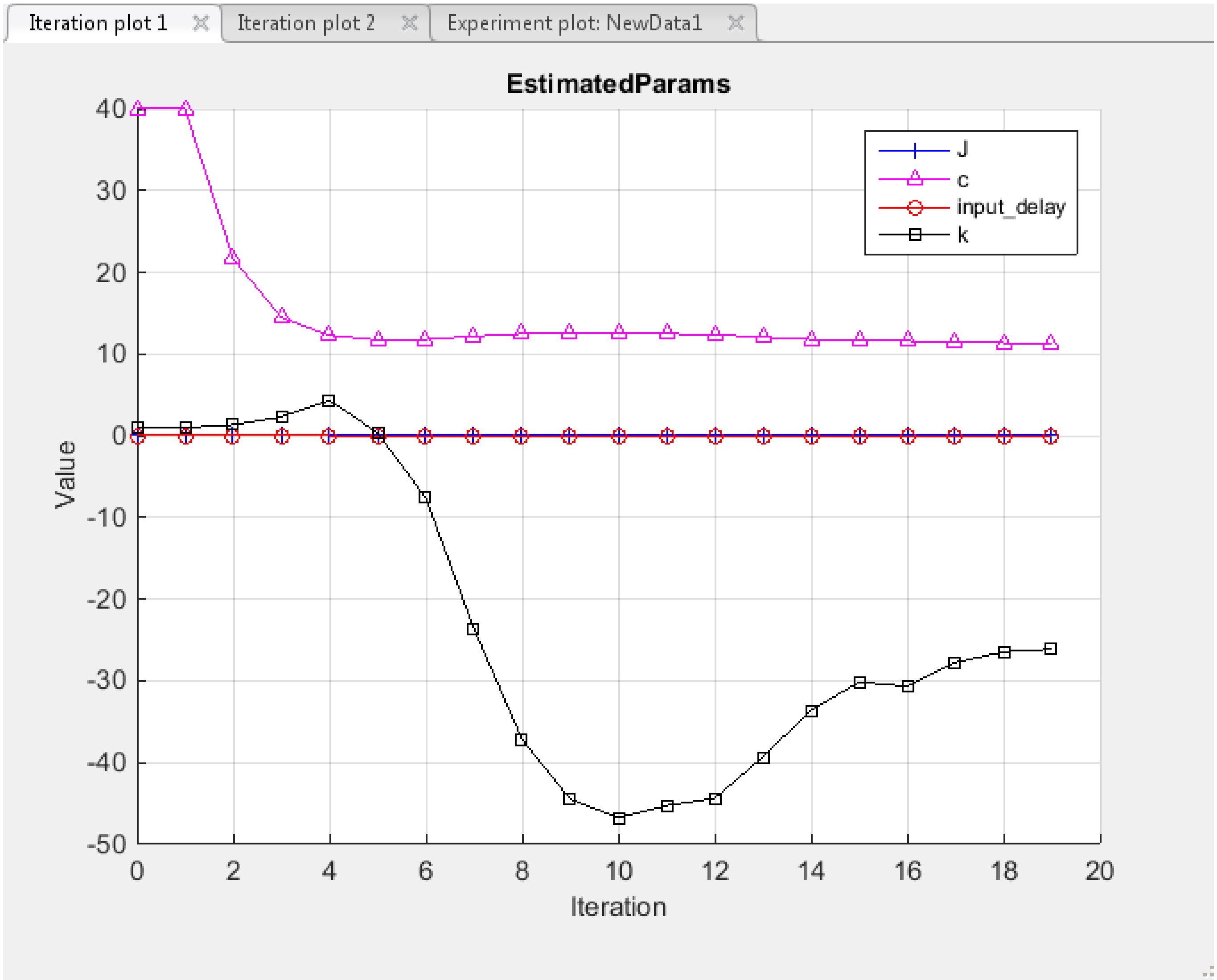
You can also first use sensitivity analysis to identify the parameters that most influence the estimation, and then specify these parameters for estimation. To open the Sensitivity Analysis tool, in the **Parameter Estimation** tab, click **Sensitivity Analysis**. In the Sensitivity Analysis tool, you can identify the model parameters that most influence the estimation problem and compute initial values for the estimation parameters.

3. Specify an experiment for estimation. On the **Parameter Estimation** tab, click **Select Experiments**, and select the box under the **Estimation** column. Click **OK**.

