Mechanical Simulation

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Brake System

The brake system in CarSim and TruckSim provides brake torque at the wheels based on control from the driver and intervention systems such as antilock brake systems (ABS) and electronic stability controls (ESC). Brake torque is reacted by an unsprung mass and always opposes the direction of rotation of a wheel.

The Brake System Model

Parameters for the brake system are set using the screens described in this document and are listed in the Braking section of the Echo file produced for each simulation (Figure 1). Note that the names of Configurable Functions used in the brake model are also given in comments in the Echo file (lines 482-484).

Top-Level Control

The top-level control for the brake system is specified either as a pedal force or a fluid pressure from the master cylinder. The parameter `OPT_BK_PEDAL` determines the form of input. If set to 0, then no information is needed about the brake pedal force—the input to the system is simply the master cylinder pressure. If `OPT_BK_PEDAL` = 1 then a pedal force is defined as the input and is converted directly to a master cylinder pressure. If `OPT_BK_PEDAL` = 2 then the pedal force is increased by a booster that provides the force (and turned into a pressure) at the master cylinder.

If the closed-loop speed controller is used, it adjusts the pedal force or master cylinder pressure based on the settings for the speed controller.

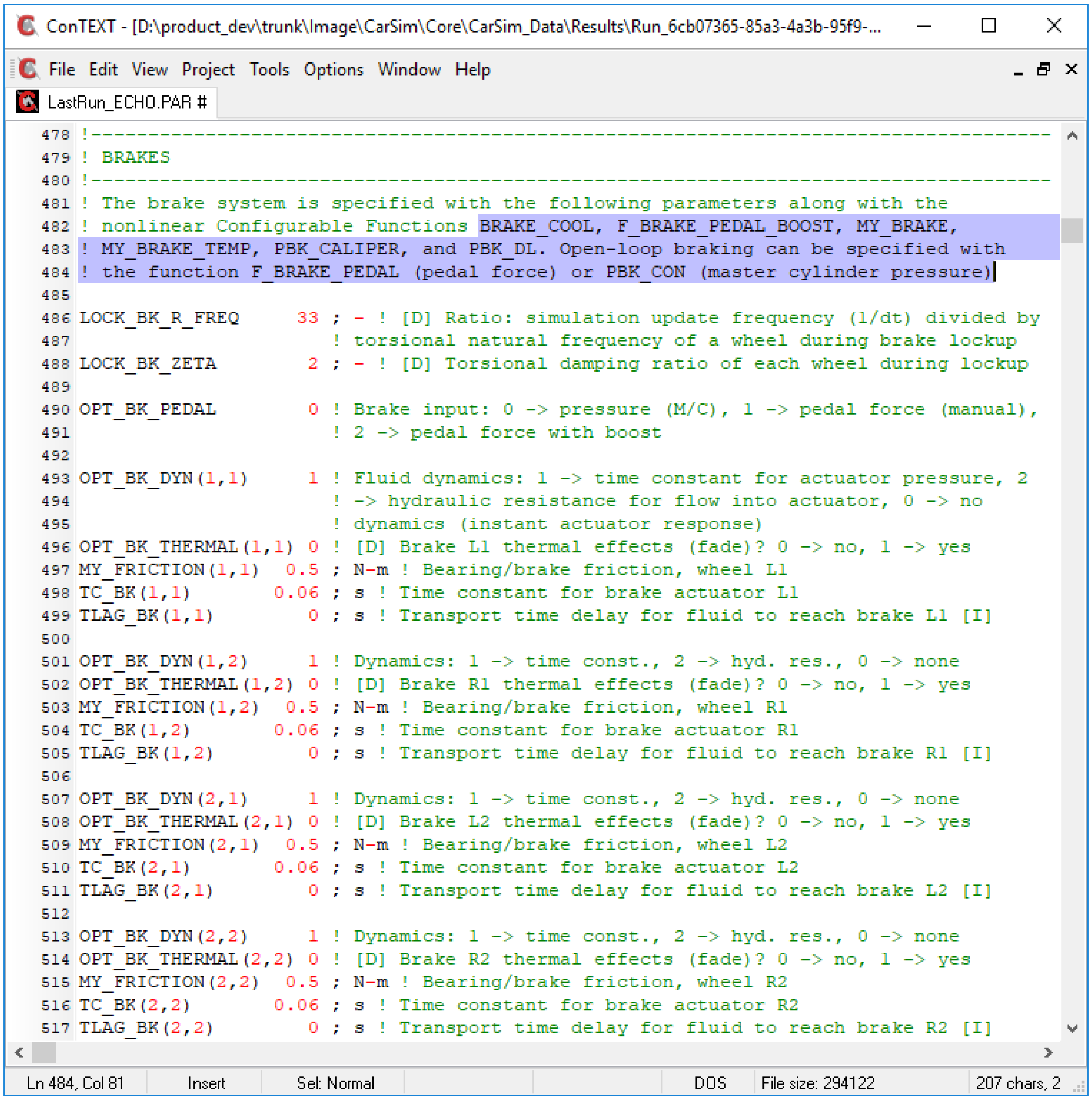

Figure 1. Section of the Echo file that lists brake parameters and Configurable Function names.

> **Note** Be aware that the open-loop brake control is always applied, even when using the internal closed-loop speed controller. If a complicated scenario goes between closed-loop and open-loop controls, be sure to set the open-loop brake control to zero when the closed-loop speed controller is active.

Master Cylinder Control

When `OPT_BK_PEDAL` = 0, any parameters or Configurable Functions involving pedal force are ignored; the input to the brake model is the master cylinder pressure. The open-loop braking is defined using the Configurable Function `PBK_CON`, as set with datasets from the library **Control: Braking MC Pressure (Open Loop).**

Pedal Force Control

When OPT_BK_PEDAL is 1 or 2, the input to the brake model is the pedal force. The open-loop braking is defined using the Configurable Function F_BRAKE_PEDAL, as set with datasets from the library **Control: Braking Pedal Force (Open Loop)**. In this case, the function PBK_CON is not used.

