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Trailer Hitches

CarSim and TruckSim support the option to link vehicle units together via hitches or other joints. Hitch forces and moments are used to connect the two adjoining vehicle units. Four types of connections are supported: (1) generic / fifth wheel, (2) ball or pintle, (3) a ball or pintle connected to a massless hinged tow bar in the trailing unit, and (4) an articulation system in the trailing unit with a turntable and separate pitch hinge that connects with the leading unit.

Hitch Locations

Hitch connections may be specified on one of several screens. In TruckSim, a trailing hitch location and linked dataset for hitch settings may be set on a **Vehicle: Lead Unit** screen (Figure 1).

Figure 1. Setting the hitch location for a TruckSim 3-axle lead unit.

A checkbox (1) is used to enable the addition of hitch data. When the box is checked, data fields for the hitch X-Y-Z coordinates in the vehicle sprung mass ((2), (3), (4)) are shown, along with a blue link (5) to a dataset that specifies properties of the hitch. The X location (2) is defined to be

the longitudinal distance behind the sprung mass coordinate system origin and is represented by the math model root keyword `LX_H`. Given that the X axis points forward, the X coordinate of the hitch is therefore `-LX_H`. The lateral coordinate (3) is defined with the keyword `Y_H`, and the height above the sprung mass coordinate system origin (Z coordinate (4)) is defined with the keyword `H_H`.

In CarSim, the hitch coordinates and dataset link are shown on the lead unit sprung mass screen (Figure 2). As with TruckSim, a checkbox (1) is used to show data fields for the X-Y-Z coordinates ((2), (3), (4)) relative to the sprung mass coordinate system origin (6). A corresponding blue link to a hitch dataset (5) has hitch properties. The math model keywords for the X-Y-Z coordinates ((2), (3), (4)) are the same for CarSim and TruckSim.

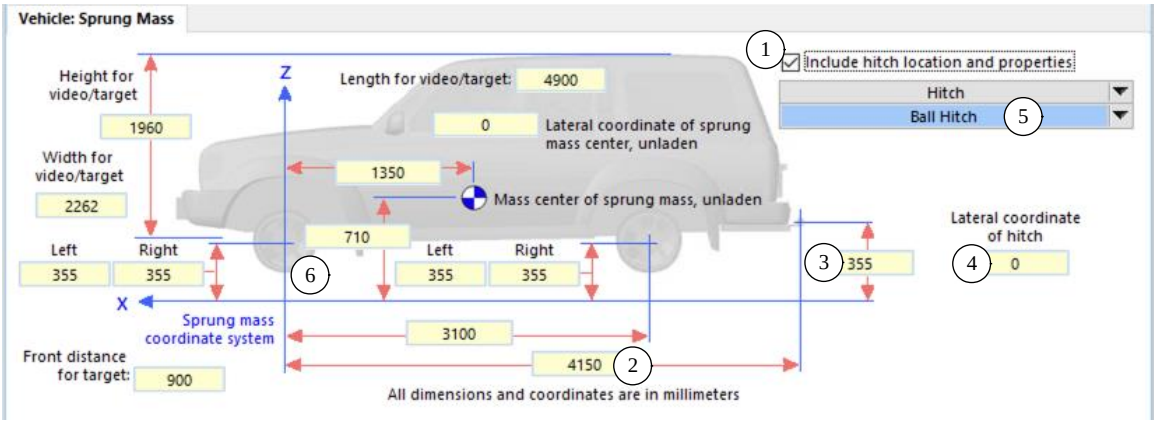

Figure 2. Setting the hitch location for a CarSim lead unit.

The number of hitches on a trailer differ between CarSim and TruckSim:

1. CarSim supports a single hitch connection between a trailer and tow vehicle. The hitch data are defined on the lead unit sprung mass screen (Figure 2) and the trailer connects to it. Trailers in CarSim cannot link to other trailers.
2. TruckSim supports a single hitch on the lead unit, and trailers support two hitches each:
    a. A mandatory front hitch links the trailer to the preceding vehicle unit. This might be the lead vehicle unit (tow vehicle) or another trailer.
    b. An optional second hitch may be used to connect with another trailer.

Given that trailers in CarSim and TruckSim cannot be used in a simulation without a lead vehicle unit, all trailers are required to have a defined hitch location in front, as shown in Figure 3 for CarSim. The hitch point (1) is shown as a vertical distance above the trailer sprung-mass coordinate system origin (2). It is set in the math model using the root keyword `H_H_FRONT`. For trailers and dollies that use a hinged tow bar or articulation system connection, a drop-down control is available (3).

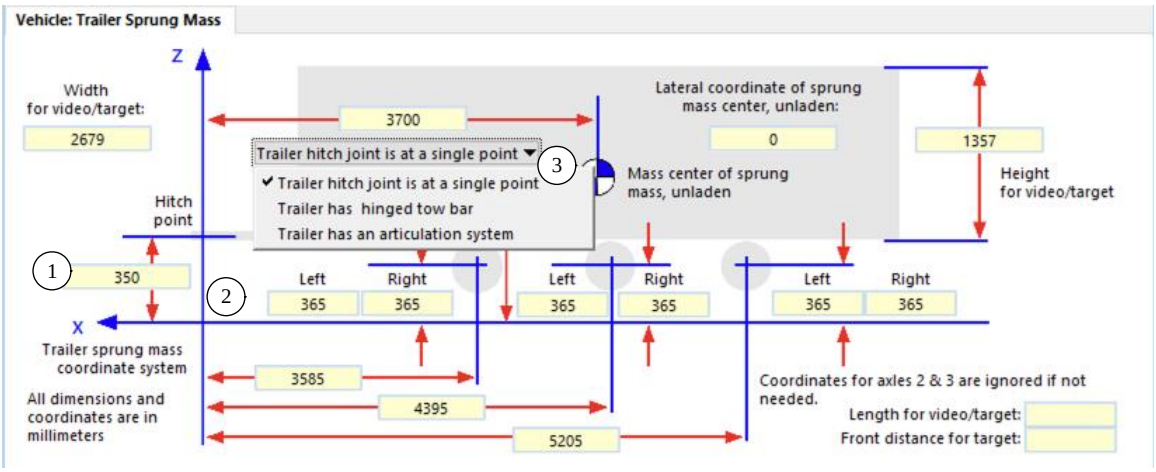

Figure 3: Height of hitch point for a CarSim trailer.

Hitch Connections

CarSim and TruckSim hitches connect vehicle units by providing three forces that act on the trailing unit to pull it (or push it, if reversing or going forward with a powertrain in the trailing unit), direct it laterally, and support it vertically.

Four types of joint connections are available, as specified by the command `OPT_HITCH_TYPE` and followed by a value of 1 - 4:

1. Generic hitches, configurated to represent fifth wheels used on heavy trucks and some pickup trucks. Along with the forces that tow a trailer, they include moments due to torsional springs, dampers, and friction. The moments may be disabled to represent ball and pintle hitches. Until the introduction of the `OPT_HITCH_TYPE` command in version 2022.0, all hitches in CarSim and TruckSim behaved in this manner.

2. Ball hitches are used in most passenger car and light truck applications. Pintle hitches are used when a fifth-wheel hitch is not practical, but the trailer loads exceed the design capabilities of ball hitches. (The VS Math Models do not include load limits, and therefore ball and pintle hitches are both handled by the setting: `OPT_HITCH_TYPE` = 2.) These hitches provide forces to pull and support the trailer but otherwise do not have torsional springs or friction to resist rotation.

3. Ball and pintle hitches may tow trailers with hinged tow bars. The hinged tow bar nearly eliminates vertical load applied to the leading unit. This type of connection requires an additional parameter for the length of the tow bar.

4. Articulated busses use articulation systems that have a turntable built into the front of the trailing unit, with a structure that connects to the leading unit with a hinge in front of the turntable. The hinge allows pitch, such that the front part of the connection follows the yaw of the lead unit but has the pitch angle of the trailer. The rest of the trailer articulates at the turntable.

Figure 4 shows the parameters needed for the simplest type of hitch: the ball / pintle hitch. In this case, the hitch provides forces necessary to connect two vehicle units but otherwise does not

provide any moments. In addition to the type, the location of the hitch in the leading unit is specified with the three coordinates: H_H, LX_H, and Y_H. The stiffness and damping coefficients are calculations from parameters HITCH_FREQ and HITCH_ZETA, as described in the next subsection.

LastRun_ECHO.PAR #

```
214 !-------------------------------------------------------------------------------------
215 ! HITCH
216 !-------------------------------------------------------------------------------------
217 ! Hitches can apply rotational damping and friction to resist pitch, roll, and
218 ! articulation. Also, the Configurable Functions MX_HITCH, MY_HITCH, and MZ_HITCH
219 ! apply resisting moments as nonlinear functions of the hitch rotation angles.
220
221 OPT_HITCH_TYPE      2 ! Type of hitch: 1 -> generic (5th wheel or ball/pintle), 2 ->
222                       ! simple ball or pintle, 3 -> hinged tow bar, 4 ->
223                       ! Articulation system [I]
224 ! FZH_L   3690.078393 ; N ! CALC -- Static load, laden vehicle, hitch
225 ! FZH_UL  2368.021482 ; N ! CALC -- Static load, unladen vehicle, hitch
226 HITCH_FREQ         40 ; Hz ! [D] Natural frequency of XYZ springs in hitch [I]
227 HITCH_ZETA        0.1 ; - ! [D] Damping ratio of XYZ dampers in hitch [I]
228 H_H               355 ; mm ! Hitch point height (Z coord.), sprung mass [I]
229 LX_H             4150 ; mm ! X dist. hitch is behind sprung mass origin [I]
230 Y_H                 0 ; mm ! Y coordinate, hitch point [I]
```

Figure 4. Hitch data for a simple ball or pintle hitch.

