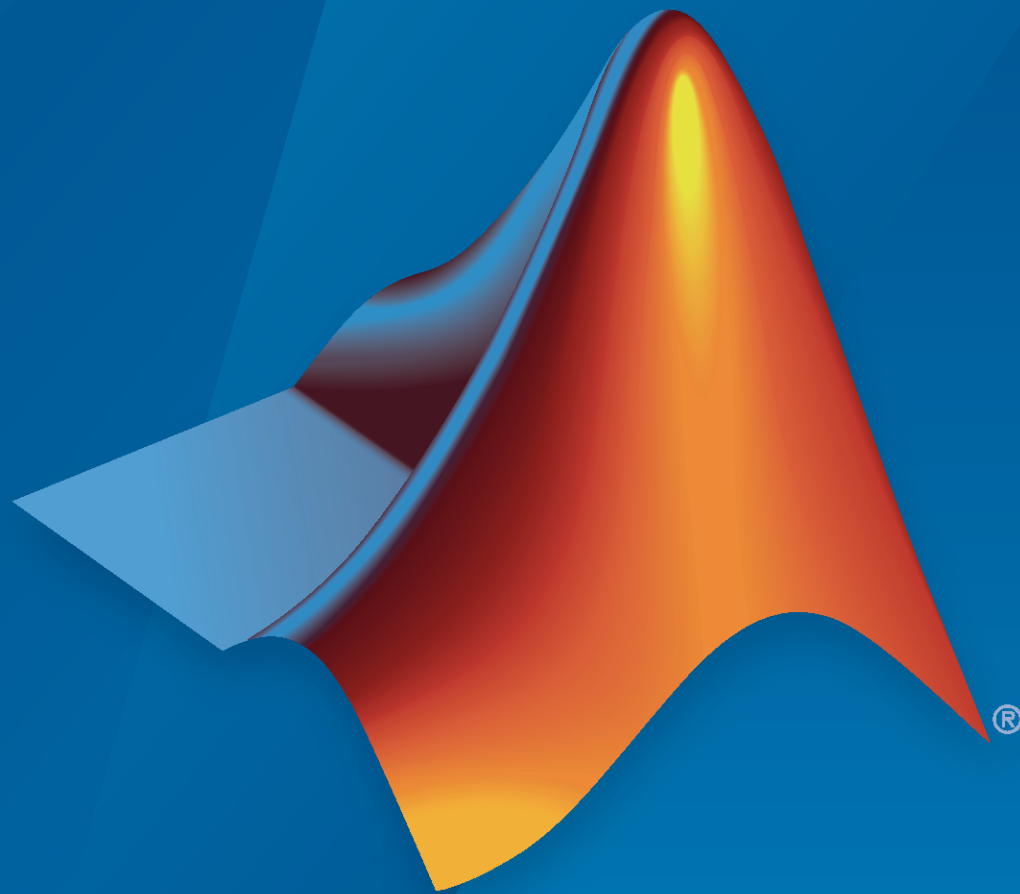


# Vehicle Dynamics Blockset™

Reference



# MATLAB® & SIMULINK®

R2020b



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## *Vehicle Dynamics Blockset™ Reference*

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### **Revision History**

March 2018	Online only	New for Version 1.0 (Release 2018a)
September 2018	Online only	Revised for Version 1.1 (Release 2018b)
March 2019	Online only	Revised for Version 1.2 (Release 2019a)
September 2019	Online only	Revised for Version 1.3 (Release 2019b)
March 2020	Online only	Revised for Version 1.4 (Release 2020a)
September 2020	Online only	Revised for Version 1.5 (Release 2020b)



<b>1</b>	<b><u>Steering and Suspension Blocks</u></b>
<b>2</b>	<b><u>Drivetrain Blocks</u></b>
<b>3</b>	<b><u>Wheel and Tire Blocks</u></b>
<b>4</b>	<b><u>Propulsion Blocks</u></b>
<b>5</b>	<b><u>Vehicle Dynamics Blocks</u></b>
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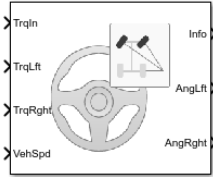
# Steering and Suspension Blocks

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# Dynamic Steering

Dynamic steering for Ackerman, rack-and-pinion, and parallel steering mechanisms

**Library:** Vehicle Dynamics Blockset / Steering



## Description

The Dynamic Steering block implements dynamic steering to calculate the wheel angles for Ackerman, rack-and-pinion, and parallel steering mechanisms. The block uses the steering wheel input torque, right wheel torque, and left wheel torque to calculate the wheel angles. The block uses the vehicle coordinate system.

If you select **Power assist**, you can specify a torque assist lookup table that is a function of the vehicle speed and steering wheel input torque. The block uses the steering wheel input torque and torque assist to calculate the steering dynamics.

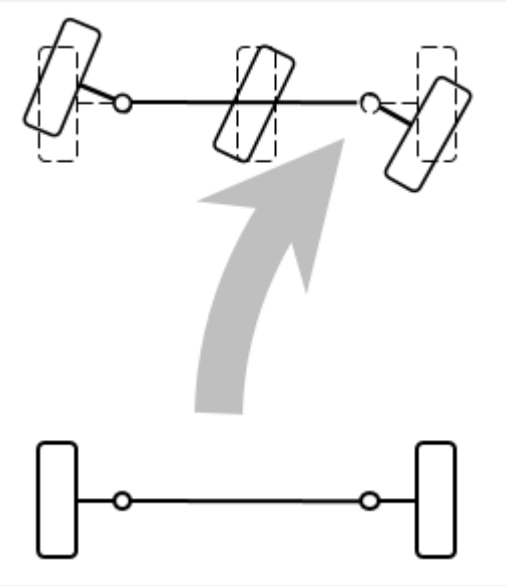
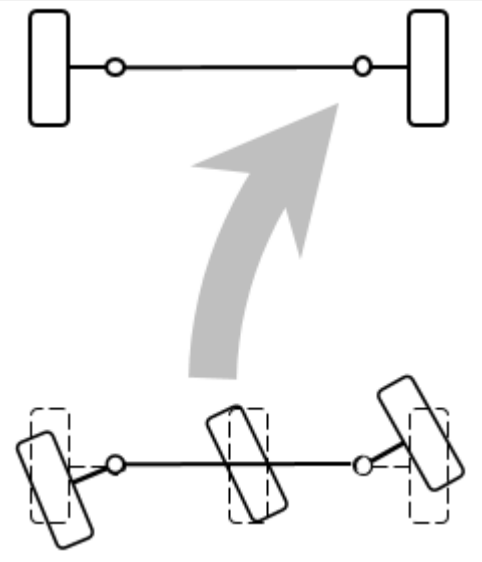
To specify the steering type, use the **Type** parameter.

Setting	Block Implementation
Ackerman	Ideal Ackerman steering. Wheel angles have a common turning circle center.
Rack and pinion	Ideal rack-and-pinion steering. Gears convert the steering rotation into linear motion.
Parallel	Parallel steering. Wheel angles are equal.

To specify the type of data for the steering mechanism, use the **Parameterized by** parameter.

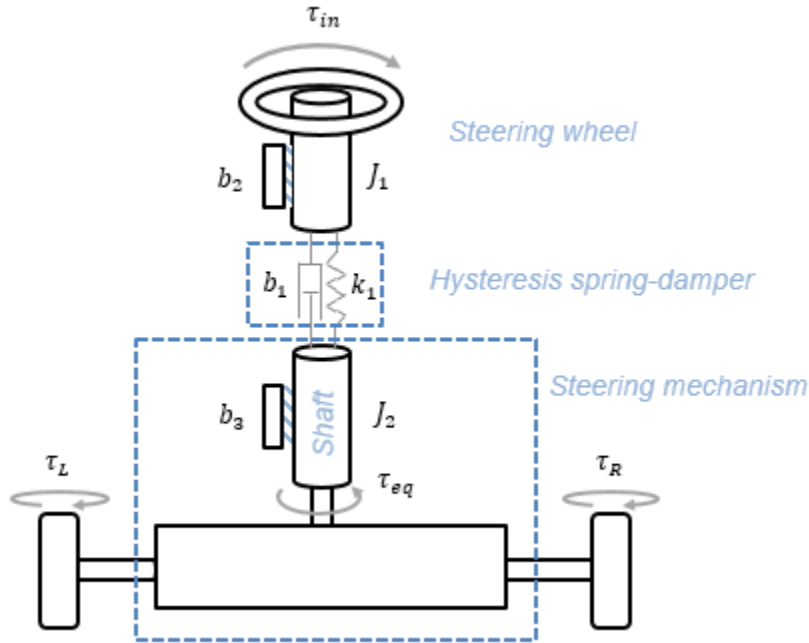
Setting	Block Implementation
Constant	Steering mechanism uses constant parameter data.
Lookup table	Steering mechanism implements tables for parameter data.

Use the **Location** parameter to specify front or rear steering.

Setting	Implementation
Front	Front steering  The diagram illustrates front steering. It shows two states: a top state where the steering wheels are turned to the right, and a bottom state where the wheels are straight. A large grey arrow points from the bottom state to the top state, indicating the transition. The wheels are connected to a central shaft, and the steering mechanism is shown in a simplified manner.
Rear	Rear steering  The diagram illustrates rear steering. It shows two states: a top state where the steering wheels are straight, and a bottom state where the wheels are turned to the right. A large grey arrow points from the bottom state to the top state, indicating the transition. The wheels are connected to a central shaft, and the steering mechanism is shown in a simplified manner.

### Dynamics

To calculate the steering dynamics, the Dynamic Steering block models the steering wheel, shaft, steering mechanism, hysteresis, and, optionally, power assist.



Calculation	Equations
Steering column and steering shaft dynamics	$J_1 \ddot{\theta}_1 = \tau_{in} - b_2 \dot{\theta}_1 - \tau_{hys}$ $J_2 \ddot{\theta}_2 = \tau_{eq} - b_3 \dot{\theta}_2 + \tau_{hys} - \tau_{fric}$
Hysteresis spring damper	$\delta = \theta_1 - \theta_2$ $\Delta\delta = \delta_{current} - \delta_{previous}$ $\tau_{hys} = (b_1 \dot{\delta} - k_1 \delta) \left( 1 + \exp\left(-\frac{ \Delta\delta }{\beta}\right) \right)$ $\beta = \begin{cases} \beta_u & \text{when } \delta > 0 \\ \beta_l & \text{when } \delta \leq 0 \end{cases}$
Optional power assist	$\tau_{ast} = f_{trq}(v, \tau_{in})$ $J_1 \ddot{\theta}_1 = \tau_{in} + \tau_{ast} - b_2 \dot{\theta}_1 - \tau_{hys}$ $J_2 \ddot{\theta}_2 = \tau_{eq} + \tau_{ast} - b_3 \dot{\theta}_2 + \tau_{hys} - \tau_{fric}$

The illustration and equations use these variables.

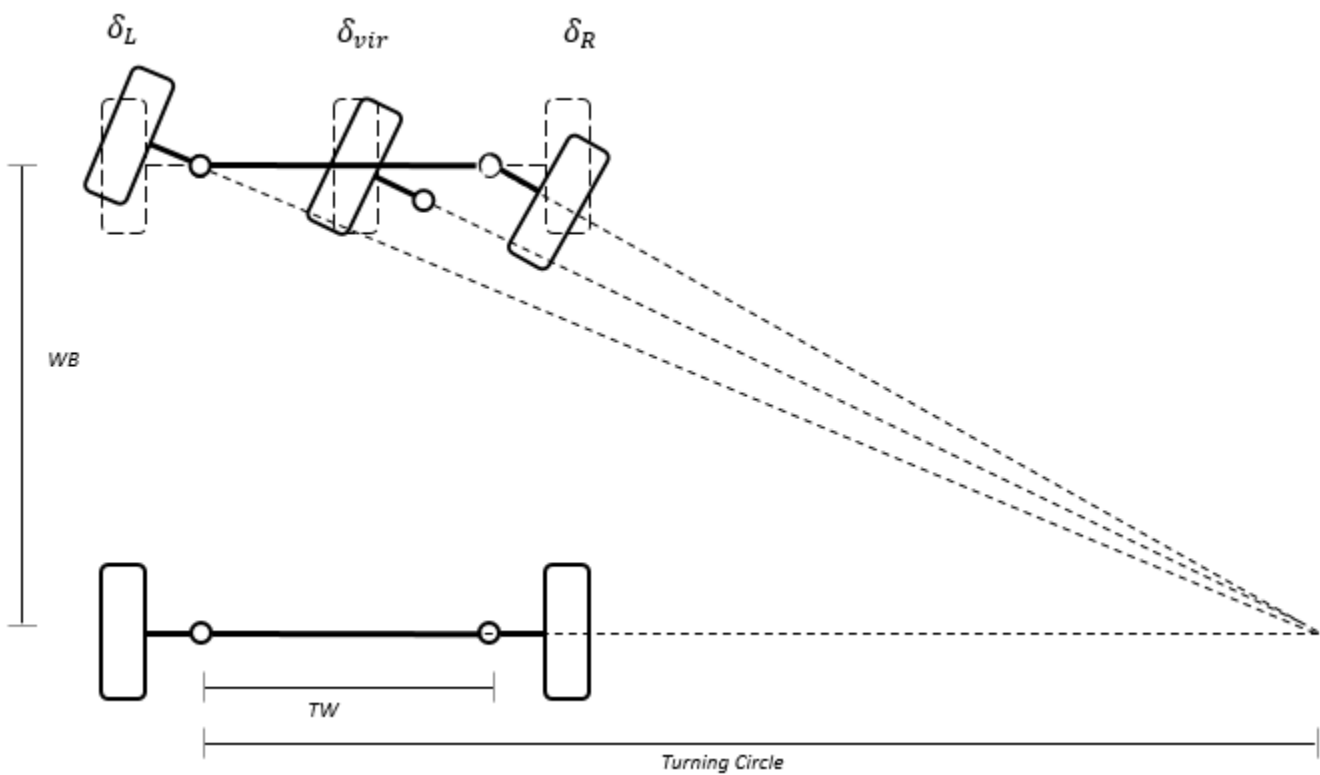
$J_1$	Steering wheel inertia
$J_2$	Steering mechanism inertia
$\theta_1, \dot{\theta}_1, \ddot{\theta}_1$	Steering wheel angle, angular velocity, and angular acceleration, respectively
$\theta_2, \dot{\theta}_2, \ddot{\theta}_2$	Shaft angle, angular velocity, and angular acceleration, respectively
$b_1, k_1$	Hysteresis spring and viscous damping coefficients, respectively

$b_2$	Steering wheel viscous damping coefficient
$b_3$	Steering mechanism damping coefficient
$\tau_{hys}$	Hysteresis spring damping torque
$\tau_{fric}$	Steering mechanism friction torque
$\tau_{eq}$	Wheel equivalent torque
$\tau_{ast}$	Torque assist
$\beta_u, \beta_l$	Upper and lower hysteresis modifiers, respectively
$v$	Vehicle speed
$f_{trq}$	Torque assist lookup table

### Steering Types

#### Ackerman

For ideal Ackerman steering, the wheel angles have a common turning circle.



To calculate the steering angles, the block uses these equations.

$$\cot(\delta_L) - \cot(\delta_R) = \frac{TW}{WB}$$

$$\delta_{vir} = \frac{\delta_{in}}{\gamma}$$

$$\delta_L = \tan^{-1}\left(\frac{WB \tan(\delta_{vir})}{WB - 0.5TW \tan(\delta_{vir})}\right)$$

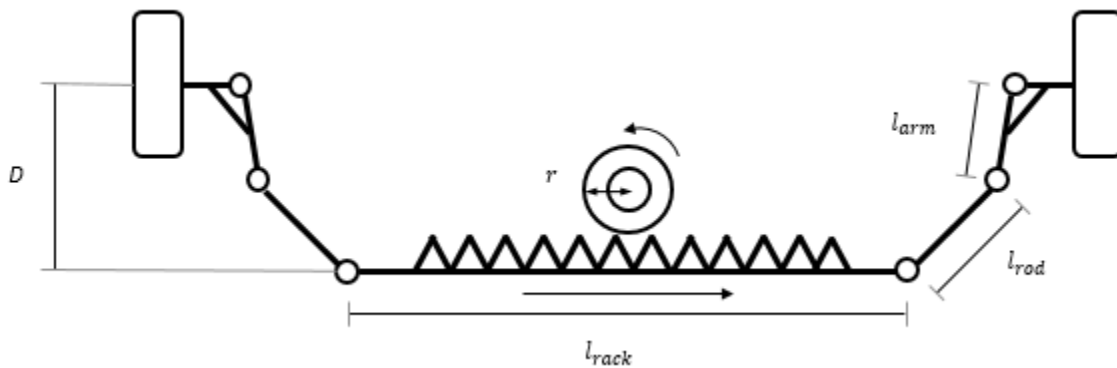
$$\delta_R = \tan^{-1}\left(\frac{WB \tan(\delta_{vir})}{WB + 0.5TW \tan(\delta_{vir})}\right)$$

The illustration and equations use these variables.

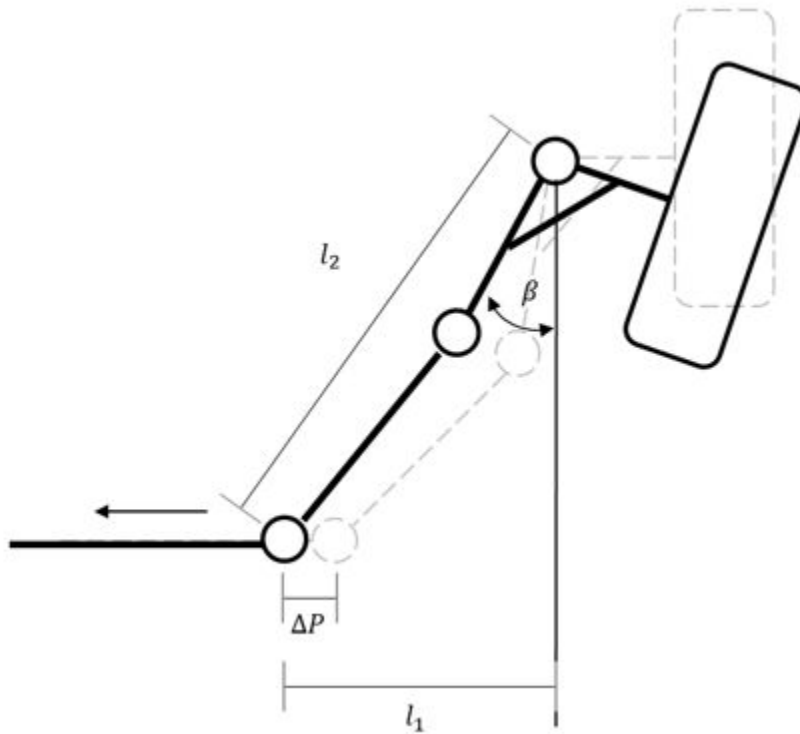
$\delta_{in}$	Steering angle
$\delta_L$	Left wheel angle
$\delta_R$	Right wheel angle
$\delta_{vir}$	Virtual wheel angle
$TW$	Track width
$WB$	Wheel base
$\gamma$	Steering ratio

**Rack-and-Pinion**

For ideal rack-and-pinion steering, the gears convert the steering rotation into linear motion.







To calculate the steering angles, the block uses these equations.

$$l_1 = \frac{TW - l_{rack}}{2} - \Delta P$$

$$l_2^2 = l_1^2 + D^2$$

$$\Delta P = r\delta_{in}$$

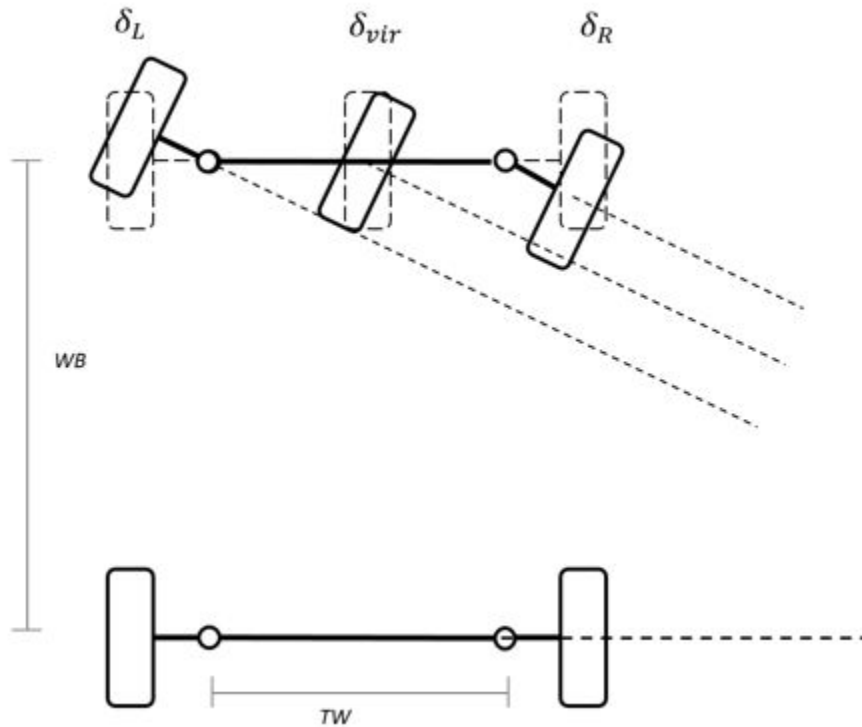
$$\beta = \frac{\pi}{2} - \tan^{-1}\left[\frac{D}{l_1}\right] - \cos^{-1}\left[\frac{l_{arm}^2 + l_2^2 - l_{rod}^2}{2l_{arm}l_2}\right]$$

The illustration and equations use these variables.

$\delta_{in}$	Steering wheel angle
$\delta_L$	Left wheel angle
$\delta_R$	Right wheel angle
$TW$	Track width
$r$	Pinion radius
$\Delta P$	Linear change in rack position
$D$	Distance between front axis and rack
$l_{rack}$	Rack casing length
$l_{arm}$	Steering arm length
$l_{rod}$	Tie rod length

**Parallel**

For parallel steering, the wheel angles are equal.



To calculate the steering angles, the block uses this equation.

$$\delta_R = \delta_L = \frac{\delta_{in}}{\gamma}$$

The illustration and equations use these variables.

$\delta_{in}$	Steering wheel angle
$\delta_L$	Left wheel angle
$\delta_R$	Right wheel angle
$\gamma$	Steering ratio

**Ports**

**Input**

**TrqIn — Torque**

scalar

Torque,  $\tau_{in}$ , in N·m.

**TrqLft — Left wheel torque**

scalar

Left wheel torque,  $\tau_L$ , in N·m.

### TrqRight – Right wheel torque

scalar

Right wheel torque,  $\tau_R$ , in N·m.

### VehSpd – Vehicle speed

scalar

Vehicle speed,  $v$ , in m/s.

### Dependencies

To create VehSpd, select **Power assist**.

### Output

### Info – Bus signal

bus

Bus signal contains these block calculations.

Signal	Description	Unit
StrgWhlAng	Steering wheel angle	rad
StrgWhlSpd	Steering wheel angular velocity	rad/s
ShftAng	Shaft angle	rad
ShftSpd	Shaft angular velocity	rad/s
AngLft	Left wheel angle	rad
SpdLft	Left wheel angular velocity	rad/s
AngRght	Right wheel angle	rad
SpdRght	Right wheel angular velocity	rad/s
TrqAst	Torque assist	N·m
PwrAst	Power assist	W
PwrLoss	Power loss	W
InstStrgRatio	Instantaneous steering ratio	NA

### AngLft – Left wheel angle

scalar

Left wheel angle,  $\delta_L$ , in rad.

### AngRght – Right wheel angle

scalar

Right wheel angle,  $\delta_R$ , in rad.

## Parameters

### Type — Select steering type

Rack and pinion (default) | Ackerman | Parallel

To specify the steering type, use the **Type** parameter.

Setting	Block Implementation
Ackerman	Ideal Ackerman steering. Wheel angles have a common turning circle center.
Rack and pinion	Ideal rack-and-pinion steering. Gears convert the steering rotation into linear motion.
Parallel	Parallel steering. Wheel angles are equal.

### Dependencies

This table summarizes the **Type** and **Parameterized by** parameter dependencies.

Type	Parameterized By	Creates Parameters
Ackerman	Constant	<b>Track width, TrckWdth</b> <b>Wheel base, WhlBase</b> <b>Steering range, StrgRng</b> <b>Steering ratio, StrgRatio</b>
	Lookup table	<b>Track width, TrckWdth</b> <b>Wheel base, WhlBase</b> <b>Steering range, StrgRng</b> <b>Steering angle breakpoints, StrgAngBpts</b> <b>Steering ratio table, StrgRatioTbl</b>
Rack and pinion	Constant	<b>Track width, TrckWdth</b> <b>Steering range, StrgRng</b> <b>Steering arm length, StrgArmLngth</b> <b>Rack casing length, RckCsLngth</b> <b>Tie rod length, TieRodLngth</b> <b>Distance between front axis and rack, D</b> <b>Pinion radius, PnnRadius</b>

Type	Parameterized By	Creates Parameters
	Lookup table	<b>Track width, TrckWdth</b> <b>Steering range, StrgRng</b> <b>Steering angle breakpoints, StrgAngBpts</b> <b>Steering arm length, StrgArmLngth</b> <b>Rack casing length, RckCsLngth</b> <b>Tie rod length, TieRodLngth</b> <b>Distance between front axis and rack, D</b> <b>Pinion radius, PnnRadiusTbl</b>
Parallel	Constant	<b>Steering range, StrgRng</b> <b>Steering ratio, StrgRatio</b>
	Lookup table	<b>Steering range, StrgRng</b> <b>Steering angle breakpoints, StrgAngBpts</b> <b>Steering ratio table, StrgRatioTbl</b>

#### Parameterized by – Select parameterization

Lookup table (default) | Constant

To specify the type of data for the steering mechanism, use the **Parameterized by** parameter.

Setting	Block Implementation
Constant	Steering mechanism uses constant parameter data.
Lookup table	Steering mechanism implements tables for parameter data.

#### Dependencies

This table summarizes the **Type** and **Parameterized by** parameter dependencies.

Type	Parameterized By	Creates Parameters
Ackerman	Constant	<b>Track width, TrckWdth</b> <b>Wheel base, WhlBase</b> <b>Steering range, StrgRng</b> <b>Steering ratio, StrgRatio</b>

Type	Parameterized By	Creates Parameters
	Lookup table	<b>Track width, TrckWdth</b> <b>Wheel base, WhlBase</b> <b>Steering range, StrgRng</b> <b>Steering angle breakpoints, StrgAngBpts</b> <b>Steering ratio table, StrgRatioTbl</b>
Rack and pinion	Constant	<b>Track width, TrckWdth</b> <b>Steering range, StrgRng</b> <b>Steering arm length, StrgArmLngth</b> <b>Rack casing length, RckCsLngth</b> <b>Tie rod length, TieRodLngth</b> <b>Distance between front axis and rack, D</b> <b>Pinion radius, PnnRadius</b>
	Lookup table	<b>Track width, TrckWdth</b> <b>Steering range, StrgRng</b> <b>Steering angle breakpoints, StrgAngBpts</b> <b>Steering arm length, StrgArmLngth</b> <b>Rack casing length, RckCsLngth</b> <b>Tie rod length, TieRodLngth</b> <b>Distance between front axis and rack, D</b> <b>Pinion radius, PnnRadiusTbl</b>
Parallel	Constant	<b>Steering range, StrgRng</b> <b>Steering ratio, StrgRatio</b>
	Lookup table	<b>Steering range, StrgRng</b> <b>Steering angle breakpoints, StrgAngBpts</b> <b>Steering ratio table, StrgRatioTbl</b>

**Power assist – Specify power assist**

on (default) | off

If you select **Power assist**, you can specify a torque assist lookup table,  $f_{trq}$ , that is a function of the vehicle speed,  $v$ , and steering wheel input torque,  $\tau_{in}$ .

$$\tau_{ast} = f_{trq}(v, \tau_{in})$$

The block uses the steering wheel input torque and torque assist to calculate the steering dynamics.

### Dependencies

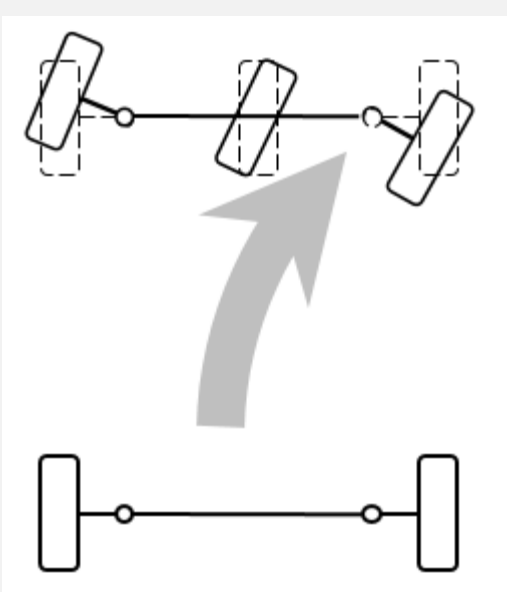
Selecting **Power assist** creates the VehSpd input port and these parameters.