> **Note** Since the Master Cylinder is located after the pedal, Master Cylinder Pressure may still be imported via IMP_PCON_BK when OPT_BK_PEDAL is 1 or 2 using either **Add** or **Replace** as import modes (**Multiply** will have no effect). The combination of pedal force and Master Cylinder Pressure as dual control modes is common in applications involving active boosters, such that the brake system can apply the booster irrespective of whether the human driver has applied force via the pedal. Examples may include booster pre-charging for ESC / roll stability control and autonomous vehicle operation.

Transport Delay

The master cylinder pressure, whether specified directly or calculated from a pedal force command, is then sent to the individual wheels that are equipped with brakes. This pressure signal is denoted as the *line pressure* for that wheel. The parameter TLAG_BK, available for each wheel, establishes a pure time delay between the master cylinder pressure and the line pressure for that wheel.

> **Note** At the beginning of a run, there is no master cylinder pressure history available for lagging the line pressure. The lagged line pressure effect for a given wheel will begin when the simulation time has equaled the wheel's TLAG_BK. Until then, the line pressure is equal to the master cylinder pressure. Similarly, when TLAG_BK is increased in duration during a run, such as with an Event, the line pressure will temporarily revert to the master cylinder pressure.

Pressure Control

The variables used to track the controls and fluid pressures follow the sequence shown in Figure 2. For each wheel, the line pressure from the master cylinder is subject to a proportioning valve resulting in a delivery pressure. An optional controller provides the controller pressure to an actuator, which might have dynamics that affect the pressure provided to the actuator. The actuator generates brake torque.

Traditional brake systems often used a proportioning valve or other fluid control to deliver different pressures to the front and rear brakes. In the VS Solver, delivery pressure is calculated using a Configurable Function of both the line pressure and the instant tire vertical load. With modern systems that have ABS controllers, this proportioning is often not included. In these cases, the Configurable Function should be set to a coefficient of 1.0.

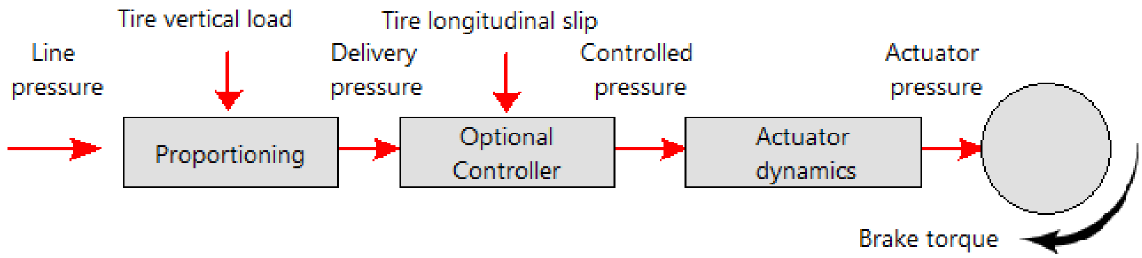

Figure 2. Flow chart for fluid pressure leading to brake torque.

CarSim and TruckSim include a simple built-in ABS controller that may be used to modulate the delivery pressure to provide a controlled pressure.

Actuator Dynamics

Three options are available in the model for representing the transient behavior of the actuator. The choice is specified for each brake using the parameter `OPT_BK_DYN`.

If `OPT_BK_DYN` = 0, there are no dynamics: the actuator pressure is simply the same as the controller pressure.

When `OPT_BK_DYN` = 1, the transient behavior of the brake actuator is characterized with a first-order delay time constant, and used in a differential equation for the actuator pressure as described later.

When `OPT_BK_DYN` = 2, the transient behavior of the brake actuator is modeled in terms of the volume of fluid in a caliper, as described later.

Brake Torque, including Lock-up Behavior

A brake applied to a non-spinning wheel behaves differently than the same brake applied to a spinning wheel. The spinning wheel has a dynamical degree of freedom; the locked-up wheel does not.

When applied to a spinning wheel, the brake torque is mainly a function of the applied fluid pressure and serves to resist the spin by dissipating energy. When applied to a non-spinning wheel, however, the brake torque reacts as needed to prevent wheel spin, but without dissipating energy or doing any work.

When the wheel is spinning, brake torque is defined as a Configurable Function of fluid pressure and possibly temperature. Details for the thermal model are described later. In the case of the model that does not include thermal effects, the torque is calculated directly from the actuator pressure.

The CarSim/TruckSim brake models account for the non-spinning state by representing the locked brake with a torsional spring and damper that winds up as needed to react to tire/ground forces. This change in the model equations occurs when the spin rate reaches zero. At that time, the equations are activated for the torsional spring and damper to allow the wheel to achieve a true static equilibrium in the locked state. The properties of the spring and damper applied at this step are determined automatically by the math model to meet requirements of numerical stability, based on the frequency and damping parameters `LOCK_BK_R_FREQ` and `LOCK_BK_ZETA` (see lines

486 – 489, Figure 1, page 2). These parameters are not represented in the GUI; however, advanced users may set them using a miscellaneous yellow field.

The brake remains locked as long as the magnitude of the torque from the spring/damper system is less than the magnitude of the current value of the applied brake torque. If the spring/damper torque exceeds the applied torque, then the spring/damper is disabled.

Configurable Functions in the Brake Model

Configurable Functions are used to describe the nonlinear relationships in the system. Table 1 lists the libraries used to specify datasets for Configurable Functions with standard editing and viewing controls as described in detail in the *VehicleSim Browser Reference Manual*. The tabular datasets are identified for the solver programs by keywords based on the root names listed in the table. These are also identified in the Echo file (see lines 481-484, Figure 1, page 2).