The keyword OPT_HITCH_TYPE applies a command that sets the value of a companion parameter shown in the Echo file. Output variables associated with the hitch are created when the OPT_HITCH_TYPE command is processed. Hitches of type 1 and 4 include moments that do not exist for types 2 and 3. Types 3 and 4 include outputs related to the hinged tow bar (type 3) or articulation rotation point (type 4) that do not exist with other hitch types. The parameters, output variables, and import variables for the four hitch types are listed in tables in a later section (page 21).

Once a hitch type has been set to 3 or 4, additional output variables are created, and it cannot be changed again; attempting to do so will generate an error message and stop the run. On the other hand, if the hitch type is set to 2 (simple ball or pintle hitch), the type may be changed later to a type 3 (ball joint plus linked tow bar). If set to 1 (generic hitch with three moments associated with three rotation angles), it may be changed to 4 (articulation system with the same three moments).

The capability of changing the value of OPT_HITCH_TYPE to 3 or 4 is supported because these hitches require information associated with the trailer sprung mass that is typically specified on a sprung mass screen (e.g., (3), Figure 3, page 3), whose settings are typically read by the VS Math Model after the hitch location parameters were set from a dataset for the leading unit (e.g., Figure 1 and Figure 2).

Hitch Forces (All Hitch Types)

Every hitch in CarSim or TruckSim includes three sets of springs and dampers that connect the trailing trailer unit to a leading unit. The stiffness and damping coefficients are calculated based on two parameters listed in Figure 4:

1. HITCH_FREQ (a target natural frequency of the connected sprung mass bodies based on their inertia and hitch spring stiffness), and

2. `HITCH_ZETA` (damping ratio for the connected bodies).

The three translational forces are oriented in the X-Y-Z axis directions of the trailing unit sprung mass and are based on relative displacement and rate of displacement in the same directions. Displacements are defined as the distance between the hitch points in the two connected sprung masses, and they're often less than a millimeter.

The hitch model is intended to provide a nearly rigid constraint without causing numerical instability. If a combination vehicle model is unstable (a rare occurrence), the frequency and damping may be adjusted to improve performance.

Figure 5 shows plots of hitch X, Y, and Z forces and deflections for the ball hitch specified in the Echo file from Figure 4. In this simulation, the vehicle is travelling at a steady speed up an 8% grade. The forces act on the towed trailer, with a positive X force pulling it forward, and a positive Z force supporting it vertically. Notice that the deflections in all three directions are less than a millimeter.

Figure 5. Plots showing hitch deflections and forces for a ball hitch.

The distances between the two points of the hitch are defined using a 3D position vector connecting the hitch point on the leading unit to the corresponding point on the trailing unit. The deflections are X-Y-Z components of the distance vector, made using the coordinate system of the trailing body. This generates a negative X deflection when the towed point is behind the towing point, and a negative Z deflection when the towed point is lower than the towing point.

Hitch Moments from Springs, Dampers, and Friction

Most heavy truck combinations use fifth-wheel hitches (Figure 6) to support large loads from the front end of a connected semi-trailer. The hitch allows large articulation angles about the Z axis, with limited pitch about the Y axis. The hitch is intended to provide significant resistance to roll about the X axis, such that the axles on the lead unit contribute a resisting roll moment to the trailer.

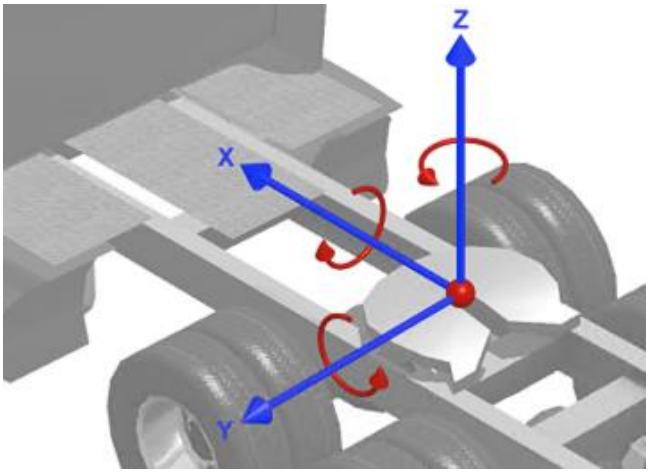

Figure 6. Fifth wheel hitch often used for heavy truck combinations.

When OPT_HITCH_TYPE is set to 1, the hitch model includes Configurable Functions to generate resistance to pitching, rolling, and articulation angle (i.e., a resisting moment vs. angular rotation about the respective axis). The joints are fixed in the leading vehicle unit containing the fifth wheel hitch, and the kingpin that connects to the fifth wheel is rigidly attached to the semi-trailer being towed. To represent this geometry in the VS Math Model, the hitch rotation angles are defined with the following sequence:

1. Rotate about the Y axis of the leading unit (also called axis 2).
2. Next, rotate about the pitched X axis of the hitch (axis 1).
3. Finally, rotate about the Z axis of the hitch, which is also the Z axis of the trailing unit (axis 3).

This rotation sequence is sometimes called a 2-1-3 sequence and the hitch model includes moments based on the 2-1-3 angles. The sequence is mentioned here because it differs from the 3-2-1 (yaw-pitch-roll) convention specified by ISO and SAE to orient vehicle sprung masses.

Figure 7 shows the Hitch section of an Echo file for a vehicle model that uses a fifth-wheel hitch. It includes the parameters shown earlier for the ball/pintle type of hitch (Figure 4), and adds parameters and tables needed to calculate hitch moments.

Each hitch moment has three components:

1. A moment from a Configurable Function based on a hitch angle. As shown in the comments, these functions are named MX_HITCH, MY_HITCH, and MZ_HITCH.
2. Friction added to the moment, with a value specified with the parameters HITCH_FRIC_X, HITCH_FRIC_Y, and HITCH_FRIC_Z along with reference angles described in a following subsection (page 8).
3. Linear damping added to the moment, calculated by multiplying the angular rotation rate with the coefficients HITCH_DMP_X, HITCH_DMP_Y, and HITCH_DMP_Z.

```
!-------------------------------------------------------------------------------
! Hitches can apply rotational damping and friction to resist pitch, roll, and
! articulation. Also, the Configurable Functions MX_HITCH, MY_HITCH, and MZ_HITCH
! apply resisting moments as nonlinear functions of the hitch rotation angles.

OPT_HITCH_TYPE(1)    1 ! Type of hitch: 1 -> generic (5th wheel or ball/pintle), 2 ->
                       ! simple ball or pintle, 3 -> hinged tow bar, 4 ->
                       ! Articulation system [I]
! FZH_L(1) 73979.38144 ; N ! CALC -- Static load, laden vehicle, hitch 1
! FZH_UL(1) 30723.36551 ; N ! CALC -- Static load, unladen vehicle, hitch 1
HITCH_DMP_X(1)       0 ; N-m-s/deg ! [D] Roll damping coefficient, hitch 1
HITCH_DMP_Y(1)       0 ; N-m-s/deg ! [D] Pitch damping coefficient, hitch 1
HITCH_DMP_Z(1)       0 ; N-m-s/deg ! [D] Articulation damping coefficient, hitch 1
HITCH_FRIC_X(1)      0 ; N-m ! [D] Roll friction, hitch 1
HITCH_FRIC_Y(1)      0 ; N-m ! [D] Pitch friction, hitch 1
HITCH_FRIC_Z(1)      0 ; N-m ! [D] Articulation friction, hitch 1
HITCH_FREQ(1)       40 ; Hz ! [D] Natural frequency of XYZ springs in hitch 1 [I]
HITCH_ZETA(1)      0.1 ; - ! [D] Damping ratio of XYZ dampers in hitch 1 [I]
H_H(1)            1100 ; mm ! Hitch point height (Z coord.), sprung mass [I]
LX_H(1)           4135 ; mm ! X dist. hitch is behind sprung mass origin [I]
Y_H(1)               0 ; mm ! Y coordinate, hitch point [I]
```

Figure 7. Echo file for fifth-wheel hitch in a heavy truck combination vehicle.

Figure 8 shows a video image and plots from the same simulation used to generate the Echo file from Figure 7. The hitch provides large forces for supporting the trailer vertically and directing it laterally.

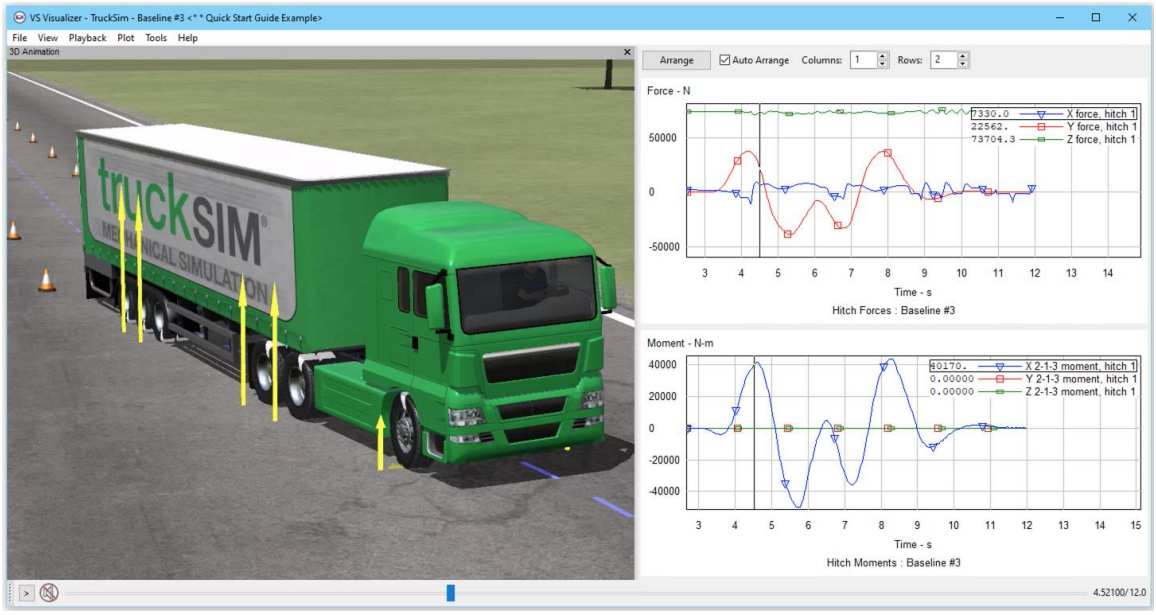

Figure 8. Video and plots for combination vehicle with fifth-wheel hitch.

