# Running a VS Math Model in Simulink

This memo is a tutorial that demonstrates how you can combine a Simulink model with a VS Math Model from BikeSim, CarSim, or TruckSim, and run the full system from within Simulink.

A simple antilock brake system (ABS) example is used in various forms in BikeSim, CarSim, and TruckSim. This memo is not intended for specialists in ABS or brake system modeling, and does not go into detail about the brake system aspects of the Simulink model. Rather, the point is to show how to set up a VS vehicle model to work in the Simulink environment.

In order to follow the tutorial, you must have both Simulink (from The MathWorks) and your VehicleSim product installed. The document assumes you are familiar with Simulink, and that you have a basic understanding of how to use your VehicleSim product as achieved by going through the Quick Start Guide.

## Find the Existing Simulink ABS Example

The tutorial is based on an example Simulink ABS model that is used for several examples in the databases provided with each product. The installed **Run Control** library has a category that includes Simulink runs (it is named **Simulink and LabVIEW Models** in CarSim and TruckSim, and **Simulink Models** in BikeSim). Within that category, there are some ABS examples. In CarSim and TruckSim, there is an example named **Ext. ABS: Split Mu** (Figure 1). For BikeSim, look for the example **ABS: Braking in Turn – Low Mu** (Figure 2).

Notice that each ABS example has an overlay of another simulation without ABS ①.

Begin by clicking the **Video** button to view the existing simulation results. You should see an overlay of two vehicles braking. For CarSim and TruckSim, you should see a split-mu surface, where one side looks like ice and the other like pavement (Figure 3). For BikeSim, you should see a wet tile surface on a closed track. In any of the cases (CarSim, TruckSim, or BikeSim), there are two vehicles, and it should be clear which has ABS and which does not.
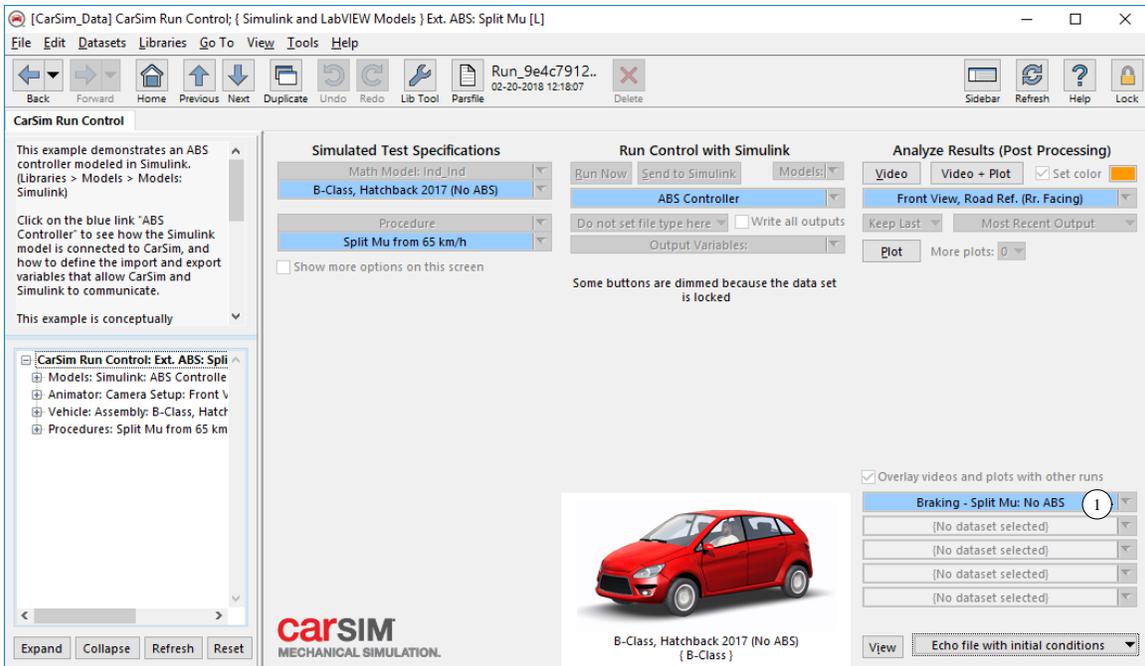
*Figure 1. Run Control screen for ABS test on a split-mu surface.*
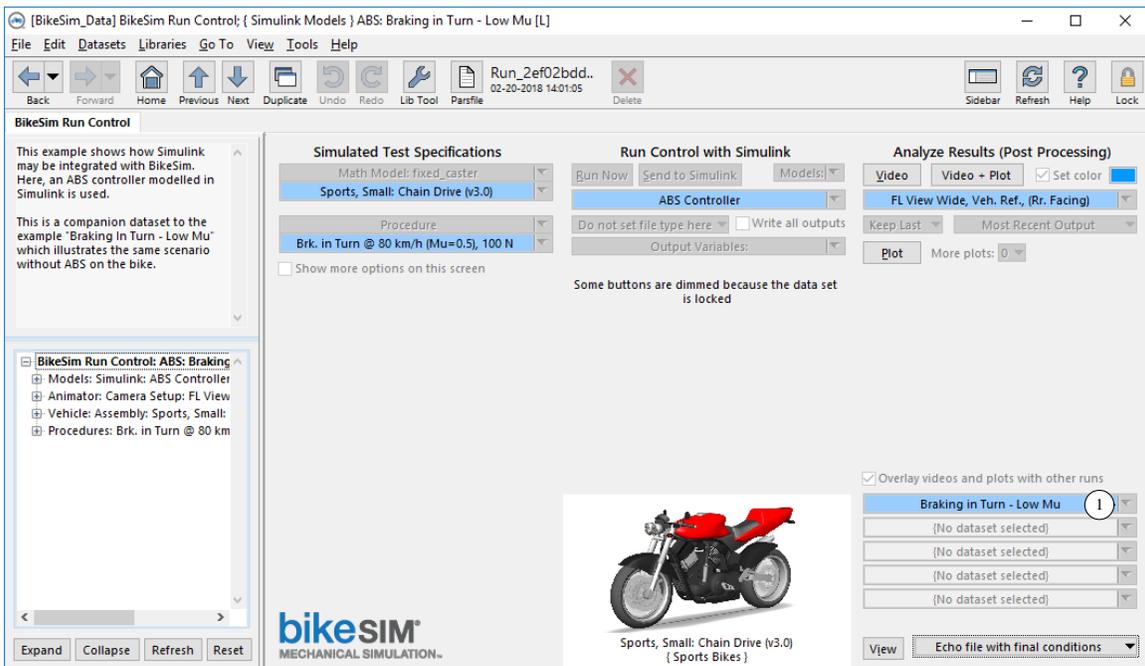


*Figure 2. Run Control screen for BikeSim ABS test in a turn.*

Close VS Visualizer when you are through viewing the example.

In the following sections, you will create a copy of the Simulink controller and go through the steps of connecting it to a VS Vehicle model. The figures will usually show the steps for CarSim and TruckSim. When needed, information will be given that is specific for the BikeSim example.
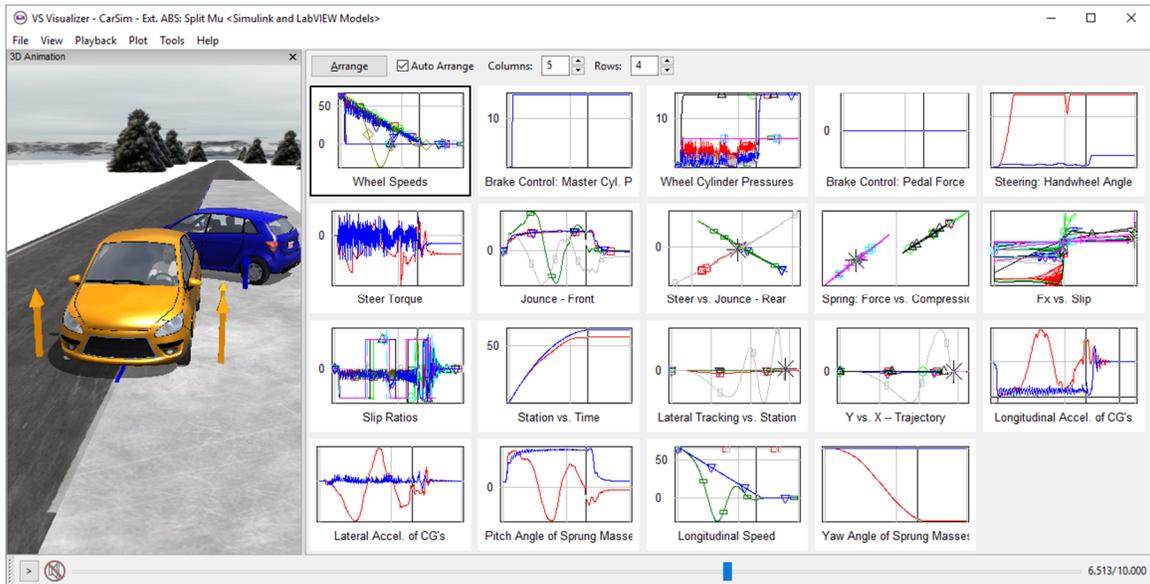
*Figure 3. Existing simulation results (CarSim).*

# Create a Copy for the Tutorial

Start by making a copy of an existing **Run Control** dataset that uses a vehicle with a brake system that does not include ABS.

1. Viewing the dataset for the Simulink ABS example (Figure 1 or Figure 2), click on the blue link for the **Run Control** dataset used for the overlay ① to view that dataset. In CarSim and TruckSim, this is a dataset with the title **Braking – Split Mu: No ABS**; in BikeSim it is named **Braking in Turn – Low Mu**.

2. Create a copy of the example dataset by clicking the **Duplicate** button ① (Figure 4). You can accept the default of appending #1 to the original name ②.

3. Uncheck the box **Overlay videos and plots** ⑤ to disable any overlays.

4. Click the **Run Math Model** button ③. In a second or so, the simulation will complete and the Video and Plot buttons will become active.

5. Click the **Video** button ④ to view the simulation results. You should see unstable vehicle behavior without ABS. Close VS Visualizer when you are through.

## Copy the Simulink Model

You will copy the existing Simulink model with the ABS controller and brake hydraulics, and use that copy to build a new connection from the vehicle model. Start by locating the model file.