Brake System Screens

The main brake system screen in CarSim is named **Brakes: Four-Wheel System**. In TruckSim, brake properties are specified on a per-axle basis using the datasets from the library **Brakes: Two-Wheel System**.

Another library is provided in CarSim named **Brakes: Trailer Two-Wheel System**. It is similar to the other two but has no user controls for setting the top-level controls.

Table 1. Summary of brake system table libraries.

Library Screen	**Root Keyword(s)**	**Description**
Brakes: Booster Force	F_BRAKE_PEDAL_BOOST	Brake booster output force vs. input (master cylinder) force
Brakes: Caliper Pressure vs. Volume	PBK_CALIPER	Brake caliper pressure vs. brake caliper volume
Brakes: Cooling Coefficient	BRAKE_COOL	Rotor cooling coefficient vs. vehicle speed
Brakes: Proportioning/Limiting Valve	PBK_DL	Pressure output from proportioning valve vs. input pressure and tire Fz
Brakes: Torque	MY_BRAKE	Brake torque vs. actuator pressure
Brakes: Torque vs. Rotor Temperature	MY_BRAKE_TEMP	Brake torque vs. actuator pressure and temperature

Brakes: Four-Wheel System and Brakes: Two-Wheel System

The CarSim library **Brakes: Four-Wheel System** (Figure 3) is used for the main vehicle, which always has four wheels. It is also used for the brakes in four-wheeled trailers. The screen for the TruckSim library **Brakes: Two-Wheel System** is nearly identical to the four-wheeled screen, but as expected from the name, it only has settings for two wheels.

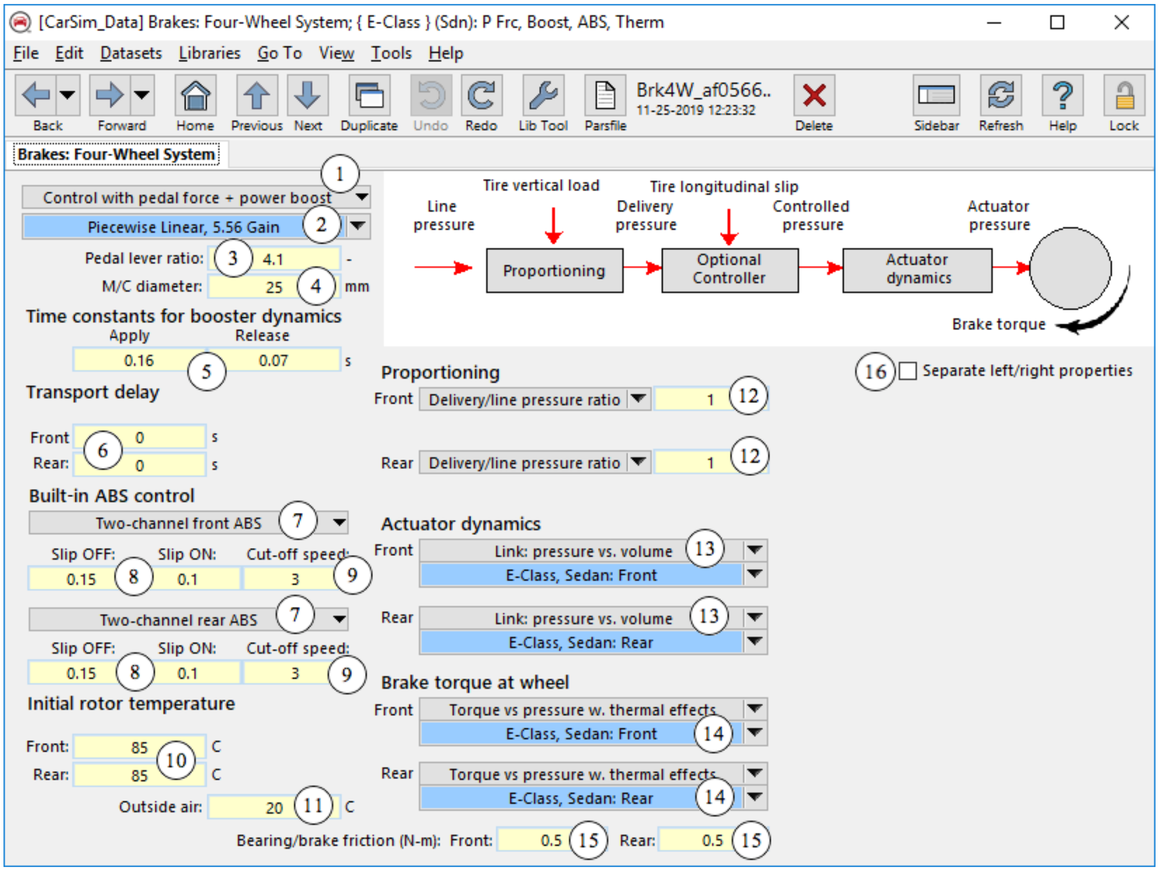

Figure 3. The Brakes: Four-Wheel System screen.

① Drop-down control for setting the type of top-level braking control (keyword = `OPT_BK_PEDAL`). The control gives four options (Figure 4).

If the first or last option is chosen, then all information related to pedal force is hidden.

If the second or third option is chosen, then two fields are shown for parameters that link pedal force to master cylinder pressure (③ and ④, Figure 3).

If the third option is chosen, then a link is shown to the library **Brakes: Booster Force** ②, and two fields are shown with time constants for the booster ⑤.

If the last option is selected, then the Parsfile does not contain any reference to the keyword `OPT_BK_PEDAL`.