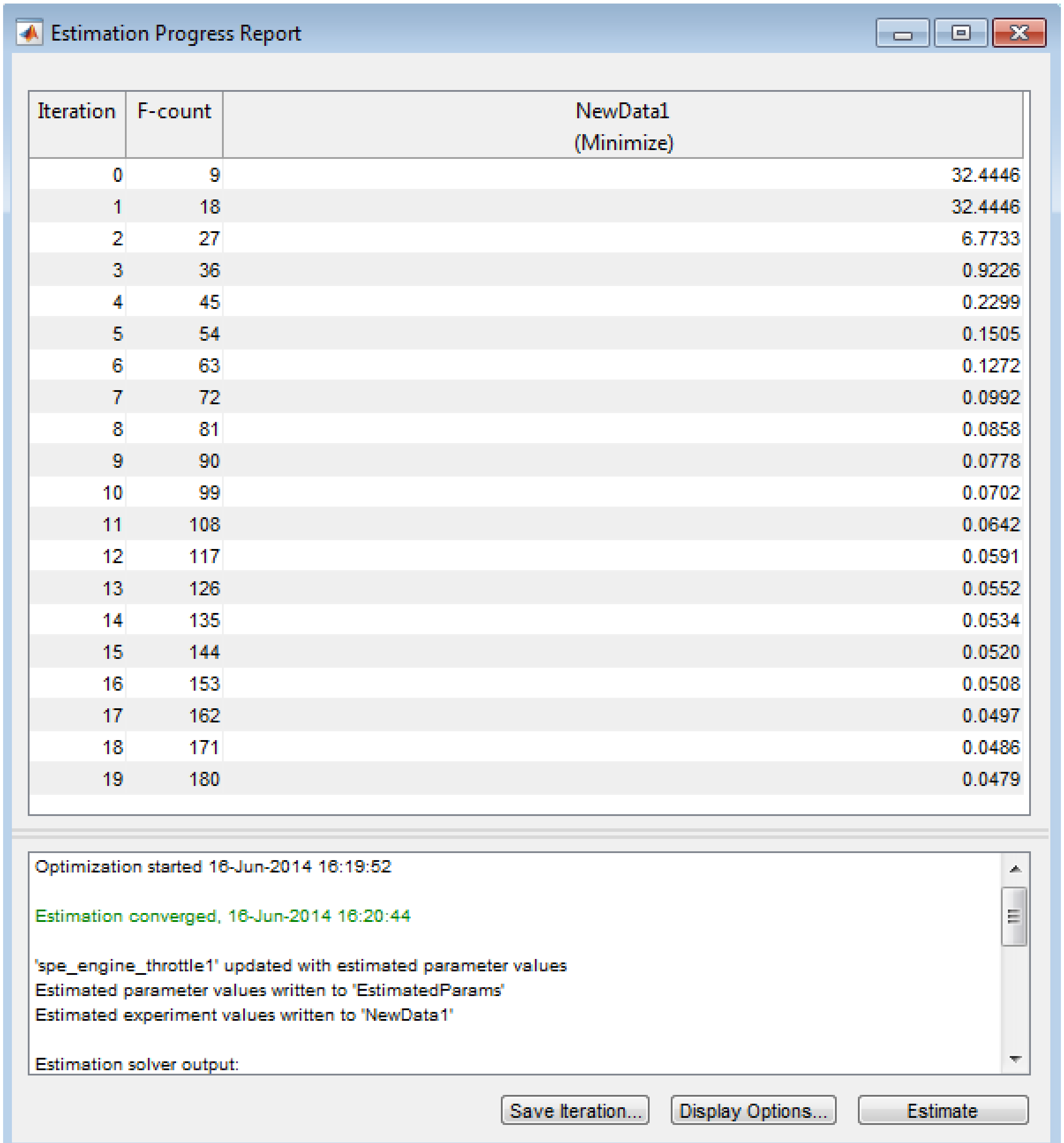


4. To add progress plots, click **Add Plot** on the **Parameter Estimation** tab. Here you can choose the **Parameter Trajectory** and **Estimation Cost** iteration plots. You can also choose an experiment plot of measured and simulated data for `NewData1`.

5. Estimate the parameters using the default settings. On the **Parameter Estimation** tab, click **Estimate** to open the **Parameter Trajectory** plot and **Estimation Progress Report** window and estimate the parameters. The **Parameter Trajectory** plot shows the change in the parameter values at each iteration.



The **Estimation Progress Report** shows the iteration number, number of times the objective function is evaluated, and the value of the cost function at the end of each iteration. After the estimation converges, the **Estimation Progress Report** looks like this figure.


Estimation Progress Report

Iteration	F-count	NewData1 (Minimize)
0	9	32.4446
1	18	32.4446
2	27	6.7733
3	36	0.9226
4	45	0.2299
5	54	0.1505
6	63	0.1272
7	72	0.0992
8	81	0.0858
9	90	0.0778
10	99	0.0702
11	108	0.0642
12	117	0.0591
13	126	0.0552
14	135	0.0534
15	144	0.0520
16	153	0.0508
17	162	0.0497
18	171	0.0486
19	180	0.0479