1. Select the last item on the **Help** menu: **About CarSim** (or **TruckSim** or **BikeSim**). This shows a small window that gives the product name, version, date, and a link to the Windows Working Directory ① (Figure 5). The working directory is also the current database for your VehicleSim product. It is underlined, indicating that it is a hyperlink to the folder on your machine.
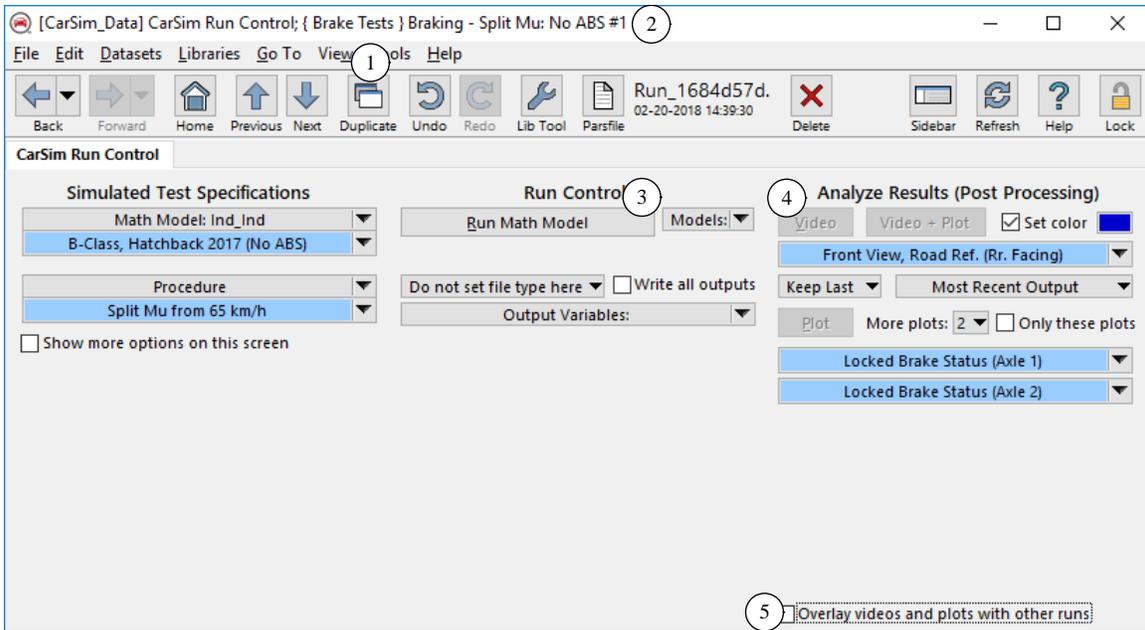
*Figure 4. Duplicate of Run Control dataset for brake test without ABS.*
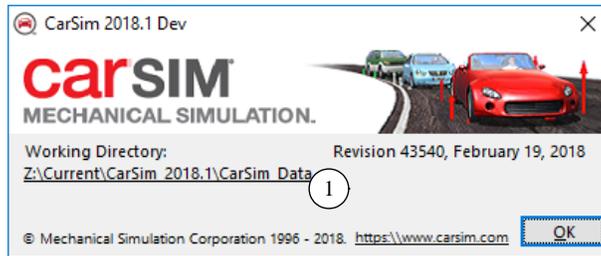


*Figure 5.Use the "About" window to locate the current working directory.*

2. Click on the pathname ①. This will bring up a view of the database folder in Windows (Figure 6).
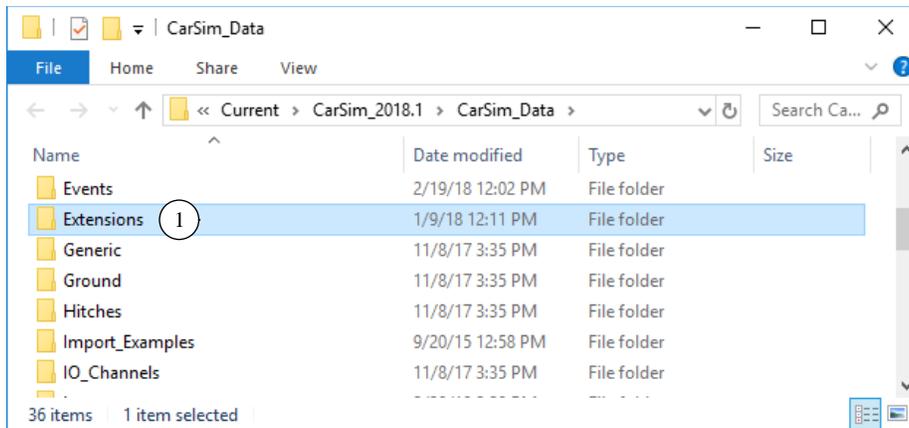


*Figure 6. Windows view of VS database folder contents, including the folder named Extensions.*

3. Notice that one of the folders is named `Extensions` ①. Double-click on that folder name to view the contents (Figure 7).
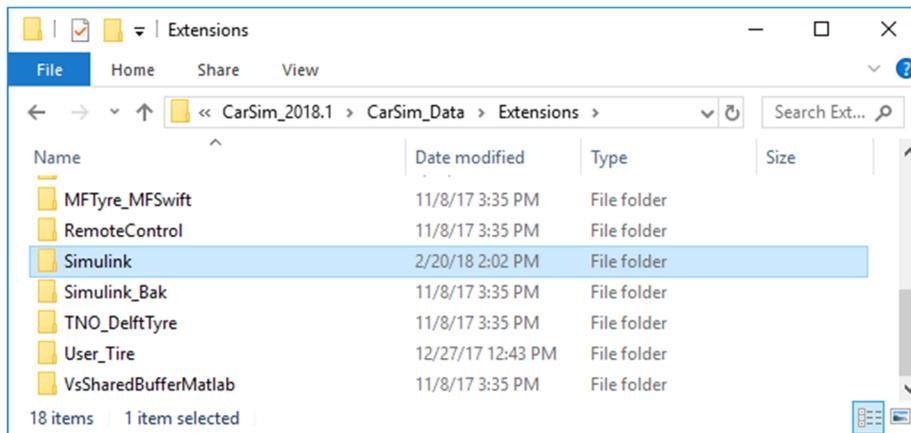


*Figure 7. Windows view Extensions folder contents, including the folder named Simulink.*

4. One of the folders in `Extensions` is named `Simulink`. Double click to open the `Simulink` folder (Figure 8). The `Simulink` folder contains many Simulink files, along with some folders with supporting MATLAB files.
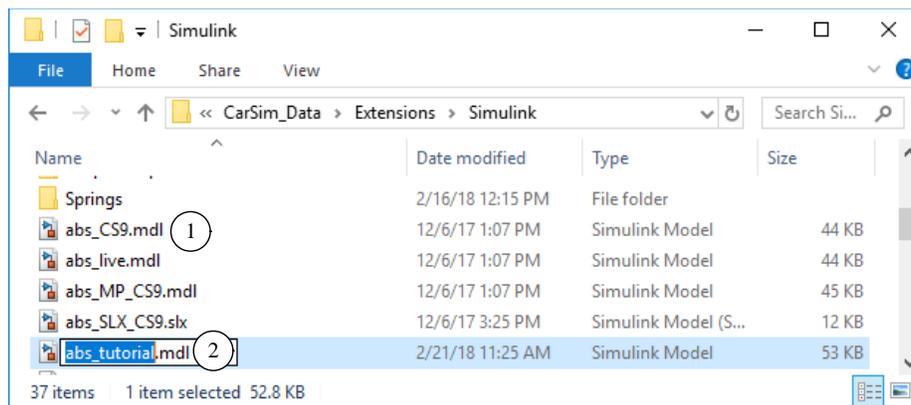


*Figure 8. Duplicate the ABS model file and give the copy a new name.*

5. Locate the ABS model file and duplicate it. For CarSim, the file is named `abs_CS9.mdl` ①; for TruckSim the file is named `ABS_TS9.mdl`; for BikeSim the file is named `abs_v90.mdl`. Change the name of the duplicate to `abs_tutorial.mdl` ②.

6. Go back to CarSim/TruckSim/BikeSim. Use Alt-Tab or click on a part of the window if visible. The **About** window (Figure 5) is probably still visible. If so, close it.

## Link to the New Simulink Model

You should now be viewing the duplicate **Run Control** dataset for the vehicle running without an ABS controller (Figure 9).
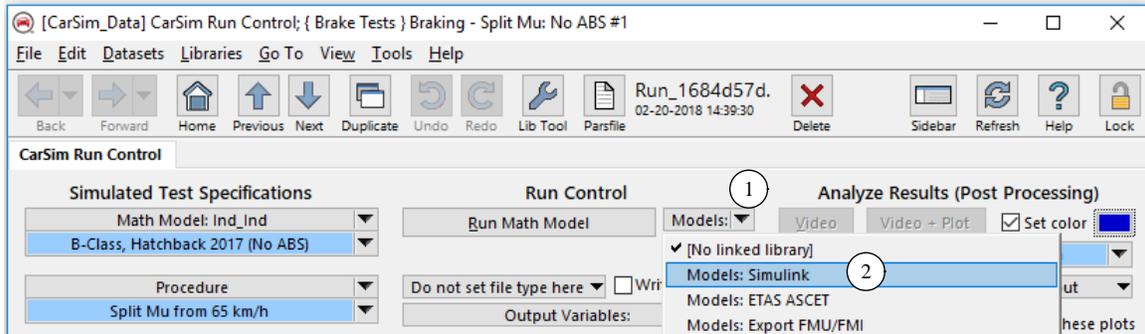
*Figure 9. Link to the Models: Simulink library.*

1.  Use the **Models** drop-down control ① to choose the **Models: Simulink** library ②. This causes a potential link to appear below the **Models** control ③ (Figure 10).
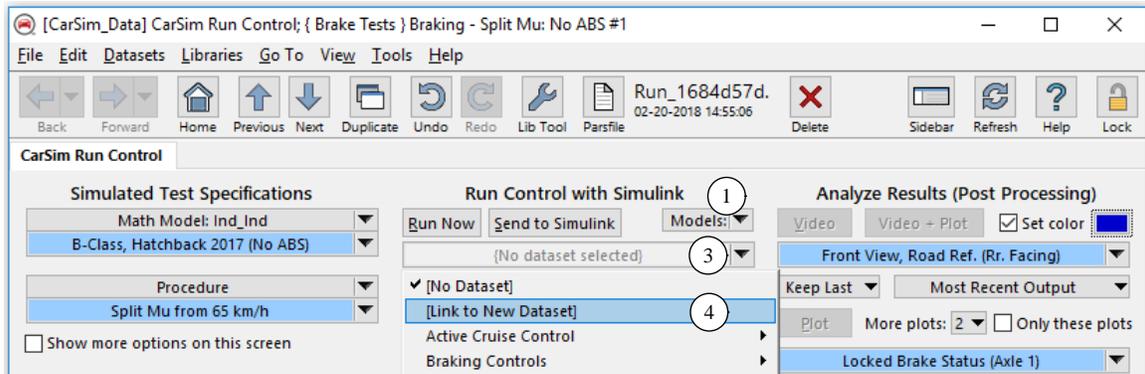