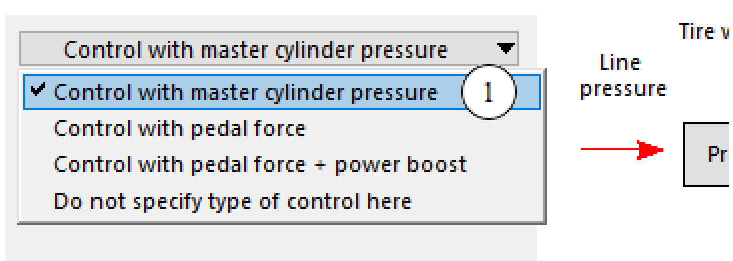

Figure 4. Options for setting the type of top-level braking control.

2 Link to the library **Brakes: Booster Force**. This link is shown only when the drop-down control 1 specifies that power boost is enabled. The linked dataset provides force after boost as a function of the pedal force multiplied by the lever ratio 3 (see equations 3 and 4, below).

3 Pedal lever ratio, used to calculate the force applied to the master cylinder (equations 2 - 4, keyword = `R_BK_PEDAL`). A value of 1.0 means the force applied to the master cylinder is the same as the pedal force. Generally speaking, linkages generate larger forces such that the ratio is greater than 1.0, resulting in a multiplication of the force applied by the human driver.

4 Master cylinder diameter, used to calculate the force applied to the master cylinder (see equation 1, keyword = `D_MC`).

5 Time constants used in the equations for boost force (equations 3 and 4, keywords = `TC_BK_APP` and `TC_BK_REL`).

6 **Transport Delay** (keyword = `TLAG_BK`). These are the time delays between the master cylinder pressure and the line pressure fed into each brake caliper or wheel cylinder.

Pedal Force User Options

The specification of the top-level control (pressure or pedal force) should be provided in the dataset that defines brake properties for the front axle. In a CarSim model without a trailer, there is no ambiguity, as a single dataset defines properties for all four wheels. In TruckSim, the top-level controls can potentially be set from the dataset used for any axle. Care should be taken to provide consistent datasets such that the data for a rear axle does not change the intended settings.

Pedal Force Equations

When pedal force is selected as the top-level control, the master cylinder pressure `Pbk_Con` is calculated using the algebraic relationship:

$$\texttt{Pbk\_Con} = F_{mc} / (\pi D^2/4) \tag{1}$$

where F_{mc} is the force into the master cylinder and D is the effective diameter of the master cylinder (keyword = `D_MC`, 4).

If there is no power boost, then:

$$F_{mc} = F_{pedal}\, R_{lever} \tag{2}$$

where F_{pedal} is the pedal force and R_{lever} is the lever ratio (parameter `R_BK_PEDAL`).

If power boost is selected, then the force into the master cylinder is increased by a boost force that includes a transient response. In this case, the lever ratio defines an input to a Configurable Function f_{boost} (keyword = `F_BRAKE_PEDAL_BOOST`). The master cylinder input force is defined with a differential equation that uses different coefficients for the time constant, depending on whether the brakes are being applied or released.

$$\frac{dF_{mc}}{dt} = \frac{f_{boost}(F_{pedal}R_{lever}) - F_{mc}}{T_{app}} \text{ (when brakes are applied)} \tag{3}$$

$$\frac{dF_{mc}}{dt} = \frac{f_{boost}(F_{pedal}R_{lever}) - F_{mc}}{T_{rel}} \text{ (when brakes are released)} \tag{4}$$

Indexed Parameters

All the parameters and Configurable Functions for a specific wheel are indexed to the axle number as indicated by the current value of the system parameter `IAXLE`. For models with trailers, they are also indexed to the vehicle unit as indicated by the current value of the system parameter `IUNIT`. Most of the properties can be applied to either the left or right side. The context is specified in the parsfile with the system parameter `ISIDE` (1 = left, 2 = right).

Built-In Antilock Brake System (ABS) Control

CarSim and TruckSim include a simple built-in ABS controller that is automatically installed by using the drop-down control (7) (Figure 3) to enable the ABS for an axle. Enabling the system causes the command `INSTALL_ABS_CONTROLLER` to be written into the Parsfile for the dataset, which then causes the built-in controller to be installed. Parameters for the controller appear in a different section of the Echo file (Figure 5).