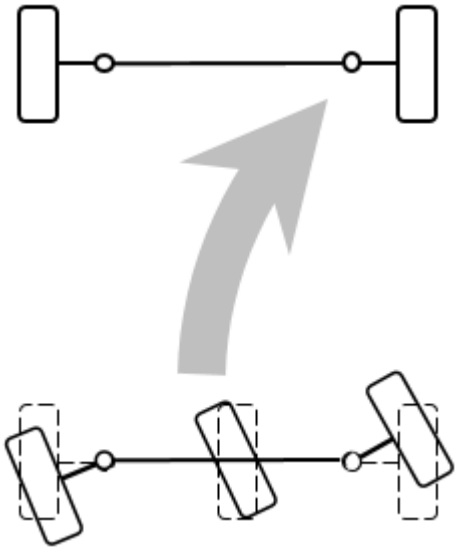
Power Assist	Parameters
on	<b>Steering wheel torque breakpoints, TrqBpts</b> <b>Vehicle speed breakpoints, VehSpdBpts</b> <b>Assisting torque table, TrqTbl</b> <b>Assisting torque limit, TrqLmt</b> <b>Assisting power limit, PwrLmt</b> <b>Assisting torque efficiency, Eta</b> <b>Cutoff frequency, omega_c</b>

### Location – Select location

**Front** (default) | **Rear**

Use the **Location** parameter to specify front or rear steering.

Setting	Implementation
<b>Front</b>	Front steering 

Setting	Implementation
<p><b>Rear</b></p>	<p>Rear steering</p> 

**General**

**Track width, TrckWdth – Width**

1 | scalar

Track width, *TW*, in m.

**Dependencies**

To create this parameter, set **Type** to Ackerman or Rack and pinion.

**Wheel base, WhlBase – Base**

1.524 (default) | scalar

Wheel base, *WB*, in m.

**Dependencies**

To create this parameter, set **Type** to Ackerman.

**Steering range, StrgRng – Range**

1.25\*pi (default) | scalar

Steering range, in rad. The block limits the wheel angles to remain within the steering range.

**Steering ratio, StrgRatio – Ratio**

13.5 (default) | scalar

Steering ratio,  $\gamma$ , dimensionless.

**Dependencies**

To create this parameter:



- Set **Type** to Ackerman or Parallel.
- Set **Parametrized by** to Constant.

#### Steering angle breakpoints, StrgAngBpts — Breakpoints

[-6.2832 -5.0265 -3.7699 -2.5133 -1.2566 0 1.2566 2.5133 3.7699 5.0265 6.2832] (default) | vector

Steering angle breakpoints, in rad.

#### Dependencies

To create this parameter, set **Parametrized by** to Lookup table.

#### Steering ratio table, StrgRatioTbl — Table

[13.5000 13.3750 13.2500 13.1250 13.0000 13.0000 13.0000 13.1250 13.2500 13.3750 13.5000] (default) | vector

Steering ratio table,  $\gamma$ , dimensionless.

#### Dependencies

To create this parameter:

- Set **Type** to Ackerman or Parallel.
- Set **Parametrized by** to Lookup table.

#### Rack-and-Pinion

#### Steering arm length, StrgArmLngth — Length

0.1 (default) | scalar

Steering arm length,  $l_{arm}$ , in m.

#### Dependencies

To create this parameter, set **Type** to Rack and pinion.

#### Rack casing length, RckCsLngth — Length

0.5 (default) | scalar

Rack casing length,  $l_{rack}$ , in m.

#### Dependencies

To create this parameter, set **Type** to Rack and pinion.

#### Tie rod length, TieRodLngth — Length

0.248 (default) | scalar

Tie rod length,  $l_{rod}$ , in m.

#### Dependencies

To create this parameter, set **Type** to Rack and pinion.

#### Distance between front axis and rack, D — Distance

0.2 (default) | scalar

Distance between front axis and rack,  $D$ , in m.

**Dependencies**

To create this parameter, set **Type** to Rack and pinion.

**Pinion radius, PnnRadius – Radius**

0.0057 (default) | scalar

Pinion radius,  $r$ , in m.

**Dependencies**

To create this parameter:

- Set **Type** to Rack and pinion.
- Set **Parametrized by** to Constant.

**Pinion radius table, PnnRadiusTbl – Table**

[0.0055 0.0055 0.0056 0.0057 0.0057 0.0057 0.0058 0.0057 0.0056 0.0055 0.0055] (default) | vector

Pinion radius table,  $r$ , in m.

**Dependencies**

To create this parameter:

- Set **Type** to Rack and pinion.
- Set **Parametrized by** to Lookup table.

**Dynamics****Steering wheel inertia, J1 – Inertia**

0.1 (default) | scalar

Steering wheel inertia,  $J_1$ , in  $\text{kg}\cdot\text{m}^2$ .

**Steering mechanism inertia, J2 – Inertia**

0.01 (default) | scalar

Steering mechanism inertia,  $J_2$ , in  $\text{kg}\cdot\text{m}^2$ .

**Upper hysteresis modifier, beta\_u – Upper hysteresis modifier**

0.1 (default) | scalar

Upper hysteresis modifier,  $\beta_u$ , dimensionless.

**Lower hysteresis modifier, beta\_l – Lower hysteresis modifier**

0.1 (default) | scalar

Lower hysteresis modifier,  $\beta_l$ , dimensionless.

**Hysteresis viscous damping, b1 – Damping**

0.001 (default) | scalar

Hysteresis damping,  $b_1$ , in  $\text{N}\cdot\text{m}\cdot\text{s}/\text{rad}$ .

**Hysteresis stiffness, k1 – Stiffness**

30 (default) | scalar

Hysteresis stiffness,  $k_1$ , in N·m/rad.**Steering wheel damping, b2 – Damping**

1 (default) | scalar

Steering wheel damping,  $b_2$ , in N·m·s/rad.**Steering mechanism damping, b3 – Damping**

0.001 (default) | scalar

Steering mechanism damping,  $b_3$ , in N·m·s/rad.**Initial steering angle, theta\_o – Angle**

0 (default) | scalar

Initial steering angle,  $\theta_o$ , in rad.**Initial steering angular velocity, omega\_o – Angular velocity**

0 (default) | scalar

Initial steering angular velocity,  $\omega_o$ , in rad/s.**Friction torque, FricTrq – Torque**

0 (default) | scalar

Friction torque,  $\tau_{fric}$ , in N·m.**Power Assist****Steering wheel torque breakpoints, TrqBpts – Breakpoints**

[-100 0 100] (default) | 1-by-M vector

Steering wheel torque breakpoints, in N·m.

**Dependencies**Selecting **Power assist** creates the VehSpd input port and these parameters.

Power Assist	Parameters
on	<b>Steering wheel torque breakpoints, TrqBpts</b> <b>Vehicle speed breakpoints, VehSpdBpts</b> <b>Assisting torque table, TrqTbl</b> <b>Assisting torque limit, TrqLmt</b> <b>Assisting power limit, PwrLmt</b> <b>Assisting torque efficiency, Eta</b> <b>Cutoff frequency, omega_c</b>

**Vehicle speed breakpoints, VehSpdBpts – Breakpoints**

[0 20] (default) | 1-by-N vector

Vehicle speed breakpoints, in m/s.

**Dependencies**

Selecting **Power assist** creates the VehSpd input port and these parameters.

Power Assist	Parameters
on	<b>Steering wheel torque breakpoints, TrqBpts</b> <b>Vehicle speed breakpoints, VehSpdBpts</b> <b>Assisting torque table, TrqTbl</b> <b>Assisting torque limit, TrqLmt</b> <b>Assisting power limit, PwrLmt</b> <b>Assisting torque efficiency, Eta</b> <b>Cutoff frequency, omega_c</b>

**Assisting torque table, TrqTbl – 2D torque table**

[0 -100;0 0;0 100] (default) | M-by-N matrix

Assisting torque table,  $f_{trq}$ , in N·m.

The torque assist lookup table is a function of the vehicle speed,  $v$ , and steering wheel input torque,  $\tau_{in}$ .

$$\tau_{ast} = f_{trq}(v, \tau_{in})$$

The block uses the steering wheel input torque and torque assist to calculate the steering dynamics.

**Dependencies**

Selecting **Power assist** creates the VehSpd input port and these parameters.

Power Assist	Parameters
on	<b>Steering wheel torque breakpoints, TrqBpts</b> <b>Vehicle speed breakpoints, VehSpdBpts</b> <b>Assisting torque table, TrqTbl</b> <b>Assisting torque limit, TrqLmt</b> <b>Assisting power limit, PwrLmt</b> <b>Assisting torque efficiency, Eta</b> <b>Cutoff frequency, omega_c</b>

**Assisting torque limit, TrqLmt – Torque limit**

100 (default) | scalar

Assisting torque limit, in N·m.

**Dependencies**Selecting **Power assist** creates the VehSpd input port and these parameters.

Power Assist	Parameters
on	<b>Steering wheel torque breakpoints, TrqBpts</b> <b>Vehicle speed breakpoints, VehSpdBpts</b> <b>Assisting torque table, TrqTbl</b> <b>Assisting torque limit, TrqLmt</b> <b>Assisting power limit, PwrLmt</b> <b>Assisting torque efficiency, Eta</b> <b>Cutoff frequency, omega_c</b>

**Assisting power limit, PwrLmt – Power limit**

1000 (default) | scalar

Assisting power limit, in N·m/s.

**Dependencies**Selecting **Power assist** creates the VehSpd input port and these parameters.

Power Assist	Parameters
on	<b>Steering wheel torque breakpoints, TrqBpts</b> <b>Vehicle speed breakpoints, VehSpdBpts</b> <b>Assisting torque table, TrqTbl</b> <b>Assisting torque limit, TrqLmt</b> <b>Assisting power limit, PwrLmt</b> <b>Assisting torque efficiency, Eta</b> <b>Cutoff frequency, omega_c</b>

**Assisting torque efficiency, Eta – Efficiency**

1 (default) | scalar

Assisting torque efficiency, dimensionless.

**Dependencies**Selecting **Power assist** creates the VehSpd input port and these parameters.

Power Assist	Parameters
on	<b>Steering wheel torque breakpoints, TrqBpts</b> <b>Vehicle speed breakpoints, VehSpdBpts</b> <b>Assisting torque table, TrqTbl</b> <b>Assisting torque limit, TrqLmt</b> <b>Assisting power limit, PwrLmt</b> <b>Assisting torque efficiency, Eta</b> <b>Cutoff frequency, omega_c</b>

**Cutoff frequency, omega\_c – Cutoff frequency**

200 (default) | scalar

Cutoff frequency, in rad/s.

**Dependencies**

Selecting **Power assist** creates the VehSpd input port and these parameters.

Power Assist	Parameters
on	<b>Steering wheel torque breakpoints, TrqBpts</b> <b>Vehicle speed breakpoints, VehSpdBpts</b> <b>Assisting torque table, TrqTbl</b> <b>Assisting torque limit, TrqLmt</b> <b>Assisting power limit, PwrLmt</b> <b>Assisting torque efficiency, Eta</b> <b>Cutoff frequency, omega_c</b>

**References**

- [1] Crolla, David, David Foster, et al. *Encyclopedia of Automotive Engineering*. Volume 4, Part 5 (*Chassis Systems*) and Part 6 (*Electrical and Electronic Systems*). Chichester, West Sussex, United Kingdom: John Wiley & Sons Ltd, 2015.
- [2] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers, 1992.
- [3] Vehicle Dynamics Standards Committee. *Vehicle Dynamics Terminology*. SAE J670. Warrendale, PA: Society of Automotive Engineers, 2008.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Kinematic Steering | Mapped Steering

### **Topics**

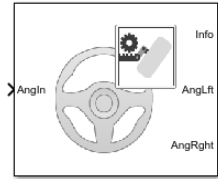
“Coordinate Systems in Vehicle Dynamics Blockset”

### **Introduced in R2018a**

## Kinematic Steering

Kinematic steering for Ackerman, rack-and-pinion, and parallel steering mechanisms

**Library:** Vehicle Dynamics Blockset / Steering



### Description

The Kinematic Steering block implements a steering model to determine the left and right wheel angles for Ackerman, rack-and-pinion, and parallel steering mechanisms. The block uses the vehicle coordinate system.

To specify the steering type, use the **Type** parameter.

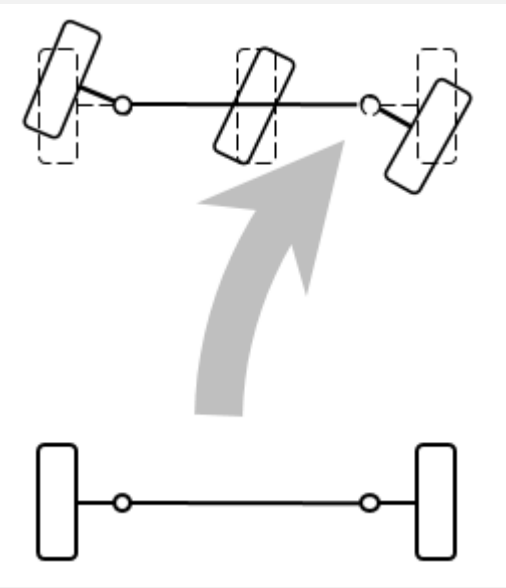
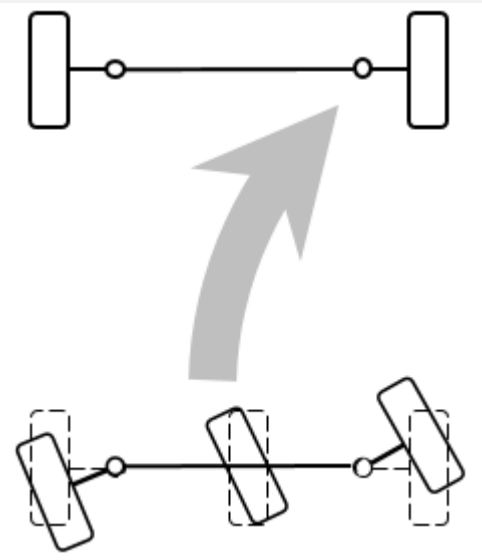
Setting	Block Implementation
Ackerman	Ideal Ackerman steering. Wheel angles have a common turning circle center.
Rack and pinion	Ideal rack-and-pinion steering. Gears convert the steering rotation into linear motion.
Parallel	Parallel steering. Wheel angles are equal.

To specify the type of data for the steering mechanism, use the **Parametrized by** parameter.

Setting	Block Implementation
Constant	Steering mechanism uses constant parameter data.
Lookup table	Steering mechanism implements tables for parameter data.

Use the **Location** parameter to specify front or rear steering.

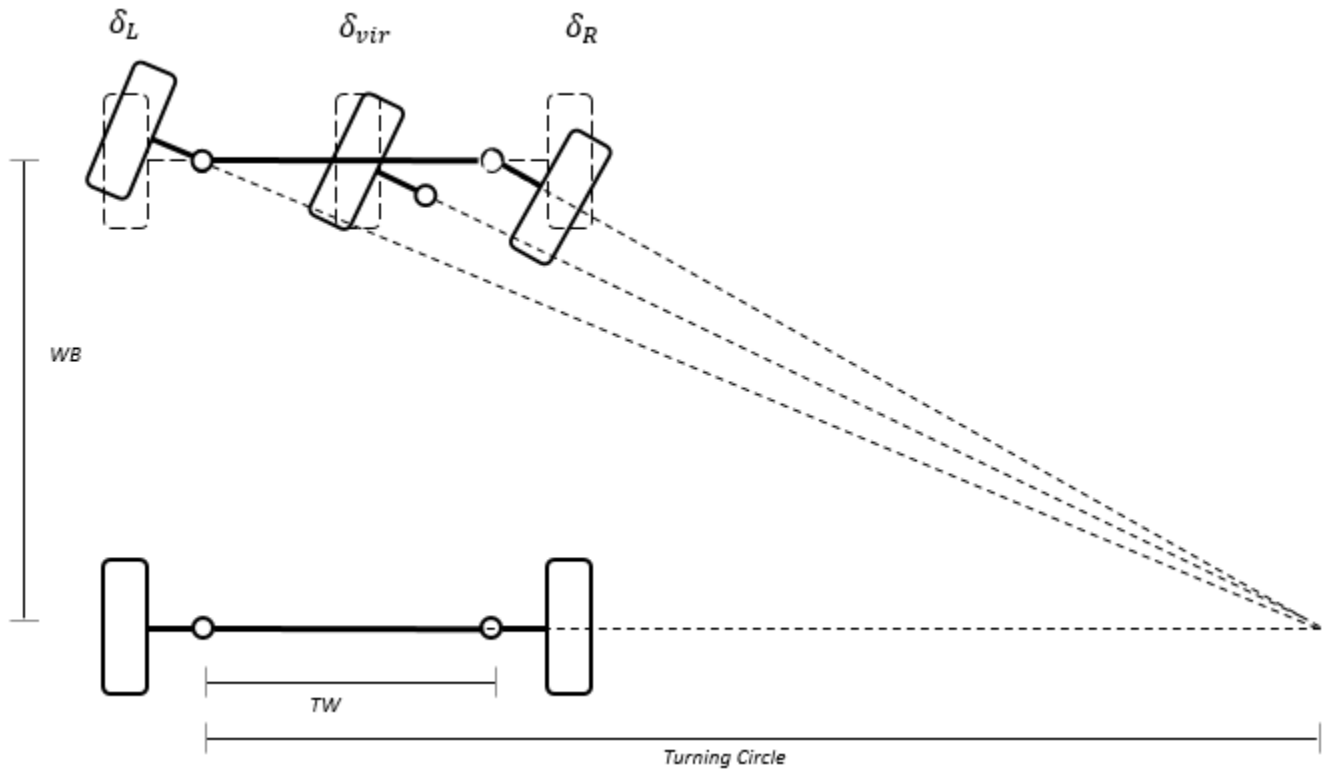


Setting	Implementation
<b>Front</b>	Front steering  <p>The diagram illustrates the implementation of front steering. It shows two states of a front axle. In the lower state, the axle is straight with two vertical wheels. In the upper state, the axle is angled, and the wheels are also angled. A large grey arrow points from the lower state to the upper state, indicating the transition from a non-steering axle to a steering axle.</p>
<b>Rear</b>	Rear steering  <p>The diagram illustrates the implementation of rear steering. It shows two states of a rear axle. In the lower state, the axle is angled, and the wheels are also angled. In the upper state, the axle is straight with two vertical wheels. A large grey arrow points from the lower state to the upper state, indicating the transition from a steering axle to a non-steering axle.</p>

## Steering Types

### Ackerman

For ideal Ackerman steering, the wheel angles have a common turning circle.



To calculate the steering angles, the block uses these equations.

$$\cot(\delta_L) - \cot(\delta_R) = \frac{TW}{WB}$$

$$\delta_{vir} = \frac{\delta_{in}}{\gamma}$$

$$\delta_L = \tan^{-1}\left(\frac{WB \tan(\delta_{vir})}{WB - 0.5TW \tan(\delta_{vir})}\right)$$

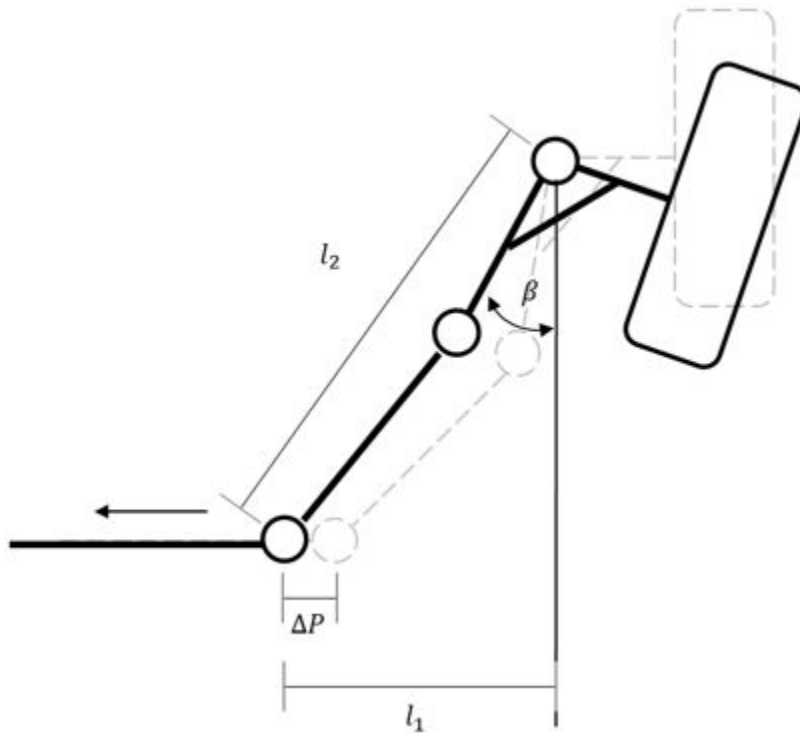
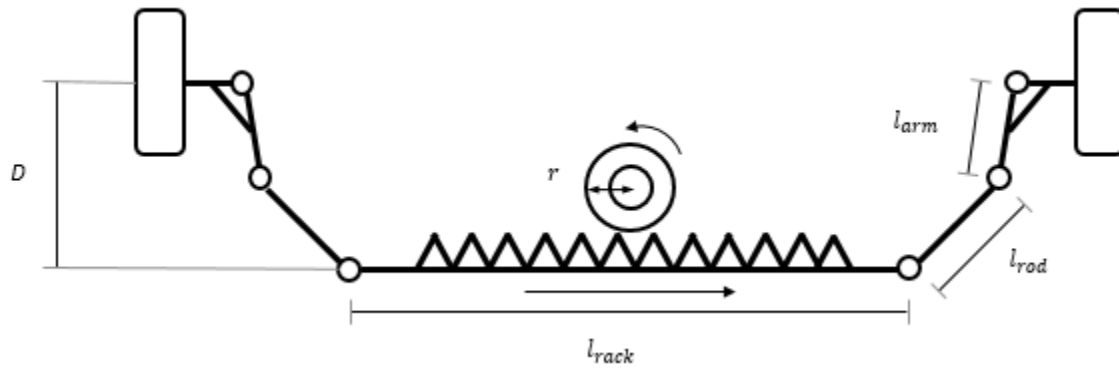
$$\delta_R = \tan^{-1}\left(\frac{WB \tan(\delta_{vir})}{WB + 0.5TW \tan(\delta_{vir})}\right)$$

The illustration and equations use these variables.

$\delta_{in}$	Steering angle
$\delta_L$	Left wheel angle
$\delta_R$	Right wheel angle
$\delta_{vir}$	Virtual wheel angle
$TW$	Track width
$WB$	Wheel base
$\gamma$	Steering ratio

### Rack-and-Pinion

For ideal rack-and-pinion steering, the gears convert the steering rotation into linear motion.



To calculate the steering angles, the block uses these equations.

$$l_1 = \frac{TW - l_{rack}}{2} - \Delta P$$

$$l_2^2 = l_1^2 + D^2$$

$$\Delta P = r\delta_{in}$$

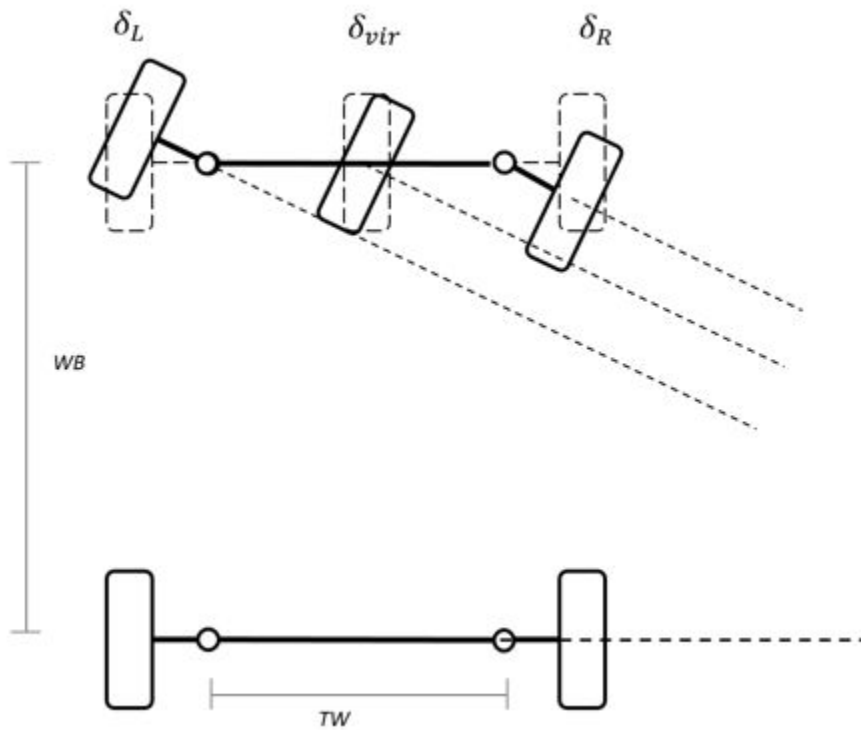
$$\beta = \frac{\pi}{2} - \tan^{-1}\left[\frac{D}{l_1}\right] - \cos^{-1}\left[\frac{l_{arm}^2 + l_2^2 - l_{rod}^2}{2l_{arm}l_2}\right]$$

The illustration and equations use these variables.

$\delta_{in}$	Steering wheel angle
$\delta_L$	Left wheel angle
$\delta_R$	Right wheel angle
$TW$	Track width
$r$	Pinion radius
$\Delta P$	Linear change in rack position
$D$	Distance between front axis and rack
$l_{rack}$	Rack casing length
$l_{arm}$	Steering arm length
$l_{rod}$	Tie rod length

**Parallel**

For parallel steering, the wheel angles are equal.



To calculate the steering angles, the block uses this equation.

$$\delta_R = \delta_L = \frac{\delta_{in}}{\gamma}$$

The illustration and equations use these variables.

$\delta_{in}$	Steering wheel angle
$\delta_L$	Left wheel angle
$\delta_R$	Right wheel angle
$\gamma$	Steering ratio

## Ports

### Input

#### AngIn — Steering angle

scalar

Steering angle,  $\delta_{in}$ , in rad.

### Output

#### Info — Bus signal

bus

Bus signal contains this block calculation.

Signal	Description	Variable	Unit
InstStrgRatio	Instantaneous steering ratio	$\gamma$	NA

#### AngLft — Left wheel angle

scalar

Left wheel angle,  $\delta_L$ , in rad.

#### AngRght — Right wheel angle

scalar

Right wheel angle,  $\delta_R$ , in rad.

## Parameters

#### Type — Select steering type

Ackerman (default) | Rack and pinion | Parallel

To specify the steering type, use the **Type** parameter.

Setting	Block Implementation
Ackerman	Ideal Ackerman steering. Wheel angles have a common turning circle center.
Rack and pinion	Ideal rack-and-pinion steering. Gears convert the steering rotation into linear motion.
Parallel	Parallel steering. Wheel angles are equal.

**Dependencies**

This table summarizes the **Type** and **Parameterized by** parameter dependencies.

<b>Type</b>	<b>Parameterized By</b>	<b>Creates Parameters</b>
Ackerman	Constant	<b>Track width, TrckWdth</b> <b>Wheel base, WhlBase</b> <b>Deadband, Db</b> <b>Steering range, StrgRng</b> <b>Steering ratio, StrgRatio</b>
	Lookup table	<b>Track width, TrckWdth</b> <b>Wheel base, WhlBase</b> <b>Deadband, Db</b> <b>Steering range, StrgRng</b> <b>Steering angle breakpoints, StrgAngBpts</b> <b>Steering ratio table, StrgRatioTbl</b>
Rack and pinion	Constant	<b>Track width, TrckWdth</b> <b>Deadband, Db</b> <b>Steering range, StrgRng</b> <b>Steering arm length, StrgArmLngth</b> <b>Rack casing length, RckCsLngth</b> <b>Tie rod length, TieRodLngth</b> <b>Distance between front axis and rack, D</b> <b>Pinion radius, PnnRadius</b>

Type	Parameterized By	Creates Parameters
	Lookup table	<b>Track width, TrckWdth</b> <b>Deadband, Db</b> <b>Steering range, StrgRng</b> <b>Steering angle breakpoints, StrgAngBpts</b> <b>Steering arm length, StrgArmLngth</b> <b>Rack casing length, RckCsLngth</b> <b>Tie rod length, TieRodLngth</b> <b>Distance between front axis and rack, D</b> <b>Pinion radius, PnnRadiusTbl</b>
Parallel	Constant	<b>Deadband, Db</b> <b>Steering range, StrgRng</b> <b>Steering ratio, StrgRatio</b>
	Lookup table	<b>Deadband, Db</b> <b>Steering range, StrgRng</b> <b>Steering angle breakpoints, StrgAngBpts</b> <b>Steering ratio table, StrgRatioTbl</b>

#### Parameterized by – Select parameterization

Constant (default) | Lookup table

To specify the type of data for the steering mechanism, use the **Parameterized by** parameter.

Setting	Block Implementation
Constant	Steering mechanism uses constant parameter data.
Lookup table	Steering mechanism implements tables for parameter data.

#### Dependencies

This table summarizes the **Type** and **Parameterized by** parameter dependencies.