Optimization started 16-Jun-2014 16:19:52

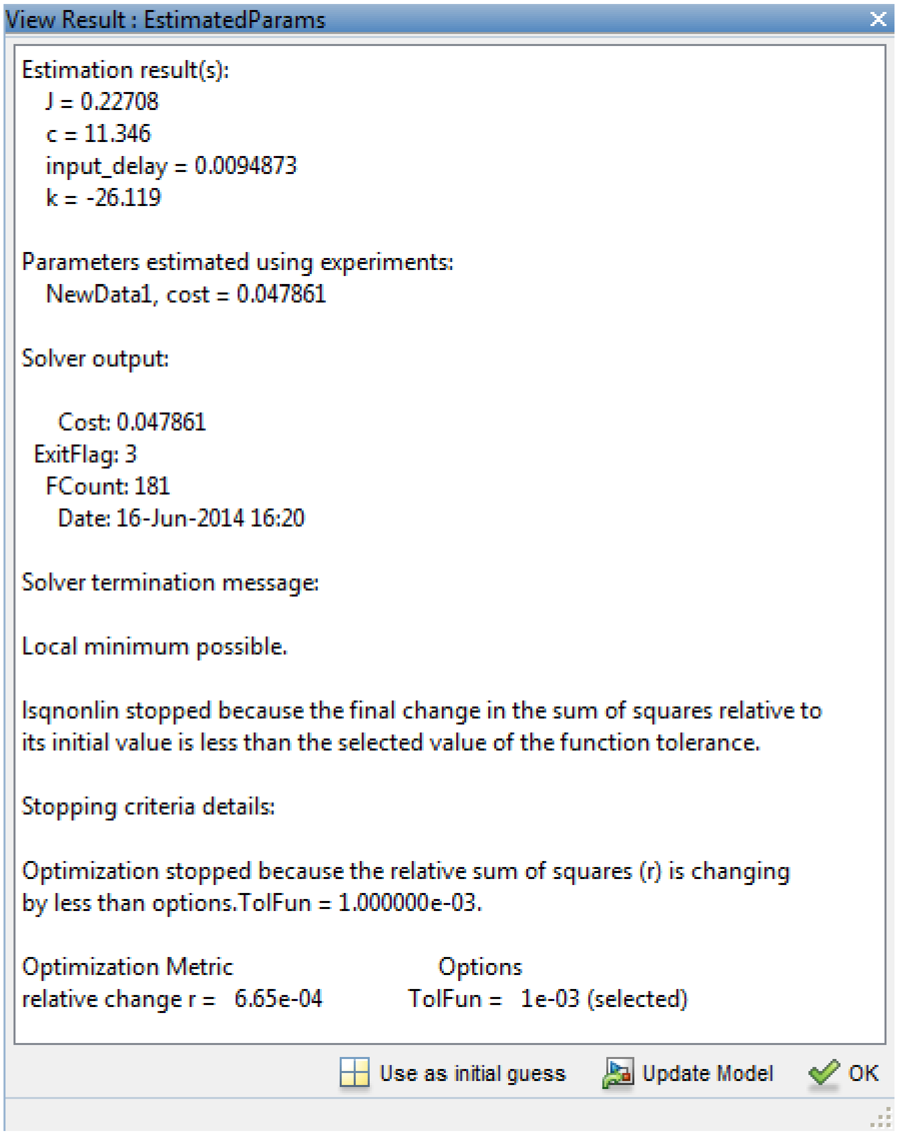
Estimation converged, 16-Jun-2014 16:20:44

'spe_engine_throttle1' updated with estimated parameter values
Estimated parameter values written to 'EstimatedParams'
Estimated experiment values written to 'NewData1'

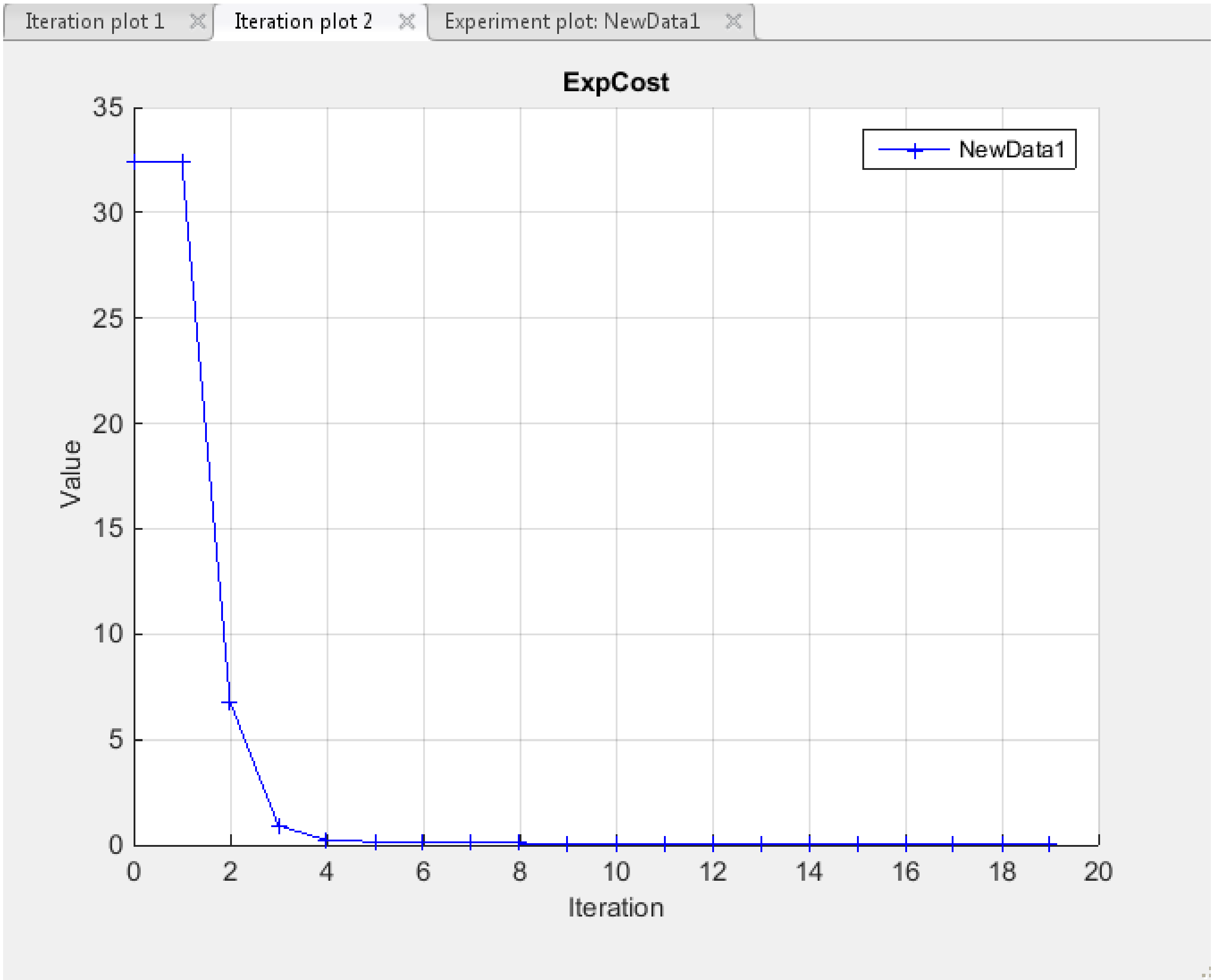
Estimation solver output:

Save Iteration... Display Options... Estimate

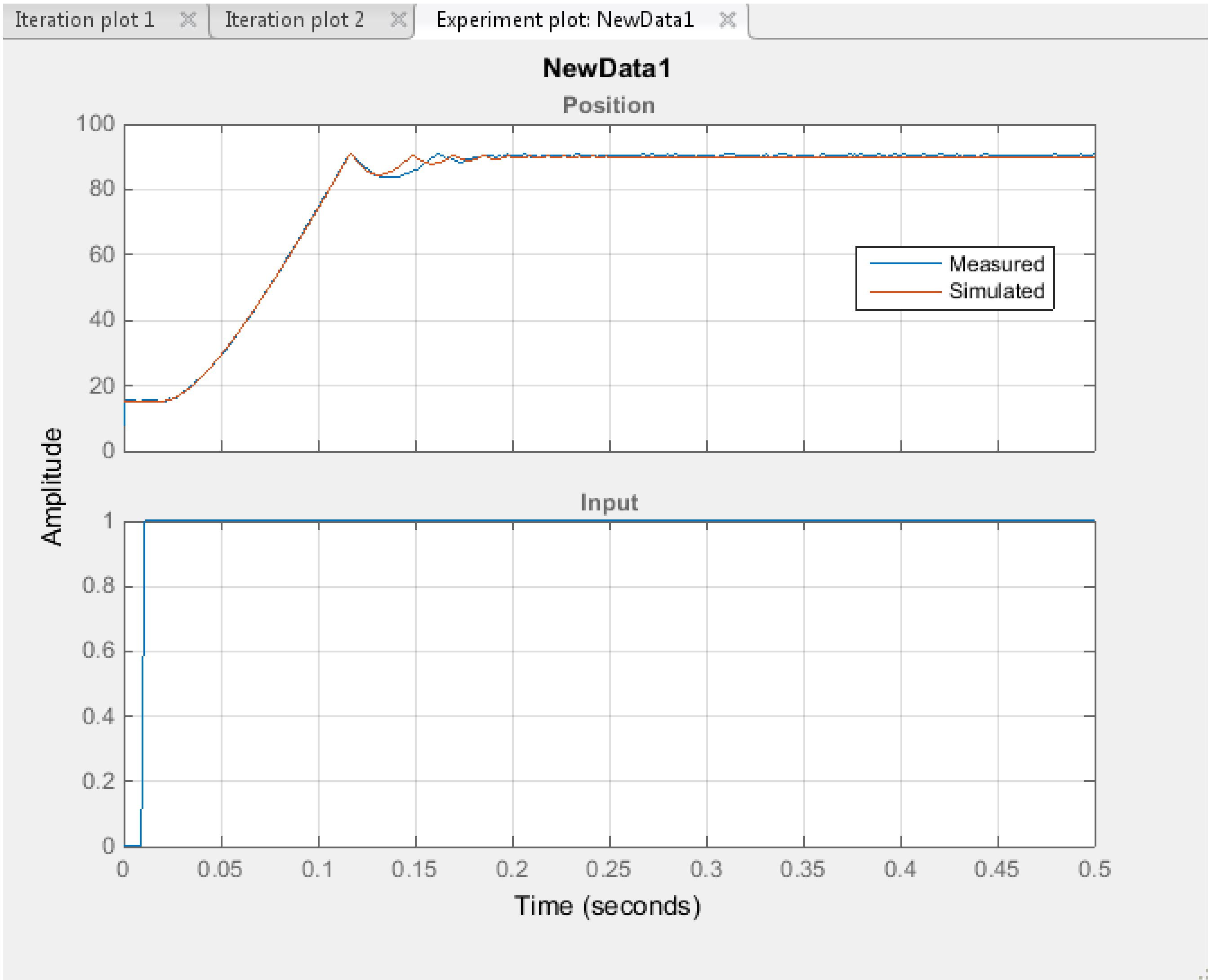
The estimated parameters are saved in the Parameter Estimation tool, in the **Results** section of the **Data Browser** pane, as `EstimatedParams`. Right-click `EstimatedParams`, and select **Open...** to view the results.



6. Examine the estimated cost function graph. Cost function is the error between the simulated and measured output. During estimation, the default optimization method `Nonlinear least squares`, `lsqnonlin`, minimizes the cost function by changing the parameter values. The following figure displays the change in the expected cost during iterations.



7. Examine the simulated response plot to see how well the simulated output matches the measured output. The experiment plot shows that the output simulated using the estimated parameters is close to the measured outputs.



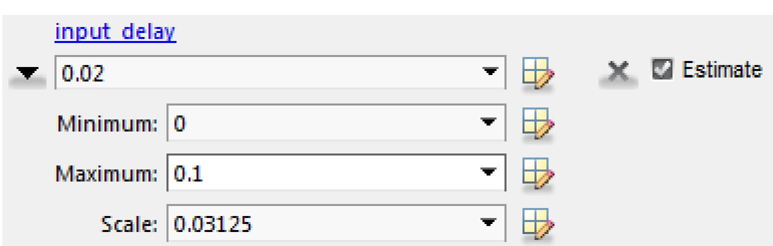
Improve Estimation Results Using Parameter Bounds

You can improve the accuracy of estimation by specifying bounds on parameter values. This technique restricts the region in which the optimization method searches for a local minima.