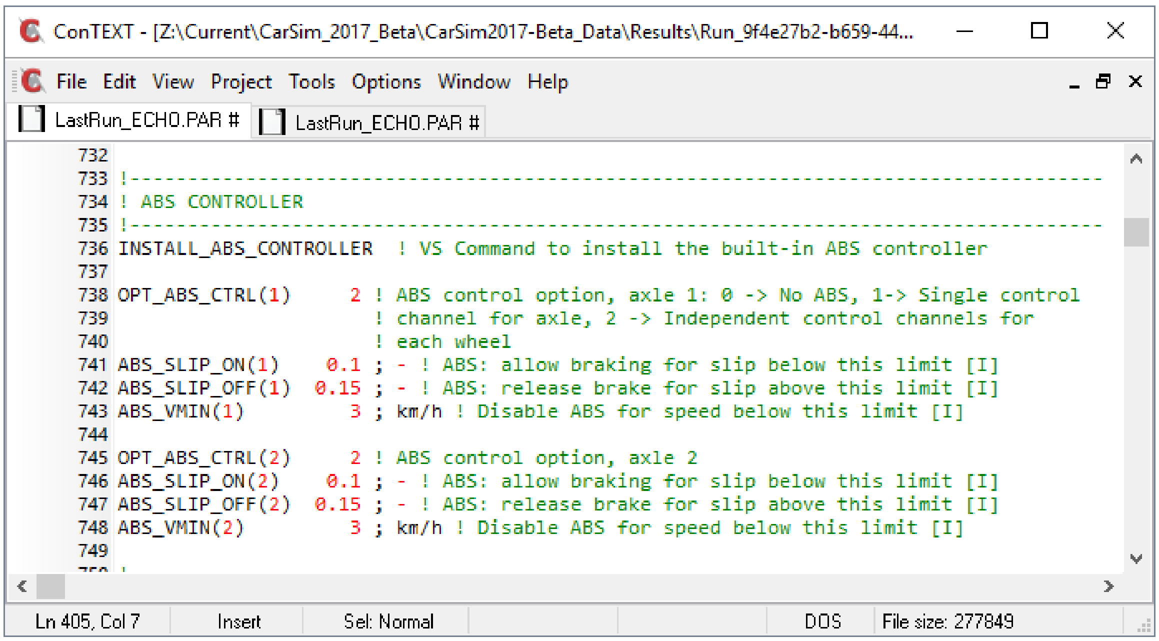

Figure 5. ABS Section of the Echo file.

The ABS is designed to prevent the wheels from completely locking during hard braking. When a wheel starts to lock up, its longitudinal slip decreases from 0 and approaches -1. When the slip decreases past some prescribed level, a valve releases the supply pressure to the wheel cylinder, allowing the wheel to spin back up. Then, when the slip again approaches zero, the valve allows the pressure to actuate the brake again. At low speed, just before the vehicle stops, the ABS is disabled and wheel lockup is allowed.

The cycling frequency during a limit stop in which the ABS controller is active is typically about 10 Hz. The frequency depends not only on the settings on this screen, but also the tire/wheel inertia (specified on the tire and suspension screens) and the tire longitudinal relaxation length (specified on the tire screen).

7 Dropdown control to select a built-in ABS function. For each axle, ABS control can be specified as single channel control, two channel control, or disabled (Figure 6). In single channel mode, both brakes on an axle are released when the slip at either wheel on that axle exceeds the value set in the Slip OFF field. They are applied again when the slip at both wheels falls below the level specified in the Slip ON field. In two-channel mode, each brake on an axle is controlled individually, releasing when slip exceeds the Slip OFF level, and applying again when slip falls below the Slip ON level. When ABS is disabled, the internal ABS logic is bypassed, and the fields used to set ABS properties (8 and 9) are hidden.

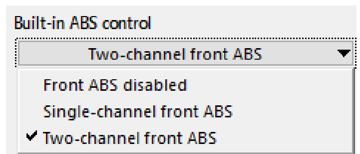

Figure 6. Options for using built-in ABS on an axle.

8 ABS parameters: longitudinal slip for turning the brake OFF and ON (keywords = `ABS_SLIP_OFF`, `ABS_SLIP_ON`). `ABS_SLIP_OFF` is the wheel slip condition at which the brakes are turned off (0 → free rolling, 1 → lock up). A typical value would be between 0.1 and 0.3.

`ABS_SLIP_ON` is the wheel slip condition at which the brakes are again turned on. It should be lower than the value for `ABS_SLIP_OFF`. A typical value would be between 0.05 and 0.3.

> **Note** Although slip ratios under braking have a negative sign, absolute values are used for these two parameters for convenience.

9 ABS minimum speed (keyword = `ABS_VMIN`). This is the minimum vehicle speed for the ABS to function. When the absolute vehicle speed drops below this level, the ABS control is turned off and wheel lock is allowed. A typical value would be in the range of 2 to 10 km/h.

Temperatures

The brake torque generated for the wheel can optionally be specified with a sensitivity to temperature 14. If this option is enabled, then fields are shown for specifying the initial temperatures used in the thermal portion of the brake system model. Details of the model are presented later (page 12).

10 **Initial Rotor Temperature**. The thermal model has state variable for the temperatures of the rotors or drums, which affect the relationships between actuator pressure and brake torque. The initial values of the state variables are set here. The keywords for the variables are `SV_TROT_`*id*, where *id* identifies the wheel: L1, L2, R1, etc.

11 Air temperature used in the thermal model (keyword = `T_AIR`).

Fluid Pressures

12 Settings for calculating delivery pressure as a Configurable Function of master cylinder pressure and tire vertical load. The root keyword for the Configurable Function is `PBK_DL`.

The drop-down control specifies whether the function should use a linear coefficient (keyword = `PBK_DL_COEFFICIENT`) or a link to tabular data from the **Brakes: Proportioning / Limiting Valve** library.

As noted earlier, a linear coefficient of 1.0 should be specified if the system does not have a proportioning valve.

13 **Actuator Dynamics**. A drop-down control provides four options for specifying the transient behavior of the actuator (Figure 7).

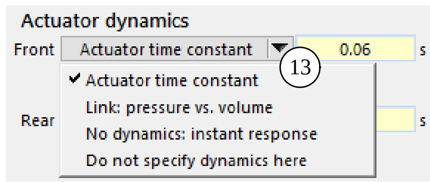

Figure 7. Options for setting actuator dynamics.

If the first option is selected, the parameter `OPT_BK_DYN` is set to 1 and a field appears for the time constant parameter T_{bk} (keyword = `TC_BK`). In this case, the transient behavior of the brake actuator is calculated using the differential equation for the brake actuator pressure P_{bk} and the controlled pressure P_{ctl}.

$$\frac{dP_{bk}}{dt} = \frac{P_{ctl}\text{-}P_{bk}}{T_{bk}} \tag{5}$$

If the second option is selected, the parameter `OPT_BK_DYN` is set to 2 and a link is made to the library **Brakes: Caliper Pressure vs Volume**, described in the next subsection.

The third option specifies that there is no dynamic delay; the actuator pressure is equal to the controlled pressure.

The fourth option specifies that the dynamic behavior is not specified here.

Brake Torque

14 Settings for calculating brake torque as a Configurable Function of fluid pressure and possibly temperature. A drop-down control specifies whether the function should use a linear coefficient or a link to tabular data from the **Brakes: Torque** library or a link to a thermal model using a dataset from the **Brakes: Caliper and Rotor Properties** library.