*Figure 10. Choose the option: [Link to New Dataset].*

| Note | Occasionally, the potential link does not appear on the first attempt. If this happens, please repeat the selection of **Models: Simulink** from the drop-down control. |
| --- | --- |

2.  Use the drop-down control for the new link ③ and select the option [**Link to New Dataset**] ④. You will be prompted to provide a name of the new dataset (Figure 11). Type a name such as `ABS for Tutorial` ① and then click the **Create** button ②.
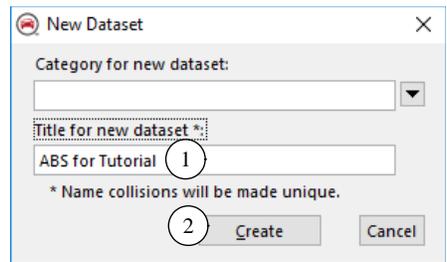


*Figure 11. Specify a name for the new dataset.*

3. Notice that the screen has new controls after the link is made to the new dataset ④ (Figure 12). The title in the center part of the screen now reads **Run Control with Simulink** ①, and there are two new buttons: **Run Now** ② and **Send to Simulink** ③. Click on the link for the newly linked dataset ④ to view it (Figure 13).
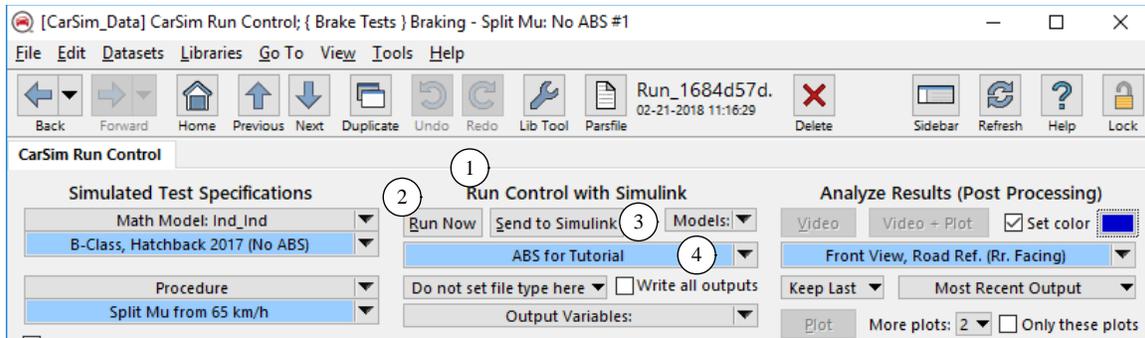


*Figure 12. Appearance of Run Control screen with link to Simulink dataset.*
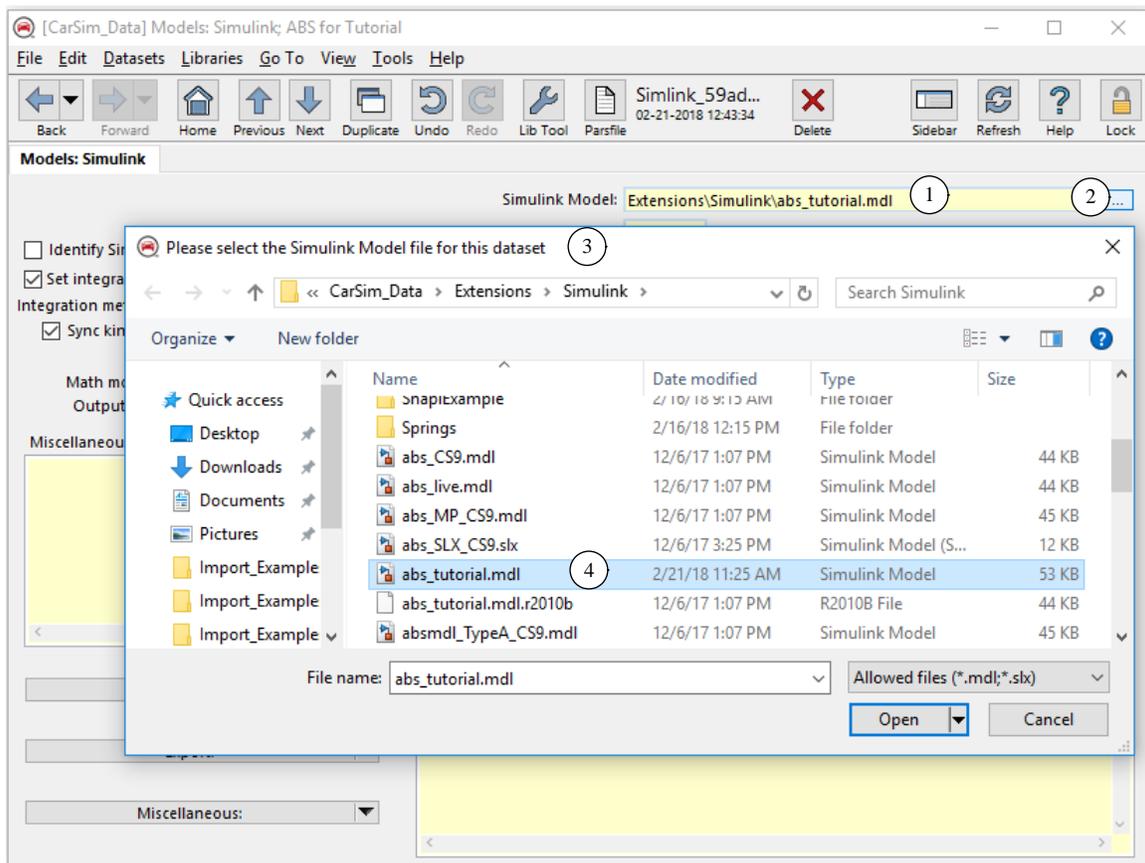


*Figure 13. Select the Simulink model using the Windows file browser.*

4. The first step in linking to a Simulink model is to specify a pathname to the file in the pathname field on the screen ①. Do this by clicking the adjacent browser button ② to bring up the Windows file browser ③. Browse to the `Extensions\Simulink` folder and select

the `abs_tutorial.mdl` file you created earlier ④, such that the relative pathname is automatically inserted in the yellow field ①.

5.  Use the **Back** button or the **Home** button to return to the **Run Control** screen (Figure 12).

6.  Click the **Send to Simulink** button ③ from the **Run Control** screen (Figure 12). The VS Browser (CarSim/TruckSim/BikeSim) will launch Simulink using the file `abs_tutorial.mdl`. Figure 14 shows the CarSim example model, with an S-Function identified with the CarSim icon ①. The TruckSim and BikeSim examples are similar, but use the icons associated with those products.
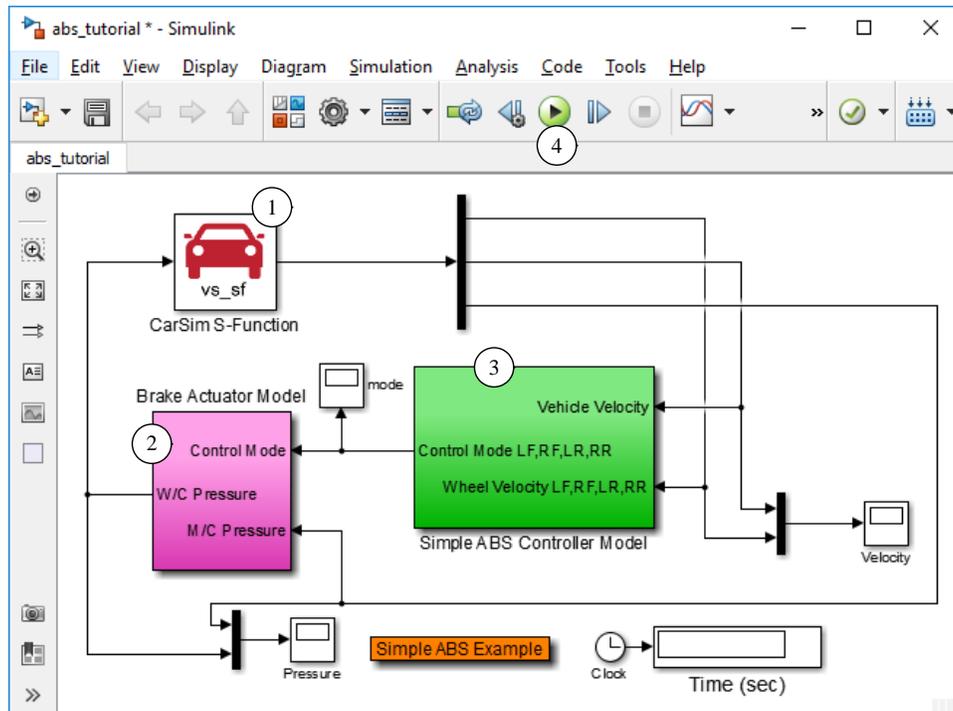


*Figure 14. ABS tutorial example before it is modified.*

7.  The model now in view is simply the copy you made earlier of the existing ABS controller. For the purpose of this tutorial, remove the S-Function from the model. Do this by selecting it and pressing the Delete key (Figure 15).