The plots of moments show that one of the hitch moments (X 2-1-3) is significant, coupling the roll of the trailer to that of the leading tractor. The other two hitch moments (with 2-1-3 in the labels) are zero. The plots also show a second set of moments that are applied from the trailer to the hitch, in the axis directions of the trailer's sprung mass coordinate system, and which differ from those of the hitch for the X and Y directions. Note that the moment about the trailer X-axis has a slightly smaller magnitude than the moment about the hitch X-axis, and that the moment about the trailer Y-axis is not zero. This is due to the trailer Y-axis not being oriented in the same direction as the hitch Y-axis.

Fifth-wheel hitches often have significant lash that can be represented with nonlinear tables in CarSim and TruckSim, as described in a later subsection (page 16).

Fifth-Wheel Roll Moments with Frame twist

Trailer hitch properties include the combined effects of components on the leading and trailing vehicle units. The moments at the hitch are typically measured by rolling the trailer. Deflection due to frame twist occurs at both connections of the hitch (i.e., both vehicle units) so a convention is needed to define the hitch angle. In CarSim and TruckSim without frame twist, the hitch angle is always defined as the difference in rigid body angles for the two units on either side of the hitch.

For hitch roll in the frame twist model, two definitions of hitch roll angle are available.

1. The default definition of hitch roll is the same without frame twist: the difference between the roll angles at the longitudinal locations of the respective torsional node points for the two units.
2. The hitch roll deflection is modified to account for the local roll angle introduced by twist of the chassis (leading and trailing) at the location of the hitch. This option is enabled with a checkbox on the Hitch screens, as shown in Figure 16 (page 13) and Figure 17 (page 15).

Hitch Friction and Damping

The friction and damping properties available for a hitch are shown again in the Echo file in Figure 9, for a simulation where they are given non-zero values.

```
!-------------------------------------------------------------------------------
! HITCHES
!-------------------------------------------------------------------------------
! Hitches can apply rotational damping and friction to resist pitch, roll, and
! articulation. Also, the Configurable Functions MX_HITCH, MY_HITCH, and MZ_HITCH
! apply resisting moments as nonlinear functions of the hitch rotation angles.

OPT_HITCH_TYPE(1)    1 ! Type of hitch: 1 -> generic (5th wheel or ball/pintle), 2 ->
                       ! simple ball or pintle, 3 -> hinged tow bar, 4 ->
                       ! Articulation system [I]
BETA_LE_X(1)       0.1 ; deg ! Reference hysteretic negative roll at hitch 1
BETA_LE_Y(1)       0.1 ; deg ! Reference hysteretic negative pitch at hitch 1
BETA_LE_Z(1)       0.1 ; deg ! Ref. hysteretic negative articulation at hitch 1
BETA_UE_X(1)       0.1 ; deg ! Reference hysteretic positive roll at hitch 1
BETA_UE_Y(1)       0.1 ; deg ! Reference hysteretic positive pitch at hitch 1
BETA_UE_Z(1)       0.1 ; deg ! Ref. hysteretic positive articulation at hitch 1
! FZH_L(1) 22663.04756 ; N ! CALC -- Static load, laden vehicle, hitch 1
! FZH_UL(1) 10041.99404 ; N ! CALC -- Static load, unladen vehicle, hitch 1
HITCH_DMP_X(1)       5 ; N-m-s/deg ! Roll damping coefficient, hitch 1
HITCH_DMP_Y(1)       5 ; N-m-s/deg ! Pitch damping coefficient, hitch 1
HITCH_DMP_Z(1)       5 ; N-m-s/deg ! Articulation damping coefficient, hitch 1
HITCH_FRIC_X(1)    100 ; N-m ! Roll friction, hitch 1
HITCH_FRIC_Y(1)    100 ; N-m ! Pitch friction, hitch 1
HITCH_FRIC_Z(1)    100 ; N-m ! Articulation friction, hitch 1
HITCH_FREQ(1)       40 ; Hz ! [D] Natural frequency of XYZ springs in hitch 1 [I]
HITCH_ZETA(1)      0.1 ; - ! [D] Damping ratio of XYZ dampers in hitch 1 [I]
H_H(1)            1100 ; mm ! Hitch point height (Z coord.), sprung mass [I]
LX_H(1)           4020 ; mm ! X dist. hitch is behind sprung mass origin [I]
Y_H(1)               0 ; mm ! Y coordinate, hitch point [I]
```

Figure 9. Echo file for vehicle with gooseneck trailer.

When the friction levels `HITCH_FRIC_xyz` are given non-zero values (where *xyz* is `X`, `Y`, or `Z`), two additional parameters are shown for each axis: `BETA_LE_xyz` and `BETA_UE_xyz`. The `BETA`

parameters are spatial equivalents of time constants, used to characterize friction in CarSim and TruckSim. A BETA angle is about 1/3 of the angle needed to travel through a torsional spring hysteresis (friction) loop when the rotation angle is changing. The BETA_LE_*xyz* parameters apply when the angle is decreasing towards a lower envelope (LE) and the BETA_UE_*xyz* parameters apply when the angle is increasing towards an upper envelope (UE).

Figure 10 shows results from the same simulation used to make the Echo file. The friction effects are clearly seen in the lower-right plot showing roll moment vs. roll angle. The value of 0.1° for the BETA parameters specify that the torsional friction requires a change of about 0.3° to cross the hysteresis loop, which covers a range of 200 N-m (twice the friction level of 100 N-m).

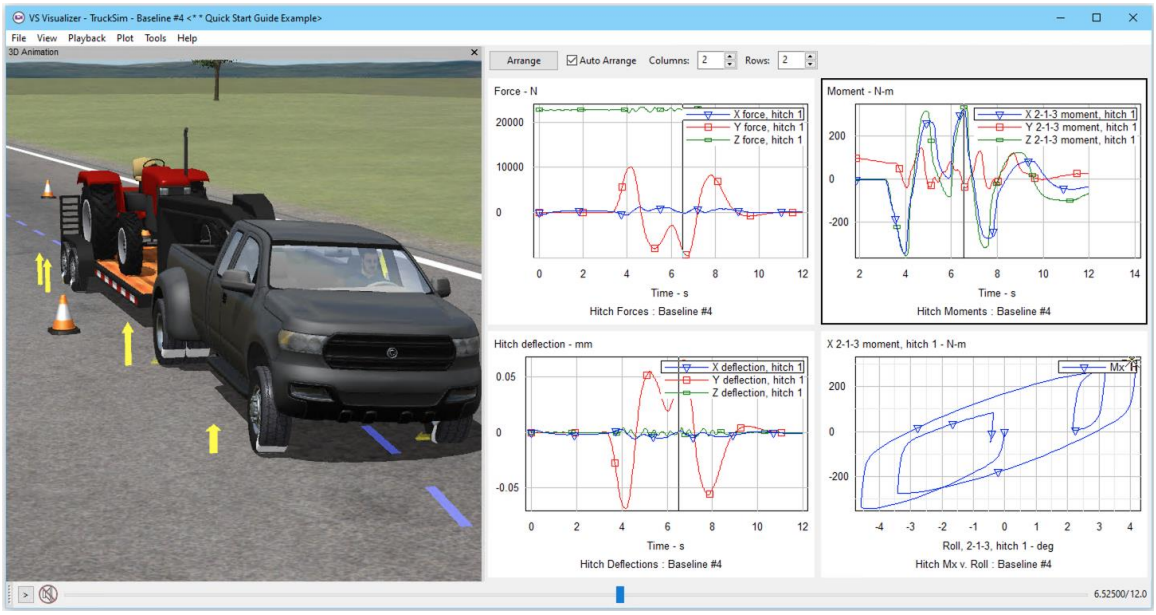

Figure 10. Gooseneck hitch with friction and damping.

Trailers with Hinged Tow Bars

Some dollies and other trailers have a hinged tow bar, a mechanism that greatly reduces the vertical load supported by a ball or pintle hitch in the leading vehicle unit. In a VS Math Model, the tow bar is massless, eliminating the vertical load (perpendicular to the pitch of the tow bar) on the hitch point. Figure 11 shows an example where a two-axle dolly has a hinged tow bar.

The CarSim and TruckSim Math Models include the calculations for the tow-bar motion within the hitch calculations when OPT_HITCH_TYPE = 3. The hitch information includes the length of the tow bar, defined with the parameter LEN_TOW_BAR (Figure 12) and set on the trailer's sprung mass screen (Figure 24, page 18). The hinge for the tow bar is located at the user-specified hitch height for the trailer's sprung mass (Figure 3, page 3, (1)).

In the Echo file, notice that the parameter LEN_TOW_BAR is identified as having an index of 2, thereby associating it with the 2nd sprung mass body (i.e., the dolly) in the vehicle combination as shown in Figure 11. The dolly has two hitch points: the leading hitch (hitch 1, OPT_HITCH_TYPE = 3) and a fifth-wheel hitch that connects it to the trailing semi-trailer (hitch 2, OPT_HITCH_TYPE = 1). (More information on vehicle and hitch indexing is in a later section, page 20.)