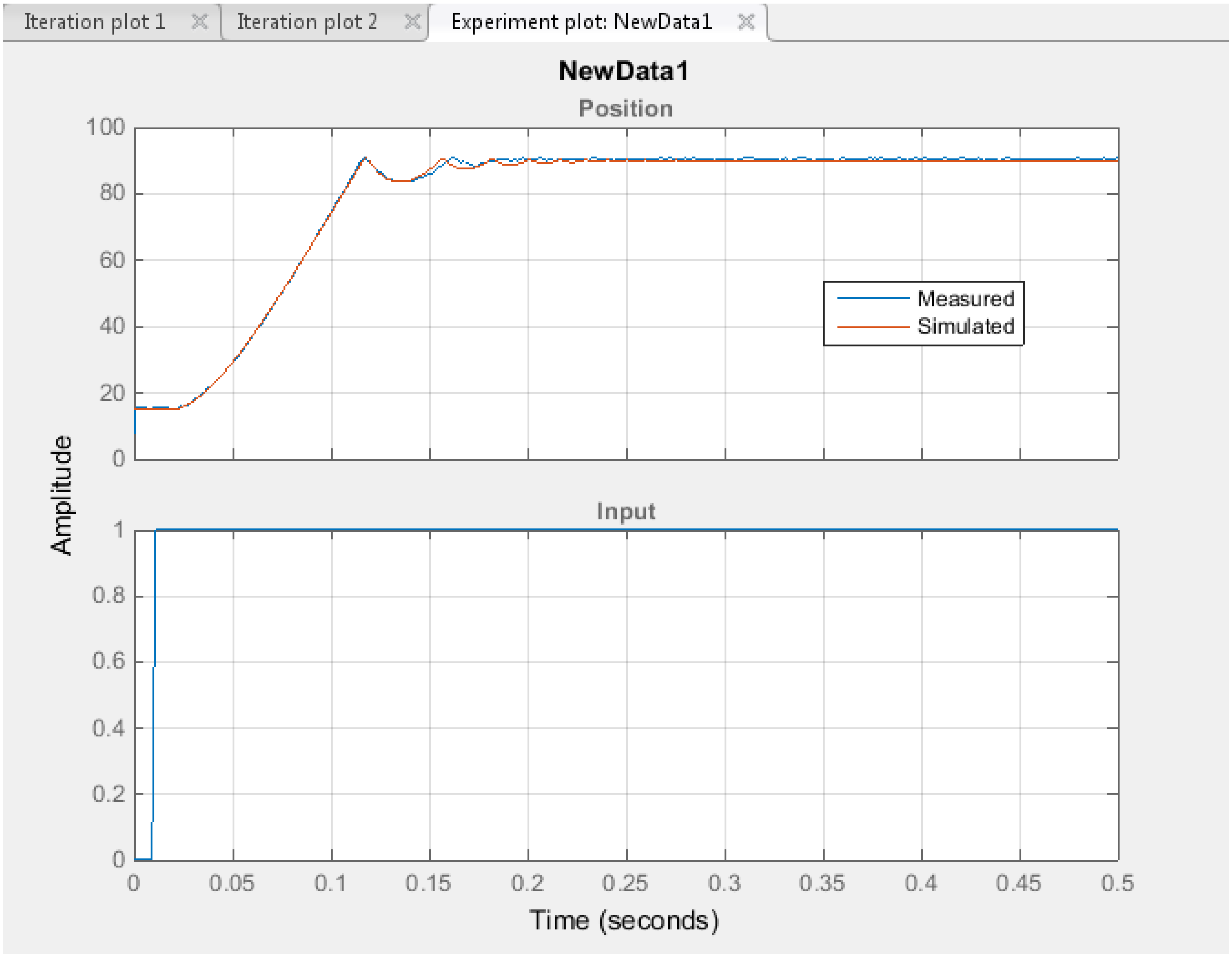
The engine throttle system has these characteristics:

- All parameter values are positive.
- Maximum time delay of the system, represented by `input_delay`, is 0.1 s.