> **Note**  This Simulink has brake hydraulics (with dynamics) ② and a simple ABS Controller ③. However, there is no longer a vehicle dynamics plant to control.
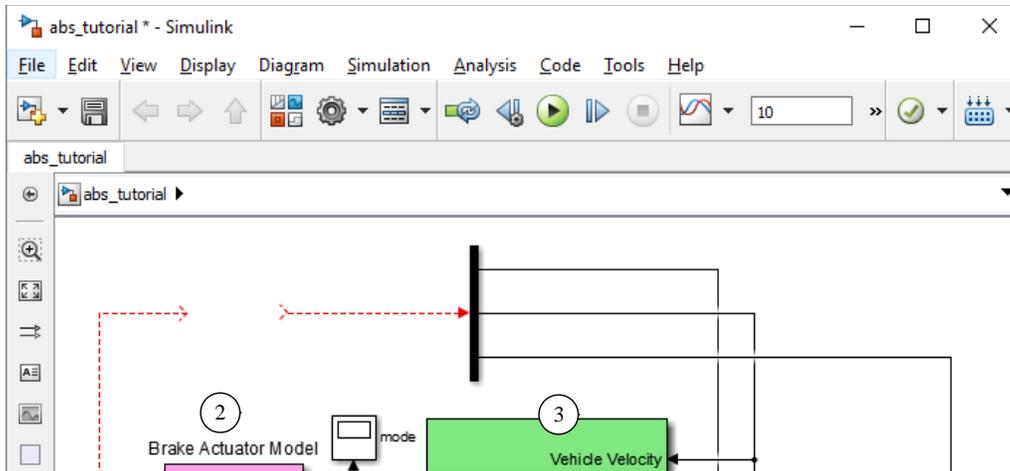
*Figure 15. Tutorial example without vehicle S-Function.*

8.  Open the Simulink Library Browser (see the Simulink **View** menu). Depending on your products, there will be a CarSim, TruckSim, or BikeSim category (Figure 16). Locate the VS S-Function category (e.g., CarSim S-Function ①) and click it to view the S-Function blocks ②, ③, and ④.
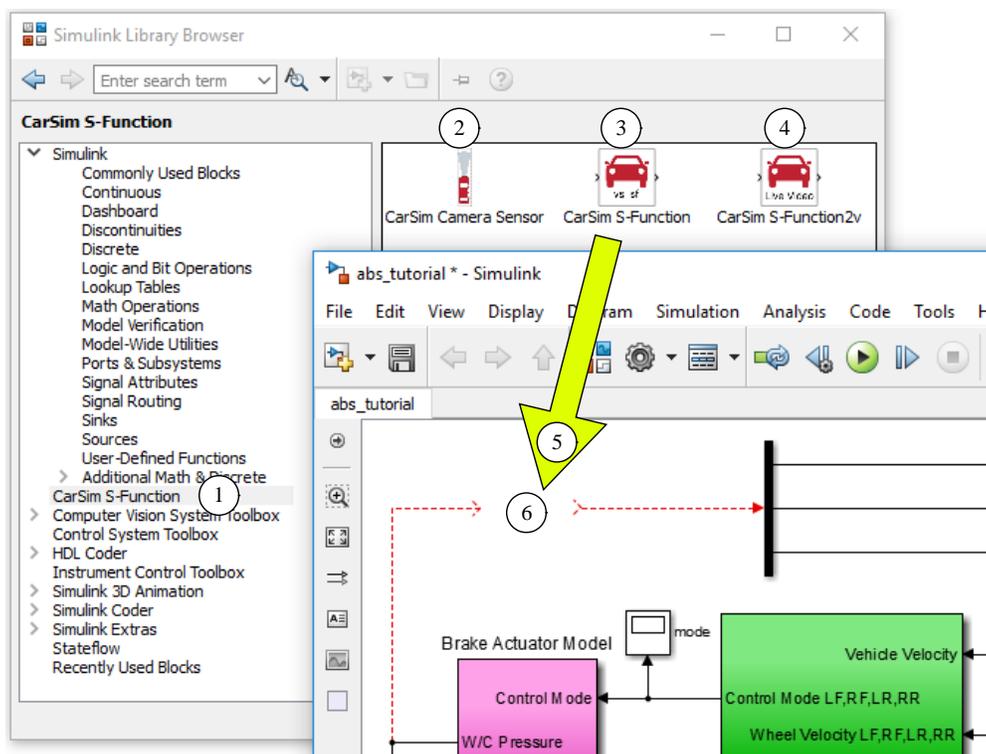


*Figure 16. Drag and drop a VS S-Function block from the Simulink Library Browser.*

CarSim, TruckSim, and BikeSim each include three library S-Functions: a general-purpose vehicle S-Function ③, an S-Function with support for a camera sensor ②, and an S-Function that supports live video ④. Other than the names and icons, the S-Functions for CarSim are

the same as those for TruckSim and BikeSim. (All use the same internal code to connect a VS Solver to Simulink.)

9. When making the Simulink model, you add the S-Function by dragging it as shown in the figure ⑤ to the intended location ⑥. You next connect input ⑦ and output signals ⑧, as you would do with any block (Figure 17).
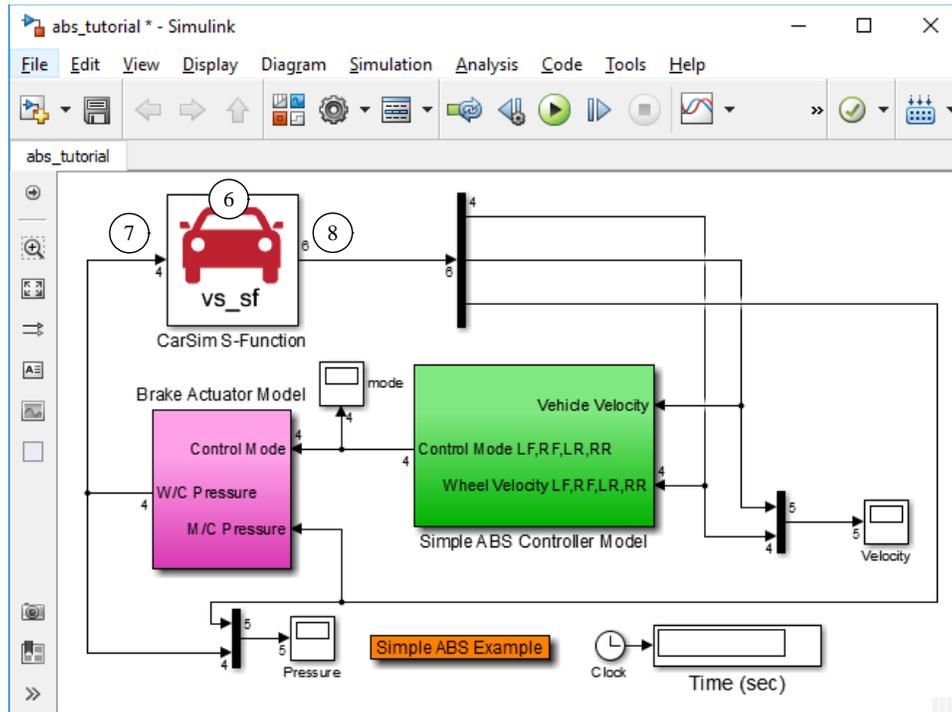


*Figure 17. Simulink model with one vehicle S-Function.*

10. Save the current version of the Simulink model using the **File** menu or type Ctrl+S.

11. Close the Simulink window (type Ctrl+W).

# Make a New Connection to Simulink

The connection between the VS Database and Simulink is made with a dataset from the **Models: Simulink** library. You just created a new dataset with the pathname for the Simulink model, and you dragged a vehicle model icon into the Simulink model workspace. Next, you will provide the rest of the information concerning the connection between the VS Solver (math model) and Simulink.

You should be viewing the **Run Control** screen linked to your new Models Simulink dataset (Figure 12, page 7). Once again, click on the blue link ④ to view the **Models: Simulink** screen (Figure 18).

This screen has various settings that specify how a vehicle model will be connected to Simulink. First is the name of the Simulink Model file ① that you set earlier.
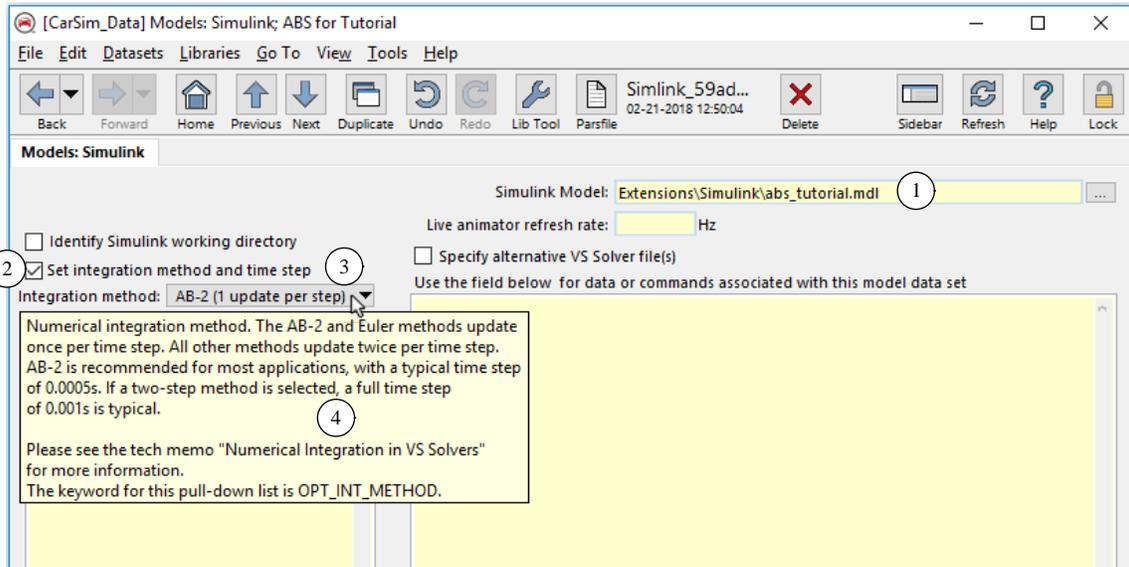
*Figure 18. Models: Simulink dataset for the ABS controller.*

In most cases, you will want to specify the integration method and time step in CarSim, in order to ensure you are coordinating with the external Simulink model. Check the box ② to show the controls to do this.

The drop-down list control provides a choice among six options for performing numerical integration ③. Right-click to see a short description of the options ④. The option used most is the AB-2 method, with a time step of 0.0005s. However, this particular example involves an ABS controller that switches the brakes on and off abruptly, leading to discontinuous hydraulic pressure. When the expected behavior is highly discontinuous, the Euler method is recommended (Figure 19).
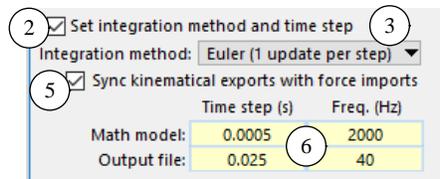


*Figure 19. Options available when the Euler method is selected.*

Besides the integration method ③, controls are shown for selecting the time step ⑥. As indicated by the right-click pop-up hint ④ (Figure 18), a typical time step when using Euler or AB-2 is 0.0005s ⑥.