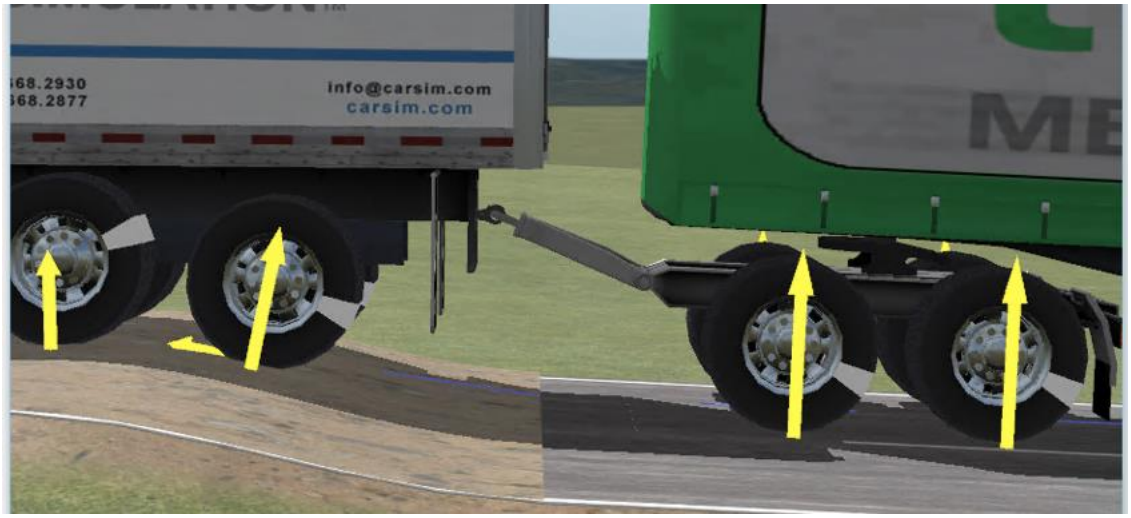

Figure 11. Dolly with hinged tow bar.

```
!-------------------------------------------------------------------------------
! HITCHES
!-------------------------------------------------------------------------------
! Hitches can apply rotational damping and friction to resist pitch, roll, and
! articulation. Also, the Configurable Functions MX_HITCH, MY_HITCH, and MZ_HITCH
! apply resisting moments as nonlinear functions of the hitch rotation angles.

OPT_HITCH_TYPE(1)    3 ! Type of hitch: 1 -> generic (5th wheel or ball/pintle), 2 ->
                       ! simple ball or pintle, 3 -> hinged tow bar, 4 ->
                       ! Articulation system [I]
! FZH_L(1)           0 ; N ! CALC -- Static load, laden vehicle, hitch 1
! FZH_UL(1)          0 ; N ! CALC -- Static load, unladen vehicle, hitch 1
HITCH_FREQ(1)       40 ; Hz ! [D] Natural frequency of XYZ springs in hitch 1 [I]
HITCH_ZETA(1)      0.1 ; - ! [D] Damping ratio of XYZ dampers in hitch 1 [I]
H_H(1)             835 ; mm ! Hitch point height (Z coord.), sprung mass [I]
LEN_TOW_BAR(2)    1000 ; mm ! Length of tow bar [I]
LX_H(1)           7800 ; mm ! X dist. hitch is behind sprung mass origin [I]
Y_H(1)               0 ; mm ! Y coordinate, hitch point [I]

OPT_HITCH_TYPE(2)    1 ! Type of hitch: 1 -> generic (5th wheel or ball/pintle), 2 ->
                       ! simple ball or pintle, 3 -> hinged tow bar, 4 ->
                       ! Articulation system [I]
! FZH_L(2) 55302.05791 ; N ! CALC -- Static load, laden vehicle, hitch 2
! FZH_UL(2) 30723.36551 ; N ! CALC -- Static load, unladen vehicle, hitch 2
HITCH_DMP_X(2)       0 ; N-m-s/deg ! [D] Roll damping coefficient, hitch 2
HITCH_DMP_Y(2)       0 ; N-m-s/deg ! [D] Pitch damping coefficient, hitch 2
```

Figure 12. Echo file a dolly with a hitched tow bar and fifth wheel.

Articulated Busses

Articulated busses have two or more vehicle units connected with joints that allow articulation in yaw, and usually allow pitch between the two units. Relative roll is restricted with stiffness. If the rotations of pitch and articulation angle are near each other, the generic fifth-wheel joint (`OPT_HITCH_TYPE` = 1) represent the behavior properly. However, in some cases, the rotation center for pitch is located some distance in front of the articulation point to reduce the vertical space needed for the physical connection parts. In these cases, `OPT_HITCH_TYPE` can be set to 4 to enable the articulation system type of connection. This is like the hinged towbar in several ways:

1. It adds a length parameter (`LX_ART`) for the distance between two rotation points.

2. The option is set from the trailer sprung-mass screen with the same drop-down menu used to possibly specify the hinged tow bar, but in this case used to choose the articulation system (3) (Figure 13).
3. Selecting this option displays a yellow field for the distance parameter (4).

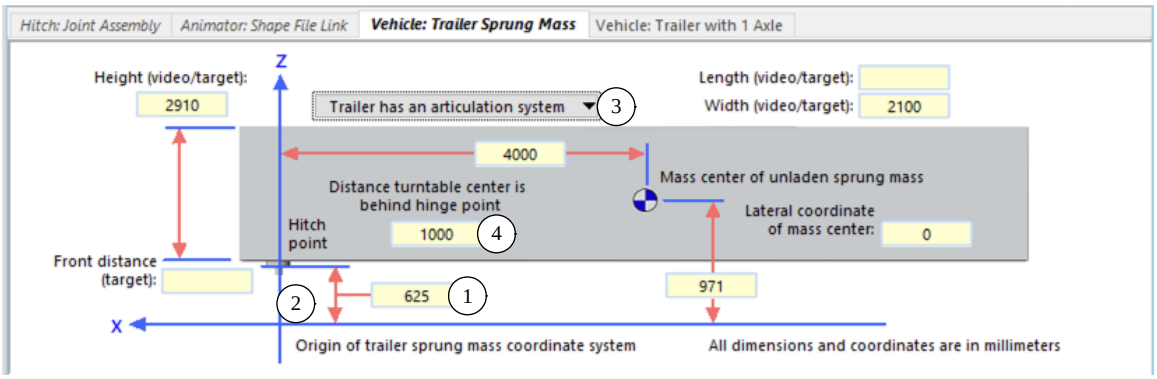

Figure 13. Use the trailer sprung-mass screen to specify an articulation system.

Articulation systems are often not visible in articulated busses (Figure 14).

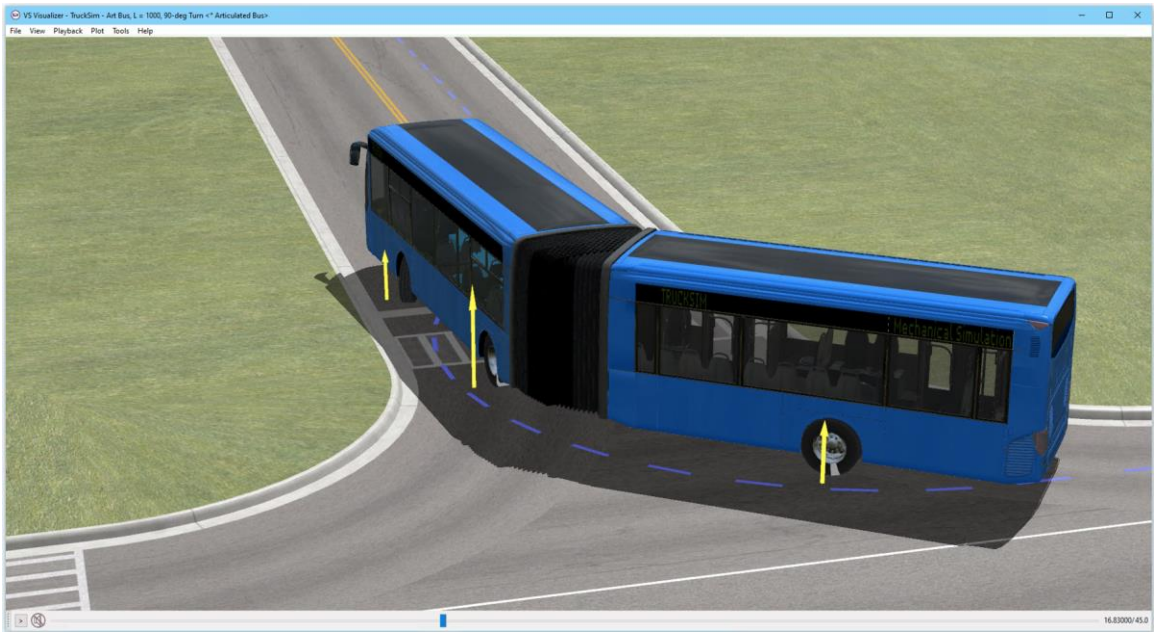

Figure 14. Articulated bus with a bellows surrounding the joint.

Figure 15 shows two animations with simple shapes to show points of interest in an articulated bus. In this figure, the two rotation points in the articulation system are shown with two spheres connected by a gray cylinder:

1. The blue sphere is at the joint point in the leading unit, which is a hinge that allows pitch (see the left-side image in the figure).