If temperature is not considered, then the Configurable Function `MY_BRAKE` is used.

15 Bearing friction for the wheel (keyword = `MY_FRICTION`). This is a friction torque that is always present and resists wheel spin. The specified torque is added to the brake torque before it is applied to the wheel in the multibody model.

Separate Left and Right Properties

16 Checkbox to specify whether different brake properties should be specified for the left and right sides of the vehicle. When unchecked (as in the figure), the specified settings are written

twice in the dataset for use on both sides. When checked, separate settings are shown on the screen for the left and right sides.

Brakes: Caliper Pressure vs Volume

The parameter `OPT_BK_DYN` can be set to choose between three methods for handling transient behavior of a brake actuator. The options are:

1. No transient (actuator pressure is the same as the controller pressure (`OPT_BK_DYN = 0`).
2. Specify time constant for use in equation 5 (`OPT_BK_DYN = 1`).
3. Calculate fluid volume in actuator and use hydraulic resistance (`OPT_BK_DYN = 2`).

The choice is made from the brake system screen with the drop-down control that specifies actuator dynamics (13, Figure 3, page 6). When the option is chosen for **Link: pressure vs. volume**, a link is made to the library **Brakes: Caliper Pressure vs Volume** (Figure 8).

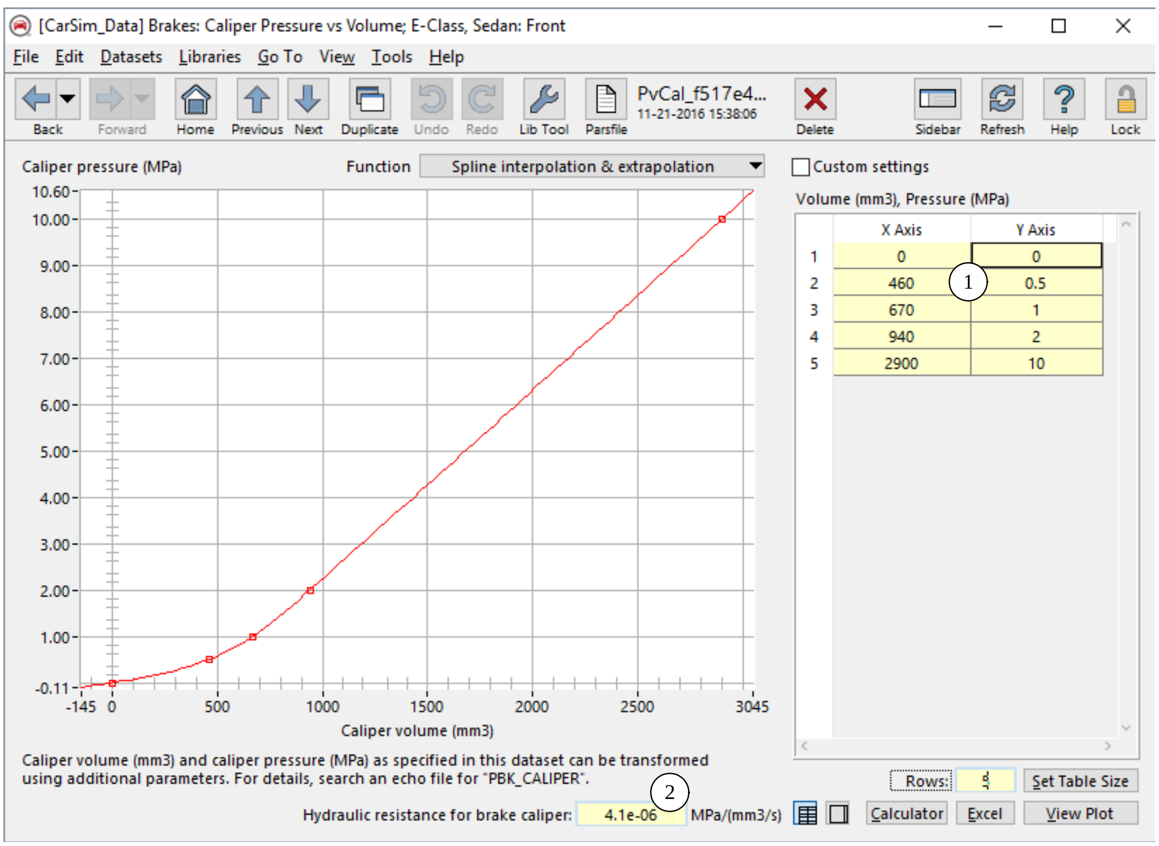

Figure 8. The Brakes: Caliper Pressure vs Volume screen.

In this case, the flow Q into each actuator is calculated from the pressure difference divided by a hydraulic resistance R (defined with the parameter `BK_HYD_RES` 2, Figure 8).

$$Q = (P_{ctl} - P_{bk})/R \tag{6}$$

Actuator volume (V) is the integral of the flow:

$$V = \int Q dt \quad (7)$$

The caliper (actuator) pressure is given by the caliper volume vs. pressure characteristics defined using the Configurable Function PBK_CALIPER 1.

Note The volumes for four wheels are summed to calculate a pedal displacement. This method was originally developed for CarSim and assumes the brake system has four wheels. The pedal displacement output variable also exists in TruckSim, but it is probably not accurate for air systems or vehicles with more than four wheels.

Brakes: Caliper and Rotor Properties

The brake model supports thermal effects when calculating brake torque.