<b>Type</b>	<b>Parameterized By</b>	<b>Creates Parameters</b>
Ackerman	Constant	<b>Track width, TrckWdth</b> <b>Wheel base, WhlBase</b> <b>Deadband, Db</b> <b>Steering range, StrgRng</b> <b>Steering ratio, StrgRatio</b>
	Lookup table	<b>Track width, TrckWdth</b> <b>Wheel base, WhlBase</b> <b>Deadband, Db</b> <b>Steering range, StrgRng</b> <b>Steering angle breakpoints, StrgAngBpts</b> <b>Steering ratio table, StrgRatioTbl</b>
Rack and pinion	Constant	<b>Track width, TrckWdth</b> <b>Deadband, Db</b> <b>Steering range, StrgRng</b> <b>Steering arm length, StrgArmLngth</b> <b>Rack casing length, RckCsLngth</b> <b>Tie rod length, TieRodLngth</b> <b>Distance between front axis and rack, D</b> <b>Pinion radius, PnnRadius</b>
	Lookup table	<b>Track width, TrckWdth</b> <b>Deadband, Db</b> <b>Steering range, StrgRng</b> <b>Steering angle breakpoints, StrgAngBpts</b> <b>Steering arm length, StrgArmLngth</b> <b>Rack casing length, RckCsLngth</b> <b>Tie rod length, TieRodLngth</b> <b>Distance between front axis and rack, D</b> <b>Pinion radius, PnnRadiusTbl</b>

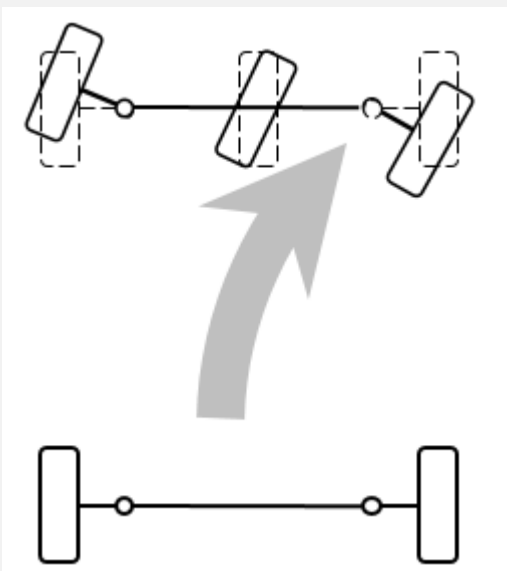


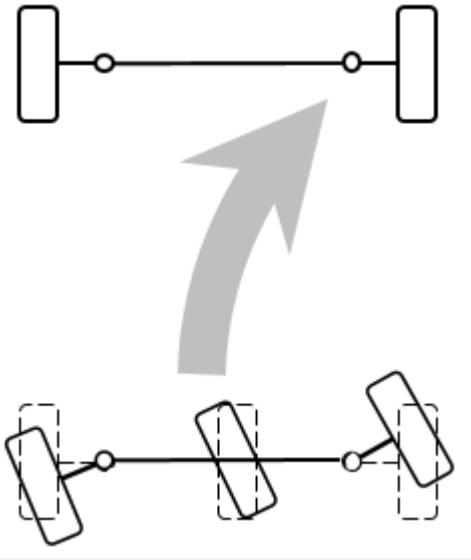
Type	Parameterized By	Creates Parameters
Parallel	Constant	<b>Deadband, Db</b> <b>Steering range, StrgRng</b> <b>Steering ratio, StrgRatio</b>
	Lookup table	<b>Deadband, Db</b> <b>Steering range, StrgRng</b> <b>Steering angle breakpoints, StrgAngBpts</b> <b>Steering ratio table, StrgRatioTbl</b>

### Location – Select location

Front (default) | Rear

Use the **Location** parameter to specify front or rear steering.

Setting	Implementation
Front	<p>Front steering</p> 

Setting	Implementation
Rear	<p>Rear steering</p> 

**Normalization factor, NrmFctr – Adjust the steering angle**  
 scalar

Factor,  $Nrm_{Fctr}$ , that the block uses to adjust the steering ratio,  $\gamma$  or pinion radius,  $r$ . The block can only normalize if you have **Parametrized by** set to Constant.

To adjust the steering ratio or pinion radius, click **Normalize**.

Steering Type	Normalization
Ackerman Parallel	Block updates the <b>Steering ratio, StrgRatio</b> parameter to the normalized value, $\gamma_{nrm}$ , specified by this equation.  $\gamma_{nrm} = \frac{1}{Nrm_{Fctr}}$
Rack and pinion	Block updates the <b>Pinion radius, PnnRadius</b> parameter to using the normalization factor, $Nrm_{Fctr}$ .

**General**

**Track width, TrckWdth – Width**  
 1 (default) | scalar

Track width,  $TW$ , in m.

**Dependencies**

To create this parameter, set **Type** to Ackerman or Rack and pinion.

**Wheel base, WhlBase – Base**  
 1.524 (default) | scalar

Wheel base,  $WB$ , in m.

#### Dependencies

To create this parameter, set **Type** to Ackerman.

#### Deadband, $Db$ — Deadband

0 (default) | scalar

Deadband steering angle before pinion engages the gear, in rad.

#### Steering range, $StrgRng$ — Range

$1.25 \cdot \pi$  (default) | scalar

Steering range, in rad. The block limits the wheel angles to remain within the steering range.

#### Steering ratio, $StrgRatio$ — Ratio

100 (default) | scalar

Steering ratio,  $\gamma$ , dimensionless.

#### Dependencies

To create this parameter:

- Set **Type** to Ackerman or Parallel.
- Set **Parametrized by** to Constant.

#### Steering angle breakpoints, $StrgAngBpts$ — Breakpoints

[-6.2832 -5.0265 -3.7699 -2.5133 -1.2566 0 1.2566 2.5133 3.7699 5.0265 6.2832] (default) | vector

Steering angle breakpoints, in rad.

#### Dependencies

To create this parameter, set **Parametrized by** to Lookup table.

#### Steering ratio table, $StrgRatioTbl$ — Table

[13.5000 13.3750 13.2500 13.1250 13.0000 13.0000 13.0000 13.1250 13.2500 13.3750 13.5000] (default) | vector

Steering ratio table,  $\gamma$ , dimensionless.

#### Dependencies

To create this parameter:

- Set **Type** to Ackerman or Parallel.
- Set **Parametrized by** to Lookup table.

#### Rack-and-Pinion

#### Steering arm length, $StrgArmLngth$ — Length

0.1 (default) | scalar

Steering arm length,  $l_{arm}$ , in m.

**Dependencies**

To create this parameter, set **Type** to Rack and pinion.

**Rack casing length, RckCsLngth — Length**

0.5 (default) | scalar

Rack casing length,  $l_{rack}$ , in m.

**Dependencies**

To create this parameter, set **Type** to Rack and pinion.

**Tie rod length, TieRodLngth — Length**

0.248 (default) | scalar

Tie rod length,  $l_{rod}$ , in m.

**Dependencies**

To create this parameter, set **Type** to Rack and pinion.

**Distance between front axis and rack, D — Distance**

0.2 (default) | scalar

Distance between front axis and rack,  $D$ , in m.

**Dependencies**

To create this parameter, set **Type** to Rack and pinion.

**Pinion radius, PnnRadius — Radius**

0.0057 (default) | scalar

Pinion radius,  $r$ , in m.

**Dependencies**

To create this parameter:

- Set **Type** to Rack and pinion.
- Set **Parametrized by** to Constant.

**Pinion radius table, PnnRadiusTbl — Table**

[0.0055 0.0055 0.0056 0.0057 0.0057 0.0057 0.0058 0.0057 0.0056 0.0055 0.0055] (default) | vector

Pinion radius table,  $r$ , in m.

**Dependencies**

To create this parameter:

- Set **Type** to Rack and pinion.
- Set **Parametrized by** to Lookup table.

## References

- [1] Crolla, David, David Foster, et al. *Encyclopedia of Automotive Engineering*. Volume 4, Part 5 (*Chassis Systems*) and Part 6 (*Electrical and Electronic Systems*). Chichester, West Sussex, United Kingdom: John Wiley & Sons Ltd, 2015.
- [2] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers, 1992.
- [3] Vehicle Dynamics Standards Committee. *Vehicle Dynamics Terminology*. SAE J670. Warrendale, PA: Society of Automotive Engineers, 2008.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

### See Also

Dynamic Steering | Mapped Steering

### Topics

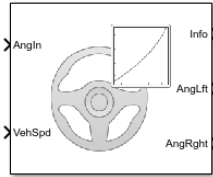
“Coordinate Systems in Vehicle Dynamics Blockset”

### Introduced in R2018a

# Mapped Steering

Mapped steering with speed-dependent option

**Library:** Vehicle Dynamics Blockset / Steering



## Description

The Mapped Steering block implements lookup tables to calculate the right and left wheel angles. Use the **Speed dependent** parameter to implement a speed-dependent table for the angle calculations. The block uses the vehicle coordinate system.

Speed Dependent	Implementation	Calculations
on (default)	Block uses three tables: <ul style="list-style-type: none"> <li><math>f_s</math> — Function of vehicle speed</li> <li><math>f_L</math> — Function of superimposed steering wheel angle</li> <li><math>f_R</math> — Function of superimposed steering wheel angle</li> </ul>	$\delta_{SpdF} = f_s(v)$ $\delta_{SuprImp} = \delta_{SpdF} \cdot \delta_{in}$ $\delta_L = f_L(\delta_{SuprImp})$ $\delta_R = f_R(\delta_{SuprImp})$
off	Block uses two tables: <ul style="list-style-type: none"> <li><math>f_L</math> — Function of steering wheel angle</li> <li><math>f_R</math> — Function of steering wheel angle</li> </ul>	$\delta_L = f_L(\delta_{in})$ $\delta_R = f_R(\delta_{in})$

The equations use these variables.

- $\delta_{in}$                       Steering wheel angle
- $\delta_{SpdF}$                     Steering wheel angle speed factor
- $\delta_{SuprImp}$                 Superimposed steering wheel angle
- $\delta_L, \delta_R$                 Left and right wheel angles, respectively

## Ports

### Input

**AngIn — Steering angle**  
scalar

Steering angle,  $\delta_{in}$ , in rad.

### VehSpd — Vehicle speed

scalar

Vehicle speed,  $Veh_{spd}$ , in m/s.

### Dependencies

To enable this port, select **Speed dependent**.

### Output

### Info — Bus signal

bus

Bus signal containing these block calculations.

Signal	Description	Variable	Unit
AngLft	Left wheel angle	$\delta_L$	rad
AngRght	Left wheel angle	$\delta_R$	rad

### AngLft — Left wheel angle

scalar

Left wheel angle,  $\delta_L$ , in rad.

### AngRght — Right wheel angle

scalar

Right wheel angle,  $\delta_R$ , in rad.

## Parameters

### Steering angle breakpoints, StrgAngBpts — Steering angle breakpoints

$[-1.5*\pi \ 1.5*\pi]$  (default) | vector

Steering angle breakpoints, in rad.

### Left wheel angle table, WhlLftTbl — Left wheel angle table

$[-1.5*\pi \ 1.5*\pi]/13.5$  (default) | vector

Left wheel angle table,  $\delta_L$ , in rad.

### Right wheel angle table, WhlRghtTbl — Right wheel angle table

$[-1.5*\pi \ 1.5*\pi]/13.5$  (default) | vector

Right wheel angle table,  $\delta_R$ , in rad.

### Vehicle speed breakpoints, VehSpdBpts — Vehicle speed breakpoints

$[-1 \ 1]$  (default) | vector

Vehicle speed breakpoints, in m/s.

## Dependencies

To create this parameter, select **Speed dependent**.

## Superimposed speed factor table, SpdFctTbl – Speed factor

[1 1] (default) | vector

Superimposed speed factor table,  $f_s$ , dimensionless. The table is a factor of vehicle speed,  $v$ .

## Dependencies

To create this parameter, select **Speed dependent**.

## References

- [1] Crolla, David, David Foster, et al. *Encyclopedia of Automotive Engineering*. Volume 4, Part 5 (*Chassis Systems*) and Part 6 (*Electrical and Electronic Systems*). Chichester, West Sussex, United Kingdom: John Wiley & Sons Ltd, 2015.
- [2] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers, 1992.
- [3] Vehicle Dynamics Standards Committee. *Vehicle Dynamics Terminology*. SAE J670. Warrendale, PA: Society of Automotive Engineers, 2008.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

Dynamic Steering | Kinematic Steering

## Topics

“Coordinate Systems in Vehicle Dynamics Blockset”

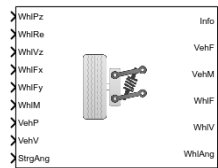
## Introduced in R2018a



# Independent Suspension - Double Wishbone

Double wishbone independent suspension

**Library:** Vehicle Dynamics Blockset / Suspension



## Description

The Independent Suspension - Double Wishbone block implements an independent double wishbone suspension for multiple axles with multiple tracks per axle.

The block models the suspension compliance, damping, and geometric effects as functions of the relative positions and velocities of the vehicle and wheel carrier with axle-specific compliance and damping parameters. Using the suspension compliance and damping, the block calculates the suspension force on the vehicle and wheel. The block uses the Z-down coordinate system (defined in SAE J670).

For Each	You Can Specify
Axle	<ul style="list-style-type: none"> <li>Multiple tracks</li> <li>An anti-sway bar for axles with two tracks</li> <li>Suspension parameters</li> </ul>
Track	<ul style="list-style-type: none"> <li>Steering angles</li> </ul>

The block contains energy-storing spring elements and energy-dissipating damper elements. It does not contain energy-storing mass elements. The block assumes that the vehicle (sprung) and wheel (unsprung) blocks connected to the block store the mass-related suspension energy.

This table summarizes the block parameter settings for a vehicle with:

- Two axles
- Two tracks per axle
- Steering angle input for both tracks on the front axle
- An anti-sway bar on the front axle

Parameter	Setting
<b>Number of axles, NumAxl</b>	2
<b>Number of tracks by axle, NumTracksByAxl</b>	[2 2]
<b>Steered axle enable by axle, StrgEnByAxl</b>	[1 0]
<b>Anti-sway axle enable by axle, AntiSwayEnByAxl</b>	[1 0]

### Suspension Compliance and Damping

The block uses a linear spring and damper to model the vertical dynamic effects of the suspension system. Using the relative positions and velocities of the vehicle and wheel carrier, the block calculates the vertical suspension forces on the wheel and vehicle. The block uses a linear equation that relates the vertical damping and compliance to the suspension height, suspension height rate of change, and absolute value of the steering angles.

The block implements this equation.

$$F_{wz_{a,t}} = F_{z0_a} + k_{z_a}(z_{v_{a,t}} - z_{w_{a,t}} + m_{hsteer_a}|\delta_{steer_{a,t}}|) + c(\dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}) + F_{zhstop_{a,t}} + F_{zasw_{y_{a,t}}}$$

The damping coefficient,  $c$ , depends on the **Enable active damping** parameter setting.

Enable active damping Setting	Damping
off	Constant, $c = c_{z_a}$
on	Lookup table that is a function of active damper duty cycle and actuator velocity  $c = f(duty, (\dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}))$

The block assumes that the suspension elements have no mass. Therefore, the suspension forces and moments applied to the vehicle are equal to the suspension forces and moments applied to the wheel.

$$F_{vx_{a,t}} = F_{wx_{a,t}}$$

$$F_{vy_{a,t}} = F_{wy_{a,t}}$$

$$F_{vz_{a,t}} = -F_{wz_{a,t}}$$

$$M_{vx_{a,t}} = M_{wx_{a,t}} + F_{wy_{a,t}}(Re_{wy_{a,t}} + H_{a,t})$$

$$M_{vy_{a,t}} = M_{wy_{a,t}} + F_{wx_{a,t}}(Re_{wx_{a,t}} + H_{a,t})$$

$$M_{vz_{a,t}} = M_{wz_{a,t}}$$

The block sets the wheel positions and velocities equal to the vehicle lateral and longitudinal positions and velocities.

$$x_{w_{a,t}} = x_{v_{a,t}}$$

$$y_{w_{a,t}} = y_{v_{a,t}}$$

$$\dot{x}_{w_{a,t}} = \dot{x}_{v_{a,t}}$$

$$\dot{y}_{w_{a,t}} = \dot{y}_{v_{a,t}}$$

The equations use these variables.

$F_{wz_{a,t}}, M_{wz_{a,t}}$  Suspension force and moment applied to the wheel on axle  $a$ , track  $t$  along wheel-fixed  $z$ -axis

$F_{wx_{a,t}}, M_{wx_{a,t}}$	Suspension force and moment applied to the wheel on axle $a$ , track $t$ along wheel-fixed $x$ -axis
$F_{wy_{a,t}}, M_{wy_{a,t}}$	Suspension force and moment applied to the wheel on axle $a$ , track $t$ along wheel-fixed $y$ -axis
$F_{vz_{a,t}}, M_{vz_{a,t}}$	Suspension force and moment applied to the vehicle on axle $a$ , track $t$ along wheel-fixed $z$ -axis
$F_{vx_{a,t}}, M_{vx_{a,t}}$	Suspension force and moment applied to the vehicle on axle $a$ , track $t$ along wheel-fixed $x$ -axis
$F_{vy_{a,t}}, M_{vy_{a,t}}$	Suspension force and moment applied to the vehicle on axle $a$ , track $t$ along wheel-fixed $y$ -axis
$F_{z0_a}$	Vertical suspension spring preload force applied to the wheels on axle $a$
$k_{z_a}$	Vertical spring constant applied to tracks on axle $a$
$m_{hsteer_a}$	Steering angle to vertical force slope applied at wheel carrier for tracks on axle $a$
$\delta_{steer_{a,t}}$	Steering angle input for axle $a$ , track $t$
$c_{z_a}$	Vertical damping constant applied to tracks on axle $a$
$Re_{w_{a,t}}$	Effective wheel radius for axle $a$ , track $t$
$F_{zhstop_{a,t}}$	Vertical hardstop force at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis
$F_{zaswy_{a,t}}$	Vertical anti-sway force at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis
$x_{v_{a,t}}, \dot{x}_{v_{a,t}}$	Vehicle displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $x$ -axis
$x_{w_{a,t}}, \dot{x}_{w_{a,t}}$	Track displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $x$ -axis
$y_{v_{a,t}}, \dot{y}_{v_{a,t}}$	Vehicle displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $y$ -axis
$y_{w_{a,t}}, \dot{y}_{w_{a,t}}$	Track displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $y$ -axis
$H_{a,t}$	Suspension height at axle $a$ , track $t$
$Re_{w_{a,t}}$	Effective wheel radius at axle $a$ , track $t$

### Hardstop Forces

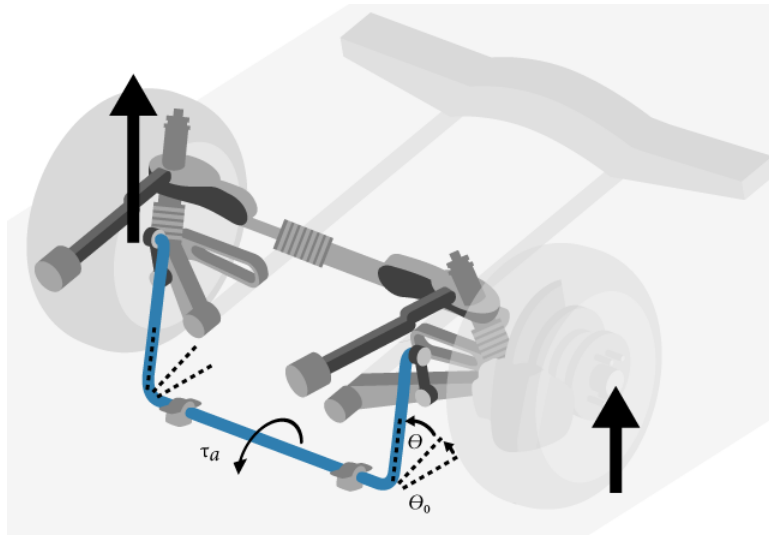
The hardstop feedback force,  $F_{zhstop_{a,t}}$ , that the block applies depends on whether the suspension is compressing or extending. The block applies the force:

- In compression, when the suspension is compressed more than the maximum distance specified by the **Suspension maximum height, Hmax** parameter.
- In extension, when the suspension extension is greater than maximum extension specified by the **Suspension maximum height, Hmax** parameter.

To calculate the force, the block uses a stiffness based on a hyperbolic tangent and exponential scaling.

### Anti-Sway Bar

Optionally, the block implements an anti-sway bar force,  $F_{zaswy_{a,t}}$ , for axles that have two tracks. This figure shows how the anti-sway bar transmits torque between two independent suspension tracks on a shared axle. Each independent suspension applies a torque to the anti-sway bar via a radius arm that extends from the anti-sway bar back to the independent suspension connection point.



To calculate the sway bar force, the block implements these equations.

Calculation	Equation
Anti-sway bar angular deflection for a given axle and track, $\Delta\theta_{a,t}$	$\theta_{0a} = \tan^{-1}\left(\frac{z_0}{r}\right)$ $\Delta\theta_{a,t} = \tan^{-1}\left(\frac{r \tan \theta_{0a} - z_{w_{a,t}} + z_{v_{a,t}}}{r}\right)$
Anti-sway bar twist angle, $\theta_a$	$\theta_a = -\tan^{-1}\left(\frac{r \tan \theta_{0a} - z_{w_{a,1}} + z_{v_{a,1}}}{r}\right)$ $-\tan^{-1}\left(\frac{r \tan \theta_{0a} - z_{w_{a,2}} + z_{v_{a,2}}}{r}\right)$
Anti-sway bar torque, $\tau_a$	$\tau_a = k_a \theta_a$
Anti-sway bar forces applied to the wheel on axle $a$ , track $t$ along wheel-fixed $z$ -axis	$F_{z_{aswy_{a,1}}} = \left(\frac{\tau_a}{r}\right) \cos\left(\theta_{0a} - \tan^{-1}\left(\frac{r \tan \theta_{0a} - z_{w_{a,1}} + z_{v_{a,1}}}{r}\right)\right)$ $F_{z_{aswy_{a,2}}} = \left(\frac{\tau_a}{r}\right) \cos\left(\theta_{0a} - \tan^{-1}\left(\frac{r \tan \theta_{0a} - z_{w_{a,2}} + z_{v_{a,2}}}{r}\right)\right)$

The equations and figure use these variables.

$\tau_a$	Anti-sway bar torque
$\theta$	Anti-sway bar twist angle
$\theta_{0a}$	Initial anti-sway bar twist angle
$\Delta\theta_{a,t}$	Anti-sway bar angular deflection at axle $a$ , track $t$
$r$	Anti-sway bar arm radius
$z_0$	Vertical distance from anti-sway bar connection point to anti-sway bar centerline
$F_{z_{aswy_{a,t}}}$	Anti-sway bar force applied to the wheel on axle $a$ , track $t$ along wheel-fixed $z$ -axis
$z_{v_{a,t}}$	Vehicle displacement at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis
$z_{w_{a,t}}$	Wheel displacement at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis

### Camber, Caster, and Toe Angles

To calculate the camber, caster, and toe angles, block uses linear functions of the suspension height and steering angle.

$$\begin{aligned}\xi_{a,t} &= \xi_{0a} + m_{hcamber_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{cambersteer_a}|\delta_{steer_{a,t}}| \\ \eta_{a,t} &= \eta_{0a} + m_{hcaster_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{castersteer_a}|\delta_{steer_{a,t}}| \\ \zeta_{a,t} &= \zeta_{0a} + m_{htoe_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{toesteer_a}|\delta_{steer_{a,t}}|\end{aligned}$$

The equations use these variables.

$\xi_{a,t}$	Camber angle of wheel on axle <b>a</b> , track <b>t</b>
$\eta_{a,t}$	Caster angle of wheel on axle <b>a</b> , track <b>t</b>
$\zeta_{a,t}$	Toe angle of wheel on axle <b>a</b> , track <b>t</b>
$\xi_{0a}, \eta_{0a}, \zeta_{0a}$	Nominal suspension axle <b>a</b> camber, caster, and toe angles, respectively, at zero steering angle
$m_{hcamber_a}, m_{hcaster_a}, m_{htoe_a}$	Camber, caster, and toe angles, respectively, versus suspension height slope for axle <b>a</b>
$m_{cambersteer_a}, m_{castersteer_a}, m_{toesteer_a}$	Camber, caster, and toe angles, respectively, versus steering angle slope for axle <b>a</b>
$m_{hsteer_a}$	Steering angle versus vertical force slope for axle <b>a</b>
$\delta_{steer_{a,t}}$	Steering angle input for axle <b>a</b> , track <b>t</b>
$z_{v_{a,t}}$	Vehicle displacement at axle <b>a</b> , track <b>t</b> , along the vehicle-fixed <i>z</i> -axis
$z_{w_{a,t}}$	Track displacement at axle <b>a</b> , track <b>t</b> , along the vehicle-fixed <i>z</i> -axis

### Steering Angles

Optionally, you can input steering angles for the tracks. To calculate the steering angles for the wheels, the block offsets the input steering angles with a linear function of the suspension height.

$$\delta_{whlsteer_{a,t}} = \delta_{steer_{a,t}} + m_{htoe_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{toesteer_a}|\delta_{steer_{a,t}}|$$

The equation uses these variables.

$m_{toesteer_a}$	Axle <b>a</b> toe angle versus steering angle slope
$m_{hsteer_a}$	Axle <b>a</b> steering angle versus vertical force slope
$m_{htoe_a}$	Axle <b>a</b> toe angle versus suspension height slope
$\delta_{whlsteer_{a,t}}$	Wheel steering angle for axle <b>a</b> , track <b>t</b>
$\delta_{steer_{a,t}}$	Steering angle input for axle <b>a</b> , track <b>t</b>
$z_{v_{a,t}}$	Vehicle displacement at axle <b>a</b> , track <b>t</b> , along the vehicle-fixed <i>z</i> -axis
$z_{w_{a,t}}$	Track displacement at axle <b>a</b> , track <b>t</b> , along the vehicle-fixed <i>z</i> -axis

### Power and Energy

The block calculates these suspension characteristics for each axle, **a**, track, **t**.

Calculation	Equation
Dissipated power, $P_{susp_{a,t}}$	$P_{susp_{a,t}} = F_{wzlookup_a}(\dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$
Absorbed energy, $E_{susp_{a,t}}$	$E_{susp_{a,t}} = F_{wzlookup_a}(z_{v_{a,t}} - z_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$
Suspension height, $H_{a,t}$	$H_{a,t} = -\left(z_{v_{a,t}} - z_{w_{a,t}} + \frac{F_{z0_a}}{k_{z_a}} + m_{hsteer_a} \delta_{steer_{a,t}} \right)$
Distance from wheel carrier center to tire/road interface	$z_{wtr_{a,t}} = Re_{w_{a,t}} + H_{a,t}$

The equations use these variables.

$m_{hsteer_a}$	Steering angle to vertical force slope applied at wheel carrier for tracks on axle a
$\delta_{steer_{a,t}}$	Steering angle input for axle a, track t
$Re_{w_{a,t}}$	Axle a, track t effective wheel radius from wheel carrier center to tire/road interface
$F_{z0_a}$	Vertical suspension spring preload force applied to the wheels on axle a
$z_{wtr_{a,t}}$	Distance from wheel carrier center to tire/road interface, along the vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along the vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along the vehicle-fixed z-axis

## Ports

### Input

#### WhlPz — Track z-axis displacement

array

Track displacement,  $z_w$ , along wheel-fixed z-axis, in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlPz:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlPz} = z_w = [z_{w1,1} \ z_{w1,2} \ z_{w2,1} \ z_{w2,2}]$$

Array Element	Axle	Track
WhlPz(1,1)	1	1
WhlPz(1,2)	1	2
WhlPz(1,3)	2	1
WhlPz(1,4)	2	2

#### WhlRe — Wheel effective radius

array

Effective wheel radius,  $Re_w$ , in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlRe:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlRe} = Re_w = [Re_{w1,1} \quad Re_{w1,2} \quad Re_{w2,1} \quad Re_{w2,2}]$$

Array Element	Axle	Track
WhlRe(1,1)	1	1
WhlRe(1,2)	1	2
WhlRe(1,3)	2	1
WhlRe(1,4)	2	2

### WhlVz — Track z-axis velocity

array

Track velocity,  $\dot{z}_w$ , along wheel-fixed z-axis, in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlVz:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlVz} = \dot{z}_w = [\dot{z}_{w1,1} \quad \dot{z}_{w1,2} \quad \dot{z}_{w2,1} \quad \dot{z}_{w2,2}]$$

Array Element	Axle	Track
WhlVz(1,1)	1	1
WhlVz(1,2)	1	2
WhlVz(1,3)	2	1
WhlVz(1,4)	2	2

### WhlFx — Longitudinal wheel force on vehicle

array

Longitudinal wheel force applied to vehicle,  $F_{wx}$ , along the vehicle-fixed x-axis. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlFx:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlFx} = F_{wx} = [F_{wx1,1} \quad F_{wx1,2} \quad F_{wx2,1} \quad F_{wx2,2}]$$

Array Element	Axle	Track
WhlFx(1,1)	1	1
WhlFx(1,2)	1	2
WhlFx(1,3)	2	1
WhlFx(1,4)	2	2

**WhlFy – Lateral wheel force on vehicle**

array

Lateral wheel force applied to vehicle,  $F_{wy}$ , along the vehicle-fixed y-axis. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlFy:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlFy} = F_{wy} = [F_{wy1,1} \ F_{wy1,2} \ F_{wy2,1} \ F_{wy2,2}]$$

Array Element	Axle	Track
WhlFy(1,1)	1	1
WhlFy(1,2)	1	2
WhlFy(1,3)	2	1
WhlFy(1,4)	2	2

**WhlM – Suspension moment on wheel**

array

Longitudinal, lateral, and vertical suspension moments at axle *a*, track *t*, applied to the wheel at the axle wheel carrier reference coordinate, in N·m. Array dimensions are 3 by the total number of tracks on the vehicle.