Another checkbox is shown for selecting an option to synchronize exports and imports. The choice for enabling this option depends on the types of input and output variables that are exchanged with the Simulink model, as will be described after we set up the imports and outputs.

First, we will create new datasets specifying the variable used for Import and Export:

1. Use the **Import** drop-down control ⑧ to specify the library **I/O Channels: Import** ⑨ (Figure 20). A potential link will appear below the control ⑩ (Figure 21).
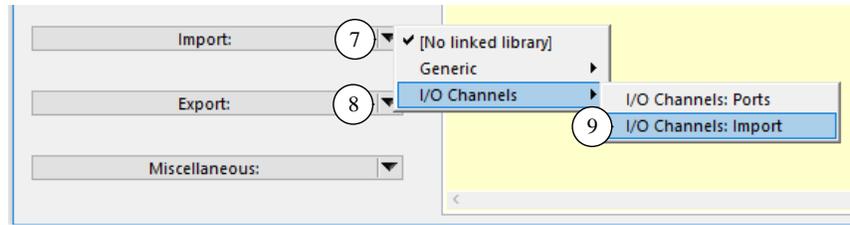
*Figure 20. Link to the I/O Channels Import library.*
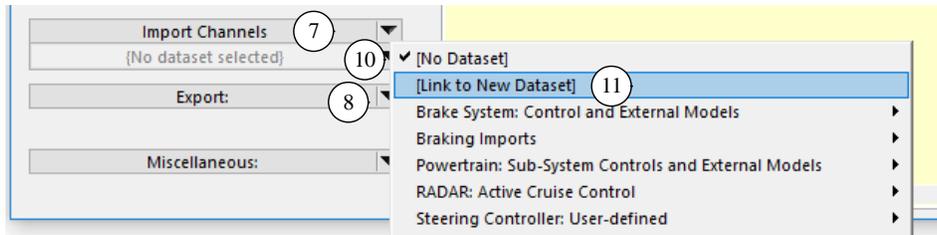


*Figure 21. Link to a new dataset for Import variables.*

2. Use the drop-down control ⑩ for the new potential link to specify the option **[Link to New Dataset]** ⑪ (Figure 21). You will be prompted to provide a name for the new dataset. Specify `ABS Imports for Tutorial`. The screen will show a link to the new dataset ⑧ (Figure 22).
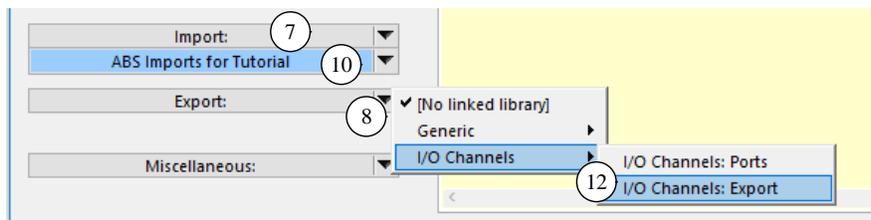


*Figure 22. Link to the I/O Channels Export library.*

3. Use the **Export** drop-down control ⑧ (Figure 22) to specify the library **I/O Channels: Export** ⑫. A potential link will appear below the control ⑬ (Figure 23).
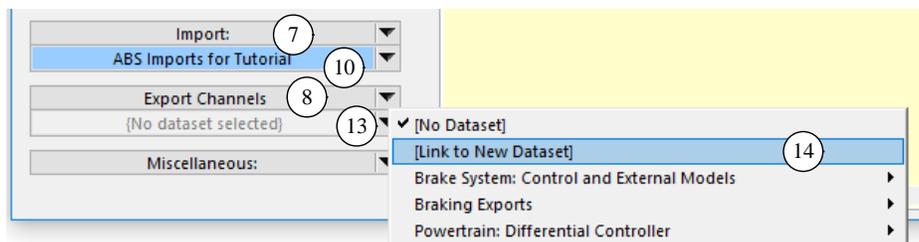


*Figure 23. Link to a new dataset for export variables.*

4. As was done for the Import link, use the drop-down control ⑬ (Figure 23) for the new potential link to specify the option **[Link to New Dataset]** ⑭. You will be prompted to provide a name for the new dataset. Specify `ABS Exports for Tutorial`. The screen will show a link to the new dataset ⑬ (Figure 24).
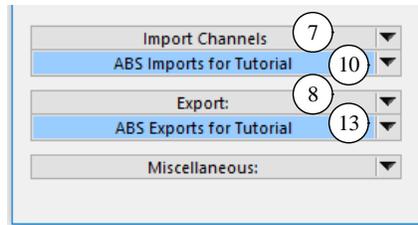
*Figure 24. Links to new Import and Export datasets from the Models: Simulink screen.*

## Import Variables

Click the Import Channels blue link ⑩ to transfer to the **I/O Channels: Import** dataset for this example. Initially, this is an empty dataset that does not name any Import variables (Figure 25).
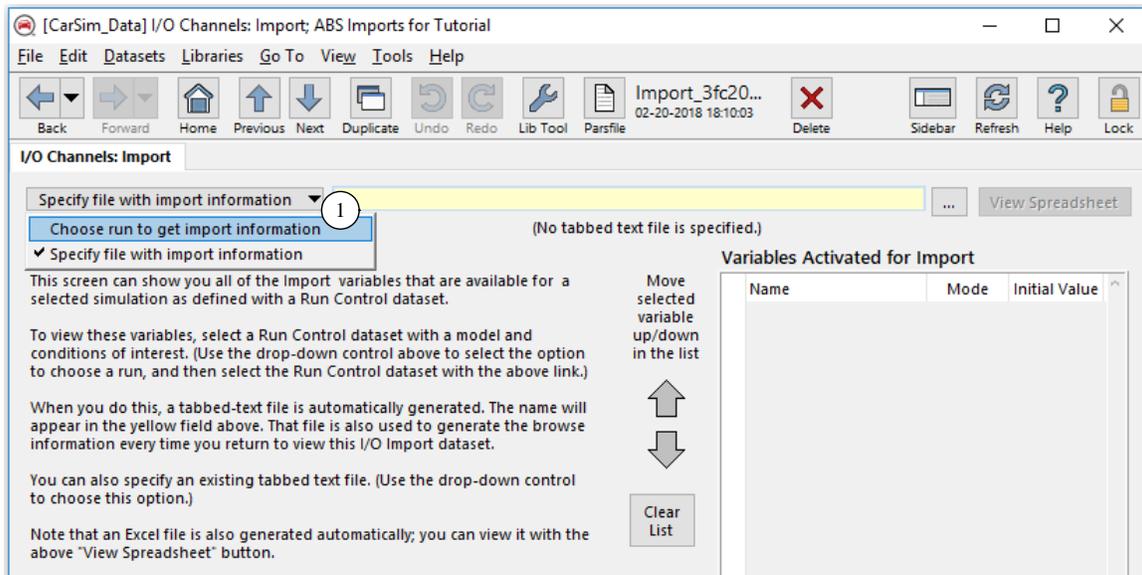


*Figure 25. Import dataset that is initially empty.*

1. Use the drop-down control to **Choose run to get import information** ①. When this option is selected, a potential link is shown for a **Run Control** dataset ② (Figure 26).
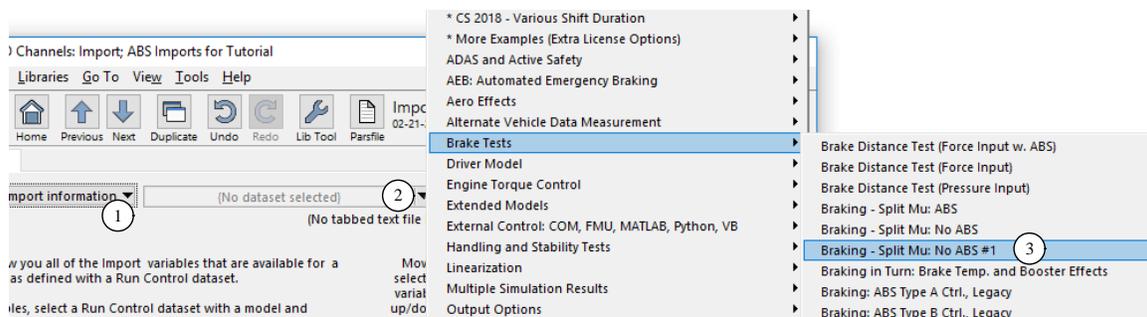


*Figure 26. Select a Run Control data with the vehicle of interest.*

2. Use the drop-down control for the potential link ② to choose a **Run Control** dataset that involves the vehicle of interest. For this example, select the braking run that was created earlier

③). When you select the **Run Control** dataset, the VS Browser will jump to the **Run Control** screen and then jump back to the Import screen. The Import screen now has information about all of the Import variables that exist in the model and can potentially be activated for use with Simulink (Figure 27).
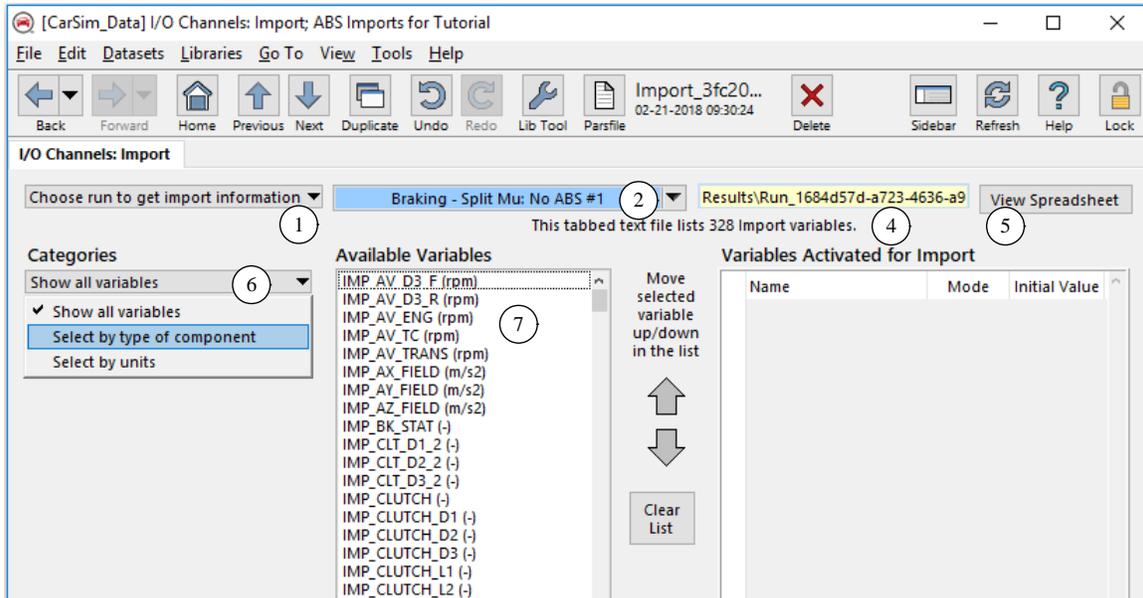


*Figure 27. Import screen appearance after a Run Control dataset was selected.*

3. When the **Run Control** dataset was specified ②, two documentation files were automatically generated that list all variables in the math model that might potentially be imported from Simulink. One of the files is a tabbed-text file. The pathname for this tabbed-text file is shown in the yellow field ④, and the number of variables is written underneath (there are 328 import variables available for this example). The other is a spreadsheet file.