When the thermal model is enabled (OPT_BK_THERMAL = 1), brake torque depends on both the caliper pressure and rotor temperature. The calculation of the brake rotor temperature uses the energy input from the brake torque and rotation speed, and energy removed by cooling. The power input (P_{in}) is:

$$P_{in} = M_{y\_bk}\, \omega \quad (8)$$

where M_{y_bk} is brake torque and ω is the wheel speed. The power removed by the cooling (P_{out}) is:

$$P_{out} = C_v\, C_p\, m_{rotor}\, (T_{rotor} - T_{air}) \quad (9)$$

where C_v is the cooling coefficient as a function of vehicle speed (calculated in the model with the Configurable Function BRAKE_COOL), m_{rotor} is the rotor mass (keyword = M_ROTOR), C_p is specific heat of the rotor as a function of the rotor temperature, T_{rotor} is the rotor temperature, and T_{air} is the air temperature (keyword = T_AIR). The specific heat C_p is calculated as a linear function of rotor temperature:

$$C_p = \mathrm{C_{p0}} + \mathrm{C_{p2}}\, \mathrm{T_{rotor}} \quad (10)$$

where $\mathrm{C_{p0}}$ is the specific heat for a temperature of 0° C (keyword = BK_CP_RTR) and $\mathrm{C_{p2}}$ is the gradient of C_p with respect to temperature in Celsius (keyword = BK_CP2_RTR). The derivative of the rotor temperature is:

$$\frac{dT}{dt} = \frac{P_{in} - P_{out}}{C_p m_{rotor}} \quad (11)$$

The thermal option is enabled with the parameter OPT_BK_THERMAL, and is made from the brake system screen with the drop-down control that specifies how brake torque is specified (14, Figure 3, page 6).When the option is selected for **Torque vs pressure w. thermal effects**, a link is made to the **Brakes: Caliper and Rotor Properties** library (Figure 9).

1. Rotor mass m_{rotor} (keyword = M_ROTOR), used in thermal equations 9 and 11.
2. Rotor specific heat (keyword = BK_CP_RTR). Specific heat of the rotor when the rotor temperature is 0° C (kJ/kg/C), $\mathrm{C_{p0}}$ in equation 10.

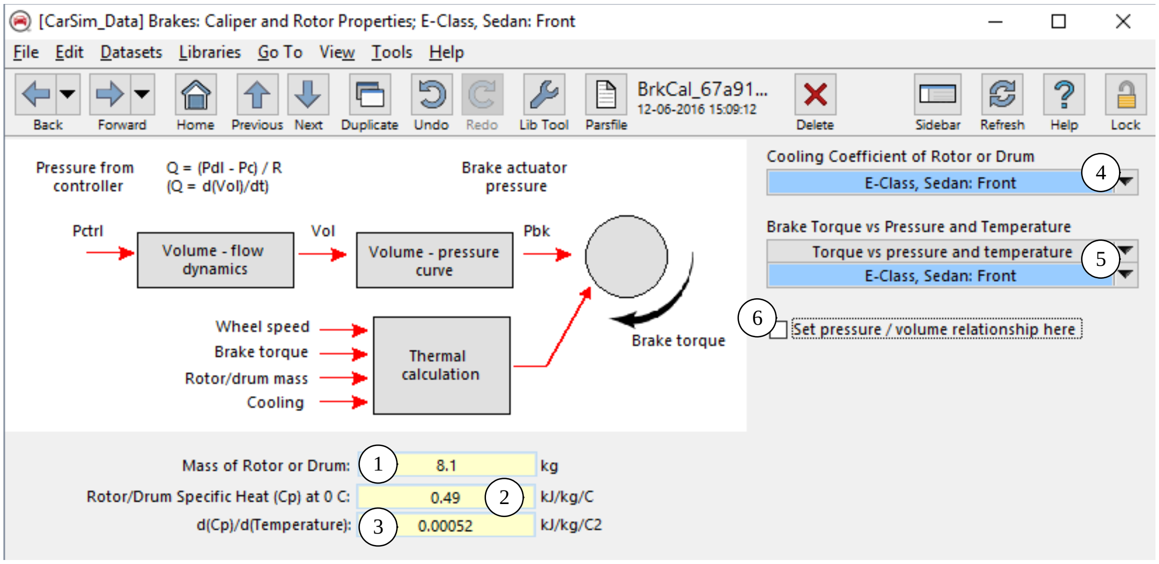

Figure 9. The Brakes: Caliper and Rotor Properties screen.

③ Linear slope of the specific heat (keyword = `BK_CP2_RTR`). This is the derivative of rotor specific heat with respect to the rotor temperature (kJ/kg/C2), C_{p2} in equation 10.

④ Link to a dataset from the **Brakes: Cooling Coefficient** library.

⑤ Setting to define the mechanical response of each brake actuator to pressure and rotor temperature. A drop-down control specifies whether the function should use a linear coefficient (keyword = `MY_BRAKE_TEMP_COFFICIENT`), or a blue link to a **Brakes: Torque vs. Rotor Temperature Properties** dataset.

> **Note** The option to specify a linear coefficient for calculating brake torque existed in earlier versions and is still available to provide backward compatibility with older datasets. However, all thermal effects are ignored if the linear option is chosen. Rather than using the linear option here, Mechanical Simulation recommends using the linear option on the **Brake System** screen (control ⑭, Figure 3, page 6).

⑥ Checkbox to set the pressure / volume relationship for the brake. When this box is checked, more controls are shown that can be used to specify actuator dynamics in terms of volume flow (Figure 10).

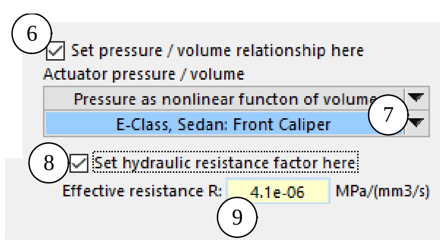

Figure 10. Controls involving pressure/volume relationship.