- WhlM(1, . . .) – Suspension moment applied to the wheel about the vehicle-fixed x-axis (longitudinal)
- WhlM(2, . . .) – Suspension moment applied to the wheel about the vehicle-fixed y-axis (lateral)
- WhlM(3, . . .) – Suspension moment applied to the wheel about the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the WhlM:

- Signal dimensions are [3x4].
- Signal contains suspension moments applied to four wheels according to their axle and track locations.

$$\text{WhlM} = M_w = \begin{bmatrix} M_{wx1,1} & M_{wx1,2} & M_{wx2,1} & M_{wx2,2} \\ M_{wy1,1} & M_{wy1,2} & M_{wy2,1} & M_{wy2,2} \\ M_{wz1,1} & M_{wz1,2} & M_{wz2,1} & M_{wz2,2} \end{bmatrix}$$



Array Element	Axle	Track	Moment Axis
WhlM(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
WhlM(1,2)	1	2	
WhlM(1,3)	2	1	
WhlM(1,4)	2	2	
WhlM(2,1)	1	1	Vehicle-fixed y-axis (lateral)
WhlM(2,2)	1	2	
WhlM(2,3)	2	1	
WhlM(2,4)	2	2	
WhlM(3,1)	1	1	Vehicle-fixed z-axis (vertical)
WhlM(3,2)	1	2	
WhlM(3,3)	2	1	
WhlM(3,4)	2	2	

### VehP – Vehicle displacement

array

Vehicle displacement from axle  $a$ , track  $t$  along vehicle-fixed coordinate system, in m. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehP(1, . . .) – Vehicle displacement from track,  $x_v$ , along the vehicle-fixed x-axis
- VehP(2, . . .) – Vehicle displacement from track,  $y_v$ , along the vehicle-fixed y-axis
- VehP(3, . . .) – Vehicle displacement from track,  $z_v$ , along the vehicle-fixed z-axis

For example, for a two-axle vehicle with two tracks per axle, the VehP:

- Signal dimensions are [3x4].
- Signal contains four track displacements according to their axle and track locations.

$$\text{VehP} = \begin{bmatrix} x_v \\ y_v \\ z_v \end{bmatrix} = \begin{bmatrix} x_{v1,1} & x_{v1,2} & x_{v2,1} & x_{v2,2} \\ y_{v1,1} & y_{v1,2} & y_{v2,1} & y_{v2,2} \\ z_{v1,1} & z_{v1,2} & z_{v2,1} & z_{v2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
VehP(1,1)	1	1	Vehicle-fixed x-axis
VehP(1,2)	1	2	
VehP(1,3)	2	1	
VehP(1,4)	2	2	
VehP(2,1)	1	1	Vehicle-fixed y-axis
VehP(2,2)	1	2	
VehP(2,3)	2	1	
VehP(2,4)	2	2	

Array Element	Axle	Track	Axis
VehP(3,1)	1	1	Vehicle-fixed z-axis
VehP(3,2)	1	2	
VehP(3,3)	2	1	
VehP(3,4)	2	2	

**VehV – Vehicle velocity**

array

Vehicle velocity at axle *a*, track *t* along vehicle-fixed coordinate system, in m. Input array dimensions are 3 by *a*\**t*.

- VehV(1, . . . ) – Vehicle velocity at track, *x<sub>v</sub>*, along the vehicle-fixed x-axis
- VehV(2, . . . ) – Vehicle velocity at track, *y<sub>v</sub>*, along the vehicle-fixed y-axis
- VehV(3, . . . ) – Vehicle velocity at track, *z<sub>v</sub>*, along the vehicle-fixed z-axis

For example, for a two-axle vehicle with two tracks per axle, the VehV:

- Signal dimensions are [3x4].
- Signal contains 4 track velocities according to their axle and track locations.

$$\text{VehV} = \begin{bmatrix} \dot{x}_v \\ \dot{y}_v \\ \dot{z}_v \end{bmatrix} = \begin{bmatrix} \dot{x}_{v1,1} & \dot{x}_{v1,2} & \dot{x}_{v2,1} & \dot{x}_{v2,2} \\ \dot{y}_{v1,1} & \dot{y}_{v1,2} & \dot{y}_{v2,1} & \dot{y}_{v2,2} \\ \dot{z}_{v1,1} & \dot{z}_{v1,2} & \dot{z}_{v2,1} & \dot{z}_{v2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
VehV(1,1)	1	1	Vehicle-fixed x-axis
VehV(1,2)	1	2	
VehV(1,3)	2	1	
VehV(1,4)	2	2	
VehV(2,1)	1	1	Vehicle-fixed y-axis
VehV(2,2)	1	2	
VehV(2,3)	2	1	
VehV(2,4)	2	2	
VehV(3,1)	1	1	Vehicle-fixed z-axis
VehV(3,2)	1	2	
VehV(3,3)	2	1	
VehV(3,4)	2	2	

**StrgAng – Steering angle, optional**

array

Optional steering angle for each wheel, *δ*. Input array dimensions are 1 by the number of steered tracks.

For example, for a two-axle vehicle with two tracks per axle, you can input steering angles for both wheels on the first axle.

- To create the `StrgAng` port, set **Steered axle enable by axle, `StrgEnByAxl`** to `[1 0]`. The input signal array dimensions are `[1x2]`.
- The `StrgAng` signal contains two steering angles according to their axle and track locations.

$$\text{StrgAng} = \delta_{steer} = [\delta_{steer1,1} \ \delta_{steer1,2}]$$

Array Element	Axle	Track
<code>StrgAng(1,1)</code>	1	1
<code>StrgAng(1,2)</code>	1	2

### Dependencies

Setting an element of the **Steered axle enable by axle, `StrgEnByAxl`** vector to 1 creates:

- Input port `StrgAng`.
- Parameters:
  - **Toe angle vs steering angle slope, `ToeStrgSlp`**
  - **Caster angle vs steering angle slope, `CasterStrgSlp`**
  - **Camber angle vs steering angle slope, `CamberStrgSlp`**
  - **Suspension height vs steering angle slope, `StrgHgtSlp`**

### Output

#### Info — Bus signal

bus

Bus signal containing block values. The signals are arrays that depend on the track location.

For example, here are the indices for a two-axle, two-track vehicle. The total number of tracks is four.

- 1D array signal (1-by-4)

Array Element	Axle	Track
<code>(1,1)</code>	1	1
<code>(1,2)</code>	1	2
<code>(1,3)</code>	2	1
<code>(1,4)</code>	2	2

- 3D array signal (3-by-4)

Array Element	Axle	Track
<code>(1,1)</code>	1	1
<code>(1,2)</code>	1	2
<code>(1,3)</code>	2	1
<code>(1,4)</code>	2	2

Array Element	Axle	Track
(2,1)	1	1
(2,2)	1	2
(2,3)	2	1
(2,4)	2	2
(3,1)	1	1
(3,2)	1	2
(3,3)	2	1
(3,4)	2	2

Signal	Description	Array Signal	Variable	Units
Camber	Wheel angles according to the axle and track location.	1D	$WhlAng[1, \dots] = \xi = [\xi_{a,t}]$	rad
Caster			$WhlAng[2, \dots] = \eta = [\eta_{a,t}]$	
Toe			$WhlAng[3, \dots] = \zeta = [\zeta_{a,t}]$	
Height	Suspension height	1D	$H$	m
Power	Suspension power dissipation	1D	$P_{susp}$	W
Energy	Suspension absorbed energy	1D	$E_{susp}$	J
VehF	Suspension forces applied to the vehicle	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $VehF = F_v = \begin{bmatrix} F_{vx1,1} & F_{vx1,2} & F_{vx2,1} & F_{vx2,2} \\ F_{vy1,1} & F_{vy1,2} & F_{vy2,1} & F_{vy2,2} \\ F_{vz1,1} & F_{vz1,2} & F_{vz2,1} & F_{vz2,2} \end{bmatrix}$	N

Signal	Description	Array Signal	Variable	Units
VehM	Suspension moments applied to vehicle	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{VehM} = M_v =$ $\begin{bmatrix} M_{vx1,1} & M_{vx1,2} & M_{vx2,1} & M_{vx2,2} \\ M_{vy1,1} & M_{vy1,2} & M_{vy2,1} & M_{vy2,2} \\ M_{vz1,1} & M_{vz1,2} & M_{vz2,1} & M_{vz2,2} \end{bmatrix}$	N·m
WhlF	Suspension force applied to wheel	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlF} = F_w =$ $\begin{bmatrix} F_{wx1,1} & F_{wx1,2} & F_{wx2,1} & F_{wx2,2} \\ F_{wy1,1} & F_{wy1,2} & F_{wy2,1} & F_{wy2,2} \\ F_{wz1,1} & F_{wz1,2} & F_{wz2,1} & F_{wz2,2} \end{bmatrix}$	N
WhlP	Track displacement	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlP} = \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix} =$ $\begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{w2,2} \\ z_{wtr1,1} & z_{wtr1,2} & z_{wtr2,1} & z_{wtr2,2} \end{bmatrix}$	m

Signal	Description	Array Signal	Variable	Units
WhlV	Track velocity	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlV} = \begin{bmatrix} \dot{x}_w \\ \dot{y}_w \\ \dot{z}_w \end{bmatrix}$ <p>=</p> $\begin{bmatrix} \dot{x}_{w1,1} & \dot{x}_{w1,2} & \dot{x}_{w2,1} & \dot{x}_{w2,2} \\ \dot{y}_{w1,1} & \dot{y}_{w1,2} & \dot{y}_{w2,1} & \dot{y}_{w2,2} \\ \dot{z}_{w1,1} & \dot{z}_{w1,2} & \dot{z}_{w2,1} & \dot{z}_{w2,2} \end{bmatrix}$	m/s
WhlAng	Wheel camber, caster, toe angles	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix}$ <p>=</p> $\begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$	rad

**VehF — Suspension force on vehicle**

array

Longitudinal, lateral, and vertical suspension force at axle a, track t, applied to the vehicle at the suspension connection point, in N. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehF(1, . . .) — Suspension force applied to vehicle along the vehicle-fixed x-axis (longitudinal)
- VehF(2, . . .) — Suspension force applied to vehicle along the vehicle-fixed y-axis (lateral)
- VehF(3, . . .) — Suspension force applied to vehicle along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the VehF:

- Signal dimensions are [3x4].
- Signal contains suspension forces applied to the vehicle according to the axle and track locations.

$$\text{VehF} = F_v = \begin{bmatrix} F_{vx1,1} & F_{vx1,2} & F_{vx2,1} & F_{vx2,2} \\ F_{vy1,1} & F_{vy1,2} & F_{vy2,1} & F_{vy2,2} \\ F_{vz1,1} & F_{vz1,2} & F_{vz2,1} & F_{vz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
VehF(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
VehF(1,2)	1	2	
VehF(1,3)	2	1	
VehF(1,4)	2	2	
VehF(2,1)	1	1	Vehicle-fixed y-axis (lateral)
VehF(2,2)	1	2	
VehF(2,3)	2	1	
VehF(2,4)	2	2	
VehF(3,1)	1	1	Vehicle-fixed z-axis (vertical)
VehF(3,2)	1	2	
VehF(3,3)	2	1	
VehF(3,4)	2	2	

### VehM – Suspension moment on vehicle

array

Longitudinal, lateral, and vertical suspension moment at axle *a*, track *t*, applied to the vehicle at the suspension connection point, in N·m. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehM(1, . . .) – Suspension moment applied to the vehicle about the vehicle-fixed x-axis (longitudinal)
- VehM(2, . . .) – Suspension moment applied to the vehicle about the vehicle-fixed y-axis (lateral)
- VehM(3, . . .) – Suspension moment applied to the vehicle about the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the VehM:

- Signal dimensions are [3×4].
- Signal contains suspension moments applied to vehicle according to the axle and track locations.

$$\text{VehM} = M_v = \begin{bmatrix} M_{vx1,1} & M_{vx1,2} & M_{vx2,1} & M_{vx2,2} \\ M_{vy1,1} & M_{vy1,2} & M_{vy2,1} & M_{vy2,2} \\ M_{vz1,1} & M_{vz1,2} & M_{vz2,1} & M_{vz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Moment Axis
VehM(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
VehM(1,2)	1	2	
VehM(1,3)	2	1	
VehM(1,4)	2	2	
VehM(2,1)	1	1	Vehicle-fixed y-axis (lateral)
VehM(2,2)	1	2	

Array Element	Axle	Track	Moment Axis
VehM(2,3)	2	1	Vehicle-fixed z-axis (vertical)
VehM(2,4)	2	2	
VehM(3,1)	1	1	
VehM(3,2)	1	2	
VehM(3,3)	2	1	
VehM(3,4)	2	2	

**WhlF – Suspension force on wheel**

array

Longitudinal, lateral, and vertical suspension forces at axle **a**, track **t**, applied to the wheel at the axle wheel carrier reference coordinate, in N. Array dimensions are 3 by the total number of tracks on the vehicle.

- WhlF(1, . . .) – Suspension force on wheel along the vehicle-fixed x-axis (longitudinal)
- WhlF(2, . . .) – Suspension force on wheel along the vehicle-fixed y-axis (lateral)
- WhlF(3, . . .) – Suspension force on wheel along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the WhlF:

- Signal dimensions are [3x4].
- Signal contains wheel forces applied to the vehicle according to the axle and track locations.

$$\text{WhlF} = F_w = \begin{bmatrix} F_{wx1,1} & F_{wx1,2} & F_{wx2,1} & F_{wx2,2} \\ F_{wy1,1} & F_{wy1,2} & F_{wy2,1} & F_{wy2,2} \\ F_{wz1,1} & F_{wz1,2} & F_{wz2,1} & F_{wz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
WhlF(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
WhlF(1,2)	1	2	
WhlF(1,3)	2	1	
WhlF(1,4)	2	2	
WhlF(2,1)	1	1	Vehicle-fixed y-axis (lateral)
WhlF(2,2)	1	2	
WhlF(2,3)	2	1	
WhlF(2,4)	2	2	
WhlF(3,1)	1	1	Vehicle-fixed z-axis (vertical)
WhlF(3,2)	1	2	
WhlF(3,3)	2	1	
WhlF(3,4)	2	2	

**WhlV – Track velocity**

array



Longitudinal, lateral, and vertical track velocity at axle  $a$ , track  $t$ , in m/s. Array dimensions are 3 by the total number of tracks on the vehicle.

- $WhlV(1, \dots)$  — Track velocity along the vehicle-fixed x-axis (longitudinal)
- $WhlV(2, \dots)$  — Track velocity along the vehicle-fixed y-axis (lateral)
- $WhlV(3, \dots)$  — Track velocity along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the  $WhlV$ :

- Signal dimensions are  $[3 \times 4]$ .
- Signal contains wheel forces applied to the vehicle according to the axle and track locations.

$$WhlV = \begin{bmatrix} \dot{x}_w \\ \dot{y}_w \\ \dot{z}_w \end{bmatrix} = \begin{bmatrix} \dot{x}_{w1,1} & \dot{x}_{w1,2} & \dot{x}_{w2,1} & \dot{x}_{w2,2} \\ \dot{y}_{w1,1} & \dot{y}_{w1,2} & \dot{y}_{w2,1} & \dot{y}_{w2,2} \\ \dot{z}_{w1,1} & \dot{z}_{w1,2} & \dot{z}_{w2,1} & \dot{z}_{w2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
$WhlV(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$WhlV(1,2)$	1	2	
$WhlV(1,3)$	2	1	
$WhlV(1,4)$	2	2	
$WhlV(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$WhlV(2,2)$	1	2	
$WhlV(2,3)$	2	1	
$WhlV(2,4)$	2	2	
$WhlV(3,1)$	1	1	Vehicle-fixed z-axis (vertical)
$WhlV(3,2)$	1	2	
$WhlV(3,3)$	2	1	
$WhlV(3,4)$	2	2	

### **WhlAng — Wheel camber, caster, toe angles**

array

Camber, caster, and toe angles at axle  $a$ , track  $t$ , in rad. Array dimensions are 3 by the total number of tracks on the vehicle.

- $WhlAng(1, \dots)$  — Camber angle
- $WhlAng(2, \dots)$  — Caster angle
- $WhlAng(3, \dots)$  — Toe angle

For example, for a two-axle vehicle with two tracks per axle, the  $WhlAng$ :

- Signal dimensions are  $[3 \times 4]$ .
- Signal contains wheel angles according to the axle and track locations.

$$\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix} = \begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$$

Array Element	Axle	Track	Angle
WhlAng(1,1)	1	1	Camber
WhlAng(1,2)	1	2	
WhlAng(1,3)	2	1	
WhlAng(1,4)	2	2	
WhlAng(2,1)	1	1	Caster
WhlAng(2,2)	1	2	
WhlAng(2,3)	2	1	
WhlAng(2,4)	2	2	
WhlAng(3,1)	1	1	Toe
WhlF(3,2)	1	2	
WhlF(3,3)	2	1	
WhlF(3,4)	2	2	

## Parameters

### Enable active damping – Include damping

off (default) | off

Include damping

### Dependencies

Selecting this parameter creates:

- **Damping coefficient map, f\_act\_susp\_cz**
- **Damping actuator duty cycle breakpoints, f\_act\_susp\_duty\_bpt**
- **Damping actuator velocity breakpoints, f\_act\_susp\_zdot\_bpt**

### Number of axles, NumAxl – Number of axles

2 (default) | scalar

Number of axles,  $N_a$ , dimensionless.

### Number of tracks by axle, NumTracksByAxl – Number of tracks per axle

[2 2] (default) | vector

Number of tracks per axle,  $N_{t_a}$ , dimensionless. Vector is 1 by the number of vehicle axles,  $N_a$ . For example, [1,2] represents one track on axle 1 and two tracks on axle 2.

### Steered axle enable by axle, StrgEnByAxl – Boolean vector to enable axle steering

[1 0] (default) | vector

Boolean vector that enables axle steering,  $En_{steer}$ , dimensionless. Vector is 1 by the number of vehicle axles,  $N_a$ . For example:

- [1 0] — For a two-axle vehicle, enables axle 1 steering and disables axle 2 steering
- [1 1] — For a two-axle vehicle, enables axle 1 and axle 2 steering

### Dependencies

Setting any element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

For example, for a two-axle vehicle with two tracks per axle, you can input steering angles for both wheels on the first axle.

- To create the StrgAng port, set **Steered axle enable by axle, StrgEnByAxl** to [1 0]. The input signal array dimensions are [1x2].
- The StrgAng signal contains two steering angles according to their axle and track locations.

$$\text{StrgAng} = \delta_{steer} = [\delta_{steer1,1} \quad \delta_{steer1,2}]$$

Array Element	Axle	Track
StrgAng(1,1)	1	1
StrgAng(1,2)	1	2

### Anti-sway axle enable by axle, AntiSwayEnByAxl — Boolean vector to enable axle anti-sway

[0 0] (default) | vector

Boolean vector that enables axle anti-sway for axle  $a$ , dimensionless. For example, [1 0] enables axle 1 anti-sway and disables axle 2 anti-sway. Vector is 1 by the number of vehicle axles,  $N_a$ .

### Dependencies

Setting an element of the **Anti-sway axle enable by axle, AntiSwayEnByAxl** vector to 1 creates these anti-sway parameters:

- **Anti-sway arm radius, AntiSwayR**
- **Anti-sway arm neutral angle, AntiSwayNtrlAng**
- **Anti-sway torsion spring constant, AntiSwayTrsK**

### Suspension

#### Compliance and Damping - Passive

#### Suspension spring constant, Kz — Suspension spring constant

64370 (default) | scalar | vector

Linear vertical spring constant for independent suspension tracks on axle a,  $k_{z_a}$ , in N/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Suspension spring preload, F0z — Suspension spring preload**

9810 (default) | scalar | vector

Vertical preload spring force applied to the wheels on the axle at wheel carrier reference coordinates,  $F_{z0_a}$ , in N. Positive preload forces:

- Cause the vehicle to lift.
- Point along the negative vehicle-fixed z-axis.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Suspension shock damping constant, Cz — Suspension shock damping constant**

10000 (default) | scalar | vector

Linear vertical damping constant for independent suspension tracks on axle a,  $c_{z_a}$ , in Ns/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Dependencies**

To create this parameter, clear **Enable active damping**.

**Suspension maximum height, Hmax — Height**

0.5 (default) | scalar | vector

Maximum suspension extension or minimum suspension compression height,  $H_{max}$ , for axle a before the suspension reaches a hardstop, in m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Compliance and Damping - Active****Damping coefficient map, f\_act\_susp\_cz — Lookup table**

[10000 10000;10000 10000] (default) | M-by-N array

Damping coefficient table as a function of active duty cycle and actuator compression velocity, in N·s/m. Each value specifies the damping for a specific combination of actuator duty cycle and velocity. The array dimensions must match the duty cycle, M, and actuator velocity, N, breakpoint vector dimensions.

**Dependencies**

To create this parameter, clear **Enable active damping**.

**Damping actuator duty cycle breakpoints, f\_act\_susp\_duty\_bpt — Duty cycle breakpoints**

[0 1] (default) | 1-by-M vector

Damping actuator duty cycle breakpoints, dimensionless.

**Dependencies**

To create this parameter, clear **Enable active damping**.

**Damping actuator velocity breakpoints, f\_act\_susp\_zdot\_bpt — Velocity breakpoints**

[ -1 1] (default) | 1-by-N vector

Damping actuator velocity breakpoints, in m/s.

**Dependencies**

To create this parameter, clear **Enable active damping**.

**Geometry****Toe angle at steering center, Toe — Toe angle**

0.0349 (default) | scalar

Nominal suspension toe angle at zero steering angle,  $\zeta_{0a}$ , in rad.

**Roll steer vs suspension height slope, RollStrgSlp — Steer angle suspension slope**

-0.2269 (default) | scalar | vector

Roll steer angle versus suspension height,  $m_{htoe_a}$  in rad/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Toe angle vs steering angle slope, ToeStrgSlp — Toe angle steering slope**

0.01 (default) | scalar | vector

Toe angle versus steering angle slope,  $m_{toesteer_a}$ , dimensionless.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Dependencies**

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

**Caster angle at steering center, Caster — Caster angle at steering center**

0.0698 (default) | scalar

Nominal suspension caster angle at zero steering angle,  $\eta_{0a}$ , in rad.

**Caster angle vs suspension height slope, CasterHslp – Caster angle versus suspension height slope**

-0.2269 (default) | scalar | vector

Caster angle versus suspension height,  $m_{h_{caster_a}}$ , in rad/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Caster angle vs steering angle slope, CasterStrgSlp – Caster angle versus steering angle slope**

0.01 (default) | scalar | vector

Caster angle versus steering angle slope,  $m_{castersteer_a}$ , dimensionless.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Dependencies**

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

**Camber angle at steering center, Camber – Camber angle at steering center**

0.0698 (default) | scalar

Nominal suspension camber angle at zero steering angle,  $\xi_{0a}$ , in rad.

**Camber angle vs suspension height slope, CamberHslp – Camber angle versus suspension height slope**

-0.2269 (default) | scalar | vector

Camber angle versus suspension height,  $m_{h_{camber_a}}$ , in rad/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Camber angle vs steering angle slope, CamberStrgSlp – Camber angle versus steering angle slope**

0.01 (default) | scalar | vector

Camber angle versus steering angle slope,  $m_{cambersteer_a}$ , dimensionless.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Dependencies**

Setting an element of the **Steered axle enable by axle**, **StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope**, **ToeStrgSlp**
  - **Caster angle vs steering angle slope**, **CasterStrgSlp**
  - **Camber angle vs steering angle slope**, **CamberStrgSlp**
  - **Suspension height vs steering angle slope**, **StrgHgtSlp**

**Suspension height vs steering angle slope**, **StrgHgtSlp** — Suspension height versus steering angle slope

0.1432 (default) | scalar | vector

Steering angle to vertical force slope applied at suspension wheel carrier reference point,  $m_{hsteer_a}$ , in m/rad.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Dependencies**

Setting an element of the **Steered axle enable by axle**, **StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope**, **ToeStrgSlp**
  - **Caster angle vs steering angle slope**, **CasterStrgSlp**
  - **Camber angle vs steering angle slope**, **CamberStrgSlp**
  - **Suspension height vs steering angle slope**, **StrgHgtSlp**

**Anti-Sway****Anti-sway arm radius**, **AntiSwayR** — Anti-sway arm radius

0.2 (default) | scalar | vector

Anti-sway arm radius,  $r$ , in m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Dependencies**

Setting an element of the **Anti-sway axle enable by axle**, **AntiSwayEnByAxl** vector to 1 creates these anti-sway parameters:

- **Anti-sway arm radius**, **AntiSwayR**
- **Anti-sway arm neutral angle**, **AntiSwayNtrlAng**
- **Anti-sway torsion spring constant**, **AntiSwayTrsK**

**Anti-sway arm neutral angle, AntiSwayNtrlAng — Anti-sway arm neutral angle**

0.5236 (default) | scalar | vector

Anti-sway arm neutral angle,  $\theta_{0a}$ , at nominal suspension height, in rad.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Dependencies**

Setting an element of the **Anti-sway axle enable by axle, AntiSwayEnByAxl** vector to 1 creates these anti-sway parameters:

- **Anti-sway arm radius, AntiSwayR**
- **Anti-sway arm neutral angle, AntiSwayNtrlAng**
- **Anti-sway torsion spring constant, AntiSwayTrsK**

**Anti-sway torsion spring constant, AntiSwayTrsK — Anti-sway torsion spring constant**

5.7296e+03 (default) | scalar | vector

Anti-sway bar torsion spring constant,  $k_a$ , in N·m/rad.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Dependencies**

Setting an element of the **Anti-sway axle enable by axle, AntiSwayEnByAxl** vector to 1 creates these anti-sway parameters:

- **Anti-sway arm radius, AntiSwayR**
- **Anti-sway arm neutral angle, AntiSwayNtrlAng**
- **Anti-sway torsion spring constant, AntiSwayTrsK**

**References**

- [1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers, 1992.
- [2] Vehicle Dynamics Standards Committee. *Vehicle Dynamics Terminology*. SAE J670. Warrendale, PA: Society of Automotive Engineers, 2008.
- [3] Technical Committee. *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*. ISO 8855:2011. Geneva, Switzerland: International Organization for Standardization, 2011.

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Independent Suspension - MacPherson | Independent Suspension - Mapped

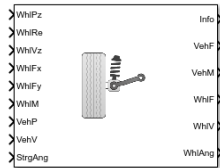


**Introduced in R2018a**

# Independent Suspension - MacPherson

MacPherson independent suspension

**Library:** Vehicle Dynamics Blockset / Suspension



## Description

The Independent Suspension - MacPherson block implements an independent MacPherson suspension for multiple axles with multiple tracks per axle.

The block models the suspension compliance, damping, and geometric effects as functions of the relative positions and velocities of the vehicle and wheel carrier with axle-specific compliance and damping parameters. Using the suspension compliance and damping, the block calculates the suspension force on the vehicle and wheel. The block uses the Z-down coordinate system (defined in SAE J670).

For Each	You Can Specify
Axle	<ul style="list-style-type: none"> <li>Multiple tracks</li> <li>An anti-sway bar for axles with two tracks</li> <li>Suspension parameters</li> </ul>
Track	<ul style="list-style-type: none"> <li>Steering angles</li> </ul>

The block contains energy-storing spring elements and energy-dissipating damper elements. It does not contain energy-storing mass elements. The block assumes that the vehicle (sprung) and wheel (unsprung) blocks connected to the block store the mass-related suspension energy.

This table summarizes the block parameter settings for a vehicle with:

- Two axles
- Two tracks per axle
- Steering angle input for both tracks on the front axle
- An anti-sway bar on the front axle

Parameter	Setting
<b>Number of axles, NumAxl</b>	2
<b>Number of tracks by axle, NumTracksByAxl</b>	[2 2]
<b>Steered axle enable by axle, StrgEnByAxl</b>	[1 0]
<b>Anti-sway axle enable by axle, AntiSwayEnByAxl</b>	[1 0]

## Suspension Compliance and Damping

The block uses a linear spring and damper to model the vertical dynamic effects of the suspension system. Using the relative positions and velocities of the vehicle and wheel carrier, the block calculates the vertical suspension forces on the wheel and vehicle. The block uses a linear equation that relates the vertical damping and compliance to the suspension height, suspension height rate of change, and absolute value of the steering angles.

The block implements this equation.

$$F_{wz_{a,t}} = F_{z0_a} + k_{z_a}(z_{v_{a,t}} - z_{w_{a,t}} + m_{hsteer_a}|\delta_{steer_{a,t}}|) + c(\dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}) + F_{zhstop_{a,t}} + F_{zasw_{y_{a,t}}}$$

The damping coefficient,  $c$ , depends on the **Enable active damping** parameter setting.

Enable active damping Setting	Damping
off	Constant, $c = c_{z_a}$
on	Lookup table that is a function of active damper duty cycle and actuator velocity  $c = f(duty, (\dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}))$

The block assumes that the suspension elements have no mass. Therefore, the suspension forces and moments applied to the vehicle are equal to the suspension forces and moments applied to the wheel.

$$F_{vx_{a,t}} = F_{wx_{a,t}}$$

$$F_{vy_{a,t}} = F_{wy_{a,t}}$$

$$F_{vz_{a,t}} = -F_{wz_{a,t}}$$

$$M_{vx_{a,t}} = M_{wx_{a,t}} + F_{wy_{a,t}}(Re_{wy_{a,t}} + H_{a,t})$$

$$M_{vy_{a,t}} = M_{wy_{a,t}} + F_{wx_{a,t}}(Re_{wx_{a,t}} + H_{a,t})$$

$$M_{vz_{a,t}} = M_{wz_{a,t}}$$

The block sets the wheel positions and velocities equal to the vehicle lateral and longitudinal positions and velocities.

$$x_{w_{a,t}} = x_{v_{a,t}}$$

$$y_{w_{a,t}} = y_{v_{a,t}}$$

$$\dot{x}_{w_{a,t}} = \dot{x}_{v_{a,t}}$$

$$\dot{y}_{w_{a,t}} = \dot{y}_{v_{a,t}}$$

The equations use these variables.