4. If you have Excel or another spreadsheet program installed, click the **View Spreadsheet** button ⑤. The spreadsheet includes all available variables, their units, descriptions, and the type of component. For example, Figure 28 shows a spreadsheet with the rows sorted based on the Component type (column C), scrolled to view some variables related to Brakes.

> **Notes** Depending on the spreadsheet tool and version, you might be given a warning about the file format and extension not matching. The file has the extension `.xls` and the format is tabbed text. It's OK to open the file.
>
> You might notice that Column E has either a 0 or the name `VARIABLE`. This provides the GUI with the information need to support the drop-down control ⑪ (Figure 29) described below.

Close the spreadsheet when you are through viewing the contents.

*Figure 28. Spreadsheet with all potential import variables for an example vehicle.*

5. Use the **Categories** drop-down control on the Imports screen ⑥ (Figure 27) to choose the option **Select by type of component**. Notice that a list of component types is shown under the control ⑧ (Figure 29).



*Figure 29. Import screen showing variables for the Braking category.*

6. Select the component type **Brakes** ⑧. The list of available variables ⑦ is adjusted to show only variables related to Brakes.

7. Right-click on any of the available variables to see a longer name in a pop-up field ⑨.

8. For CarSim and TruckSim, find the Import variable in the **Available Variables** list with the name `IMP_PBK_L1` and double-click on it. The variable will appear in the list **Variables Activated for Import** ⑩. A drop-down control is shown next to the variable name with options **Replace**, **Add**, and **Multiply** ⑪.  The default option is **Replace**, which is appropriate for this example.

9. Add three more variables by double-clicking on their names in the **Available Variables** list: `IMP_PBK_L2`, `IMP_PBK_R1`, and `IMP_PBK_R2`. The list **Variables Activated for Import** ⑩ should match Figure 30.
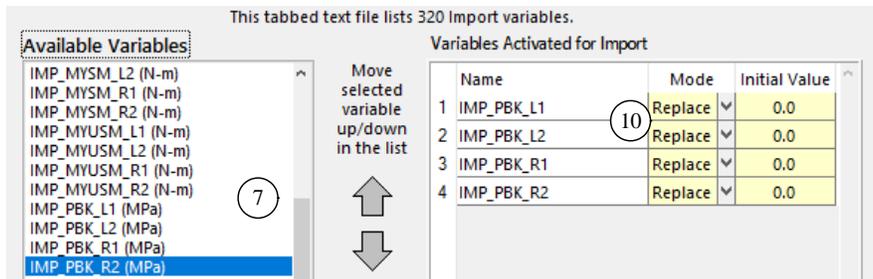


*Figure 30. Four variables activated for Import in CarSim and TruckSim examples.*

For BikeSim, activate the Import variables `IMP_PBK_1` and `IMP_PBK_2` (Figure 31).
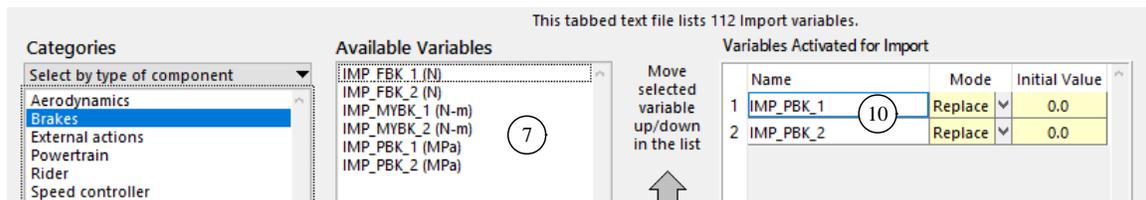


*Figure 31. Two variables activated for Import in BikeSim.*

## Export Variables

A similar screen is used to define the set of variables that are exported from the VS solver to Simulink. Navigate to the **I/O Channels: Export** screen by first clicking the **Back** button to return to the **Models: Simulink** screen (Figure 24, page 13) and then clicking on the blue link for the **Export Channels** ⑬.

You should now be viewing the **I/O Channels: Export** screen (Figure 32, shown for CarSim during step 6 below). Initially, there will be no variables shown (similar to the Import screen as shown in Figure 25, page 13). You will go through similar steps to obtain information about all available output variables, and select those that should be activated for export to Simulink.

1. Use the drop-down control to **Choose run to get export information** ①. When this option is selected, a potential link is shown for a **Run Control** dataset ②.
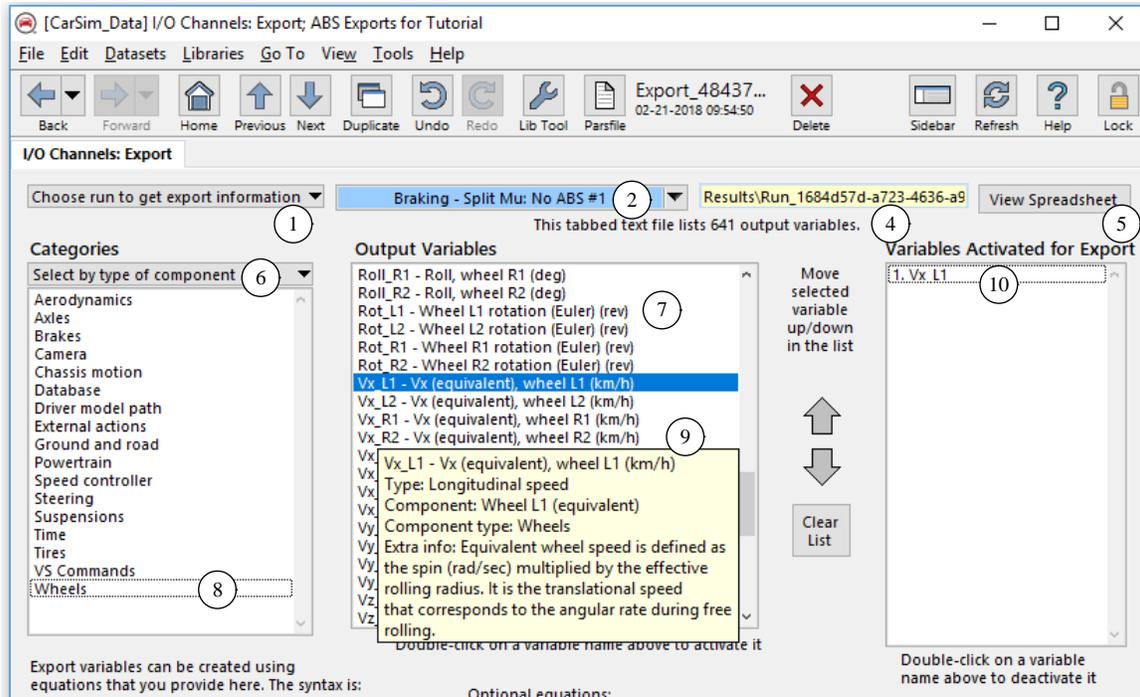
*Figure 32. Activating variables for export out of the vehicle S-Function block.*

2. Use the drop-down control for the potential link ②  to choose the same **Run Control** dataset that you selected as a reference for the Import variable screen (the new braking run). As before, two documentation files are automatically generated. In this case, they list all variables in the math model that might potentially be exported to Simulink. One of the files is the tabbed-text file shown in the yellow field ④ . The number of variables is written underneath (there are 641 output variables for this example). The other is a spreadsheet file, accessible with the **View Spreadsheet** button ⑤ .

3. As before, use the **Categories** drop-down control ⑥  to choose the option **Select by type of component**. Notice that a list of component types is shown under the control ⑧ .

4. Select the component type **Wheels** ⑧ . The list of available variables ⑦  is adjusted to show only variables related to Wheels.

5. Right-click on any of the available variables to see a longer name in a pop-up field ⑨ .

> **Note** Some of the right-click descriptions have extra information. For example, the information shown for variable Vx_L1 includes a description of how it is defined mathematically. When there are groups of similar variables applied for repeated parts, such as the four wheels of this vehicle, only the first variable in the group has the extra information. If you right-click on the next variable (Vx_L2), the description has only basic information.

6. For CarSim and TruckSim, find the output variable in the **Available Variables** list with the name Vx_L1 and double-click on it. The variable will appear in the list **Variables Activated for Export** ⑩ .

Add three more wheel variables by double-clicking on their names in the **Available Variables** list: `Vx_L2`, `Vx_R1`, and `Vx_R2`.

Two more variables are needed for the CarSim and TruckSim examples that are not in the **Wheel** category. To access them, use the **Categories** drop-down control ⑥ to choose the option **Show all variables**, and then select the variables `Vx_SM` and `Pbk_Con`.