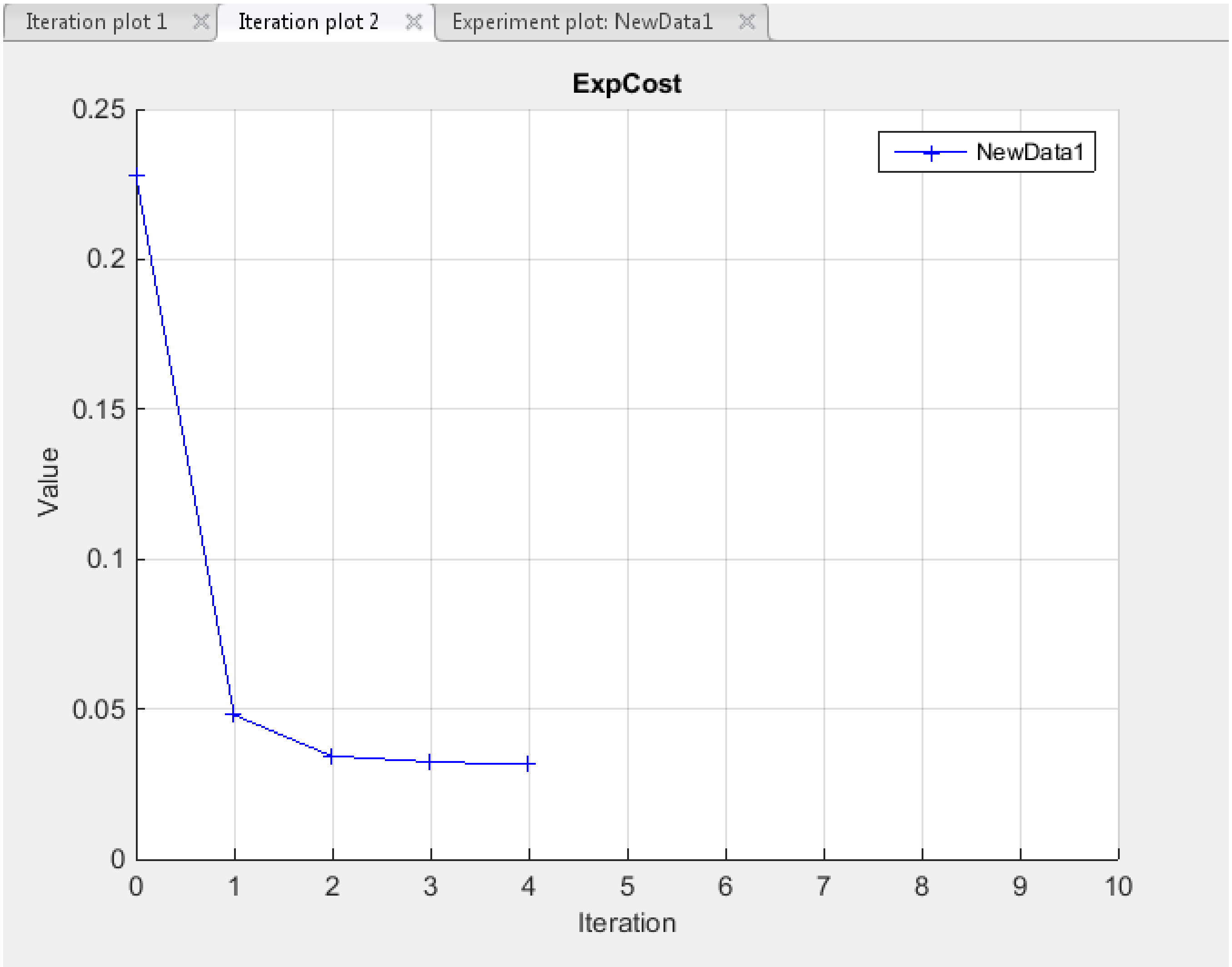
Therefore, specify 0 as the minimum value for all parameters, and 0.1 as the maximum value of `input_delay`. In the Parameter Estimation tool, click the **Select Parameters** button to specify bounds on the parameter values. For each parameter, click the right arrow toggle to display the minimum, maximum, and scale fields. Specify the minimum value for each parameter by replacing `-Inf` with `0` in the **Minimum** field. Specify the maximum value for `input_delay` by replacing `+Inf` with `0.1` in the corresponding **Maximum** field.



After estimating the parameters, analyze the results using the experiment plot and the plot for expected cost.



The data simulated using the estimated parameter values agree better with the measured data than when the parameter limits were not specified.

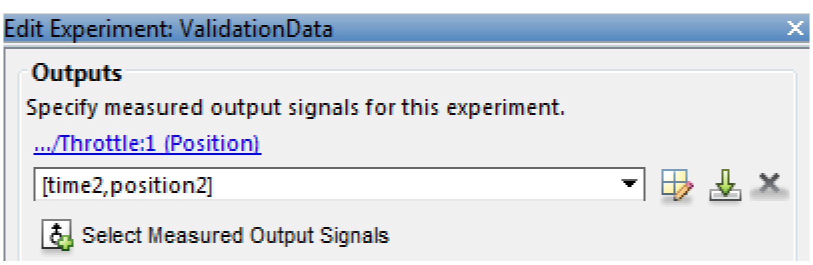


Validate Estimated Model Parameters

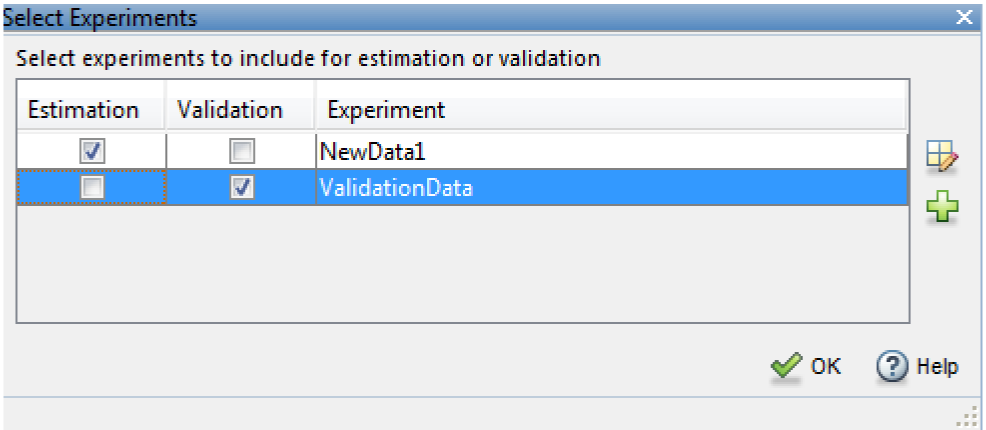
After estimating model parameters, validate the model using another data set *(validation data)*. A good match between the simulated response and the validation data indicates that you have not overfitted the model.

To validate the estimated parameters using a validation data set:

1. Create a new experiment to use for validation. Name it `ValidationData`. Import the validation I/O data, `input2` and `position2`, and the time vector, `time2` in the `ValidationData` experiment. To do this, in the Parameter Estimation tool, in the Experiments pane, right-click `ValidationData` and select **Edit...** to open the experiment editor. Then, type `[time2,position2]` in the output dialog box and `[time2,input2]` in the input dialog box. For more information, see Import Data for Parameter Estimation.