$F_{wz_{a,t}}$ ,  $M_{wz_{a,t}}$  Suspension force and moment applied to the wheel on axle  $a$ , track  $t$  along wheel-fixed  $z$ -axis

$F_{wx_{a,t}}, M_{wx_{a,t}}$	Suspension force and moment applied to the wheel on axle $a$ , track $t$ along wheel-fixed $x$ -axis
$F_{wy_{a,t}}, M_{wy_{a,t}}$	Suspension force and moment applied to the wheel on axle $a$ , track $t$ along wheel-fixed $y$ -axis
$F_{vz_{a,t}}, M_{vz_{a,t}}$	Suspension force and moment applied to the vehicle on axle $a$ , track $t$ along wheel-fixed $z$ -axis
$F_{vx_{a,t}}, M_{vx_{a,t}}$	Suspension force and moment applied to the vehicle on axle $a$ , track $t$ along wheel-fixed $x$ -axis
$F_{vy_{a,t}}, M_{vy_{a,t}}$	Suspension force and moment applied to the vehicle on axle $a$ , track $t$ along wheel-fixed $y$ -axis
$F_{z0_a}$	Vertical suspension spring preload force applied to the wheels on axle $a$
$k_{z_a}$	Vertical spring constant applied to tracks on axle $a$
$m_{hsteer_a}$	Steering angle to vertical force slope applied at wheel carrier for tracks on axle $a$
$\delta_{steer_{a,t}}$	Steering angle input for axle $a$ , track $t$
$c_{z_a}$	Vertical damping constant applied to tracks on axle $a$
$Re_{w_{a,t}}$	Effective wheel radius for axle $a$ , track $t$
$F_{zhstop_{a,t}}$	Vertical hardstop force at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis
$F_{zaswy_{a,t}}$	Vertical anti-sway force at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis
$x_{v_{a,t}}, \dot{x}_{v_{a,t}}$	Vehicle displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $x$ -axis
$x_{w_{a,t}}, \dot{x}_{w_{a,t}}$	Track displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $x$ -axis
$y_{v_{a,t}}, \dot{y}_{v_{a,t}}$	Vehicle displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $y$ -axis
$y_{w_{a,t}}, \dot{y}_{w_{a,t}}$	Track displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $y$ -axis
$H_{a,t}$	Suspension height at axle $a$ , track $t$
$Re_{w_{a,t}}$	Effective wheel radius at axle $a$ , track $t$

### Hardstop Forces

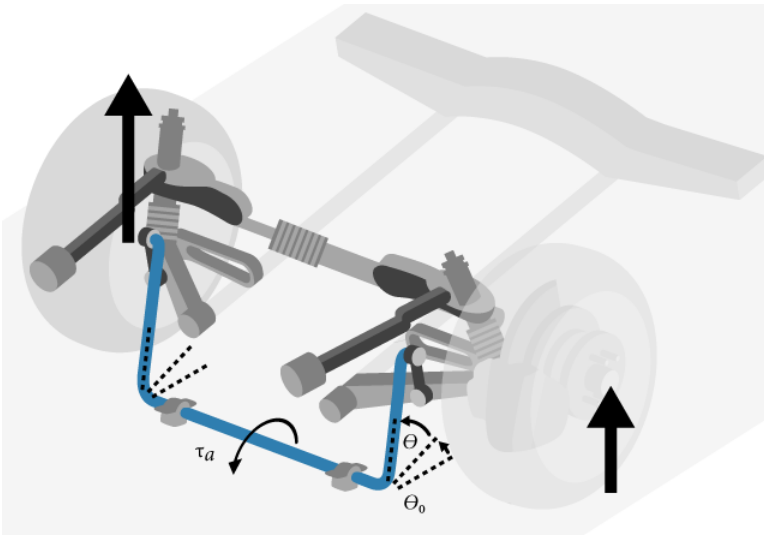
The hardstop feedback force,  $F_{zhstop_{a,t}}$ , that the block applies depends on whether the suspension is compressing or extending. The block applies the force:

- In compression, when the suspension is compressed more than the maximum distance specified by the **Suspension maximum height, Hmax** parameter.
- In extension, when the suspension extension is greater than maximum extension specified by the **Suspension maximum height, Hmax** parameter.

To calculate the force, the block uses a stiffness based on a hyperbolic tangent and exponential scaling.

### Anti-Sway Bar

Optionally, the block implements an anti-sway bar force,  $F_{zaswy_{a,t}}$ , for axles that have two tracks. This figure shows how the anti-sway bar transmits torque between two independent suspension tracks on a shared axle. Each independent suspension applies a torque to the anti-sway bar via a radius arm that extends from the anti-sway bar back to the independent suspension connection point.



To calculate the sway bar force, the block implements these equations.

Calculation	Equation
Anti-sway bar angular deflection for a given axle and track, $\Delta\theta_{a,t}$	$\theta_{0a} = \tan^{-1}\left(\frac{z_0}{r}\right)$ $\Delta\theta_{a,t} = \tan^{-1}\left(\frac{r \tan\theta_{0a} - z_{w_{a,t}} + z_{v_{a,t}}}{r}\right)$
Anti-sway bar twist angle, $\theta_a$	$\theta_a = -\tan^{-1}\left(\frac{r \tan\theta_{0a} - z_{w_{a,1}} + z_{v_{a,1}}}{r}\right)$ $-\tan^{-1}\left(\frac{r \tan\theta_{0a} - z_{w_{a,2}} + z_{v_{a,2}}}{r}\right)$
Anti-sway bar torque, $\tau_a$	$\tau_a = k_a \theta_a$
Anti-sway bar forces applied to the wheel on axle a, track t along wheel-fixed z-axis	$F_{z_{aswy_{a,1}}} = \left(\frac{\tau_a}{r}\right) \cos\left(\theta_{0a} - \tan^{-1}\left(\frac{r \tan\theta_{0a} - z_{w_{a,1}} + z_{v_{a,1}}}{r}\right)\right)$ $F_{z_{aswy_{a,2}}} = \left(\frac{\tau_a}{r}\right) \cos\left(\theta_{0a} - \tan^{-1}\left(\frac{r \tan\theta_{0a} - z_{w_{a,2}} + z_{v_{a,2}}}{r}\right)\right)$

The equations and figure use these variables.

$\tau_a$	Anti-sway bar torque
$\theta$	Anti-sway bar twist angle
$\theta_{0a}$	Initial anti-sway bar twist angle
$\Delta\theta_{a,t}$	Anti-sway bar angular deflection at axle a, track t
$r$	Anti-sway bar arm radius
$z_0$	Vertical distance from anti-sway bar connection point to anti-sway bar centerline
$F_{z_{aswy_{a,t}}}$	Anti-sway bar force applied to the wheel on axle a, track t along wheel-fixed z-axis
$z_{v_{a,t}}$	Vehicle displacement at axle a, track t, along the vehicle-fixed z-axis
$z_{w_{a,t}}$	Wheel displacement at axle a, track t, along the vehicle-fixed z-axis

### Camber, Caster, and Toe Angles

To calculate the camber, caster, and toe angles, block uses linear functions of the suspension height and steering angle.

$$\begin{aligned}\xi_{a,t} &= \xi_{0a} + m_{hcamber_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{cambersteer_a}|\delta_{steer_{a,t}}| \\ \eta_{a,t} &= \eta_{0a} + m_{hcaster_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{castersteer_a}|\delta_{steer_{a,t}}| \\ \zeta_{a,t} &= \zeta_{0a} + m_{htoe_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{toesteer_a}|\delta_{steer_{a,t}}|\end{aligned}$$

The equations use these variables.

$\xi_{a,t}$	Camber angle of wheel on axle a, track t
$\eta_{a,t}$	Caster angle of wheel on axle a, track t
$\zeta_{a,t}$	Toe angle of wheel on axle a, track t
$\xi_{0a}, \eta_{0a}, \zeta_{0a}$	Nominal suspension axle a camber, caster, and toe angles, respectively, at zero steering angle
$m_{hcamber_a}, m_{hcaster_a}, m_{htoe_a}$	Camber, caster, and toe angles, respectively, versus suspension height slope for axle a
$m_{cambersteer_a}, m_{castersteer_a}, m_{toesteer_a}$	Camber, caster, and toe angles, respectively, versus steering angle slope for axle a
$m_{hsteer_a}$	Steering angle versus vertical force slope for axle a
$\delta_{steer_{a,t}}$	Steering angle input for axle a, track t
$z_{v_{a,t}}$	Vehicle displacement at axle a, track t, along the vehicle-fixed z-axis
$z_{w_{a,t}}$	Track displacement at axle a, track t, along the vehicle-fixed z-axis

### Steering Angles

Optionally, you can input steering angles for the tracks. To calculate the steering angles for the wheels, the block offsets the input steering angles with a linear function of the suspension height.

$$\delta_{whlsteer_{a,t}} = \delta_{steer_{a,t}} + m_{htoe_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{toesteer_a}|\delta_{steer_{a,t}}|$$

The equation uses these variables.

$m_{toesteer_a}$	Axle a toe angle versus steering angle slope
$m_{hsteer_a}$	Axle a steering angle versus vertical force slope
$m_{htoe_a}$	Axle a toe angle versus suspension height slope
$\delta_{whlsteer_{a,t}}$	Wheel steering angle for axle a, track t
$\delta_{steer_{a,t}}$	Steering angle input for axle a, track t
$z_{v_{a,t}}$	Vehicle displacement at axle a, track t, along the vehicle-fixed z-axis
$z_{w_{a,t}}$	Track displacement at axle a, track t, along the vehicle-fixed z-axis

### Power and Energy

The block calculates these suspension characteristics for each axle, a, track, t.

Calculation	Equation
Dissipated power, $P_{susp_{a,t}}$	$P_{susp_{a,t}} = F_{wzlookup_a}(\dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$
Absorbed energy, $E_{susp_{a,t}}$	$E_{susp_{a,t}} = F_{wzlookup_a}(z_{v_{a,t}} - z_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$
Suspension height, $H_{a,t}$	$H_{a,t} = -\left(z_{v_{a,t}} - z_{w_{a,t}} + \frac{F_{z0_a}}{k_{z_a}} + m_{hsteer_a} \delta_{steer_{a,t}} \right)$
Distance from wheel carrier center to tire/road interface	$z_{wtr_{a,t}} = Re_{w_{a,t}} + H_{a,t}$

The equations use these variables.

$m_{hsteer_a}$	Steering angle to vertical force slope applied at wheel carrier for tracks on axle a
$\delta_{steer_{a,t}}$	Steering angle input for axle a, track t
$Re_{w_{a,t}}$	Axle a, track t effective wheel radius from wheel carrier center to tire/road interface
$F_{z0_a}$	Vertical suspension spring preload force applied to the wheels on axle a
$z_{wtr_{a,t}}$	Distance from wheel carrier center to tire/road interface, along the vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along the vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along the vehicle-fixed z-axis

## Ports

### Input

#### WhlPz — Track z-axis displacement

array

Track displacement,  $z_w$ , along wheel-fixed z-axis, in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlPz:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlPz} = z_w = [z_{w1,1} \ z_{w1,2} \ z_{w2,1} \ z_{w2,2}]$$

Array Element	Axle	Track
WhlPz(1,1)	1	1
WhlPz(1,2)	1	2
WhlPz(1,3)	2	1
WhlPz(1,4)	2	2

#### WhlRe — Wheel effective radius

array

Effective wheel radius,  $Re_w$ , in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlRe:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlRe} = Re_w = [Re_{w1,1} \quad Re_{w1,2} \quad Re_{w2,1} \quad Re_{w2,2}]$$

Array Element	Axle	Track
WhlRe(1,1)	1	1
WhlRe(1,2)	1	2
WhlRe(1,3)	2	1
WhlRe(1,4)	2	2

**WhlVz — Track z-axis velocity**

array

Track velocity,  $\dot{z}_w$ , along wheel-fixed z-axis, in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlVz:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlVz} = \dot{z}_w = [\dot{z}_{w1,1} \quad \dot{z}_{w1,2} \quad \dot{z}_{w2,1} \quad \dot{z}_{w2,2}]$$

Array Element	Axle	Track
WhlVz(1,1)	1	1
WhlVz(1,2)	1	2
WhlVz(1,3)	2	1
WhlVz(1,4)	2	2

**WhlFx — Longitudinal wheel force on vehicle**

array

Longitudinal wheel force applied to vehicle,  $F_{wx}$ , along the vehicle-fixed x-axis. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlFx:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlFx} = F_{wx} = [F_{wx1,1} \quad F_{wx1,2} \quad F_{wx2,1} \quad F_{wx2,2}]$$



Array Element	Axle	Track
WhlFx(1,1)	1	1
WhlFx(1,2)	1	2
WhlFx(1,3)	2	1
WhlFx(1,4)	2	2

### WhlFy – Lateral wheel force on vehicle

array

Lateral wheel force applied to vehicle,  $F_{wy}$ , along the vehicle-fixed y-axis. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlFy:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlFy} = F_{wy} = [F_{wy1,1} \ F_{wy1,2} \ F_{wy2,1} \ F_{wy2,2}]$$

Array Element	Axle	Track
WhlFy(1,1)	1	1
WhlFy(1,2)	1	2
WhlFy(1,3)	2	1
WhlFy(1,4)	2	2

### WhlM – Suspension moment on wheel

array

Longitudinal, lateral, and vertical suspension moments at axle  $a$ , track  $t$ , applied to the wheel at the axle wheel carrier reference coordinate, in N·m. Array dimensions are 3 by the total number of tracks on the vehicle.

- WhlM(1, . . .) – Suspension moment applied to the wheel about the vehicle-fixed x-axis (longitudinal)
- WhlM(2, . . .) – Suspension moment applied to the wheel about the vehicle-fixed y-axis (lateral)
- WhlM(3, . . .) – Suspension moment applied to the wheel about the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the WhlM:

- Signal dimensions are [3x4].
- Signal contains suspension moments applied to four wheels according to their axle and track locations.

$$\text{WhlM} = M_w = \begin{bmatrix} M_{wx1,1} & M_{wx1,2} & M_{wx2,1} & M_{wx2,2} \\ M_{wy1,1} & M_{wy1,2} & M_{wy2,1} & M_{wy2,2} \\ M_{wz1,1} & M_{wz1,2} & M_{wz2,1} & M_{wz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Moment Axis
WhlM(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
WhlM(1,2)	1	2	
WhlM(1,3)	2	1	
WhlM(1,4)	2	2	
WhlM(2,1)	1	1	Vehicle-fixed y-axis (lateral)
WhlM(2,2)	1	2	
WhlM(2,3)	2	1	
WhlM(2,4)	2	2	
WhlM(3,1)	1	1	Vehicle-fixed z-axis (vertical)
WhlM(3,2)	1	2	
WhlM(3,3)	2	1	
WhlM(3,4)	2	2	

**VehP – Vehicle displacement**

array

Vehicle displacement from axle *a*, track *t* along vehicle-fixed coordinate system, in m. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehP(1, . . .) – Vehicle displacement from track,  $x_v$ , along the vehicle-fixed x-axis
- VehP(2, . . .) – Vehicle displacement from track,  $y_v$ , along the vehicle-fixed y-axis
- VehP(3, . . .) – Vehicle displacement from track,  $z_v$ , along the vehicle-fixed z-axis

For example, for a two-axle vehicle with two tracks per axle, the VehP:

- Signal dimensions are [3x4].
- Signal contains four track displacements according to their axle and track locations.

$$\text{VehP} = \begin{bmatrix} x_v \\ y_v \\ z_v \end{bmatrix} = \begin{bmatrix} x_{v1,1} & x_{v1,2} & x_{v2,1} & x_{v2,2} \\ y_{v1,1} & y_{v1,2} & y_{v2,1} & y_{v2,2} \\ z_{v1,1} & z_{v1,2} & z_{v2,1} & z_{v2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
VehP(1,1)	1	1	Vehicle-fixed x-axis
VehP(1,2)	1	2	
VehP(1,3)	2	1	
VehP(1,4)	2	2	
VehP(2,1)	1	1	Vehicle-fixed y-axis
VehP(2,2)	1	2	
VehP(2,3)	2	1	
VehP(2,4)	2	2	

Array Element	Axle	Track	Axis
VehP(3,1)	1	1	Vehicle-fixed z-axis
VehP(3,2)	1	2	
VehP(3,3)	2	1	
VehP(3,4)	2	2	

**VehV – Vehicle velocity**

array

Vehicle velocity at axle  $a$ , track  $t$  along vehicle-fixed coordinate system, in m. Input array dimensions are 3 by  $a*t$ .

- $VehV(1, \dots)$  – Vehicle velocity at track,  $x_v$ , along the vehicle-fixed x-axis
- $VehV(2, \dots)$  – Vehicle velocity at track,  $y_v$ , along the vehicle-fixed y-axis
- $VehV(3, \dots)$  – Vehicle velocity at track,  $z_v$ , along the vehicle-fixed z-axis

For example, for a two-axle vehicle with two tracks per axle, the VehV:

- Signal dimensions are [3x4].
- Signal contains 4 track velocities according to their axle and track locations.

$$VehV = \begin{bmatrix} \dot{x}_v \\ \dot{y}_v \\ \dot{z}_v \end{bmatrix} = \begin{bmatrix} \dot{x}_{v1,1} & \dot{x}_{v1,2} & \dot{x}_{v2,1} & \dot{x}_{v2,2} \\ \dot{y}_{v1,1} & \dot{y}_{v1,2} & \dot{y}_{v2,1} & \dot{y}_{v2,2} \\ \dot{z}_{v1,1} & \dot{z}_{v1,2} & \dot{z}_{v2,1} & \dot{z}_{v2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
VehV(1,1)	1	1	Vehicle-fixed x-axis
VehV(1,2)	1	2	
VehV(1,3)	2	1	
VehV(1,4)	2	2	
VehV(2,1)	1	1	Vehicle-fixed y-axis
VehV(2,2)	1	2	
VehV(2,3)	2	1	
VehV(2,4)	2	2	
VehV(3,1)	1	1	Vehicle-fixed z-axis
VehV(3,2)	1	2	
VehV(3,3)	2	1	
VehV(3,4)	2	2	

**StrgAng – Steering angle, optional**

array

Optional steering angle for each wheel,  $\delta$ . Input array dimensions are 1 by the number of steered tracks.

For example, for a two-axle vehicle with two tracks per axle, you can input steering angles for both wheels on the first axle.

- To create the `StrgAng` port, set **Steered axle enable by axle, `StrgEnByAxl`** to `[1 0]`. The input signal array dimensions are `[1x2]`.
- The `StrgAng` signal contains two steering angles according to their axle and track locations.

$$\text{StrgAng} = \delta_{steer} = [\delta_{steer1,1} \ \delta_{steer1,2}]$$

Array Element	Axle	Track
<code>StrgAng(1,1)</code>	1	1
<code>StrgAng(1,2)</code>	1	2

**Dependencies**

Setting an element of the **Steered axle enable by axle, `StrgEnByAxl`** vector to 1 creates:

- Input port `StrgAng`.
- Parameters:
  - **Toe angle vs steering angle slope, `ToeStrgSlp`**
  - **Caster angle vs steering angle slope, `CasterStrgSlp`**
  - **Camber angle vs steering angle slope, `CamberStrgSlp`**
  - **Suspension height vs steering angle slope, `StrgHgtSlp`**

**Output**

**Info – Bus signal**

bus

Bus signal containing block values. The signals are arrays that depend on the track location.

For example, here are the indices for a two-axle, two-track vehicle. The total number of tracks is four.

- 1D array signal (1-by-4)

Array Element	Axle	Track
<code>(1,1)</code>	1	1
<code>(1,2)</code>	1	2
<code>(1,3)</code>	2	1
<code>(1,4)</code>	2	2

- 3D array signal (3-by-4)

Array Element	Axle	Track
<code>(1,1)</code>	1	1
<code>(1,2)</code>	1	2
<code>(1,3)</code>	2	1
<code>(1,4)</code>	2	2

Array Element	Axle	Track
(2,1)	1	1
(2,2)	1	2
(2,3)	2	1
(2,4)	2	2
(3,1)	1	1
(3,2)	1	2
(3,3)	2	1
(3,4)	2	2

Signal	Description	Array Signal	Variable	Units
Camber	Wheel angles according to the axle and track location.	1D	$WhlAng[1, \dots] = \xi = [\xi_{a,t}]$	rad
Caster			$WhlAng[2, \dots] = \eta = [\eta_{a,t}]$	
Toe			$WhlAng[3, \dots] = \zeta = [\zeta_{a,t}]$	
Height	Suspension height	1D	$H$	m
Power	Suspension power dissipation	1D	$P_{susp}$	W
Energy	Suspension absorbed energy	1D	$E_{susp}$	J
VehF	Suspension forces applied to the vehicle	3D	For a two-axle, two tracks per axle vehicle:  $VehF = F_v = \begin{bmatrix} F_{vx1,1} & F_{vx1,2} & F_{vx2,1} & F_{vx2,2} \\ F_{vy1,1} & F_{vy1,2} & F_{vy2,1} & F_{vy2,2} \\ F_{vz1,1} & F_{vz1,2} & F_{vz2,1} & F_{vz2,2} \end{bmatrix}$	N

Signal	Description	Array Signal	Variable	Units
VehM	Suspension moments applied to vehicle	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{VehM} = M_v =$ $\begin{bmatrix} M_{vx1,1} & M_{vx1,2} & M_{vx2,1} & M_{vx2,2} \\ M_{vy1,1} & M_{vy1,2} & M_{vy2,1} & M_{vy2,2} \\ M_{vz1,1} & M_{vz1,2} & M_{vz2,1} & M_{vz2,2} \end{bmatrix}$	N·m
WhlF	Suspension force applied to wheel	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlF} = F_w =$ $\begin{bmatrix} F_{wx1,1} & F_{wx1,2} & F_{wx2,1} & F_{wx2,2} \\ F_{wy1,1} & F_{wy1,2} & F_{wy2,1} & F_{wy2,2} \\ F_{wz1,1} & F_{wz1,2} & F_{wz2,1} & F_{wz2,2} \end{bmatrix}$	N
WhlP	Track displacement	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlP} = \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix} =$ $\begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{w2,2} \\ z_{wtr1,1} & z_{wtr1,2} & z_{wtr2,1} & z_{wtr2,2} \end{bmatrix}$	m

Signal	Description	Array Signal	Variable	Units
WhlV	Track velocity	3D	For a two-axle, two tracks per axle vehicle:  $\text{WhlV} = \begin{bmatrix} \dot{x}_w \\ \dot{y}_w \\ \dot{z}_w \end{bmatrix}$  =  $\begin{bmatrix} \dot{x}_{w1,1} & \dot{x}_{w1,2} & \dot{x}_{w2,1} & \dot{x}_{w2,2} \\ \dot{y}_{w1,1} & \dot{y}_{w1,2} & \dot{y}_{w2,1} & \dot{y}_{w2,2} \\ \dot{z}_{w1,1} & \dot{z}_{w1,2} & \dot{z}_{w2,1} & \dot{z}_{w2,2} \end{bmatrix}$	m/s
WhlAng	Wheel camber, caster, toe angles	3D	For a two-axle, two tracks per axle vehicle:  $\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix}$  =  $\begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$	rad

### VehF — Suspension force on vehicle

array

Longitudinal, lateral, and vertical suspension force at axle *a*, track *t*, applied to the vehicle at the suspension connection point, in N. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehF(1, . . .) — Suspension force applied to vehicle along the vehicle-fixed x-axis (longitudinal)
- VehF(2, . . .) — Suspension force applied to vehicle along the vehicle-fixed y-axis (lateral)
- VehF(3, . . .) — Suspension force applied to vehicle along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the VehF:

- Signal dimensions are [3x4].
- Signal contains suspension forces applied to the vehicle according to the axle and track locations.

$$\text{VehF} = F_v = \begin{bmatrix} F_{vx1,1} & F_{vx1,2} & F_{vx2,1} & F_{vx2,2} \\ F_{vy1,1} & F_{vy1,2} & F_{vy2,1} & F_{vy2,2} \\ F_{vz1,1} & F_{vz1,2} & F_{vz2,1} & F_{vz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
VehF(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
VehF(1,2)	1	2	
VehF(1,3)	2	1	
VehF(1,4)	2	2	
VehF(2,1)	1	1	Vehicle-fixed y-axis (lateral)
VehF(2,2)	1	2	
VehF(2,3)	2	1	
VehF(2,4)	2	2	
VehF(3,1)	1	1	Vehicle-fixed z-axis (vertical)
VehF(3,2)	1	2	
VehF(3,3)	2	1	
VehF(3,4)	2	2	

**VehM – Suspension moment on vehicle**

array

Longitudinal, lateral, and vertical suspension moment at axle *a*, track *t*, applied to the vehicle at the suspension connection point, in N·m. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehM(1, . . . ) – Suspension moment applied to the vehicle about the vehicle-fixed x-axis (longitudinal)
- VehM(2, . . . ) – Suspension moment applied to the vehicle about the vehicle-fixed y-axis (lateral)
- VehM(3, . . . ) – Suspension moment applied to the vehicle about the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the VehM:

- Signal dimensions are [3x4].
- Signal contains suspension moments applied to vehicle according to the axle and track locations.

$$VehM = M_v = \begin{bmatrix} M_{vx1,1} & M_{vx1,2} & M_{vx2,1} & M_{vx2,2} \\ M_{vy1,1} & M_{vy1,2} & M_{vy2,1} & M_{vy2,2} \\ M_{vz1,1} & M_{vz1,2} & M_{vz2,1} & M_{vz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Moment Axis
VehM(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
VehM(1,2)	1	2	
VehM(1,3)	2	1	
VehM(1,4)	2	2	
VehM(2,1)	1	1	Vehicle-fixed y-axis (lateral)
VehM(2,2)	1	2	



Array Element	Axle	Track	Moment Axis
VehM(2,3)	2	1	Vehicle-fixed z-axis (vertical)
VehM(2,4)	2	2	
VehM(3,1)	1	1	
VehM(3,2)	1	2	
VehM(3,3)	2	1	
VehM(3,4)	2	2	

### WhlF – Suspension force on wheel

array

Longitudinal, lateral, and vertical suspension forces at axle **a**, track **t**, applied to the wheel at the axle wheel carrier reference coordinate, in N. Array dimensions are 3 by the total number of tracks on the vehicle.

- WhlF(1, . . .) – Suspension force on wheel along the vehicle-fixed x-axis (longitudinal)
- WhlF(2, . . .) – Suspension force on wheel along the vehicle-fixed y-axis (lateral)
- WhlF(3, . . .) – Suspension force on wheel along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the WhlF:

- Signal dimensions are [3x4].
- Signal contains wheel forces applied to the vehicle according to the axle and track locations.

$$\text{WhlF} = F_w = \begin{bmatrix} F_{wx1,1} & F_{wx1,2} & F_{wx2,1} & F_{wx2,2} \\ F_{wy1,1} & F_{wy1,2} & F_{wy2,1} & F_{wy2,2} \\ F_{wz1,1} & F_{wz1,2} & F_{wz2,1} & F_{wz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
WhlF(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
WhlF(1,2)	1	2	
WhlF(1,3)	2	1	
WhlF(1,4)	2	2	
WhlF(2,1)	1	1	Vehicle-fixed y-axis (lateral)
WhlF(2,2)	1	2	
WhlF(2,3)	2	1	
WhlF(2,4)	2	2	
WhlF(3,1)	1	1	Vehicle-fixed z-axis (vertical)
WhlF(3,2)	1	2	
WhlF(3,3)	2	1	
WhlF(3,4)	2	2	

### WhlV – Track velocity

array

Longitudinal, lateral, and vertical track velocity at axle *a*, track *t*, in m/s. Array dimensions are 3 by the total number of tracks on the vehicle.

- $WhlV(1, \dots)$  — Track velocity along the vehicle-fixed x-axis (longitudinal)
- $WhlV(2, \dots)$  — Track velocity along the vehicle-fixed y-axis (lateral)
- $WhlV(3, \dots)$  — Track velocity along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the  $WhlV$ :

- Signal dimensions are [3x4].
- Signal contains wheel forces applied to the vehicle according to the axle and track locations.

$$WhlV = \begin{bmatrix} \dot{x}_w \\ \dot{y}_w \\ \dot{z}_w \end{bmatrix} = \begin{bmatrix} \dot{x}_{w1,1} & \dot{x}_{w1,2} & \dot{x}_{w2,1} & \dot{x}_{w2,2} \\ \dot{y}_{w1,1} & \dot{y}_{w1,2} & \dot{y}_{w2,1} & \dot{y}_{w2,2} \\ \dot{z}_{w1,1} & \dot{z}_{w1,2} & \dot{z}_{w2,1} & \dot{z}_{w2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
$WhlV(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$WhlV(1,2)$	1	2	
$WhlV(1,3)$	2	1	
$WhlV(1,4)$	2	2	
$WhlV(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$WhlV(2,2)$	1	2	
$WhlV(2,3)$	2	1	
$WhlV(2,4)$	2	2	
$WhlV(3,1)$	1	1	Vehicle-fixed z-axis (vertical)
$WhlV(3,2)$	1	2	
$WhlV(3,3)$	2	1	
$WhlV(3,4)$	2	2	

**WhlAng — Wheel camber, caster, toe angles**

array

Camber, caster, and toe angles at axle *a*, track *t*, in rad. Array dimensions are 3 by the total number of tracks on the vehicle.