The list **Variables Activated for Export** ⑩ should match Figure 33.
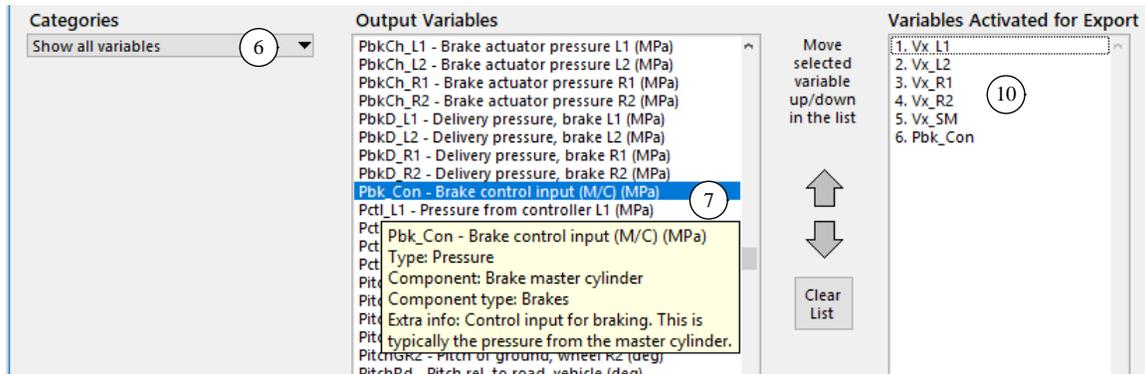


*Figure 33. Six variables activated for Export in CarSim and TruckSim examples.*

For BikeSim, activate the five output variables listed in Figure 34.
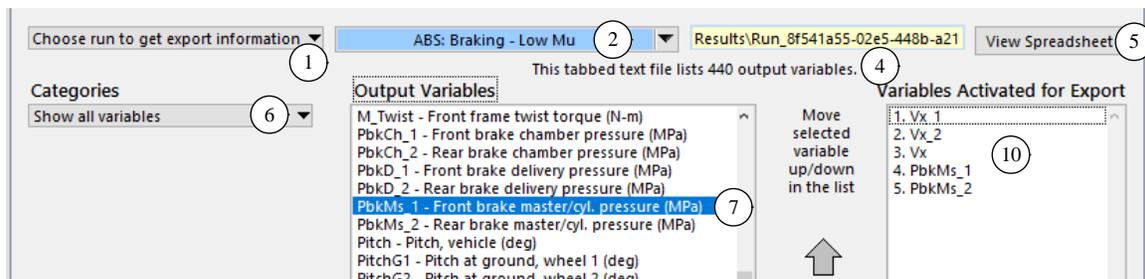


*Figure 34. Five variables activated for Export from BikeSim.*

7.  You have now completely specified all of the variables that will be exchanged between the vehicle model and the external Simulink model for this example. Having done this, we will now consider one more control on the **Models: Simulink** screen. Click the **Back** button to return to this screen (Figure 35).

8.  Right-click on the checkbox **Sync kinematical exports with force imports** ⑤. This checkbox is only shown when the integration method is Euler or AB-2; it is not applicable for other methods. With these two integration methods (Euler and AB-2), VS Solvers support two options for controlling the timing of the communication with outside software, specified with the system parameter `OPT_IO_SYNC_FM` that is set with this checkbox.
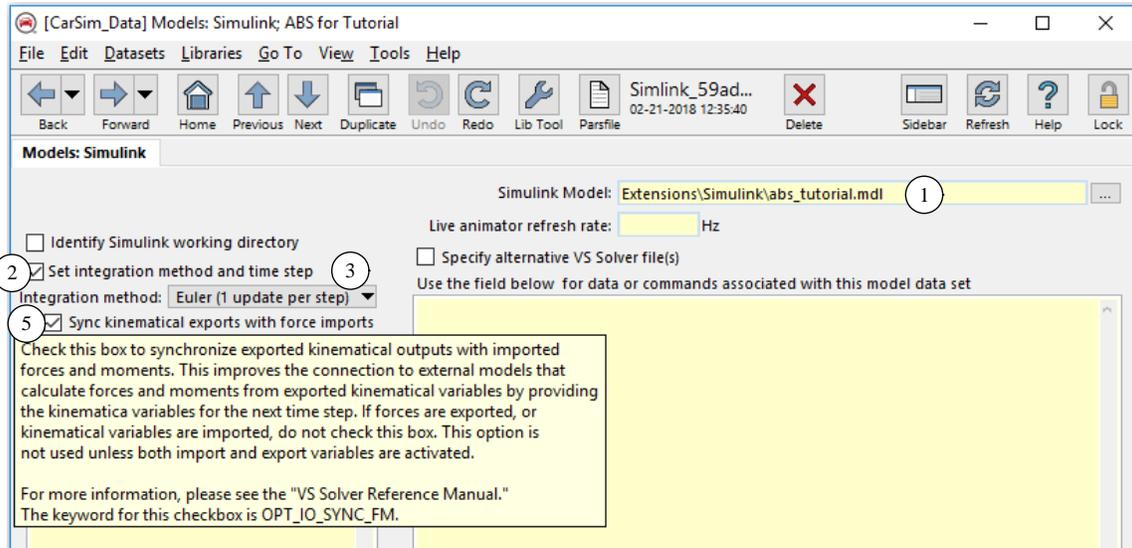
*Figure 35. The option to synchronize exports with force imports.*

    a.  When the box is not checked (OPT_IO_SYNC_FM = 0), all of the model calculations are made for the simulation time T that is received from Simulink. This sequence works perfectly if the variables imported into the VS S-Function are based on factors external to the vehicle model, such as clock time.

    b.  On the other hand, if the Simulink model calculates forces, moments, or brake pressures for the vehicle model based on variables that were exported by the vehicle model, then there is a time delay of one step introduced because the forces and moments won't be provided to the model until the next time step. When the box ⑤ is checked (OPT_IO_SYNC_FM = 1), kinematical variables exported from the VS S-Function are calculated for the next time step (T + TSTEP). With this option, forces and moment variables from Simulink will be synchronized for the next time step, when they are imported.

In this ABS example, five of the exports are kinematical variables (speeds) and the sixth is a control (master cylinder brake pressure). Be sure the box is checked.

For more information about this advanced feature, please see the *VS Solver Programs Reference Manual*.

9.  Return to the **Run Control** screen by clicking the **Home** button ① (Figure 36).
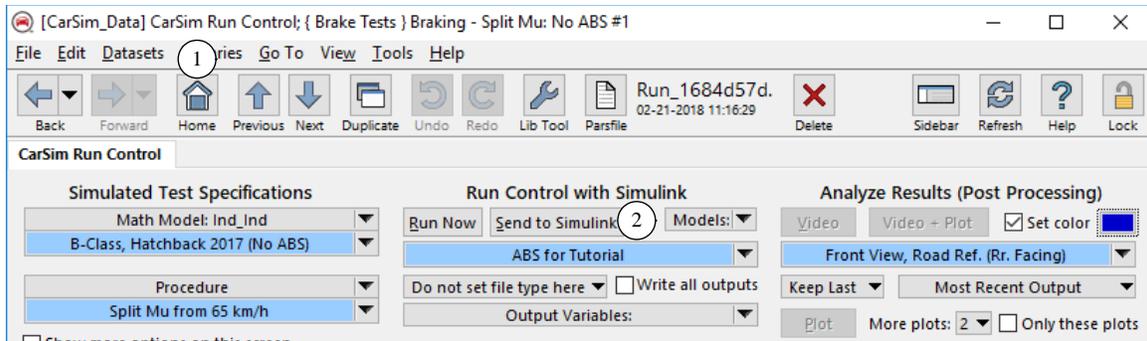
*Figure 36. The Run Control dataset.*

10. Click the **Send to Simulink** button ②. The VS Browser will again load the Simulink model (Figure 37), using updated connection information.
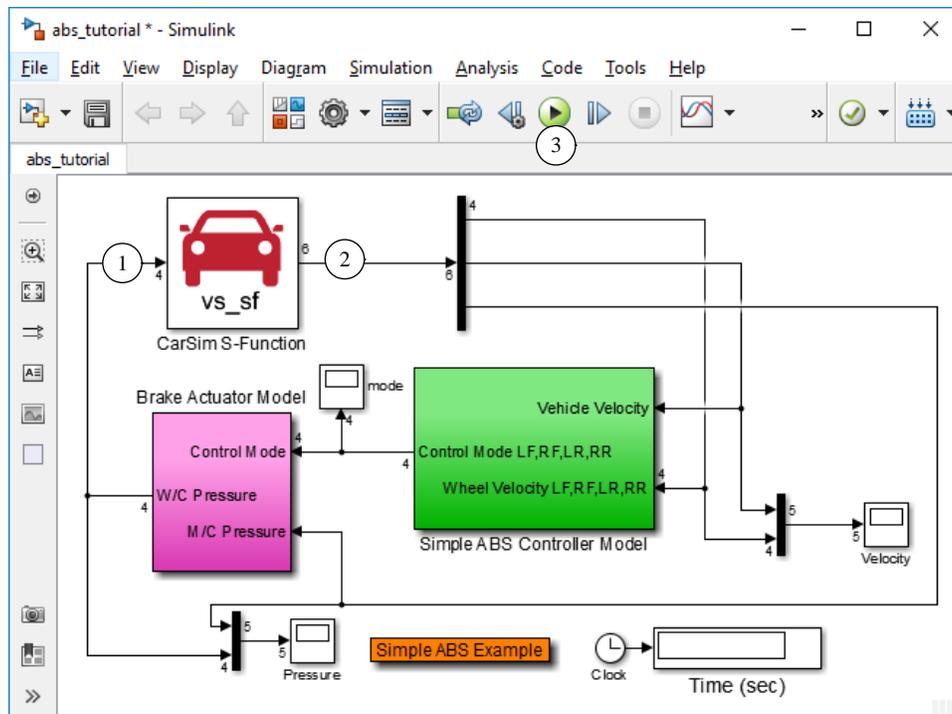


*Figure 37. Simulink model with connections to the CarSim S-Function.*

11. Display the signal dimensions. Note that Figure 37 shows four imports ① and six exports ② (CarSim and TruckSim), matching the setups made earlier with the Import and Export datasets. Figure 38 shows similar information for BikeSim (two imports ① and five exports ②).

12. Run the model from Simulink by clicking the Play button ③ (Figure 37) and confirm that the same results are obtained as were seen in the original example.
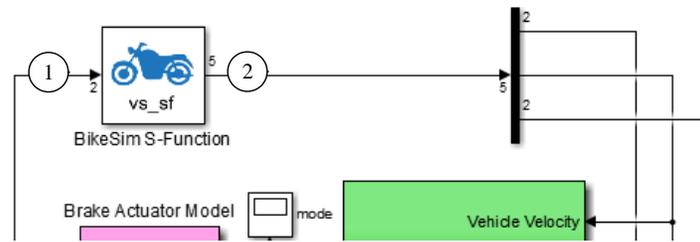
*Figure 38. Simulink model with connections to the BikeSim S-Function.*

# About the Vehicle S-Function Block

Now that the link between the vehicle model and the Simulink model has been specified and confirmed, we will look at the S-Function block in the Simulink model shown in Figure 37.