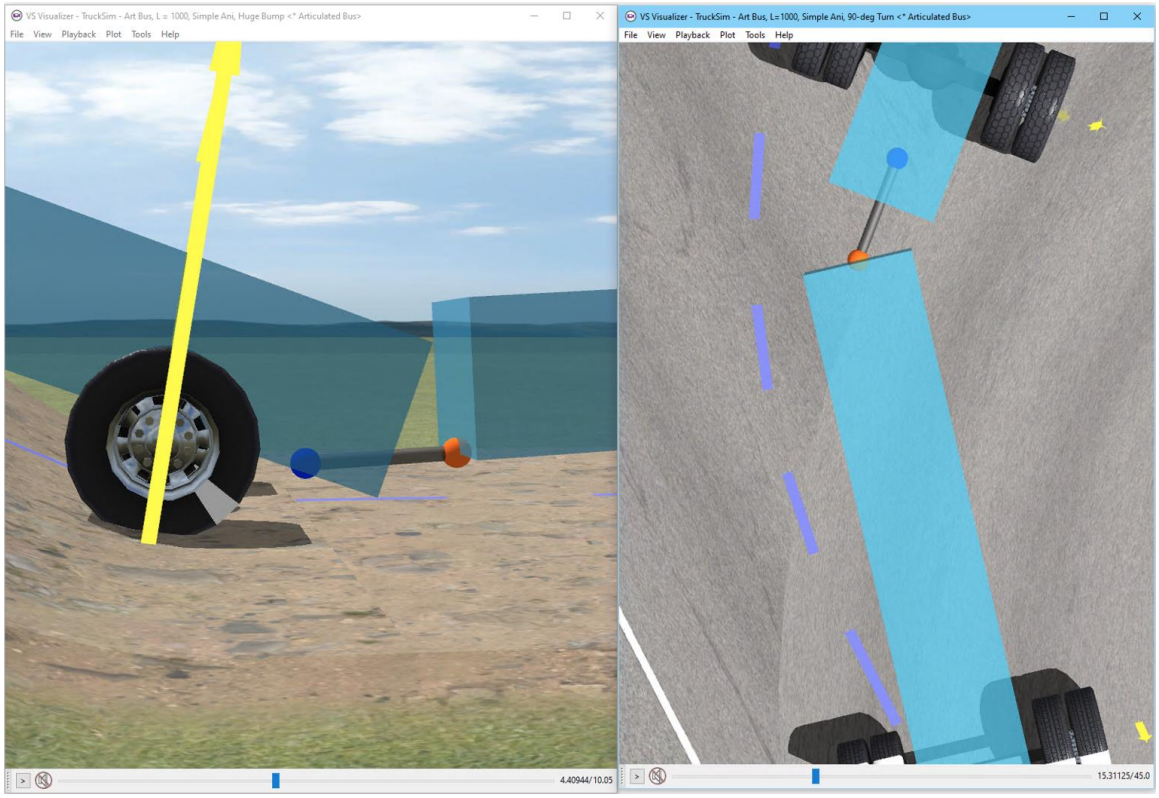

Figure 15. Side view showing large hitch pitch and top view showing large hitch articulation.

2. The orange sphere is at the center of a turntable that allows articulation (see the right-side image in the figure).

Hitch Library Screens

Two library screens are available to define hitch properties. Both make use of the same internal hitch module in VS Math Models, and both support the use of nonlinear Configurable Functions to define Pitch, Roll, and Yaw moments as functions of the corresponding angles for the case of fifth-wheel or articulation systems (i.e., when `OPT_HITCH_TYPE` = 1 or 4). In addition, each moment may include a linear damping proportional to angular rate, and a hysteretic angular friction defined with a friction level and characteristic "beta" angle.

Both screens include an option to use the simpler ball or pintle hitch (`OPT_HITCH_TYPE` = 2), and both screens include a link to an animation dataset that shows the hitch visually as an object attached to the leading unit.

Hitch: Joint Assembly Library

Use this screen (Figure 16) to specify non-linear relationships between the resisting moments and angles of rotation directly using tables (e.g., Figure 22, page 17).

This screen may also be used to specify a ball/pintle joint, in which case controls related to calculating hitch moments are hidden.

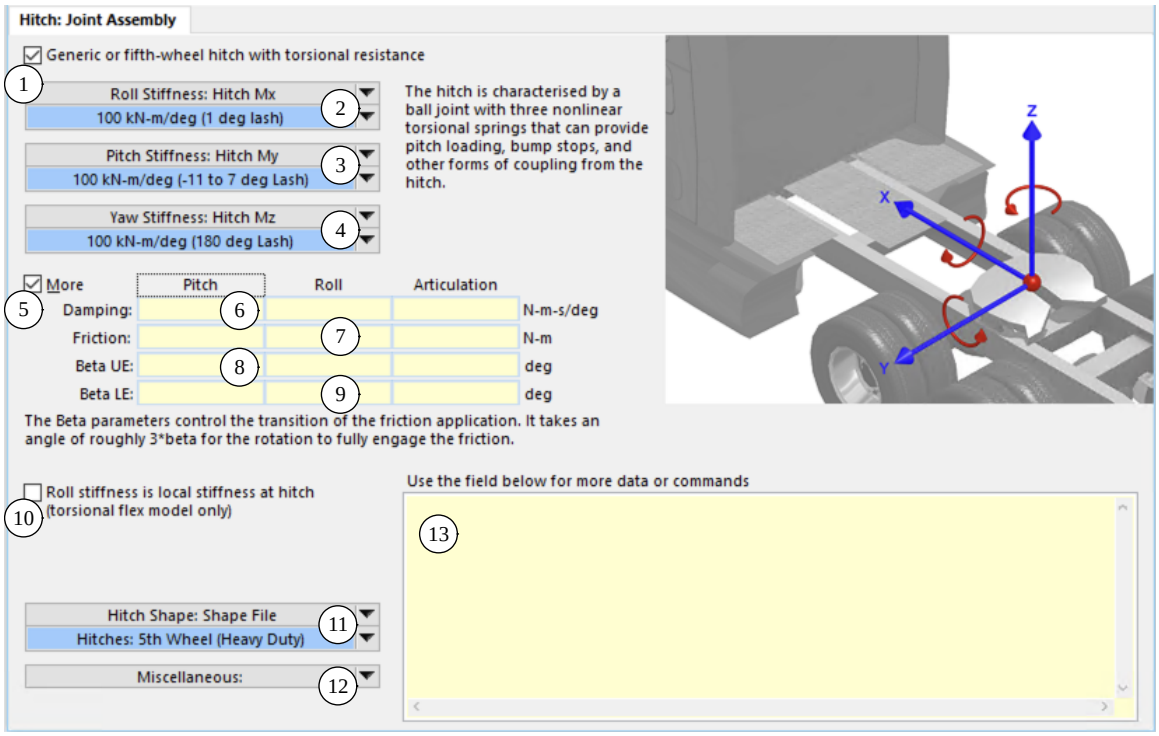

Figure 16. The Hitch Joint Assembly screen.

1 Checkbox to indicate the hitch is a fifth-wheel or articulation system. When checked, the three blue links are visible (2, 3, 4) along with two other checkboxes (5 and 10). The parameter `OPT_HITCH_TYPE` (shown in the Hitch section of the Echo file) is set to 1.

When unchecked, `OPT_HITCH_TYPE` is set to 2, indicating that the hitch is a ball or pintle (possibly with a hinged tow bar on the trailing unit) that will not resist rotations. In this case, controls 2 - 10 are hidden.

If the trailer that is to be connected to this hitch will have a hinged tow bar, the box should be unchecked. The dataset from the semitrailer will change `OPT_HITCH_TYPE` from 2 to 3, as described in a later subsection (page 18).

If the trailer that is to be connected to this hitch will have an articulation system, the box should be checked, and appropriate settings should be made involving the torsional springs and dampers. The dataset from the semitrailer will change `OPT_HITCH_TYPE` from 1 to 4, as described in a later subsection (page 19).

2 Link to a Configurable Function dataset that defines a relationship between hitch roll moment and roll angle, such as the example shown later in Figure 22 (page 17). The root name for this function is `MX_HITCH`.

3 Link to a Configurable Function dataset that defines a relationship between hitch pitch moment and pitch angle. The root name for this function is `MY_HITCH`.

4 Link to a Configurable Function dataset that defines a relationship between hitch articulation moment and articulation angle. The root name for this function is `MZ_HITCH`.

(5) **More** checkbox. Check to view more parameters: (6) - (9). This option is available only when the first checkbox (1) is checked.

(6) Torsional damping coefficients for each rotation axis (keywords = `HITCH_DMP_X`, `HITCH_DMP_Y`, `HITCH_DMP_Z`).

(7) Torsional friction about each rotation axis (keywords = `HITCH_FRIC_X`, `HITCH_FRIC_Y`, `HITCH_FRIC_Z`).

(8) Beta parameters for approaching the upper friction limits when the friction torque goes from negative to positive (keywords = `BETA_UE_X`, `BETA_UE_Y`, and `BETA_UE_Z`). These are approximately 1/3 the angle needed to travel through a torsional spring hysteresis (friction) loop when the rotation angle is increasing.

(9) Beta parameters for approaching the lower friction limits when the friction torque goes from positive to negative (keywords = `BETA_LE_X`, `BETA_LE_Y`, and `BETA_LE_Z`). These are approximately 1/3 the angle needed to travel through a torsional spring hysteresis (friction) loop when the rotation angle is decreasing.

(10) Checkbox to enable the alternate use of relative roll for use with models that have frame twist, as described earlier (page 8, Keyword = `OPT_ROLL_HITCH`). This option is used under the following conditions: (1) the first checkbox (1) is checked, and (2) it applies for simulations with the frame twist feature enabled on the License Settings window (**Tools** > **License Settings**. The frame twist feature is available as an extra license option in CarSim and TruckSim).

(11) Link to an animator shape file to show the hitch in animations using VS Visualizer. The shape is located based on the user-specified X-Y-Z coordinates of the hitch (Figure 1, Figure 2).

(12) **Miscellaneous** link. This has no predefined purpose but can be linked to a dataset that specifies parameters for extensions to the model or information for the animator. The data for this link applies to the current hitch and/or sprung mass containing the hitch.