- $WhlAng(1, \dots)$  — Camber angle
- $WhlAng(2, \dots)$  — Caster angle
- $WhlAng(3, \dots)$  — Toe angle

For example, for a two-axle vehicle with two tracks per axle, the  $WhlAng$ :

- Signal dimensions are [3x4].
- Signal contains wheel angles according to the axle and track locations.

$$\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix} = \begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$$

Array Element	Axle	Track	Angle
WhlAng(1,1)	1	1	Camber
WhlAng(1,2)	1	2	
WhlAng(1,3)	2	1	
WhlAng(1,4)	2	2	
WhlAng(2,1)	1	1	Caster
WhlAng(2,2)	1	2	
WhlAng(2,3)	2	1	
WhlAng(2,4)	2	2	
WhlAng(3,1)	1	1	Toe
WhlF(3,2)	1	2	
WhlF(3,3)	2	1	
WhlF(3,4)	2	2	

## Parameters

### Enable active damping – Include damping

off (default) | off

Include damping

### Dependencies

Selecting this parameter creates:

- **Damping coefficient map, f\_act\_susp\_cz**
- **Damping actuator duty cycle breakpoints, f\_act\_susp\_duty\_bpt**
- **Damping actuator velocity breakpoints, f\_act\_susp\_zdot\_bpt**

### Number of axles, NumAxl – Number of axles

2 (default) | scalar

Number of axles,  $N_a$ , dimensionless.

### Number of tracks by axle, NumTracksByAxl – Number of tracks per axle

[2 2] (default) | vector

Number of tracks per axle,  $N_{t_a}$ , dimensionless. Vector is 1 by the number of vehicle axles,  $N_a$ . For example, [1, 2] represents one track on axle 1 and two tracks on axle 2.

### Steered axle enable by axle, StrgEnByAxl – Boolean vector to enable axle steering

[1 0] (default) | vector

Boolean vector that enables axle steering,  $En_{steer}$ , dimensionless. Vector is 1 by the number of vehicle axles,  $N_a$ . For example:

- [1 0] — For a two-axle vehicle, enables axle 1 steering and disables axle 2 steering
- [1 1] — For a two-axle vehicle, enables axle 1 and axle 2 steering

**Dependencies**

Setting any element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

For example, for a two-axle vehicle with two tracks per axle, you can input steering angles for both wheels on the first axle.

- To create the StrgAng port, set **Steered axle enable by axle, StrgEnByAxl** to [1 0]. The input signal array dimensions are [1x2].
- The StrgAng signal contains two steering angles according to their axle and track locations.

$$\text{StrgAng} = \delta_{steer} = [\delta_{steer1,1} \ \delta_{steer1,2}]$$

Array Element	Axle	Track
StrgAng(1,1)	1	1
StrgAng(1,2)	1	2

**Anti-sway axle enable by axle, AntiSwayEnByAxl — Boolean vector to enable axle anti-sway**

[0 0] (default) | vector

Boolean vector that enables axle anti-sway for axle  $a$ , dimensionless. For example, [1 0] enables axle 1 anti-sway and disables axle 2 anti-sway. Vector is 1 by the number of vehicle axles,  $N_a$ .

**Dependencies**

Setting an element of the **Anti-sway axle enable by axle, AntiSwayEnByAxl** vector to 1 creates these anti-sway parameters:

- **Anti-sway arm radius, AntiSwayR**
- **Anti-sway arm neutral angle, AntiSwayNtrlAng**
- **Anti-sway torsion spring constant, AntiSwayTrsK**

**Suspension**

**Compliance and Damping - Passive**

**Suspension spring constant, Kz — Suspension spring constant**

64370 (default) | scalar | vector

Linear vertical spring constant for independent suspension tracks on axle a,  $k_{z_a}$ , in N/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

### **Suspension spring preload, F0z — Suspension spring preload**

9810 (default) | scalar | vector

Vertical preload spring force applied to the wheels on the axle at wheel carrier reference coordinates,  $F_{z0_a}$ , in N. Positive preload forces:

- Cause the vehicle to lift.
- Point along the negative vehicle-fixed z-axis.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

### **Suspension shock damping constant, Cz — Suspension shock damping constant**

10000 (default) | scalar | vector

Linear vertical damping constant for independent suspension tracks on axle a,  $c_{z_a}$ , in Ns/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Dependencies**

To create this parameter, clear **Enable active damping**.

### **Suspension maximum height, Hmax — Height**

0.5 (default) | scalar | vector

Maximum suspension extension or minimum suspension compression height,  $H_{max}$ , for axle a before the suspension reaches a hardstop, in m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Compliance and Damping - Active**

### **Damping coefficient map, f\_act\_susp\_cz — Lookup table**

[10000 10000;10000 10000] (default) | M-by-N array

Damping coefficient table as a function of active duty cycle and actuator compression velocity, in N·s/m. Each value specifies the damping for a specific combination of actuator duty cycle and velocity. The array dimensions must match the duty cycle, M, and actuator velocity, N, breakpoint vector dimensions.

#### **Dependencies**

To create this parameter, clear **Enable active damping**.

### **Damping actuator duty cycle breakpoints, f\_act\_susp\_duty\_bpt — Duty cycle breakpoints**

[0 1] (default) | 1-by-M vector

Damping actuator duty cycle breakpoints, dimensionless.

**Dependencies**

To create this parameter, clear **Enable active damping**.

**Damping actuator velocity breakpoints, f\_act\_susp\_zdot\_bpt — Velocity breakpoints**

[-1 1] (default) | 1-by-N vector

Damping actuator velocity breakpoints, in m/s.

**Dependencies**

To create this parameter, clear **Enable active damping**.

**Geometry****Toe angle at steering center, Toe — Toe angle**

0.0349 (default) | scalar

Nominal suspension toe angle at zero steering angle,  $\zeta_{0a}$ , in rad.

**Roll steer vs suspension height slope, RollStrgSlp — Steer angle suspension slope**

-0.2269 (default) | scalar | vector

Roll steer angle versus suspension height,  $m_{htoe_a}$  in rad/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Toe angle vs steering angle slope, ToeStrgSlp — Toe angle steering slope**

0.01 (default) | scalar | vector

Toe angle versus steering angle slope,  $m_{toesteer_a}$ , dimensionless.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Dependencies**

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

**Caster angle at steering center, Caster — Caster angle at steering center**

0.0698 (default) | scalar

Nominal suspension caster angle at zero steering angle,  $\eta_{0a}$ , in rad.

**Caster angle vs suspension height slope, CasterHslp – Caster angle versus suspension height slope**

-0.2269 (default) | scalar | vector

Caster angle versus suspension height,  $m_{h_{caster}_a}$ , in rad/m.Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.**Caster angle vs steering angle slope, CasterStrgSlp – Caster angle versus steering angle slope**

0.01 (default) | scalar | vector

Caster angle versus steering angle slope,  $m_{castersteer_a}$ , dimensionless.Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.**Dependencies**Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

**Camber angle at steering center, Camber – Camber angle at steering center**

0.0698 (default) | scalar

Nominal suspension camber angle at zero steering angle,  $\xi_{0a}$ , in rad.**Camber angle vs suspension height slope, CamberHslp – Camber angle versus suspension height slope**

-0.2269 (default) | scalar | vector

Camber angle versus suspension height,  $m_{h_{camber}_a}$ , in rad/m.Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.**Camber angle vs steering angle slope, CamberStrgSlp – Camber angle versus steering angle slope**

0.01 (default) | scalar | vector

Camber angle versus steering angle slope,  $m_{cambersteer_a}$ , dimensionless.Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Dependencies**

Setting an element of the **Steered axle enable by axle**, **StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope**, **ToeStrgSlp**
  - **Caster angle vs steering angle slope**, **CasterStrgSlp**
  - **Camber angle vs steering angle slope**, **CamberStrgSlp**
  - **Suspension height vs steering angle slope**, **StrgHgtSlp**

**Suspension height vs steering angle slope, StrgHgtSlp — Suspension height versus steering angle slope**

0.1432 (default) | scalar | vector

Steering angle to vertical force slope applied at suspension wheel carrier reference point,  $m_{hsteer}$ , in m/rad.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Dependencies**

Setting an element of the **Steered axle enable by axle**, **StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope**, **ToeStrgSlp**
  - **Caster angle vs steering angle slope**, **CasterStrgSlp**
  - **Camber angle vs steering angle slope**, **CamberStrgSlp**
  - **Suspension height vs steering angle slope**, **StrgHgtSlp**

**Anti-Sway****Anti-sway arm radius, AntiSwayR — Anti-sway arm radius**

0.2 (default) | scalar | vector

Anti-sway arm radius,  $r$ , in m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Dependencies**

Setting an element of the **Anti-sway axle enable by axle**, **AntiSwayEnByAxl** vector to 1 creates these anti-sway parameters:

- **Anti-sway arm radius**, **AntiSwayR**
- **Anti-sway arm neutral angle**, **AntiSwayNtrlAng**
- **Anti-sway torsion spring constant**, **AntiSwayTrsK**



**Anti-sway arm neutral angle, AntiSwayNtrlAng — Anti-sway arm neutral angle**

0.5236 (default) | scalar | vector

Anti-sway arm neutral angle,  $\theta_{0a}$ , at nominal suspension height, in rad.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Dependencies**

Setting an element of the **Anti-sway axle enable by axle, AntiSwayEnByAxl** vector to 1 creates these anti-sway parameters:

- **Anti-sway arm radius, AntiSwayR**
- **Anti-sway arm neutral angle, AntiSwayNtrlAng**
- **Anti-sway torsion spring constant, AntiSwayTrsK**

**Anti-sway torsion spring constant, AntiSwayTrsK — Anti-sway torsion spring constant**

5.7296e+03 (default) | scalar | vector

Anti-sway bar torsion spring constant,  $k_a$ , in N·m/rad.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Dependencies**

Setting an element of the **Anti-sway axle enable by axle, AntiSwayEnByAxl** vector to 1 creates these anti-sway parameters:

- **Anti-sway arm radius, AntiSwayR**
- **Anti-sway arm neutral angle, AntiSwayNtrlAng**
- **Anti-sway torsion spring constant, AntiSwayTrsK**

**References**

- [1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers, 1992.
- [2] Vehicle Dynamics Standards Committee. *Vehicle Dynamics Terminology*. SAE J670. Warrendale, PA: Society of Automotive Engineers, 2008.
- [3] Technical Committee. *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*. ISO 8855:2011. Geneva, Switzerland: International Organization for Standardization, 2011.

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

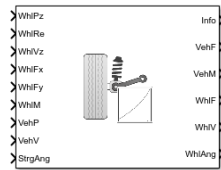
Independent Suspension - Double Wishbone | Independent Suspension - Mapped

**Introduced in R2018a**

# Independent Suspension - Mapped

Mapped independent suspension

**Library:** Vehicle Dynamics Blockset / Suspension



## Description

The Independent Suspension - Mapped block implements a mapped independent suspension for multiple axles with multiple tracks per axle. You can use the block to model suspension geometry, compliance, and damping effects from measured or simulated suspension response data.

The block models the suspension compliance, damping, and geometric effects as functions of the relative positions and velocities of the vehicle and wheel carrier with axle-specific compliance and damping parameters. Using the suspension compliance and damping, the block calculates the suspension force on the vehicle and wheel. The block uses the Z-down coordinate system (defined in SAE J670).

For Each	You Can Specify
Axle	<ul style="list-style-type: none"> <li>Multiple tracks</li> <li>An anti-sway bar for axles with two tracks</li> <li>Suspension parameters</li> </ul>
Track	<ul style="list-style-type: none"> <li>Steering angles</li> </ul>

The block contains energy-storing spring elements and energy-dissipating damper elements. It does not contain energy-storing mass elements. The block assumes that the vehicle (sprung) and wheel (unsprung) blocks connected to the block store the mass-related suspension energy.

This table summarizes the block parameter settings for a vehicle with:

- Two axles
- Two tracks per axle
- Steering angle input for both tracks on the front axle
- An anti-sway bar on the front axle

Parameter	Setting
<b>Number of axles, NumAxl</b>	2
<b>Number of tracks by axle, NumTracksByAxl</b>	[2 2]
<b>Steered axle enable by axle, StrgEnByAxl</b>	[1 0]
<b>Anti-sway axle enable by axle, AntiSwayEnByAxl</b>	[1 0]

### Suspension Compliance and Damping

The block uses a lookup table that relates the vertical damping and compliance to the suspension height, suspension height rate of change, and steering angle. You can calibrate the wheel force lookup table so that steering angle changes from the nominal center position generate a force that increases the vehicle height.

The block implements these equations.

$$F_{wzlookup_a} = f(z_{v_{a,t}} - z_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$$

$$F_{wz_{a,t}} = F_{wzlookup_a} + F_{zaswy_{a,t}}$$

The block assumes that the suspension elements have no mass. Therefore, the suspension forces and moments applied to the vehicle are equal to the suspension forces and moments applied to the wheel.

$$F_{vx_{a,t}} = F_{wx_{a,t}}$$

$$F_{vy_{a,t}} = F_{wy_{a,t}}$$

$$F_{vz_{a,t}} = -F_{wz_{a,t}}$$

$$M_{vx_{a,t}} = M_{wx_{a,t}} + F_{wy_{a,t}}(Re_{wy_{a,t}} + H_{a,t})$$

$$M_{vy_{a,t}} = M_{wy_{a,t}} + F_{wx_{a,t}}(Re_{wx_{a,t}} + H_{a,t})$$

$$M_{vz_{a,t}} = M_{wz_{a,t}}$$

The block sets the wheel positions and velocities equal to the vehicle lateral and longitudinal positions and velocities.

$$x_{w_{a,t}} = x_{v_{a,t}}$$

$$y_{w_{a,t}} = y_{v_{a,t}}$$

$$\dot{x}_{w_{a,t}} = \dot{x}_{v_{a,t}}$$

$$\dot{y}_{w_{a,t}} = \dot{y}_{v_{a,t}}$$

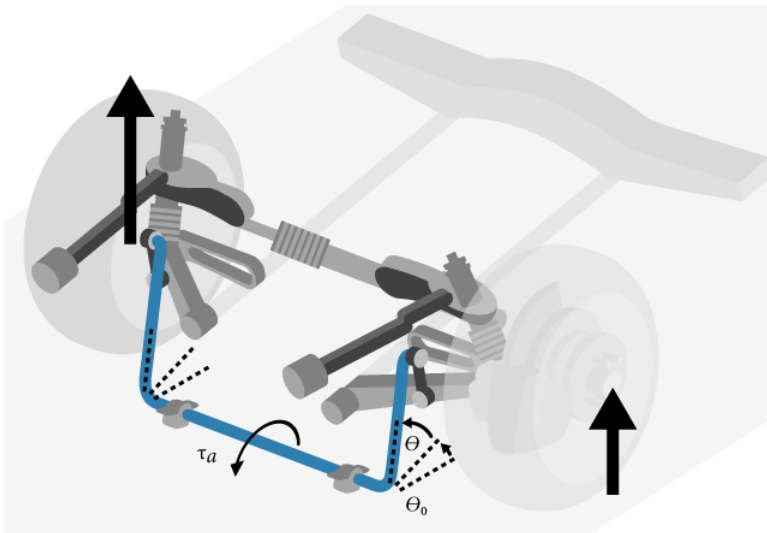
The equations use these variables.

$F_{wz_{a,t}}, M_{wz_{a,t}}$	Suspension force and moment applied to the wheel on axle a, track t along wheel-fixed z-axis
$F_{wx_{a,t}}, M_{wx_{a,t}}$	Suspension force and moment applied to the wheel on axle a, track t along wheel-fixed x-axis
$F_{wy_{a,t}}, M_{wy_{a,t}}$	Suspension force and moment applied to the wheel on axle a, track t along wheel-fixed y-axis
$F_{vz_{a,t}}, M_{vz_{a,t}}$	Suspension force and moment applied to the vehicle on axle a, track t along wheel-fixed z-axis
$F_{vx_{a,t}}, M_{vx_{a,t}}$	Suspension force and moment applied to the vehicle on axle a, track t along wheel-fixed x-axis
$F_{vy_{a,t}}, M_{vy_{a,t}}$	Suspension force and moment applied to the vehicle on axle a, track t along wheel-fixed y-axis

$F_{z0_a}$	Vertical suspension spring preload force applied to the wheels on axle a
$k_{z_a}$	Vertical spring constant applied to tracks on axle a
$m_{hsteer_a}$	Steering angle to vertical force slope applied at wheel carrier for tracks on axle a
$\delta_{steer_{a,t}}$	Steering angle input for axle a, track t
$c_{z_a}$	Vertical damping constant applied to tracks on axle a
$Re_{w_{a,t}}$	Effective wheel radius for axle a, track t
$F_{zhstop_{a,t}}$	Vertical hardstop force at axle a, track t, along the vehicle-fixed z-axis
$F_{zaswy_{a,t}}$	Vertical anti-sway force at axle a, track t, along the vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along the vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along the vehicle-fixed z-axis
$x_{v_{a,t}}, \dot{x}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along the vehicle-fixed x-axis
$x_{w_{a,t}}, \dot{x}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along the vehicle-fixed x-axis
$y_{v_{a,t}}, \dot{y}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along the vehicle-fixed y-axis
$y_{w_{a,t}}, \dot{y}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along the vehicle-fixed y-axis
$H_{a,t}$	Suspension height at axle a, track t
$Re_{w_{a,t}}$	Effective wheel radius at axle a, track t

### Anti-Sway Bar

Optionally, the block implements an anti-sway bar force,  $F_{zaswy_{a,t}}$ , for axles that have two tracks. This figure shows how the anti-sway bar transmits torque between two independent suspension tracks on a shared axle. Each independent suspension applies a torque to the anti-sway bar via a radius arm that extends from the anti-sway bar back to the independent suspension connection point.



To calculate the sway bar force, the block implements these equations.

Calculation	Equation
Anti-sway bar angular deflection for a given axle and track, $\Delta\theta_{a,t}$	$\theta_{0a} = \tan^{-1}\left(\frac{z_0}{r}\right)$ $\Delta\theta_{a,t} = \tan^{-1}\left(\frac{r\tan\theta_{0a} - z_{w_{a,t}} + z_{v_{a,t}}}{r}\right)$
Anti-sway bar twist angle, $\theta_a$	$\theta_a = -\tan^{-1}\left(\frac{r\tan\theta_{0a} - z_{w_{a,1}} + z_{v_{a,1}}}{r}\right)$ $-\tan^{-1}\left(\frac{r\tan\theta_{0a} - z_{w_{a,2}} + z_{v_{a,2}}}{r}\right)$
Anti-sway bar torque, $\tau_a$	$\tau_a = k_a\theta_a$
Anti-sway bar forces applied to the wheel on axle <b>a</b> , track <b>t</b> along wheel-fixed <b>z</b> -axis	$F_{z_{aswy_{a,1}}} = \left(\frac{\tau_a}{r}\right)\cos\left(\theta_{0a} - \tan^{-1}\left(\frac{r\tan\theta_{0a} - z_{w_{a,1}} + z_{v_{a,1}}}{r}\right)\right)$ $F_{z_{aswy_{a,2}}} = \left(\frac{\tau_a}{r}\right)\cos\left(\theta_{0a} - \tan^{-1}\left(\frac{r\tan\theta_{0a} - z_{w_{a,2}} + z_{v_{a,2}}}{r}\right)\right)$

The equations and figure use these variables.

$\tau_a$	Anti-sway bar torque
$\theta$	Anti-sway bar twist angle
$\theta_{0a}$	Initial anti-sway bar twist angle
$\Delta\theta_{a,t}$	Anti-sway bar angular deflection at axle <b>a</b> , track <b>t</b>
$r$	Anti-sway bar arm radius
$z_0$	Vertical distance from anti-sway bar connection point to anti-sway bar centerline
$F_{z_{aswy_{a,t}}}$	Anti-sway bar force applied to the wheel on axle <b>a</b> , track <b>t</b> along wheel-fixed <b>z</b> -axis
$z_{v_{a,t}}$	Vehicle displacement at axle <b>a</b> , track <b>t</b> , along the vehicle-fixed <b>z</b> -axis
$z_{w_{a,t}}$	Wheel displacement at axle <b>a</b> , track <b>t</b> , along the vehicle-fixed <b>z</b> -axis

### Camber, Caster, and Toe Angles

To calculate the camber, caster, and toe angles, the block uses a lookup table,  $G_{lookup}$ , that is a function of the suspension height and steering angle.

$$[\xi_{a,t} \ \eta_{a,t} \ \zeta_{a,t}] = G_{lookup}(z_{w_{a,t}} - z_{v_{a,t}}, \delta_{steer_{a,t}})$$

The equations use these variables.

$\xi_{a,t}$	Camber angle of wheel on axle <b>a</b> , track <b>t</b>
$\eta_{a,t}$	Caster angle of wheel on axle <b>a</b> , track <b>t</b>
$\zeta_{a,t}$	Toe angle of wheel on axle <b>a</b> , track <b>t</b>
$\delta_{steer_{a,t}}$	Steering angle input for axle <b>a</b> , track <b>t</b>
$z_{v_{a,t}}$	Vehicle displacement at axle <b>a</b> , track <b>t</b> , along vehicle-fixed <b>z</b> -axis
$z_{w_{a,t}}$	Wheel displacement at axle <b>a</b> , track <b>t</b> , along vehicle-fixed <b>z</b> -axis

## Steering Angles

Optionally, you can input steering angles for the tracks. To calculate the steering angles for the wheels, the block offsets the input steering angles as a function of the suspension height. For the calculation, the block uses a lookup table,  $G_{lookup}$ , that is a function of the suspension position and steering angle.

$$\delta_{whlsteer_{a,t}} = \delta_{steer_{a,t}} + G_{lookup}(z_{w_{a,t}} - z_{v_{a,t}}, \delta_{steer_{a,t}})$$

The equation uses these variables.

$\delta_{whlsteer_{a,t}}$	Wheel steering angle for axle <b>a</b> , track <b>t</b>
$\delta_{steer_{a,t}}$	Steering angle input for axle <b>a</b> , track <b>t</b>
$z_{v_{a,t}}$	Vehicle displacement at axle <b>a</b> , track <b>t</b> , along the vehicle-fixed z-axis
$z_{w_{a,t}}$	Wheel displacement at axle <b>a</b> , track <b>t</b> , along the vehicle-fixed z-axis

## Power and Energy

The block calculates these suspension characteristics for each axle, **a**, track, **t**.

Calculation	Equation
Dissipated power, $P_{susp_{a,t}}$	$P_{susp_{a,t}} = F_{wzlookup_a}(\dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$
Absorbed energy, $E_{susp_{a,t}}$	$E_{susp_{a,t}} = F_{wzlookup_a}(\dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$
Suspension height, $H_{a,t}$	$H_{a,t} = -(z_{v_{a,t}} - z_{w_{a,t}} - \text{median}(f\_susp\_dz\_bp))$
Distance from wheel carrier center to tire/road interface	$z_{wtr_{a,t}} = Re_{w_{a,t}} + H_{a,t}$

The equations use these variables.

$m_{hsteer_a}$	Steering angle to vertical force slope applied at wheel carrier for tracks on axle <b>a</b>
$\delta_{steer_{a,t}}$	Steering angle input for axle <b>a</b> , track <b>t</b>
$Re_{w_{a,t}}$	Axle <b>a</b> , track <b>t</b> effective wheel radius from wheel carrier center to tire/road interface
$f\_susp\_dz\_bp$	Vertical axis suspension height breakpoints
$z_{wtr_{a,t}}$	Distance from wheel carrier center to tire/road interface, along the vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle <b>a</b> , track <b>t</b> , along the vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle <b>a</b> , track <b>t</b> , along the vehicle-fixed z-axis

## Ports

### Input

#### WhlPz — Track z-axis displacement

array

Track displacement,  $z_w$ , along wheel-fixed  $z$ -axis, in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlPz:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlPz} = z_w = [z_{w1,1} \ z_{w1,2} \ z_{w2,1} \ z_{w2,2}]$$

Array Element	Axle	Track
WhlPz(1,1)	1	1
WhlPz(1,2)	1	2
WhlPz(1,3)	2	1
WhlPz(1,4)	2	2

**WhlRe – Wheel effective radius**

array

Effective wheel radius,  $Re_w$ , in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlRe:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlRe} = Re_w = [Re_{w1,1} \ Re_{w1,2} \ Re_{w2,1} \ Re_{w2,2}]$$

Array Element	Axle	Track
WhlRe(1,1)	1	1
WhlRe(1,2)	1	2
WhlRe(1,3)	2	1
WhlRe(1,4)	2	2

**WhlVz – Track z-axis velocity**

array

Track velocity,  $\dot{z}_w$ , along wheel-fixed  $z$ -axis, in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlVz:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlVz} = \dot{z}_w = [\dot{z}_{w1,1} \ \dot{z}_{w1,2} \ \dot{z}_{w2,1} \ \dot{z}_{w2,2}]$$



Array Element	Axle	Track
WhlVz(1,1)	1	1
WhlVz(1,2)	1	2
WhlVz(1,3)	2	1
WhlVz(1,4)	2	2

### WhlFx – Longitudinal wheel force on vehicle

array

Longitudinal wheel force applied to vehicle,  $F_{wx}$ , along the vehicle-fixed x-axis. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlFx:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlFx} = F_{wx} = [F_{wx1,1} \ F_{wx1,2} \ F_{wx2,1} \ F_{wx2,2}]$$

Array Element	Axle	Track
WhlFx(1,1)	1	1
WhlFx(1,2)	1	2
WhlFx(1,3)	2	1
WhlFx(1,4)	2	2

### WhlFy – Lateral wheel force on vehicle

array

Lateral wheel force applied to vehicle,  $F_{wy}$ , along the vehicle-fixed y-axis. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlFy:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlFy} = F_{wy} = [F_{wy1,1} \ F_{wy1,2} \ F_{wy2,1} \ F_{wy2,2}]$$

Array Element	Axle	Track
WhlFy(1,1)	1	1
WhlFy(1,2)	1	2
WhlFy(1,3)	2	1
WhlFy(1,4)	2	2

### WhlM – Suspension moment on wheel

array

Longitudinal, lateral, and vertical suspension moments at axle *a*, track *t*, applied to the wheel at the axle wheel carrier reference coordinate, in N·m. Array dimensions are 3 by the total number of tracks on the vehicle.

- $WhlM(1, \dots)$  — Suspension moment applied to the wheel about the vehicle-fixed *x*-axis (longitudinal)
- $WhlM(2, \dots)$  — Suspension moment applied to the wheel about the vehicle-fixed *y*-axis (lateral)
- $WhlM(3, \dots)$  — Suspension moment applied to the wheel about the vehicle-fixed *z*-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the  $WhlM$ :

- Signal dimensions are [3×4].
- Signal contains suspension moments applied to four wheels according to their axle and track locations.

$$WhlM = M_w = \begin{bmatrix} M_{wx1,1} & M_{wx1,2} & M_{wx2,1} & M_{wx2,2} \\ M_{wy1,1} & M_{wy1,2} & M_{wy2,1} & M_{wy2,2} \\ M_{wz1,1} & M_{wz1,2} & M_{wz2,1} & M_{wz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Moment Axis
$WhlM(1,1)$	1	1	Vehicle-fixed <i>x</i> -axis (longitudinal)
$WhlM(1,2)$	1	2	
$WhlM(1,3)$	2	1	
$WhlM(1,4)$	2	2	
$WhlM(2,1)$	1	1	Vehicle-fixed <i>y</i> -axis (lateral)
$WhlM(2,2)$	1	2	
$WhlM(2,3)$	2	1	
$WhlM(2,4)$	2	2	
$WhlM(3,1)$	1	1	Vehicle-fixed <i>z</i> -axis (vertical)
$WhlM(3,2)$	1	2	
$WhlM(3,3)$	2	1	
$WhlM(3,4)$	2	2	

**VehP — Vehicle displacement**

array

Vehicle displacement from axle *a*, track *t* along vehicle-fixed coordinate system, in m. Array dimensions are 3 by the total number of tracks on the vehicle.

- $VehP(1, \dots)$  — Vehicle displacement from track,  $x_v$ , along the vehicle-fixed *x*-axis
- $VehP(2, \dots)$  — Vehicle displacement from track,  $y_v$ , along the vehicle-fixed *y*-axis
- $VehP(3, \dots)$  — Vehicle displacement from track,  $z_v$ , along the vehicle-fixed *z*-axis

For example, for a two-axle vehicle with two tracks per axle, the  $VehP$ :

- Signal dimensions are [3×4].

- Signal contains four track displacements according to their axle and track locations.

$$\text{VehP} = \begin{bmatrix} x_v \\ y_v \\ z_v \end{bmatrix} = \begin{bmatrix} x_{v1,1} & x_{v1,2} & x_{v2,1} & x_{v2,2} \\ y_{v1,1} & y_{v1,2} & y_{v2,1} & y_{v2,2} \\ z_{v1,1} & z_{v1,2} & z_{v2,1} & z_{v2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
VehP(1,1)	1	1	Vehicle-fixed x-axis
VehP(1,2)	1	2	
VehP(1,3)	2	1	
VehP(1,4)	2	2	
VehP(2,1)	1	1	Vehicle-fixed y-axis
VehP(2,2)	1	2	
VehP(2,3)	2	1	
VehP(2,4)	2	2	
VehP(3,1)	1	1	Vehicle-fixed z-axis
VehP(3,2)	1	2	
VehP(3,3)	2	1	
VehP(3,4)	2	2	

### VehV – Vehicle velocity

array

Vehicle velocity at axle  $a$ , track  $t$  along vehicle-fixed coordinate system, in m. Input array dimensions are 3 by  $a*t$ .