The VS S-Function has several properties that are set automatically to both represent the vehicle as specified in the VehicleSim product and to fit with the signal requirements of the Simulink model. These include the organization of the import variables ① and the export variables ②.

> **Note**  If you change the vehicle, its properties, or the sets of import or export variables from the VS browser, you must click the **Send to Simulink** button to update the model in Simulink.

## Import and Export Variables

When you click the **Send to Simulink** button to update the model in Simulink, the VS S-Function sets up import and export arrays based on settings from the Import and Export datasets that are linked to the **Models: Simulink** dataset, as shown in the previous section.

In order for the Simulink model to work properly, it is critical that the number of Import and Export variables defined from the VS side match the signal dimension in the Simulink model. It is equally critical that the variables be specified in the order expected in the Simulink model.

The selection process used in the previous section was specific to the design of the ABS controller models provided in CarSim, TruckSim, and BikeSim. If the Simulink model expects different variables for Import or Export, then the Import and Export datasets must be manually created to match the requirements.

## Simulink Configuration Parameters

The Simulink model may involve underlying differential equations that are solved by Simulink using numerical methods. For example, the ABS controller models provided with CarSim, TruckSim, and BikeSim each have a brake actuator system (the magenta box) with fluid dynamics represented with transfer function blocks. Some of the methods used to solve the equations can be viewed and adjusted. To do this, use the Simulink **Simulation** menu item **Model Configuration Parameters** to display a dialog box (Figure 39).
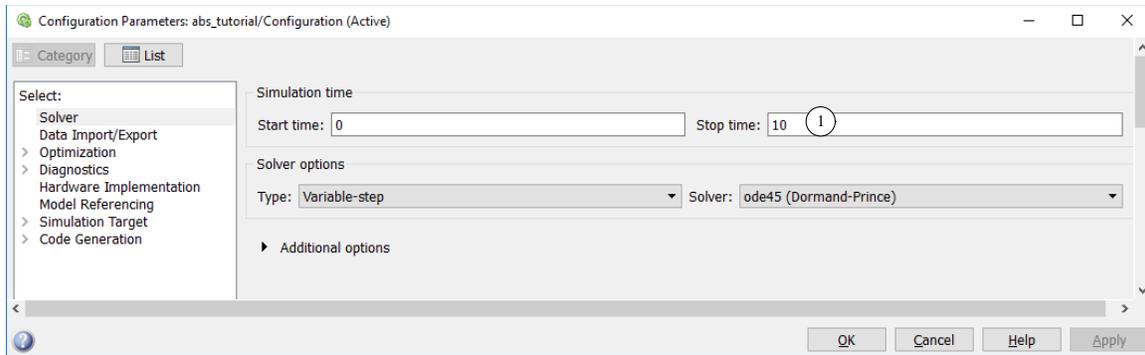
*Figure 39. Simulink Configuration Parameters.*

The VS Solver always solves its own equations at a fixed time step, whether it runs by itself, with Simulink, or with other software. From the point of view of Simulink, the VS S-Function block is always a discrete system.

You can configure the Simulink model as a continuous system with either fixed or variable-step solvers, so long as the Simulink parameter settings are compatible with the discrete time step used by the VS solver.

When transferring control from the VS Browser to Simulink, simulation parameters such as the start time and stop time are sent automatically. For example, the stop time of 10 s ① was specified in the **Procedure** dataset for this example simulation.

## Multiple Ports

The VS S-Function supports Simulink models with multiple Import and Export ports. The database for your VehicleSim product includes a multiport version of the ABS example, such as the CarSim example shown in Figure 40.

In comparing the multiport version to the single-port version shown earlier (Figure 37, page 20), you see the same blocks for the Brake Actuator Model ⑧, the ABS Controller Model ⑨, and the CarSim S-Function ⑥. However, in in the multiple-port case, there are four import ports for CarSim ⑤ and three export ports ⑦.

The setup for this model from the VS Browser is almost the same as shown earlier. Figure 41 shows the lower-left part of the **Models: Simulink** dataset, with the sidebar visible in order to see the linked datasets ①. In this case, the blue links for Import ⑦ and Export ⑧ channels are not used, and a link is made to an **I/O Channels: Ports** dataset ⑨. The **I/O Channels: Ports** dataset is shown in the background of Figure 40.

The **I/O Channels: Ports** screen shows drop-down controls that specify four import ports ② (Figure 40) and three export ports ③. Each Import port is represented with an Import dataset ① and each Export port is represented with an Export dataset ④. The number of ports can be set to anything between 0 and 20. The Import and Export datasets are made from the same libraries shown for single-port models, in the previous section.
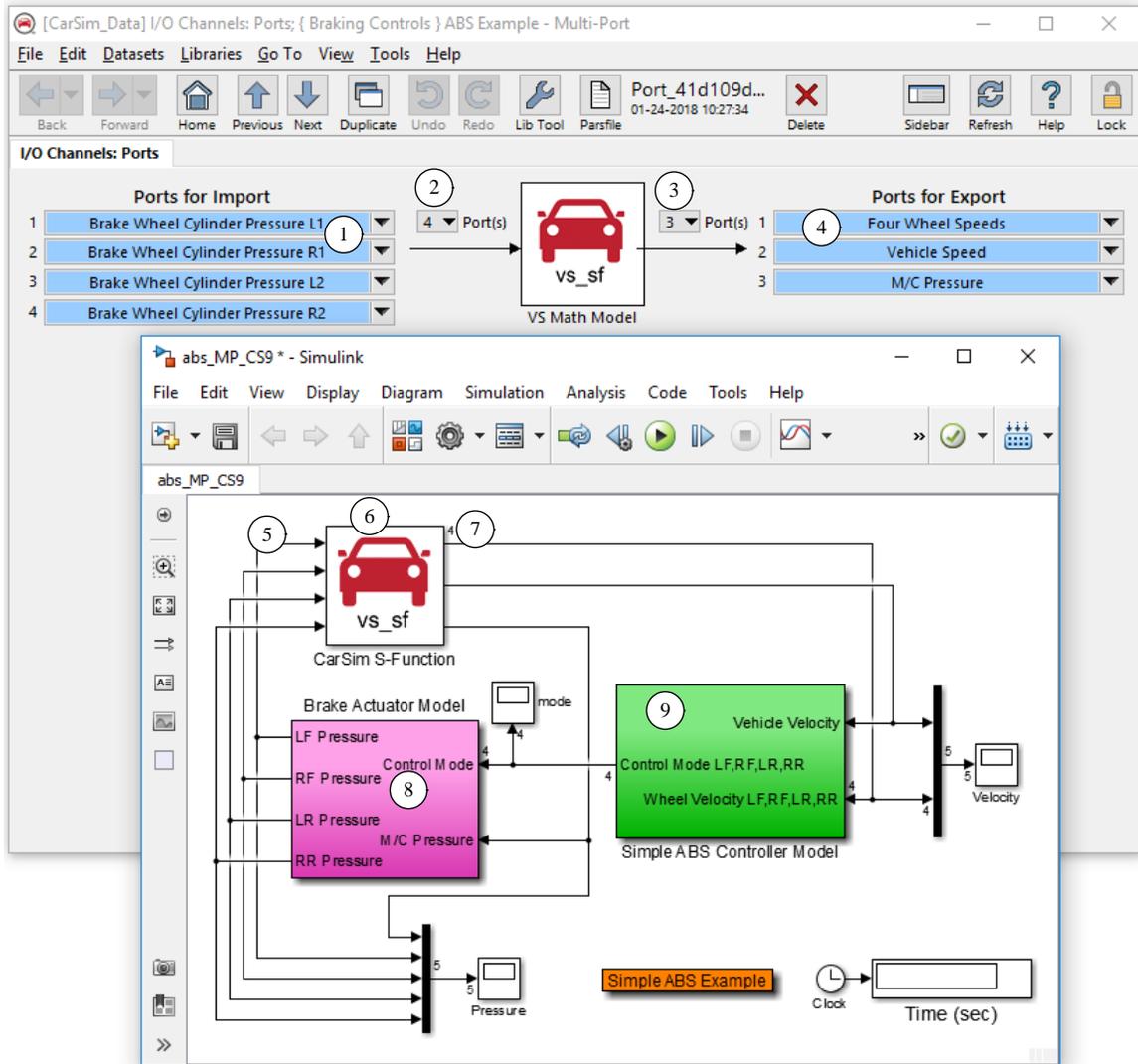
*Figure 40. Alternate version of the ABS Model using multiple ports.*
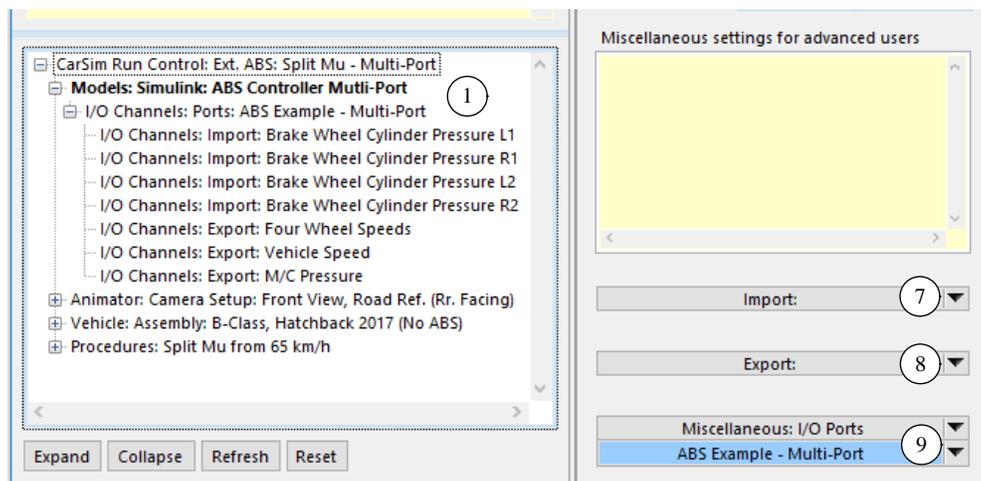


*Figure 41. Models: Simulink dataset for multiport version of ABS example.*