(13) Miscellaneous yellow field, used to specify parameters and variables defined with VS Commands.

Hitch: Parameters Screen

As an alternative to describing the hitch's roll, pitch, and yaw stiffnesses directly via tables in the GUI, the hitch may instead be described with parameters used to automatically build the nonlinear tables for the three moments. The **Hitch: Parameters** screen (Figure 17) has all the controls shown on the **Hitch: Joint Assembly** screen, except for the three links to the hitch moment Configurable Functions (Figure 16, (2), (3), (4)). These are replaced with parameters ((14) - (17)) used to build the tables automatically. For example, Figure 18 shows the three hitch moment tables written for the dataset shown in Figure 17.

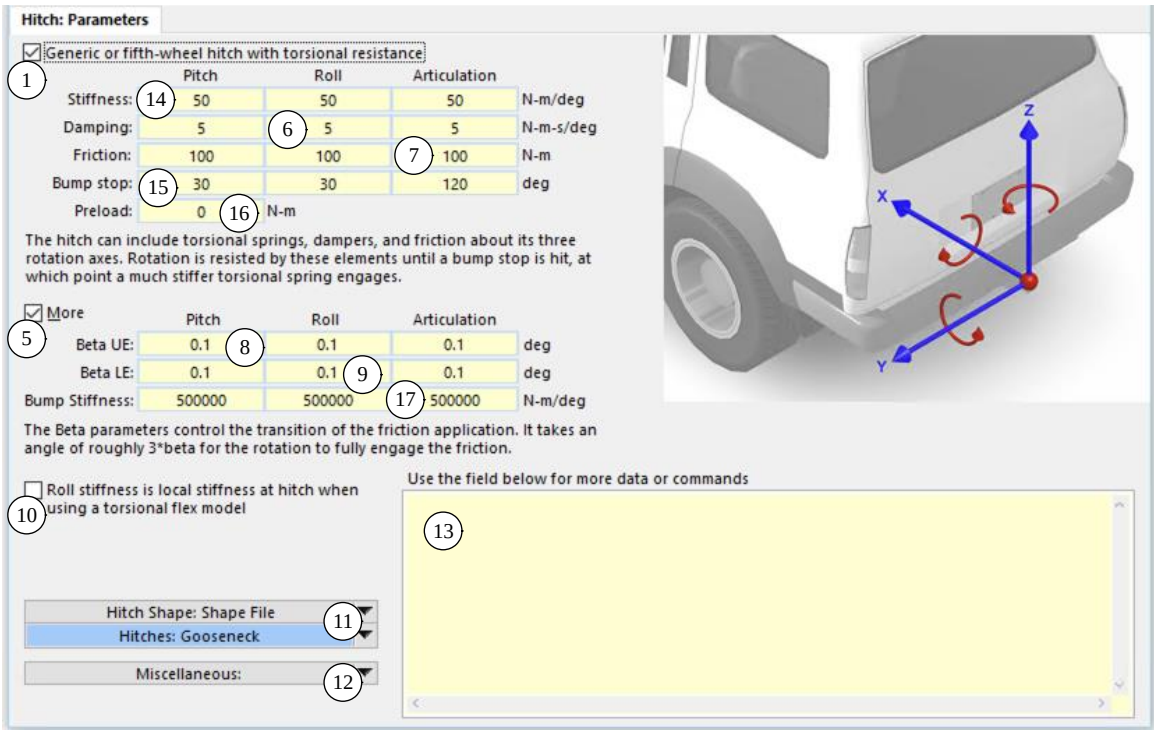

Figure 17. The Hitch: Parameters screen.

```
*STOP_Z 120
HITCH_FRIC_Y 100
HITCH_FRIC_X 100
HITCH_FRIC_Z 100
BETA_UE_Y 0.1
BETA_UE_X 0.1
BETA_UE_Z 0.1
BETA_LE_Y 0.1
BETA_LE_X 0.1
BETA_LE_Z 0.1
*BUMP_Y 500000
*BUMP_X 500000
*BUMP_Z 500000
*PRELOAD 0

MY_HITCH_TABLE LINEAR
-31, -501500
-30, -1500
30, 1500
31, 501500
ENDTABLE

MX_HITCH_TABLE LINEAR
-31, -501500
-30, -1500
30, 1500
31, 501500
ENDTABLE

MZ_HITCH_TABLE LINEAR
-121, -506000
-120, -6000
120, 6000
121, 506000
ENDTABLE
```

Figure 18. Tables written automatically using parameters from the dataset shown in Figure 17.

The following parameters are unique to the **Hitch: Parameters** screen.

(14) Nominal torsional spring stiffness values about each rotation axis. These linear spring rates apply until the specified bump stops are reached (15).

(15) Bump stop limit for each rotation axis. When the rotation reaches this limit, a much stiffer spring (17) engages to limit further rotation.

(16) Pitch moment pre-load. This moment always exists about the pitch (Y) axis. It is usually positive, distributing some of the hitch load to the front wheels of the towing vehicle and is used to generate the pitch moment table `MY_HITCH_TABLE` as shown in Figure 18.

(17) Bump-stop torsional spring stiffness values about each rotation axis. These linear spring rates apply after the specified bump stops are reached (15).

Fifth-Wheel Lash

With a heavy truck combination vehicle, the trailer sits on a fifth-wheel plate attached to the tractor or possibly a leading trailer or dolly. A kingpin attached to the trailer projects vertically through a hole in the center of the fifth wheel (Figure 19), while a flange on the bottom of the kingpin prevents the trailer from pulling up and out of the fifth wheel.

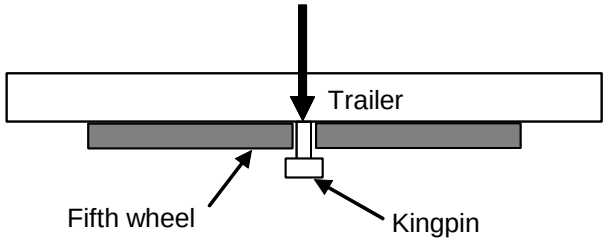

Figure 19. Loading of fifth-wheel hitch in the nominal condition.

Under the influence of lateral acceleration, the trailer experiences a roll moment that's applied to the fifth wheel. The effect is to shift the position of the trailer loading force in the lateral direction (Figure 20) away from the center of the fifth wheel's mating surface.

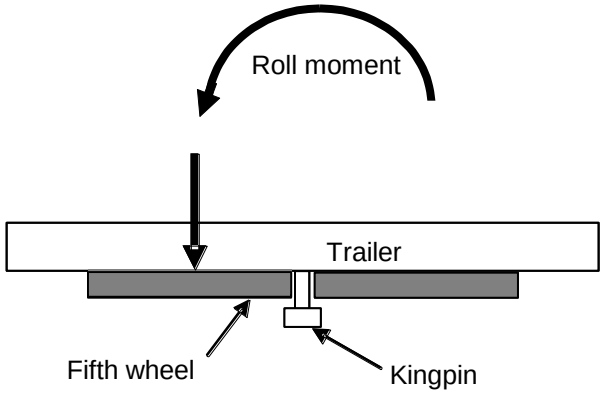

Figure 20. Loading of fifth-wheel hitch under the influence of lateral acceleration.

When the roll moment generated by the lateral acceleration becomes large enough to shift the trailer's vertical load to the edge of the fifth wheel, the trailer can tip and contact the edge of the fifth-wheel's mating surface (Figure 21). Under these conditions the trailer is free to move through the lash in the fifth-wheel coupling, equivalent to about 1 or 2 degrees. This behavior can be captured in CarSim and TruckSim using the Configurable Function for **Hitch: Roll Moment** (Keyword = `MX_HITCH`, Figure 22).

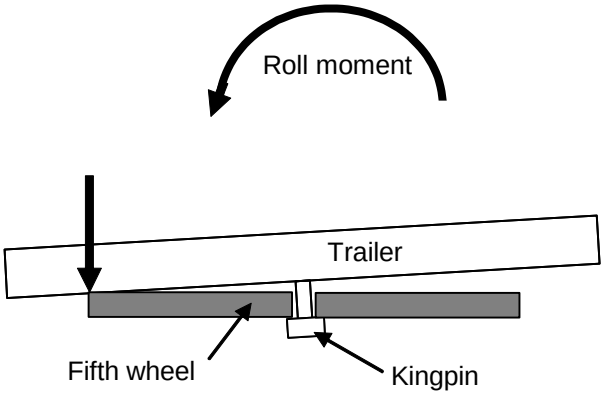

Figure 21. Tipping through lash.