- VehV(1, . . .) – Vehicle velocity at track,  $x_v$ , along the vehicle-fixed x-axis
- VehV(2, . . .) – Vehicle velocity at track,  $y_v$ , along the vehicle-fixed y-axis
- VehV(3, . . .) – Vehicle velocity at track,  $z_v$ , along the vehicle-fixed z-axis

For example, for a two-axle vehicle with two tracks per axle, the VehV:

- Signal dimensions are [3x4].
- Signal contains 4 track velocities according to their axle and track locations.

$$\text{VehV} = \begin{bmatrix} \dot{x}_v \\ \dot{y}_v \\ \dot{z}_v \end{bmatrix} = \begin{bmatrix} \dot{x}_{v1,1} & \dot{x}_{v1,2} & \dot{x}_{v2,1} & \dot{x}_{v2,2} \\ \dot{y}_{v1,1} & \dot{y}_{v1,2} & \dot{y}_{v2,1} & \dot{y}_{v2,2} \\ \dot{z}_{v1,1} & \dot{z}_{v1,2} & \dot{z}_{v2,1} & \dot{z}_{v2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
VehV(1,1)	1	1	Vehicle-fixed x-axis
VehV(1,2)	1	2	
VehV(1,3)	2	1	

Array Element	Axle	Track	Axis
VehV(1,4)	2	2	
VehV(2,1)	1	1	Vehicle-fixed y-axis
VehV(2,2)	1	2	
VehV(2,3)	2	1	
VehV(2,4)	2	2	
VehV(3,1)	1	1	Vehicle-fixed z-axis
VehV(3,2)	1	2	
VehV(3,3)	2	1	
VehV(3,4)	2	2	

**StrgAng — Steering angle, optional**

array

Optional steering angle for each wheel,  $\delta$ . Input array dimensions are 1 by the number of steered tracks.

For example, for a two-axle vehicle with two tracks per axle, you can input steering angles for both wheels on the first axle.

- To create the StrgAng port, set **Steered axle enable by axle, StrgEnByAxl** to [1 0]. The input signal array dimensions are [1x2].
- The StrgAng signal contains two steering angles according to their axle and track locations.

$$\text{StrgAng} = \delta_{steer} = [\delta_{steer_{1,1}} \ \delta_{steer_{1,2}}]$$

Array Element	Axle	Track
StrgAng(1,1)	1	1
StrgAng(1,2)	1	2

**Dependencies**

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

**Output**

**Info — Bus signal**

bus

Bus signal containing block values. The signals are arrays that depend on the track location.

For example, here are the indices for a two-axle, two-track vehicle. The total number of tracks is four.

- 1D array signal (1-by-4)

Array Element	Axle	Track
(1,1)	1	1
(1,2)	1	2
(1,3)	2	1
(1,4)	2	2

- 3D array signal (3-by-4)

Array Element	Axle	Track
(1,1)	1	1
(1,2)	1	2
(1,3)	2	1
(1,4)	2	2
(2,1)	1	1
(2,2)	1	2
(2,3)	2	1
(2,4)	2	2
(3,1)	1	1
(3,2)	1	2
(3,3)	2	1
(3,4)	2	2

Signal	Description	Array Signal	Variable	Units
Camber	Wheel angles according to the axle and track location.	1D	$\text{WhlAng}[1, \dots] = \xi = [\xi_{a,t}]$	rad
Caster			$\text{WhlAng}[2, \dots] = \eta = [\eta_{a,t}]$	
Toe			$\text{WhlAng}[3, \dots] = \zeta = [\zeta_{a,t}]$	
Height	Suspension height	1D	$H$	m
Power	Suspension power dissipation	1D	$P_{\text{susp}}$	W
Energy	Suspension absorbed energy	1D	$E_{\text{susp}}$	J

Signal	Description	Array Signal	Variable	Units
VehF	Suspension forces applied to the vehicle	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{VehF} = F_v =$ $\begin{bmatrix} F_{vx1,1} & F_{vx1,2} & F_{vx2,1} & F_{vx2,2} \\ F_{vy1,1} & F_{vy1,2} & F_{vy2,1} & F_{vy2,2} \\ F_{vz1,1} & F_{vz1,2} & F_{vz2,1} & F_{vz2,2} \end{bmatrix}$	N
VehM	Suspension moments applied to vehicle	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{VehM} = M_v =$ $\begin{bmatrix} M_{vx1,1} & M_{vx1,2} & M_{vx2,1} & M_{vx2,2} \\ M_{vy1,1} & M_{vy1,2} & M_{vy2,1} & M_{vy2,2} \\ M_{vz1,1} & M_{vz1,2} & M_{vz2,1} & M_{vz2,2} \end{bmatrix}$	N·m
WhlF	Suspension force applied to wheel	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlF} = F_w =$ $\begin{bmatrix} F_{wx1,1} & F_{wx1,2} & F_{wx2,1} & F_{wx2,2} \\ F_{wy1,1} & F_{wy1,2} & F_{wy2,1} & F_{wy2,2} \\ F_{wz1,1} & F_{wz1,2} & F_{wz2,1} & F_{wz2,2} \end{bmatrix}$	N

Signal	Description	Array Signal	Variable	Units
WhlP	Track displacement	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlP} = \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix} = \begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{w2,2} \\ z_{wtr1,1} & z_{wtr1,2} & z_{wtr2,1} & z_{wtr2,2} \end{bmatrix}$	m
WhlV	Track velocity	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlV} = \begin{bmatrix} \dot{x}_w \\ \dot{y}_w \\ \dot{z}_w \end{bmatrix} = \begin{bmatrix} \dot{x}_{w1,1} & \dot{x}_{w1,2} & \dot{x}_{w2,1} & \dot{x}_{w2,2} \\ \dot{y}_{w1,1} & \dot{y}_{w1,2} & \dot{y}_{w2,1} & \dot{y}_{w2,2} \\ \dot{z}_{w1,1} & \dot{z}_{w1,2} & \dot{z}_{w2,1} & \dot{z}_{w2,2} \end{bmatrix}$	m/s
WhlAng	Wheel camber, caster, toe angles	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix} = \begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$	rad

**VehF – Suspension force on vehicle**

array

Longitudinal, lateral, and vertical suspension force at axle *a*, track *t*, applied to the vehicle at the suspension connection point, in N. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehF(1, . . .) — Suspension force applied to vehicle along the vehicle-fixed x-axis (longitudinal)
- VehF(2, . . .) — Suspension force applied to vehicle along the vehicle-fixed y-axis (lateral)
- VehF(3, . . .) — Suspension force applied to vehicle along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the VehF:

- Signal dimensions are [3x4].
- Signal contains suspension forces applied to the vehicle according to the axle and track locations.

$$\text{VehF} = F_v = \begin{bmatrix} F_{vx1,1} & F_{vx1,2} & F_{vx2,1} & F_{vx2,2} \\ F_{vy1,1} & F_{vy1,2} & F_{vy2,1} & F_{vy2,2} \\ F_{vz1,1} & F_{vz1,2} & F_{vz2,1} & F_{vz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
VehF(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
VehF(1,2)	1	2	
VehF(1,3)	2	1	
VehF(1,4)	2	2	
VehF(2,1)	1	1	Vehicle-fixed y-axis (lateral)
VehF(2,2)	1	2	
VehF(2,3)	2	1	
VehF(2,4)	2	2	
VehF(3,1)	1	1	Vehicle-fixed z-axis (vertical)
VehF(3,2)	1	2	
VehF(3,3)	2	1	
VehF(3,4)	2	2	

**VehM — Suspension moment on vehicle**

array

Longitudinal, lateral, and vertical suspension moment at axle a, track t, applied to the vehicle at the suspension connection point, in N·m. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehM(1, . . .) — Suspension moment applied to the vehicle about the vehicle-fixed x-axis (longitudinal)
- VehM(2, . . .) — Suspension moment applied to the vehicle about the vehicle-fixed y-axis (lateral)
- VehM(3, . . .) — Suspension moment applied to the vehicle about the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the VehM:

- Signal dimensions are [3x4].
- Signal contains suspension moments applied to vehicle according to the axle and track locations.



$$\text{VehM} = M_v = \begin{bmatrix} M_{vx1,1} & M_{vx1,2} & M_{vx2,1} & M_{vx2,2} \\ M_{vy1,1} & M_{vy1,2} & M_{vy2,1} & M_{vy2,2} \\ M_{vz1,1} & M_{vz1,2} & M_{vz2,1} & M_{vz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Moment Axis
VehM(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
VehM(1,2)	1	2	
VehM(1,3)	2	1	
VehM(1,4)	2	2	
VehM(2,1)	1	1	Vehicle-fixed y-axis (lateral)
VehM(2,2)	1	2	
VehM(2,3)	2	1	
VehM(2,4)	2	2	
VehM(3,1)	1	1	Vehicle-fixed z-axis (vertical)
VehM(3,2)	1	2	
VehM(3,3)	2	1	
VehM(3,4)	2	2	

### WhlF — Suspension force on wheel

array

Longitudinal, lateral, and vertical suspension forces at axle **a**, track **t**, applied to the wheel at the axle wheel carrier reference coordinate, in N. Array dimensions are 3 by the total number of tracks on the vehicle.

- WhlF(1, ...) — Suspension force on wheel along the vehicle-fixed x-axis (longitudinal)
- WhlF(2, ...) — Suspension force on wheel along the vehicle-fixed y-axis (lateral)
- WhlF(3, ...) — Suspension force on wheel along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the WhlF:

- Signal dimensions are [3x4].
- Signal contains wheel forces applied to the vehicle according to the axle and track locations.

$$\text{WhlF} = F_w = \begin{bmatrix} F_{wx1,1} & F_{wx1,2} & F_{wx2,1} & F_{wx2,2} \\ F_{wy1,1} & F_{wy1,2} & F_{wy2,1} & F_{wy2,2} \\ F_{wz1,1} & F_{wz1,2} & F_{wz2,1} & F_{wz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
WhlF(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
WhlF(1,2)	1	2	
WhlF(1,3)	2	1	
WhlF(1,4)	2	2	

Array Element	Axle	Track	Force Axis
WhlF(2,1)	1	1	Vehicle-fixed y-axis (lateral)
WhlF(2,2)	1	2	
WhlF(2,3)	2	1	
WhlF(2,4)	2	2	
WhlF(3,1)	1	1	Vehicle-fixed z-axis (vertical)
WhlF(3,2)	1	2	
WhlF(3,3)	2	1	
WhlF(3,4)	2	2	

**WhlV — Track velocity**

array

Longitudinal, lateral, and vertical track velocity at axle *a*, track *t*, in m/s. Array dimensions are 3 by the total number of tracks on the vehicle.

- WhlV(1, . . .) — Track velocity along the vehicle-fixed x-axis (longitudinal)
- WhlV(2, . . .) — Track velocity along the vehicle-fixed y-axis (lateral)
- WhlV(3, . . .) — Track velocity along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the WhlV:

- Signal dimensions are [3x4].
- Signal contains wheel forces applied to the vehicle according to the axle and track locations.

$$\text{WhlV} = \begin{bmatrix} \dot{x}_w \\ \dot{y}_w \\ \dot{z}_w \end{bmatrix} = \begin{bmatrix} \dot{x}_{w1,1} & \dot{x}_{w1,2} & \dot{x}_{w2,1} & \dot{x}_{w2,2} \\ \dot{y}_{w1,1} & \dot{y}_{w1,2} & \dot{y}_{w2,1} & \dot{y}_{w2,2} \\ \dot{z}_{w1,1} & \dot{z}_{w1,2} & \dot{z}_{w2,1} & \dot{z}_{w2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
WhlV(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
WhlV(1,2)	1	2	
WhlV(1,3)	2	1	
WhlV(1,4)	2	2	
WhlV(2,1)	1	1	Vehicle-fixed y-axis (lateral)
WhlV(2,2)	1	2	
WhlV(2,3)	2	1	
WhlV(2,4)	2	2	
WhlV(3,1)	1	1	Vehicle-fixed z-axis (vertical)
WhlV(3,2)	1	2	
WhlV(3,3)	2	1	
WhlV(3,4)	2	2	

**WhlAng — Wheel camber, caster, toe angles**

array

Camber, caster, and toe angles at axle  $a$ , track  $t$ , in rad. Array dimensions are 3 by the total number of tracks on the vehicle.

- $\text{WhlAng}(1, \dots)$  — Camber angle
- $\text{WhlAng}(2, \dots)$  — Caster angle
- $\text{WhlAng}(3, \dots)$  — Toe angle

For example, for a two-axle vehicle with two tracks per axle, the  $\text{WhlAng}$ :

- Signal dimensions are  $[3 \times 4]$ .
- Signal contains wheel angles according to the axle and track locations.

$$\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix} = \begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$$

Array Element	Axle	Track	Angle
$\text{WhlAng}(1,1)$	1	1	Camber
$\text{WhlAng}(1,2)$	1	2	
$\text{WhlAng}(1,3)$	2	1	
$\text{WhlAng}(1,4)$	2	2	
$\text{WhlAng}(2,1)$	1	1	Caster
$\text{WhlAng}(2,2)$	1	2	
$\text{WhlAng}(2,3)$	2	1	
$\text{WhlAng}(2,4)$	2	2	
$\text{WhlAng}(3,1)$	1	1	Toe
$\text{WhlF}(3,2)$	1	2	
$\text{WhlF}(3,3)$	2	1	
$\text{WhlF}(3,4)$	2	2	

**Parameters****Axles****Number of axles, NumAxl — Number of axles**

2 (default) | scalar

Number of axles,  $N_a$ , dimensionless.

**Number of tracks by axle, NumTracksByAxl — Number of tracks per axle** $[2 \ 2]$  (default) | vector

Number of tracks per axle,  $N_{t_a}$ , dimensionless. Vector is 1 by the number of vehicle axles,  $N_a$ . For example,  $[1, 2]$  represents one track on axle 1 and two tracks on axle 2.

**Steered axle enable by axle, StrgEnByAxl — Boolean vector to enable axle steering**

[1 0] (default) | vector

Boolean vector that enables axle steering,  $En_{steer}$ , dimensionless. Vector is 1 by the number of vehicle axles,  $N_a$ . For example:

- [1 0] — For a two-axle vehicle, enables axle 1 steering and disables axle 2 steering
- [1 1] — For a two-axle vehicle, enables axle 1 and axle 2 steering

**Dependencies**

Setting any element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

For example, for a two-axle vehicle with two tracks per axle, you can input steering angles for both wheels on the first axle.

- To create the StrgAng port, set **Steered axle enable by axle, StrgEnByAxl** to [1 0]. The input signal array dimensions are [1x2].
- The StrgAng signal contains two steering angles according to their axle and track locations.

$$\text{StrgAng} = \delta_{steer} = [\delta_{steer1,1} \ \delta_{steer1,2}]$$

Array Element	Axle	Track
StrgAng(1,1)	1	1
StrgAng(1,2)	1	2

**Anti-sway axle enable by axle, AntiSwayEnByAxl — Boolean vector to enable axle anti-sway**

[0 0] (default) | vector

Boolean vector that enables axle anti-sway for axle  $a$ , dimensionless. For example, [1 0] enables axle 1 anti-sway and disables axle 2 anti-sway. Vector is 1 by the number of vehicle axles,  $N_a$ .

**Dependencies**

Setting an element of the **Anti-sway axle enable by axle, AntiSwayEnByAxl** vector to 1 creates these anti-sway parameters:

- **Anti-sway arm radius, AntiSwayR**
- **Anti-sway arm neutral angle, AntiSwayNtrlAng**
- **Anti-sway torsion spring constant, AntiSwayTrsK**

## Suspension

### Mapped

#### Axle breakpoints, `f_susp_axl_bp` — Breakpoints

[1 2] (default) | 1-by-P array

Axle breakpoints, dimensionless.

#### Vertical axis suspension height breakpoints, `f_susp_dz_bp` — Breakpoints

1-by-M array

Vertical axis suspension height breakpoints, in m.

#### Vertical axis suspension height velocity breakpoints, `f_susp_dzdot_bp` — Breakpoints

1-by-N array

Vertical axis suspension height velocity breakpoints, in m/s.

#### Vertical axis suspension force and moment responses, `f_susp_fmz` — Output array

`zeros(31,31,61,2,4)` (default) | M-by-N-by-0-by-P-by-4 array

Array of output values as a function of:

- Vertical suspension height,  $M$
- Vertical suspension height velocity,  $N$
- Steering angle,  $O$
- Axle,  $P$
- 4 output types
  - 1 — Vertical force, in N·m
  - 2 — User-defined
  - 3 — Stored energy, in J
  - 4 — Absorbed power, in W

The array dimensions must match the breakpoint dimensions

#### Suspension geometry responses, `f_susp_geom` — Suspension geometry responses

`zeros(31,61,2,3)` (default) | M-by-0-by-P-by-3 array

Array of geometric suspension values as a function of:

- Vertical suspension height,  $M$
- Steering angle,  $O$
- Axle,  $P$
- 3 output types
  - 1 — Camber angle, in rad
  - 2 — Caster angle, in rad
  - 3 — Toe angle, in rad

The array dimensions must match the breakpoint dimensions

**Steering angle breakpoints, f\_susp\_strgdelta\_bp — Steering angle breakpoints**  
1-by-0 array

Steering angle breakpoints, in rad.

### **Anti-Sway**

**Anti-sway arm radius, AntiSwayR — Anti-sway arm radius**  
0.2 (default) | scalar | vector

Anti-sway arm radius,  $r$ , in m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Dependencies**

Setting an element of the **Anti-sway axle enable by axle, AntiSwayEnByAxl** vector to 1 creates these anti-sway parameters:

- **Anti-sway arm radius, AntiSwayR**
- **Anti-sway arm neutral angle, AntiSwayNtrlAng**
- **Anti-sway torsion spring constant, AntiSwayTrsK**

**Anti-sway arm neutral angle, AntiSwayNtrlAng — Anti-sway arm neutral angle**  
0.5236 (default) | scalar | vector

Anti-sway arm neutral angle,  $\theta_{0a}$ , at nominal suspension height, in rad.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Dependencies**

Setting an element of the **Anti-sway axle enable by axle, AntiSwayEnByAxl** vector to 1 creates these anti-sway parameters:

- **Anti-sway arm radius, AntiSwayR**
- **Anti-sway arm neutral angle, AntiSwayNtrlAng**
- **Anti-sway torsion spring constant, AntiSwayTrsK**

**Anti-sway torsion spring constant, AntiSwayTrsK — Anti-sway torsion spring constant**  
5.7296e+03 (default) | scalar | vector

Anti-sway bar torsion spring constant,  $k_a$ , in N·m/rad.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Dependencies**

Setting an element of the **Anti-sway axle enable by axle, AntiSwayEnByAxl** vector to 1 creates these anti-sway parameters:

- **Anti-sway arm radius, AntiSwayR**
- **Anti-sway arm neutral angle, AntiSwayNtrlAng**
- **Anti-sway torsion spring constant, AntiSwayTrsK**

## References

- [1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers, 1992.
- [2] Vehicle Dynamics Standards Committee. *Vehicle Dynamics Terminology*. SAE J670. Warrendale, PA: Society of Automotive Engineers, 2008.
- [3] Technical Committee. *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*. ISO 8855:2011. Geneva, Switzerland: International Organization for Standardization, 2011.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

### See Also

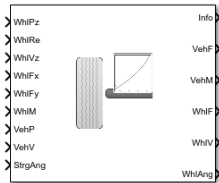
Independent Suspension - Double Wishbone | Independent Suspension - MacPherson

**Introduced in R2018a**

## Solid Axle Suspension - Mapped

Mapped solid axle suspension

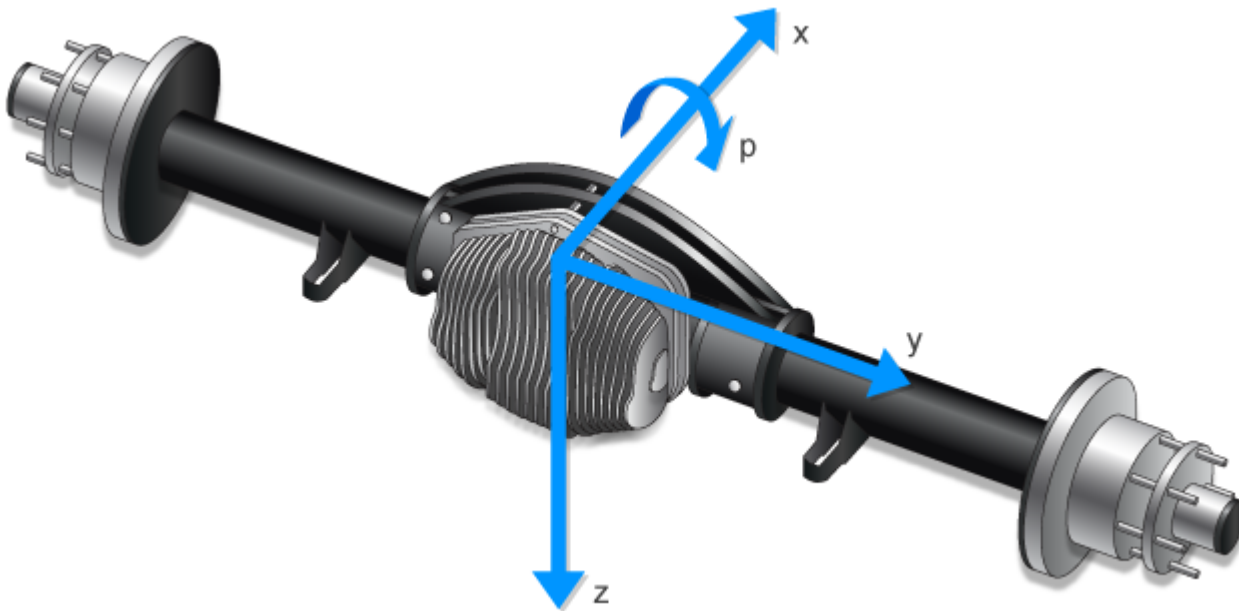
**Library:** Vehicle Dynamics Blockset / Suspension



### Description

The Solid Axle Suspension - Mapped block implements a mapped solid axle suspension for multiple axles with multiple tracks per axle.

The block models the suspension compliance, damping, and geometric effects as functions of the track positions and velocities, with axle-specific compliance and damping parameters. Using the track position and velocity, the block calculates the vertical track position and suspension forces on the vehicle and wheel. The block uses the Z-down (defined in SAE J670) and a solid axle coordinate system. The solid axle coordinate system, shown here, is aligned with the Z-down vehicle coordinate system, with the x-axis in the direction of forward vehicle motion.



For Each	You Can Specify
Axle	<ul style="list-style-type: none"> <li>Multiple tracks.</li> <li>Suspension parameters.</li> </ul>
Track	<ul style="list-style-type: none"> <li>Steering angles.</li> </ul>



The block contains energy-storing spring elements and energy-dissipating damper elements. The block also stores energy via the axle roll angular acceleration and axle center of mass vertical and lateral acceleration.

This table summarizes the block parameter settings for a vehicle with:

- Two axles.
- Two tracks per axle.
- Steering angle input for both tracks on the front axle.

Parameter	Setting
Number of axles, NumAxl	2
Number of tracks by axle, NumTracksByAxl	[2 2]
Steered axle enable by axle, StrgEnByAxl	[1 0]

### Suspension Compliance and Damping

The block uses a lookup table that relates the vertical damping and compliance to the suspension height, suspension height rate of change, and steering angle. You can calibrate the wheel force lookup table so that steering angle changes from the nominal center position generate a force that increases the vehicle height. Specifically, the block:

Uses	To Calculate
<ul style="list-style-type: none"> <li>• Longitudinal and lateral displacement and velocity of the vehicle.</li> <li>• Longitudinal and lateral displacement and velocity of the track.</li> <li>• Vertical wheel forces applied to the vehicle.</li> </ul>	<ul style="list-style-type: none"> <li>• Suspension forces applied to the axle center.</li> <li>• Vertical displacements and velocities of the vehicle and track.</li> <li>• Longitudinal, lateral, and vertical suspension forces and moments applied to the vehicle.</li> <li>• Longitudinal, lateral, and vertical suspension forces and moments applied to the wheel.</li> </ul>

To calculate the dynamics of the axle, the block implements these equations. The block neglects the effects of:

- Lateral and longitudinal translational velocity.
- Angular velocity about the vertical and lateral axes.

$$\begin{bmatrix} \ddot{x}_a \\ \ddot{y}_a \\ \ddot{z}_a \end{bmatrix} = \frac{1}{M_a} \begin{bmatrix} F_{xa} \\ F_{ya} \\ F_{za} \end{bmatrix} + \begin{bmatrix} \dot{x}_a \\ \dot{y}_a \\ \dot{z}_a \end{bmatrix} \times \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \frac{1}{M_a} \begin{bmatrix} 0 \\ 0 \\ F_{za} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{z}_a \end{bmatrix} \times \begin{bmatrix} p \\ q \\ r \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix} = \begin{bmatrix} 0 \\ p\dot{z}_a \\ \frac{F_{za}}{M_a} + g \end{bmatrix}$$

$$\begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix} - \begin{bmatrix} p \\ q \\ r \end{bmatrix} \times \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}^{-1}$$

$$= \begin{bmatrix} M_x \\ 0 \\ 0 \end{bmatrix} - \begin{bmatrix} p \\ q \\ 0 \end{bmatrix} \times \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} p \\ q \\ 0 \end{bmatrix} \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}^{-1} = \begin{bmatrix} \frac{M_x}{I_{xx}} \\ 0 \\ 0 \end{bmatrix}$$

For the forces and moments, the block uses lookup tables.

$$F_{wz_{a,t}} = f(z_{v_{a,t}} - z_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$$

$$M_{vz_{a,t}} = f(z_{v_{a,t}} - z_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$$

The suspension forces and moments applied to the vehicle are equal to the suspension forces and moments applied to the wheel.

$$F_{vx_{a,t}} = F_{wx_{a,t}}$$

$$F_{vy_{a,t}} = F_{wy_{a,t}}$$

$$F_{vz_{a,t}} = -F_{wz_{a,t}}$$

$$M_{vx_{a,t}} = M_{wx_{a,t}} + F_{wy_{a,t}}(Re_{wy_{a,t}} + H_{a,t})$$

$$M_{vy_{a,t}} = M_{wy_{a,t}} + F_{wx_{a,t}}(Re_{wx_{a,t}} + H_{a,t})$$

$$M_{vz_{a,t}} = M_{wz_{a,t}}$$

The equations use these variables.

$F_{wz_{a,t}}, M_{wz_{a,t}}$	Suspension force and moment applied to the wheel on axle a, track t along wheel-fixed z-axis
$F_{wx_{a,t}}, M_{wx_{a,t}}$	Suspension force and moment applied to the wheel on axle a, track t along wheel-fixed x-axis
$F_{wy_{a,t}}, M_{wy_{a,t}}$	Suspension force and moment applied to the wheel on axle a, track t along wheel-fixed y-axis
$F_{vz_{a,t}}, M_{vz_{a,t}}$	Suspension force and moment applied to the vehicle on axle a, track t along wheel-fixed z-axis
$F_{vx_{a,t}}, M_{vx_{a,t}}$	Suspension force and moment applied to the vehicle on axle a, track t along wheel-fixed x-axis
$F_{vy_{a,t}}, M_{vy_{a,t}}$	Suspension force and moment applied to the vehicle on axle a, track t along wheel-fixed y-axis
$F_{z0_a}$	Vertical suspension spring preload force applied to the wheels on axle a
$k_{z_a}$	Vertical spring constant applied to tracks on axle a
$m_{hsteer_a}$	Steering angle to vertical force slope applied at wheel carrier for tracks on axle a
$\delta_{steer_{a,t}}$	Steering angle input for axle a, track t
$c_{z_a}$	Vertical damping constant applied to tracks on axle a
$Re_{w_{a,t}}$	Effective wheel radius for axle a, track t
$F_{zhstop_{a,t}}$	Vertical hardstop force at axle a, track t, along the vehicle-fixed z-axis
$F_{zaswy_{a,t}}$	Vertical anti-sway force at axle a, track t, along the vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along the vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along the vehicle-fixed z-axis
$x_{v_{a,t}}, \dot{x}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along the vehicle-fixed x-axis
$x_{w_{a,t}}, \dot{x}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along the vehicle-fixed x-axis
$y_{v_{a,t}}, \dot{y}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along the vehicle-fixed y-axis

$y_{w_{a,t}}, \dot{y}_{w_{a,t}}$	Track displacement and velocity at axle <b>a</b> , track <b>t</b> , along the vehicle-fixed y-axis
$H_{a,t}$	Suspension height at axle <b>a</b> , track <b>t</b>
$Re_{w_{a,t}}$	Effective wheel radius at axle <b>a</b> , track <b>t</b>

### Camber, Caster, and Toe Angles

To calculate the camber, caster, and toe angles, the block uses a lookup table,  $G_{lookup}$ , that is a function of the suspension height and steering angle.

$$[\xi_{a,t} \ \eta_{a,t} \ \zeta_{a,t}] = G_{lookup}f(z_{w_{a,t}} - z_{v_{a,t}}, \delta_{steer_{a,t}})$$

The equations use these variables.