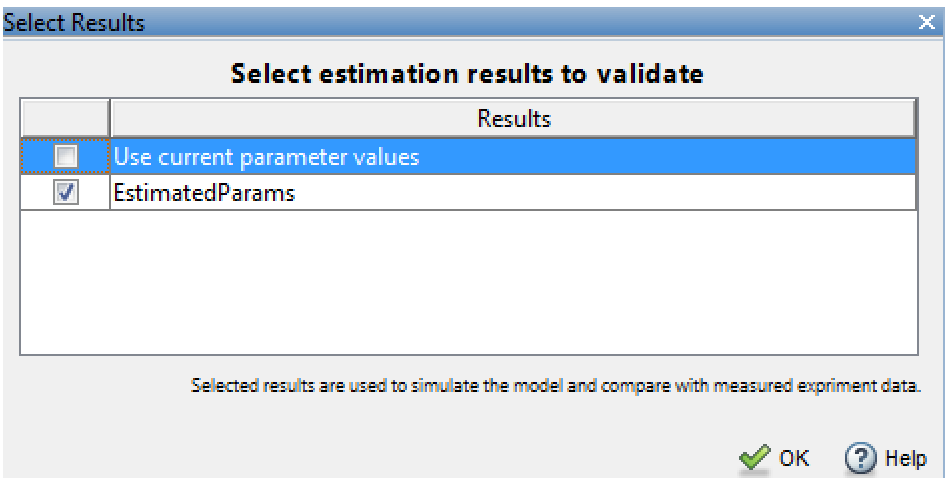


2. Select the experiment for validation. On the **Parameter Estimation** tab, click **Select Experiments**. By default, the `ValidationData` experiment is selected for estimation. Deselect the check box that corresponds to `ValidationData`for estimation and select the check box for validation.

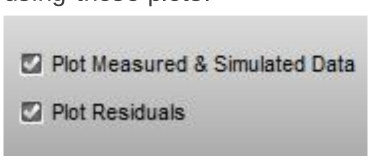


3. Select results to use. On the **Validation** tab, click **Select Results to Validate**.

Deselect `Use current parameter values` and select `EstimatedParams`, and click **OK**.



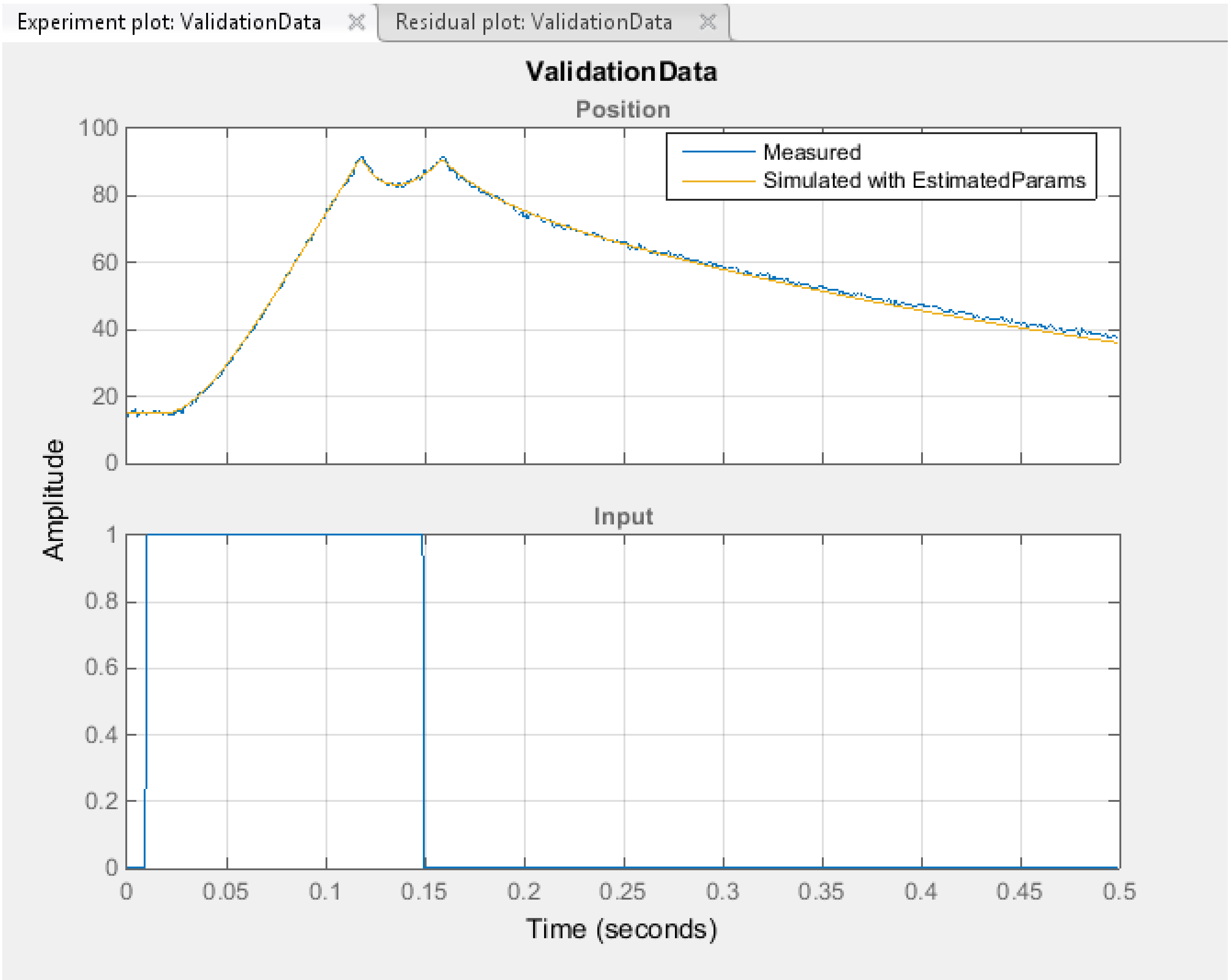
4. Select the plots for measured and simulated data, and residuals on the **Validation** tab. You can assess how much the data simulated using the estimated parameters agrees with the measured data using these plots.