Note	The brake system modeling was rewritten for version 2017 to allow more built-in options, support for external model options, and to add the thermal model to TruckSim (it was originally only included in CarSim). This screen supports several options in support of backward compatibility with older CarSim datasets. This checkbox shows information unrelated to the thermal part of the brake model. The option to use the volume-based actuator dynamics model via the **Brakes: Caliper Pressure vs Volume** library can now be made on the **Brake System** screen.

7 Setting to specify caliper pressure as a Configurable Function of caliper volume. A drop-down control specifies whether the function should use a linear coefficient (keyword = `PBK_CALIPER_COFFICIENT`), or a blue link to a **Brakes: Caliper Volume vs. Pressure** dataset.

8 Checkbox to set hydraulic resistance here. When checked, the field 9 is shown. The effective resistance can also be set on the **Brakes: Caliper Volume vs. Pressure** screen. If set in both places, the value from this screen (field 9) overrides the value from the linked dataset.

9 Effective resistance (keyword = `BK_HYD_RES`). The hydraulic resistance for the brake caliper, described in the previous subsection for the **Brakes: Caliper Volume vs. Pressure** library.

Replacing Parts of the Brake System

I/O Variables for the Brake System

Table 2 lists the Import variables for the brake system top-level control and the two wheels on axle 1. Note that the wheel-based variables have the suffix _L1 or _R1. Similar variables exist for all axles, with corresponding suffixes up to the number of axles on the vehicle (L2, R2, L3, …).

Table 3 lists the output variables for the brake system controller and axle 1.

Referring to the flow chart shown in Figure 2, page 4 (and also on the screen shown in Figure 3), the pressure variables for each wheel are available from four locations:

1. Line input (after the master cylinder); to replace, export `PbkL_L1` and import `IMP_PLIN_L1`
2. Delivery (after the proportioning valve); to replace, export `PbkD_L1` and import `IMP_PDEL_L1`
3. Controlled (after the optional controller); to replace, export `Pctl_L1` and import `IMP_PCTL_L1`
4. Actuator (after actuator dynamics); to replace, export `PbkCh_L1` and import `IMP_PBK_L1`

Table 2. Imports for brake system top-level and axle 1.

Import keyword	Units	Description
IMP_BK_STAT	-	Brake apply status: 0 or 1 (based on control pressure)
IMP_DVBK_L1	mm3/s	L1 caliper flow rate
IMP_DVBK_R1	mm3/s	R1 caliper flow rate
IMP_FBK_BSTIN	N	Brake booster input force
IMP_FBK_PDL	N	Brake pedal force
IMP_MYBK_L1	N-m	Brake moment L1
IMP_MYBK_R1	N-m	Brake moment R1
IMP_MYSM_L1	N-m	Ext. moment applied from sprung mass to wheel L1
IMP_MYSM_R1	N-m	Ext. moment applied from sprung mass to wheel R1
IMP_MYUSM_L1	N-m	Ext. moment applied from unsprung mass to wheel L1
IMP_MYUSM_R1	N-m	Ext. moment applied from unsprung mass to wheel R1
IMP_PBK_L1	MPa	Brake actuator pressure L1
IMP_PBK_R1	MPa	Brake actuator pressure R1
IMP_PCON_BK	MPa	Brake master cylinder pressure
IMP_PCTL_L1	MPa	Control pressure (without dynamics) for brake actuator L1
IMP_PCTL_R1	MPa	Control pressure (without dynamics) for brake actuator R1
IMP_PDEL_L1	MPa	Delivery pressure (after proportioning) for brake L1
IMP_PDEL_R1	MPa	Delivery pressure (after proportioning) for brake R1
IMP_PLIN_L1	MPa	Brake line pressure L1 before proportioning
IMP_PLIN_R1	MPa	Brake line pressure R1 before proportioning

Using an External ABS Controller: Types A and B

CarSim versions prior to 2017 had a “dynamic brake” option that included the pedal force input with booster, the volume/pressure method for handling actuator dynamics, and the thermal effects. It supported two options for linking to an external ABS controller: Type A and Type B. Type A had the controller before the proportioning valve and Type B had it after the valve.

To create a Type A controller for axle 1, export the master cylinder pressure `Pbk_Con` to Simulink and Import the delivery pressures `IMP_PLIN_L1` and `IMP_PLIN_R1` with the `REPLACE` mode.

To create a Type B controller for axle 1, export the delivery pressure `PbkD_L1` and `PbkD_R1` to Simulink and Import the controlled pressures `IMP_PCTL_L1`and `IMP_PCTL_R1` using the `REPLACE` mode.

Table 3. Output variables available for export.

Short Name	Units	Full Name
ABS_L1	-	ABS apply command, L1
ABS_R1	-	ABS apply command, R1
Bk_Boost	mm	Brake booster displacement
Bk_Pedal	mm	Brake pedal displacement
Bk_Stat	-	Brake apply status
FbkB_In	N	Brake input force before boost
FbkB_Out	N	Brake booster output force
F_Pedal	N	Brake pedal force
My_Bk_L1	N-m	Brake moment L1
My_Bk_R1	N-m	Brake moment R1
PbkCh_L1	MPa	Brake actuator pressure L1
PbkCh_R1	MPa	Brake actuator pressure R1
PbkD_L1	MPa	Delivery pressure, brake L1
PbkD_R1	MPa	Delivery pressure, brake R1
PbkL_L1	MPa	Line pressure, brake L1
PbkL_R1	MPa	Line pressure, brake R1
Pbk_Con	MPa	Brake control input (M/C)
Pctl_L1	MPa	Pressure from controller L1
Pctl_R1	MPa	Pressure from controller R1
T_Rtr_L1	C	Brake rotor L1 temperature
T_Rtr_R1	C	Brake rotor R1 temperature
Vbk_Tot	mm3	Total brake corner volume