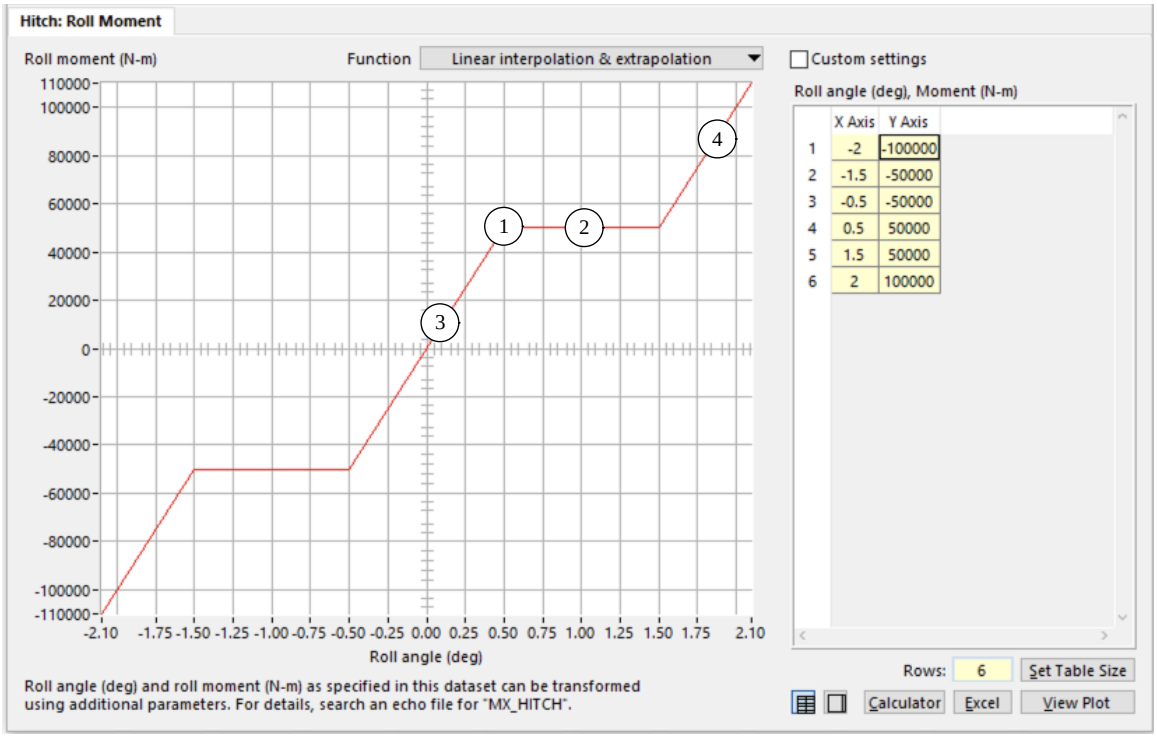

Figure 22: A typical Roll Stiffness dataset for a fifth wheel.

The magnitude of the moment is the hitch load multiplied by half the fifth-wheel width in the lateral direction. Typical trailer loads for heavy trucks will be about 50,000 N for each rear axle on the tractor. Typical fifth-wheel widths are about 1 m. Thus, for a tandem axle tractor, the moment producing lift-off would be about 50,000 N-m (1).

Before the trailer lift-off, the stiffness of the fifth-wheel coupling causes the tractor and trailer roll angles to have similar values for any lateral acceleration (2). However, there is an additional compliance of both the tractor and trailer in roll. In videos of tilt table tests, one can often see the trailer rolling slightly more than the tractor before lift-off. Giving the fifth wheel some roll stiffness allows us to duplicate this effect (i.e., a value on the order of 100,000 N-m per degree works well, (3). Once the trailer rolls through the backlash, it engages the roll stiffness of the tractor chassis again; since the roll stiffness should be equivalent both before and after the backlash, we can represent this behavior with the same slope: 100,000 N-m per degree (4).

Setting up Trailers with Hinged Tow Bars

The case of a trailer with a hinged tow bar requires that the trailer sprung mass dataset include a trailer parameter: `LEN_TOW_BAR`, the length of the tow bar.

Settings are necessary on two separate dataset screens to set up a trailer with a hinged tow bar.

1. The hitch towing the trailer (either the **Hitch: Joint Assembly** screen or the **Hitch: Parameters** screen has a checkbox **Generic or fifth-wheel hitch with torsional** resistance (1) (Figure 16, page 13, or Figure 17, page 15). This box must be *unchecked* (1) (Figure 23).

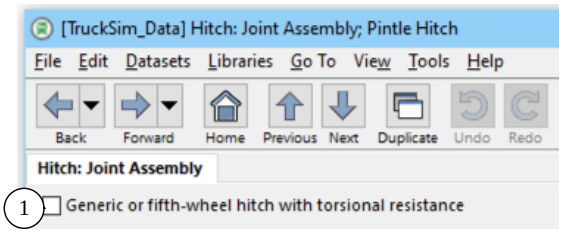

Figure 23. Hitch screen with Generic/fifth-wheel button unchecked for pintle hitch.

2. The trailer sprung mass screen needs to be configured for the tow bar by selecting the option **Trailer has hinged tow bar** from the drop-down list control (1) (Figure 24). This will present a yellow field, allowing the length of the tow bar to be entered with units of mm (2).

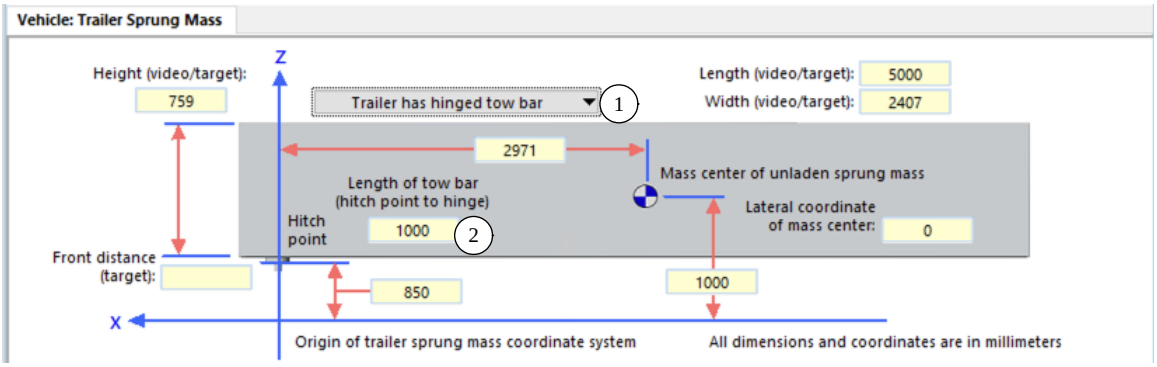

Figure 24. Drop-down control and field to specify a hinged tow bar.

Note	When the **hinged tow bar** option (1) is set, the dataset for this screen will apply the command `OPT_HITCH_TYPE = 3`. An error is generated by the VS Math Model if the hitch type was already set to 1 (the box in Figure 23 was checked). To use the hinged tow bar option on the sprung mass screen, the hitch type must be set to either 2 (in which case the value will be changed to 3) or 3 (in which case the intended setting has already been made).

The CarSim and TruckSim screens for assembling vehicle units typically use a blue link to an **Animator Vehicles and Sensor Targets** dataset that links to a vehicle shape dataset that has animation information and is set up to scale for different sized vehicles, possibly with support for brake lights and reverse lights. Please see the **Help** document **Animator > Vehicles and Sensor Targets** for details on how to use this library screen to animator trailers with hinged tow bars.

Setting Up Articulated Busses

If an articulated bus uses the hitch articulation system where the pitch rotation occurs about a point located in front of the point where the yaw rotation occurs, then two settings are needed:

1. The hitch towing the trailer (either the **Hitch: Joint Assembly** screen or the **Hitch: Parameters** screen has a checkbox **Generic or fifth-wheel hitch with torsional** resistance (1) (Figure 16, page 13, or Figure 17, page 15). This box must be *checked* (Figure 25).

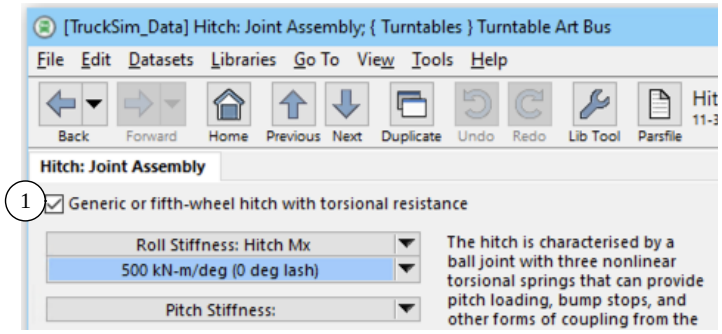

Figure 25. Hitch screen with Generic button checked for articulation system.

2. The trailer sprung mass screen needs to be configured for an articulation system by selecting the option **Trailer has an articulation system** from the drop-down list control (1) (Figure 26). This will present a yellow field that is used for the parameter `LX_ART` (2).

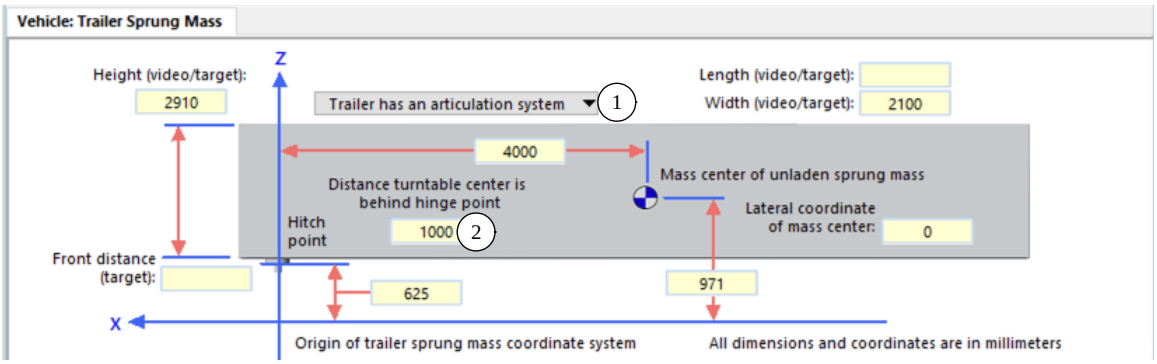

Figure 26. Drop-down control and field to specify an articulation system.

Note When the **articulation system** option is set (1), the dataset for this screen will apply the command `OPT_HITCH_TYPE = 4`. An error is generated by the VS Math Model if the hitch type was set to 1 (the checkbox in Figure 23 is unchecked). To use the articulation system option on the sprung mass screen, the hitch type must be set to either 1 (in which case the value will be changed to 4) or 4 (in which case the intended setting has already been made).