On the **Validation** tab, click **Validate** to start validation.

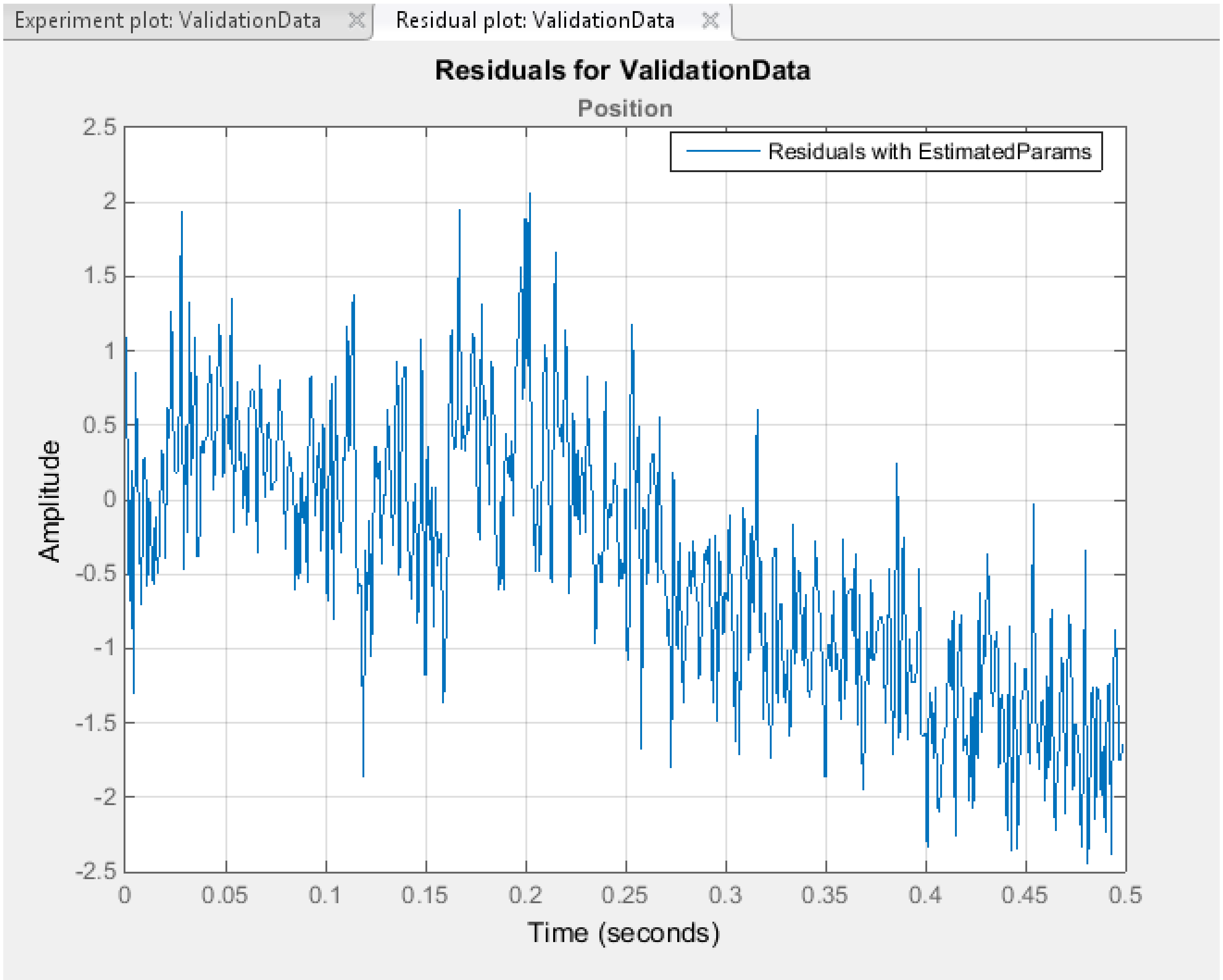
5. Examine the plots.

   a. Examine the experiment plot to see how well the simulated output matches the output data.



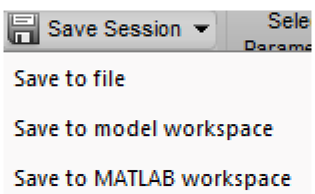
The simulated response as shown in light brown on the top experiment plot is overlaid on the measured out put data, and closely matches the measured validation data.

b. Examine the residuals plot to compare the difference between the simulated response and measured data.



The difference between the simulated and measured data varies between 2 and -2.5. The residuals lie within 6% of the maximum output variation and do not display any systematic patterns. This indicates a good fit between the simulated output and measured data.

6. Save the session. On the **Parameter Estimation** tab, click **Save Session**.



From the drop-down list select where to save the session. Specify the file name, and click **Save** or **OK** to save your parameter estimation session as a MAT-file.