Hitch Indexing for Multiple Trailers and Vehicles

TruckSim supports many trailers. The Trailer vehicle assembly screens support a trailing hitch, used to assemble trains of trailers (e.g., B-Train, B-Triples, Turnpike Double, etc.). To avoid any possibility of accidentally overriding hitch parameters by reading data for a trailing hitch that is not used, hitch parameters in TruckSim are always indexed. The parameters use the vehicle unit index for the leading unit (e.g., `H_H(1)` is the height of the hitch point at the rear of unit 1). Output variables for additional hitches have the number of the hitch appended as a suffix, e.g., the X deflection for the hitch on unit 2 is named `DefX_H2`.

Every semitrailer has a parameter for the height of the front hitch point, `H_H_FRONT`. This is always indexed for the trailing semitrailer. For example, in a hitch connecting units 2 and 3, `H_H_FRONT` for unit 3 would have index 3.

The hinged tow bar (`OPT_HITCH_TYPE` = 3) and articulation system (`OPT_HITCH_TYPE` = 4) both involve an extra moving part on the trailing unit, with an associated length parameter (`LEN_TOW_BAR` for a tow bar length, and `LX_ART` for the distance between two rotation points in an articulation system). These parameters are indexed the same as the other semitrailer parameters. For example, if Hitch #2 is a pintle towing a semitrailer with a tow bar, then `OPT_HITCH_TYPE` will be indexed to 2 (the unit of the leading semitrailer), along with all other hitch parameters except `LEN_TOW_BAR`, which is indexed to the trailing unit, `IUNIT` 3.

CarSim and TruckSim both support multiple vehicles in a single simulation. In these cases, the vehicle units are numbered sequentially based on the order in which they are defined. For example, in a simulation with the first vehicle having no trailer and a second vehicle that includes a trailer, the VS Math Model would contain two vehicle combinations and a total of three vehicle units. The

first vehicle would consist of unit 1, and the second would consist of vehicle units 2 and 3. In this case, the hitch would be associated with unit 2 (lead unit of second vehicle). All import and output variables for that hitch would have the suffix "2" for that unit.

CarSim Trailer normally supports a single trailer and therefore just one hitch. Hitches in CarSim will only be indexed if the simulation has multiple vehicle combinations and those vehicle combinations have trailers. An exception to this convention in CarSim is that import variables always have a suffix, even for hitch #1.

Hitch Parameters and Variables

The number of hitch parameters and Configurable Functions that are used in the model depends on the type and possibly a few other parameter values. The parameters that are used by the model are listed in the Echo file, as shown in several figures in this document. Table 1 lists all hitch parameters, for all types (OPT_HITCH_TYPE = 1 – 4).

Table 1. Parameters and Configurable Functions used to define hitch behavior.

Keyword	Description	Units	When Used
OPT_HITCH_TYPE	Command that specifies type of hitch: 1-4	N/A	Always
HITCH_FREQ	Natural frequency target for hitch springs.	Hz	
HITCH_ZETA	Damping ratio target for hitch dampers.	–	
H_H	Z coord. of hitch point in sprung mass	mm	
LX_H	Distance hitch point is behind origin		
Y_H	Y coord. of hitch point in sprung mass		
MX_HITCH	X moment: Config. Function, pitch	N-m	Types 1 and 4
MY_HITCH	Y moment: Configurable Function, pitch		
MZ_HITCH	Z moment: Config. Function, articulation		
HITCH_DMP_X	X moment coefficient for roll rate	Nms/deg	
HITCH_DMP_Y	Y moment coefficient for pitch rate		
HITCH_DMP_Z	Z moment coefficient, articulation rate		
HITCH_FRIC_X	Roll friction	N-m	
HITCH_FRIC_Y	Pitch friction		
HITCH_FRIC_Z	Articulation friction		
BETA_LE_X	Reference roll for negative hysteresis	deg	Non-zero HITCH_FRIC_X
BETA_UE_X	Reference roll for positive hysteresis		
BETA_LE_Y	Reference pitch for negative hysteresis		Non-zero HITCH_FRIC_Y
BETA_UE_Y	Reference pitch for positive hysteresis		
BETA_LE_Z	Reference articulation, negative hysteresis		Non-zero HITCH_FRIC_Z
BETA_UE_Z	Reference articulation, positive hysteresis		
LEN_TOW_BAR	Length of hinged tow bar	mm	Type 3
LX_ART	Length of arm connecting front pitch hinge with articulation joint		Type 4

Table 2 lists the hitch variables available for output for all types of hitches. The hitch number *h* is blank for the first hitch when used in a short name and is otherwise the number of the hitch. The symbol *t* indicates the number of the trailing unit. For hitch 1, this would be unit 2.

Table 2. Output variables for all hitch types.

Short Name	**Long Name**	**Units**	**Type**	**Notes**
`DefX_H`*h*	X deflection, hitch *h*	mm	Hitch deflection	Always exist
`DefY_H`*h*	Y deflection, hitch *h*			
`DefZ_H`*h*	Z deflection, hitch *h*			
`Fx_H`*h*	X force from hitch *h* on unit *t*	N	Hitch forces	
`Fy_H`*h*	Y force from hitch *h* on unit *t*			
`Fz_H`*h*	Z force from hitch *h* on unit *t*			
`Mx_T`*h*	X moment, hitch *h*, from unit *t*	N-m	Hitch moments on 3-2-1 axes	
`My_T`*h*	Y moment, hitch *h*, from unit *t*			
`Mz_T`*h*	Z moment, hitch *h*, from unit *t*			
`Pitch_H`*h*	Hitch pitch angle	deg	Hitch angles	For types 1 and 4, these are Euler 2-1-3 rotations; for types 2 and 3, these are difference between trailing and lead sprung-mass angles
`Roll_H`*h*	Hitch roll angle			
`Art_H`*h*	Hitch articulation angle			
`PitchR_H`*h*	Hitch pitch angle rate	deg/s	Hitch angular rates	
`RollR_H`*h*	Hitch roll angle rate			
`ArtR_H`*h*	Hitch articulation angle rate			
`Xo_HF_`*t*	X coord, unit *t* front hitch point	m	Global coordinates	Always exist; hitch point is fixed in front of trailer *t* sprung mass
`Yo_HF_`*t*	Y coord, unit *t* front hitch point			
`Zo_HF_`*t*	Z coord, unit *t* front hitch point			

There is a subtle difference between how the hitch angles (`Pitch_H`*h*, `Roll_H`*h*, etc.) are defined for ball/pintle joints (types 1 and 4) and fifth wheel and articulation system joints (types 2 and 3).

- The angles used for fifth-wheel joints mimic the physical geometry, in which a pitch axis Y is fixed to the leading unit sprung mass, the turntable axis Z is fixed to the trailing unit mass, and the roll axis is perpendicular to the Y and Z axes. The sequence of rotations to go from the lead unit sprung mass axis directions is pitch-roll-yaw, also called 2-1-3. These angles are used to generate hitch moments about the hitch axes that are transformed as needed in the VS Math Model to be applied to the leading and trailing sprung masses.
- The simple pintle hitch does not have any moments generated as functions of angles, and therefore, the angles do not affect the built-in equations for the vehicle model. There may be applications where hitch angles are helpful (e.g., controllers for stability or driving backwards). In these cases, the hitch angles are simply defined by subtracting the global angle of the leading unit (e.g., yaw) from the corresponding global angle of the trailer.

Table 3 lists the additional hitch output variables available for generic hitches and articulation system hitches that generate moments using angles defined with a 2-1-3 rotation sequence (OPT_HITCH_TYPE = 1 and 4).

Table 3. Additional output variables when OPT_HITCH_TYPE = 1 or 4.

Short Name	Long Name	Units	Type
Mx_H*h*	X 2-1-3 moment, hitch *h*	N-m	Hitch moments
My_H*h*	Y 2-1-3 moment, hitch *h*		
Mz_H*h*	Z 2-1-3 moment, hitch *h*		

There is a difference between the X, Y, and Z moments listed in Table 2 and those shown for hitches with torsional stiffness in Table 3.

- The trailer T moments listed in Table 2 exist for all types of hitches and include both hitch moments from torsional elements and moments of hitch forces for types 3 and 4. These are built into the multibody equations for all trailers and are provided mainly for debugging and diagnosing behaviors. Each moment is a component in the direction of an axis in the trailing unit, but has the sign set as applied to the leading unit. (This is done to help compare the trailer T moments with hitch H moments.)
- The hitch H moments listed in Table 3 only exist for hitches with type 1 or 4, which include moments generated from physical characteristics of the physical hitch. The output variables are based on the hitch rotations, following the 2-1-3 sequence.

Table 4 lists hitch output variables that are added for trailers with a hinged tow bar when OPT_HITCH_TYPE = 3. The global coordinates and 3-2-1 Euler angles are used to animate the two parts of the trailer (sprung mass body and tow bar). The relative pitch angle is essential in the calculations and might be interest for plotting. All variables in this table are identified by the trailing unit number *t*.

Table 4. Output variables for hinged tow bar trailers when OPT_HITCH_TYPE = 3.

Short Name	Long Name	Units	Type
YawBar_*t*	Yaw, unit *t* tow bar	deg	3-2-1 Euler angles
PitchBar*t*	Pitch, unit *t* tow bar		
RollBar*t*	Roll, unit *t* tow bar		
PtchBarRel*t*	Relative pitch, unit *t* tow bar		Relative angle

Table 5 lists the three variables that can be imported from an external hitch model when OPT_HITCH_TYPE = 1 or 4. (When the type is 2 or 3, there are no hitch moments in the model.)

Table 5. Import variables for hitch h moments when `OPT_HITCH_TYPE` = 1 or 4.

Short Name	**Long Name**	**Units**
`IMP_MHX`*h*	Roll Moment, 2-1-3, hitch *h*	N-m
`IMP_MHY`*h*	Pitch moment, 2-1-3, hitch *h*	
`IMP_MHZ`*h*	Articulation moment, 2-1-3, hitch *h*	