$\xi_{a,t}$	Camber angle of wheel on axle <b>a</b> , track <b>t</b>
$\eta_{a,t}$	Caster angle of wheel on axle <b>a</b> , track <b>t</b>
$\zeta_{a,t}$	Toe angle of wheel on axle <b>a</b> , track <b>t</b>
$\delta_{steer_{a,t}}$	Steering angle input for axle <b>a</b> , track <b>t</b>
$z_{v_{a,t}}$	Vehicle displacement at axle <b>a</b> , track <b>t</b> , along vehicle-fixed z-axis
$z_{w_{a,t}}$	Wheel displacement at axle <b>a</b> , track <b>t</b> , along vehicle-fixed z-axis

### Steering Angles

Optionally, you can input steering angles for the tracks. To calculate the steering angles for the wheels, the block offsets the input steering angles as a function of the suspension height. For the calculation, the block uses a lookup table,  $G_{lookup}$ , that is a function of the suspension position and steering angle.

$$\delta_{whlsteer_{a,t}} = \delta_{steer_{a,t}} + G_{lookup}f(z_{w_{a,t}} - z_{v_{a,t}}, \delta_{steer_{a,t}})$$

The equation uses these variables.

$\delta_{whlsteer_{a,t}}$	Wheel steering angle for axle <b>a</b> , track <b>t</b>
$\delta_{steer_{a,t}}$	Steering angle input for axle <b>a</b> , track <b>t</b>
$z_{v_{a,t}}$	Vehicle displacement at axle <b>a</b> , track <b>t</b> , along the vehicle-fixed z-axis
$z_{w_{a,t}}$	Wheel displacement at axle <b>a</b> , track <b>t</b> , along the vehicle-fixed z-axis

### Power and Energy

The block calculates these suspension characteristics for each axle, **a**, track, **t**.

Calculation	Equation
Dissipated power, $P_{susp_{a,t}}$	$P_{susp_{a,t}} = F_{wzlookup_a}(\dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$
Absorbed energy, $E_{susp_{a,t}}$	$E_{susp_{a,t}} = F_{wzlookup_a}(z_{v_{a,t}} - z_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$
Suspension height, $H_{a,t}$	$H_{a,t} = -(z_{v_{a,t}} - z_{w_{a,t}} - \text{median}(f\_susp\_dz\_bp))$

Calculation	Equation
Distance from wheel carrier center to tire/road interface	$z_{wtr_{a,t}} = Re_{w_{a,t}} + H_{a,t}$

The equations use these variables.

$m_{hsteer_a}$	Steering angle to vertical force slope applied at wheel carrier for tracks on axle a
$\delta_{steer_{a,t}}$	Steering angle input for axle a, track t
$Re_{w_{a,t}}$	Axle a, track t effective wheel radius from wheel carrier center to tire/road interface
$f_{susp\_dz\_bp}$	Vertical axis suspension height breakpoints
$z_{wtr_{a,t}}$	Distance from wheel carrier center to tire/road interface, along the vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along the vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along the vehicle-fixed z-axis

## Ports

### Input

#### WhlPz — Track z-axis displacement

array

Track displacement,  $z_w$ , along wheel-fixed z-axis, in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlPz:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlPz} = z_w = [z_{w1,1} \ z_{w1,2} \ z_{w2,1} \ z_{w2,2}]$$

Array Element	Axle	Track
WhlPz(1,1)	1	1
WhlPz(1,2)	1	2
WhlPz(1,3)	2	1
WhlPz(1,4)	2	2

#### WhlRe — Wheel effective radius

array

Effective wheel radius,  $Re_w$ , in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlRe:

- Signal array dimensions are [1x4].

- Array dimensions are axle by track.

$$\text{WhlRe} = Re_w = [Re_{w1,1} \quad Re_{w1,2} \quad Re_{w2,1} \quad Re_{w2,2}]$$

Array Element	Axle	Track
WhlRe(1,1)	1	1
WhlRe(1,2)	1	2
WhlRe(1,3)	2	1
WhlRe(1,4)	2	2

### WhlVz — Track z-axis velocity

array

Track velocity,  $\dot{z}_w$ , along wheel-fixed z-axis, in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlVz:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlVz} = \dot{z}_w = [\dot{z}_{w1,1} \quad \dot{z}_{w1,2} \quad \dot{z}_{w2,1} \quad \dot{z}_{w2,2}]$$

Array Element	Axle	Track
WhlVz(1,1)	1	1
WhlVz(1,2)	1	2
WhlVz(1,3)	2	1
WhlVz(1,4)	2	2

### WhlFx — Longitudinal wheel force on vehicle

array

Longitudinal wheel force applied to vehicle,  $F_{wx}$ , along the vehicle-fixed x-axis. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlFx:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlFx} = F_{wx} = [F_{wx1,1} \quad F_{wx1,2} \quad F_{wx2,1} \quad F_{wx2,2}]$$

Array Element	Axle	Track
WhlFx(1,1)	1	1
WhlFx(1,2)	1	2
WhlFx(1,3)	2	1
WhlFx(1,4)	2	2

**WhlFy — Lateral wheel force on vehicle**

array

Lateral wheel force applied to vehicle,  $F_{wy}$ , along the vehicle-fixed y-axis. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlFy:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlFy} = F_{wy} = [F_{wy1,1} \ F_{wy1,2} \ F_{wy2,1} \ F_{wy2,2}]$$

Array Element	Axle	Track
WhlFy(1,1)	1	1
WhlFy(1,2)	1	2
WhlFy(1,3)	2	1
WhlFy(1,4)	2	2

**WhlM — Suspension moment on wheel**

array

Longitudinal, lateral, and vertical suspension moments at axle a, track t, applied to the wheel at the axle wheel carrier reference coordinate, in N·m. Array dimensions are 3 by the total number of tracks on the vehicle.

- WhlM(1, . . .) — Suspension moment applied to the wheel about the vehicle-fixed x-axis (longitudinal)
- WhlM(2, . . .) — Suspension moment applied to the wheel about the vehicle-fixed y-axis (lateral)
- WhlM(3, . . .) — Suspension moment applied to the wheel about the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the WhlM:

- Signal dimensions are [3x4].
- Signal contains suspension moments applied to four wheels according to their axle and track locations.

$$\text{WhlM} = M_w = \begin{bmatrix} M_{wx1,1} & M_{wx1,2} & M_{wx2,1} & M_{wx2,2} \\ M_{wy1,1} & M_{wy1,2} & M_{wy2,1} & M_{wy2,2} \\ M_{wz1,1} & M_{wz1,2} & M_{wz2,1} & M_{wz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Moment Axis
WhlM(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
WhlM(1,2)	1	2	
WhlM(1,3)	2	1	
WhlM(1,4)	2	2	
WhlM(2,1)	1	1	Vehicle-fixed y-axis (lateral)

Array Element	Axle	Track	Moment Axis
WhlM(2,2)	1	2	
WhlM(2,3)	2	1	
WhlM(2,4)	2	2	
WhlM(3,1)	1	1	Vehicle-fixed z-axis (vertical)
WhlM(3,2)	1	2	
WhlM(3,3)	2	1	
WhlM(3,4)	2	2	

**VehP – Vehicle displacement**

array

Vehicle displacement from axle *a*, track *t* along vehicle-fixed coordinate system, in m. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehP(1, . . .) – Vehicle displacement from track,  $x_v$ , along the vehicle-fixed x-axis
- VehP(2, . . .) – Vehicle displacement from track,  $y_v$ , along the vehicle-fixed y-axis
- VehP(3, . . .) – Vehicle displacement from track,  $z_v$ , along the vehicle-fixed z-axis

For example, for a two-axle vehicle with two tracks per axle, the VehP:

- Signal dimensions are [3x4].
- Signal contains four track displacements according to their axle and track locations.

$$\text{VehP} = \begin{bmatrix} x_v \\ y_v \\ z_v \end{bmatrix} = \begin{bmatrix} x_{v1,1} & x_{v1,2} & x_{v2,1} & x_{v2,2} \\ y_{v1,1} & y_{v1,2} & y_{v2,1} & y_{v2,2} \\ z_{v1,1} & z_{v1,2} & z_{v2,1} & z_{v2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
VehP(1,1)	1	1	Vehicle-fixed x-axis
VehP(1,2)	1	2	
VehP(1,3)	2	1	
VehP(1,4)	2	2	
VehP(2,1)	1	1	Vehicle-fixed y-axis
VehP(2,2)	1	2	
VehP(2,3)	2	1	
VehP(2,4)	2	2	
VehP(3,1)	1	1	Vehicle-fixed z-axis
VehP(3,2)	1	2	
VehP(3,3)	2	1	
VehP(3,4)	2	2	

**VehV – Vehicle velocity**

array

Vehicle velocity at axle *a*, track *t* along vehicle-fixed coordinate system, in m. Input array dimensions are 3 by *a*\**t*.

- *VehV*(1, . . .) — Vehicle velocity at track, *x<sub>v</sub>*, along the vehicle-fixed *x*-axis
- *VehV*(2, . . .) — Vehicle velocity at track, *y<sub>v</sub>*, along the vehicle-fixed *y*-axis
- *VehV*(3, . . .) — Vehicle velocity at track, *z<sub>v</sub>*, along the vehicle-fixed *z*-axis

For example, for a two-axle vehicle with two tracks per axle, the *VehV*:

- Signal dimensions are [3x4].
- Signal contains 4 track velocities according to their axle and track locations.

$$\mathbf{VehV} = \begin{bmatrix} \dot{x}_v \\ \dot{y}_v \\ \dot{z}_v \end{bmatrix} = \begin{bmatrix} \dot{x}_{v1,1} & \dot{x}_{v1,2} & \dot{x}_{v2,1} & \dot{x}_{v2,2} \\ \dot{y}_{v1,1} & \dot{y}_{v1,2} & \dot{y}_{v2,1} & \dot{y}_{v2,2} \\ \dot{z}_{v1,1} & \dot{z}_{v1,2} & \dot{z}_{v2,1} & \dot{z}_{v2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
<i>VehV</i> (1, 1)	1	1	Vehicle-fixed <i>x</i> -axis
<i>VehV</i> (1, 2)	1	2	
<i>VehV</i> (1, 3)	2	1	
<i>VehV</i> (1, 4)	2	2	
<i>VehV</i> (2, 1)	1	1	Vehicle-fixed <i>y</i> -axis
<i>VehV</i> (2, 2)	1	2	
<i>VehV</i> (2, 3)	2	1	
<i>VehV</i> (2, 4)	2	2	
<i>VehV</i> (3, 1)	1	1	Vehicle-fixed <i>z</i> -axis
<i>VehV</i> (3, 2)	1	2	
<i>VehV</i> (3, 3)	2	1	
<i>VehV</i> (3, 4)	2	2	

**StrgAng — Steering angle, optional**

array

Optional steering angle for each wheel, *δ*. Input array dimensions are 1 by the number of steered tracks.

For example, for a two-axle vehicle with two tracks per axle, you can input steering angles for both wheels on the first axle.

- To create the *StrgAng* port, set **Steered axle enable by axle, StrgEnByAxl** to [1 0]. The input signal array dimensions are [1x2].
- The *StrgAng* signal contains two steering angles according to their axle and track locations.

$$\mathbf{StrgAng} = \delta_{steer} = [\delta_{steer1,1} \quad \delta_{steer1,2}]$$



Array Element	Axle	Track
StrgAng(1,1)	1	1
StrgAng(1,2)	1	2

### Dependencies

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

### Output

#### Info — Bus signal

bus

Bus signal containing block values. The signals are arrays that depend on the track location.

For example, here are the indices for a two-axle, two-track vehicle. The total number of tracks is four.

- 1D array signal (1-by-4)

Array Element	Axle	Track
(1,1)	1	1
(1,2)	1	2
(1,3)	2	1
(1,4)	2	2

- 3D array signal (3-by-4)

Array Element	Axle	Track
(1,1)	1	1
(1,2)	1	2
(1,3)	2	1
(1,4)	2	2
(2,1)	1	1
(2,2)	1	2
(2,3)	2	1
(2,4)	2	2
(3,1)	1	1
(3,2)	1	2

Array Element	Axle	Track
(3,3)	2	1
(3,4)	2	2

Signal	Description	Array Signal	Variable	Units
Camber	Wheel angles according to the axle.	1D	$WhlAng[1, \dots] = \xi = [\xi_{a,t}]$	rad
Caster			$WhlAng[2, \dots] = \eta = [\eta_{a,t}]$	
Toe			$WhlAng[3, \dots] = \zeta = [\zeta_{a,t}]$	
Height	Suspension height	1D	$H$	m
Power	Suspension power dissipation	1D	$P_{susp}$	W
Energy	Suspension absorbed energy	1D	$E_{susp}$	J
VehF	Suspension forces applied to the vehicle	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $VehF = F_v =$ $\begin{bmatrix} F_{vx1,1} & F_{vx1,2} & F_{vx2,1} & F_{vx2,2} \\ F_{vy1,1} & F_{vy1,2} & F_{vy2,1} & F_{vy2,2} \\ F_{vz1,1} & F_{vz1,2} & F_{vz2,1} & F_{vz2,2} \end{bmatrix}$	N
VehM	Suspension moments applied to vehicle	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $VehM = M_v =$ $\begin{bmatrix} M_{vx1,1} & M_{vx1,2} & M_{vx2,1} & M_{vx2,2} \\ M_{vy1,1} & M_{vy1,2} & M_{vy2,1} & M_{vy2,2} \\ M_{vz1,1} & M_{vz1,2} & M_{vz2,1} & M_{vz2,2} \end{bmatrix}$	N·m

Signal	Description	Array Signal	Variable	Units
WhlF	Suspension force applied to wheel	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlF} = F_w =$ $\begin{bmatrix} F_{wx1,1} & F_{wx1,2} & F_{wx2,1} & F_{wx2,2} \\ F_{wy1,1} & F_{wy1,2} & F_{wy2,1} & F_{wy2,2} \\ F_{wz1,1} & F_{wz1,2} & F_{wz2,1} & F_{wz2,2} \end{bmatrix}$	N
WhlP	Track displacement	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlP} = \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix} =$ $\begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{w2,2} \\ z_{wtr1,1} & z_{wtr1,2} & z_{wtr2,1} & z_{wtr2,2} \end{bmatrix}$	m
WhlV	Track velocity	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlV} = \begin{bmatrix} \dot{x}_w \\ \dot{y}_w \\ \dot{z}_w \end{bmatrix}$ $=$ $\begin{bmatrix} \dot{x}_{w1,1} & \dot{x}_{w1,2} & \dot{x}_{w2,1} & \dot{x}_{w2,2} \\ \dot{y}_{w1,1} & \dot{y}_{w1,2} & \dot{y}_{w2,1} & \dot{y}_{w2,2} \\ \dot{z}_{w1,1} & \dot{z}_{w1,2} & \dot{z}_{w2,1} & \dot{z}_{w2,2} \end{bmatrix}$	m/s

Signal	Description	Array Signal	Variable	Units
WhlAng	Wheel camber, caster, toe angles	3D	For a two-axle, two tracks per axle vehicle:  $\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix}$ $= \begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$	rad

**VehF – Suspension force on vehicle**

array

Longitudinal, lateral, and vertical suspension force at axle *a*, track *t*, applied to the vehicle at the suspension connection point, in N. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehF(1, . . .) – Suspension force applied to vehicle along the vehicle-fixed x-axis (longitudinal)
- VehF(2, . . .) – Suspension force applied to vehicle along the vehicle-fixed y-axis (lateral)
- VehF(3, . . .) – Suspension force applied to vehicle along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the VehF:

- Signal dimensions are [3x4].
- Signal contains suspension forces applied to the vehicle according to the axle and track locations.

$$\text{VehF} = F_v = \begin{bmatrix} F_{vx1,1} & F_{vx1,2} & F_{vx2,1} & F_{vx2,2} \\ F_{vy1,1} & F_{vy1,2} & F_{vy2,1} & F_{vy2,2} \\ F_{vz1,1} & F_{vz1,2} & F_{vz2,1} & F_{vz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
VehF(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
VehF(1,2)	1	2	
VehF(1,3)	2	1	
VehF(1,4)	2	2	
VehF(2,1)	1	1	Vehicle-fixed y-axis (lateral)
VehF(2,2)	1	2	
VehF(2,3)	2	1	
VehF(2,4)	2	2	
VehF(3,1)	1	1	Vehicle-fixed z-axis (vertical)
VehF(3,2)	1	2	
VehF(3,3)	2	1	
VehF(3,4)	2	2	

**VehM — Suspension moment on vehicle**

array

Longitudinal, lateral, and vertical suspension moment at axle **a**, track **t**, applied to the vehicle at the suspension connection point, in N·m. Array dimensions are 3 by the total number of tracks on the vehicle.

- $\text{VehM}(1, \dots)$  — Suspension moment applied to the vehicle about the vehicle-fixed x-axis (longitudinal)
- $\text{VehM}(2, \dots)$  — Suspension moment applied to the vehicle about the vehicle-fixed y-axis (lateral)
- $\text{VehM}(3, \dots)$  — Suspension moment applied to the vehicle about the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the VehM:

- Signal dimensions are [3×4].
- Signal contains suspension moments applied to vehicle according to the axle and track locations.

$$\text{VehM} = M_v = \begin{bmatrix} M_{vx1,1} & M_{vx1,2} & M_{vx2,1} & M_{vx2,2} \\ M_{vy1,1} & M_{vy1,2} & M_{vy2,1} & M_{vy2,2} \\ M_{vz1,1} & M_{vz1,2} & M_{vz2,1} & M_{vz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Moment Axis
VehM(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
VehM(1,2)	1	2	
VehM(1,3)	2	1	
VehM(1,4)	2	2	
VehM(2,1)	1	1	Vehicle-fixed y-axis (lateral)
VehM(2,2)	1	2	
VehM(2,3)	2	1	
VehM(2,4)	2	2	
VehM(3,1)	1	1	Vehicle-fixed z-axis (vertical)
VehM(3,2)	1	2	
VehM(3,3)	2	1	
VehM(3,4)	2	2	

**WhlF — Suspension force on wheel**

array

Longitudinal, lateral, and vertical suspension forces at axle **a**, track **t**, applied to the wheel at the axle wheel carrier reference coordinate, in N. Array dimensions are 3 by the total number of tracks on the vehicle.

- $\text{WhlF}(1, \dots)$  — Suspension force on wheel along the vehicle-fixed x-axis (longitudinal)
- $\text{WhlF}(2, \dots)$  — Suspension force on wheel along the vehicle-fixed y-axis (lateral)
- $\text{WhlF}(3, \dots)$  — Suspension force on wheel along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the WhlF:

- Signal dimensions are [3x4].
- Signal contains wheel forces applied to the vehicle according to the axle and track locations.

$$\text{WhlF} = F_w = \begin{bmatrix} F_{wx1,1} & F_{wx1,2} & F_{wx2,1} & F_{wx2,2} \\ F_{wy1,1} & F_{wy1,2} & F_{wy2,1} & F_{wy2,2} \\ F_{wz1,1} & F_{wz1,2} & F_{wz2,1} & F_{wz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
WhlF(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
WhlF(1,2)	1	2	
WhlF(1,3)	2	1	
WhlF(1,4)	2	2	
WhlF(2,1)	1	1	Vehicle-fixed y-axis (lateral)
WhlF(2,2)	1	2	
WhlF(2,3)	2	1	
WhlF(2,4)	2	2	
WhlF(3,1)	1	1	Vehicle-fixed z-axis (vertical)
WhlF(3,2)	1	2	
WhlF(3,3)	2	1	
WhlF(3,4)	2	2	

**WhlV — Track velocity**

array

Longitudinal, lateral, and vertical track velocity at axle **a**, track **t**, in m/s. Array dimensions are 3 by the total number of tracks on the vehicle.

- WhlV(1, . . .) — Track velocity along the vehicle-fixed x-axis (longitudinal)
- WhlV(2, . . .) — Track velocity along the vehicle-fixed y-axis (lateral)
- WhlV(3, . . .) — Track velocity along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the WhlV:

- Signal dimensions are [3x4].
- Signal contains wheel forces applied to the vehicle according to the axle and track locations.

$$\text{WhlV} = \begin{bmatrix} \dot{x}_w \\ \dot{y}_w \\ \dot{z}_w \end{bmatrix} = \begin{bmatrix} \dot{x}_{w1,1} & \dot{x}_{w1,2} & \dot{x}_{w2,1} & \dot{x}_{w2,2} \\ \dot{y}_{w1,1} & \dot{y}_{w1,2} & \dot{y}_{w2,1} & \dot{y}_{w2,2} \\ \dot{z}_{w1,1} & \dot{z}_{w1,2} & \dot{z}_{w2,1} & \dot{z}_{w2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
WhlV(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)

Array Element	Axle	Track	Force Axis
WhlV(1,2)	1	2	
WhlV(1,3)	2	1	
WhlV(1,4)	2	2	
WhlV(2,1)	1	1	Vehicle-fixed y-axis (lateral)
WhlV(2,2)	1	2	
WhlV(2,3)	2	1	
WhlV(2,4)	2	2	
WhlV(3,1)	1	1	Vehicle-fixed z-axis (vertical)
WhlV(3,2)	1	2	
WhlV(3,3)	2	1	
WhlV(3,4)	2	2	

### WhlAng – Wheel camber, caster, toe angles

array

Camber, caster, and toe angles at axle  $a$ , track  $t$ , in rad. Array dimensions are 3 by the total number of tracks on the vehicle.

- WhlAng(1, ...) – Camber angle
- WhlAng(2, ...) – Caster angle
- WhlAng(3, ...) – Toe angle

For example, for a two-axle vehicle with two tracks per axle, the WhlAng:

- Signal dimensions are [3x4].
- Signal contains wheel angles according to the axle and track locations.

$$\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix} = \begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$$

Array Element	Axle	Track	Angle
WhlAng(1,1)	1	1	Camber
WhlAng(1,2)	1	2	
WhlAng(1,3)	2	1	
WhlAng(1,4)	2	2	
WhlAng(2,1)	1	1	Caster
WhlAng(2,2)	1	2	
WhlAng(2,3)	2	1	
WhlAng(2,4)	2	2	
WhlAng(3,1)	1	1	Toe
WhlF(3,2)	1	2	

Array Element	Axle	Track	Angle
WhlF(3,3)	2	1	
WhlF(3,4)	2	2	

## Parameters

### Axles

#### Number of axles, NumAxl – Number of axles

2 (default) | scalar

Number of axles,  $N_a$ , dimensionless.

#### Number of tracks by axle, NumTracksByAxl – Number of tracks per axle

[2 2] (default) | vector

Number of tracks per axle,  $N_{t_a}$ , dimensionless. Vector is 1 by the number of vehicle axles,  $N_a$ . For example, [1, 2] represents one track on axle 1 and two tracks on axle 2.

#### Steered axle enable by axle, StrgEnByAxl – Boolean vector to enable axle steering

[1 0] (default) | vector

Boolean vector that enables axle steering,  $En_{steer}$ , dimensionless. Vector is 1 by the number of vehicle axles,  $N_a$ . For example:

- [1 0]—For a two-axle vehicle, enables axle 1 steering and disables axle 2 steering
- [1 1]—For a two-axle vehicle, enables axle 1 and axle 2 steering

### Dependencies

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1:

- Creates input port StrgAng.
- Creates these parameters
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

For example, for a two-axle vehicle with two tracks per axle, you can input steering angles for both wheels on the first axle.

- To create the StrgAng port, set **Steered axle enable by axle, StrgEnByAxl** to [1 0]. The input signal array dimensions are [1x2].
- The StrgAng signal contains two steering angles according to their axle and track locations.

$$\text{StrgAng} = \delta_{steer} = [\delta_{steer1,1} \quad \delta_{steer1,2}]$$



Array Element	Axle	Track
StrgAng(1,1)	1	1
StrgAng(1,2)	1	2

### Axle and wheels lumped principal moments of inertia about longitudinal axis, AxlIxx – Inertia

300 (default) | vector

Axle and wheels lumped principal moments of inertia about longitudinal axis, AxleIxx  $a$ , in  $\text{kg}\cdot\text{m}^2$ .

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

### Axle and wheels lumped mass, AxlM – Mass

[2 2] (default) | vector

Axle and wheels lumped mass,  $a$ , in kg.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

### Track hardpoint coordinates relative to axle center, TrackCoords – Point

[0 0 0 0; -1 1 -1 1; 0 0 0 0] (default) | array

Track hardpoint coordinates,  $T_{C_t}$ , along the solid axle  $x$ ,  $y$ , and  $z$ -axes, in m.

For example, for a two-axle vehicle with two tracks per axle, the TrackCoords array:

- Dimensions are [3x4].
- Contains four track hardpoint coordinates according to their axle and track locations.

$$T_{C_t} = \begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{w2,2} \\ z_{w1,1} & z_{w1,2} & z_{w2,1} & z_{w2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
TrackCoords(1,1)	1	1	Solid axle x-axis
TrackCoords(1,2)	1	2	
TrackCoords(1,3)	2	1	
TrackCoords(1,4)	2	2	
TrackCoords(2,1)	1	1	Solid axle y-axis
TrackCoords(2,2)	1	2	

Array Element	Axle	Track	Axis
TrackCoords(2, 3)	2	1	Solid axle z-axis
TrackCoords(2, 4)	2	2	
TrackCoords(3, 1)	1	1	
TrackCoords(3, 2)	1	2	
TrackCoords(3, 3)	2	1	
TrackCoords(3, 4)	2	2	

**Suspension hardpoint coordinates relative to axle center, SuspCoords – Point**  
`[0 0 0 0; -1 1 -1 1; 0 0 0 0]` (default) | array

Suspension hardpoint coordinates,  $Sc_t$ , along the solid axle x-, y-, and z-axes, in m.

For example, for a two-axle vehicle with two tracks per axle, the SuspCoords array:

- Dimensions are [3x4].
- Contains four track hardpoint coordinates according to their axle and track locations.

$$Sc_t = \begin{bmatrix} x_{s1,1} & x_{s1,2} & x_{s2,1} & x_{s2,2} \\ y_{s1,1} & y_{s1,2} & y_{s2,1} & y_{s2,2} \\ z_{s1,1} & z_{s1,2} & z_{s2,1} & z_{s2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
SuspCoords(1, 1)	1	1	Solid axle x-axis
SuspCoords(1, 2)	1	2	
SuspCoords(1, 3)	2	1	
SuspCoords(1, 4)	2	2	
SuspCoords(2, 1)	1	1	Solid axle y-axis
SuspCoords(2, 2)	1	2	
SuspCoords(2, 3)	2	1	
SuspCoords(2, 4)	2	2	

Array Element	Axle	Track	Axis
SuspCoords(3,1)	1	1	Solid axle z-axis
SuspCoords(3,2)	1	2	
SuspCoords(3,3)	2	1	
SuspCoords(3,4)	2	2	

**Wheel and axle interface compliance constant,  $K_{zWhlAxl}$  – Spring rate**  
6437000 (default) | scalar

Wheel and axle interface compliance constant,  $K_z$ , in N/m.

**Wheel and axle interface compliance preload,  $F_{0zWhlAxl}$  – Spring rate**  
9810 (default) | scalar

Wheel and axle interface compliance preload,  $F_{0z}$ , in N.

**Wheel and axle interface damping constant,  $C_{zWhlAxl}$  – Damping**  
10000 (default) | scalar

Wheel and axle interface damping constant,  $C_z$ , in m.

## Suspension

### Mapped

**Axle breakpoints,  $f\_susp\_axl\_bp$  – Breakpoints**  
[1 2] (default) | 1-by-P array

Axle breakpoints, dimensionless.

**Vertical axis suspension height breakpoints,  $f\_susp\_dz\_bp$  – Breakpoints**  
1-by-M array

Vertical axis suspension height breakpoints, in m.

**Vertical axis suspension height velocity breakpoints,  $f\_susp\_dzdot\_bp$  – Breakpoints**  
1-by-N array

Vertical axis suspension height velocity breakpoints, in m/s.

**Vertical axis suspension force and moment responses,  $f\_susp\_fmz$  – Output array**  
zeros(31,31,61,2,4) (default) | M-by-N-by-0-by-P-by-4 array

Array of output values as a function of:

- Vertical suspension height,  $M$
- Vertical suspension height velocity,  $N$

- Steering angle,  $O$
- Axle,  $P$
- 4 output types
  - 1 — Vertical force, in N·m
  - 2 — User-defined
  - 3 — Stored energy, in J
  - 4 — Absorbed power, in W

The array dimensions must match the breakpoint dimensions

## **Suspension geometry responses, `f_susp_geom` — Suspension geometry responses**

`zeros(31,61,2,3)` (default) | M-by-0-by-P-by-3 array

Array of geometric suspension values as a function of:

- Vertical suspension height,  $M$
- Steering angle,  $O$
- Axle,  $P$
- 3 output types
  - 1 — Camber angle, in rad
  - 2 — Caster angle, in rad
  - 3 — Toe angle, in rad

The array dimensions must match the breakpoint dimensions

## **Steering angle breakpoints, `f_susp_strgdelta_bp` — Steering angle breakpoints**

1-by-0 array

Steering angle breakpoints, in rad.

## **References**

- [1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers, 1992.
- [2] Vehicle Dynamics Standards Committee. *Vehicle Dynamics Terminology*. SAE J670. Warrendale, PA: Society of Automotive Engineers, 2008.
- [3] Technical Committee. *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*. ISO 8855:2011. Geneva, Switzerland: International Organization for Standardization, 2011.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

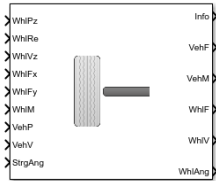
Solid Axle Suspension | Solid Axle Suspension - Coil Spring | Solid Axle Suspension - Leaf Spring

**Introduced in R2018a**

# Solid Axle Suspension

Solid axle suspension for multiple axles

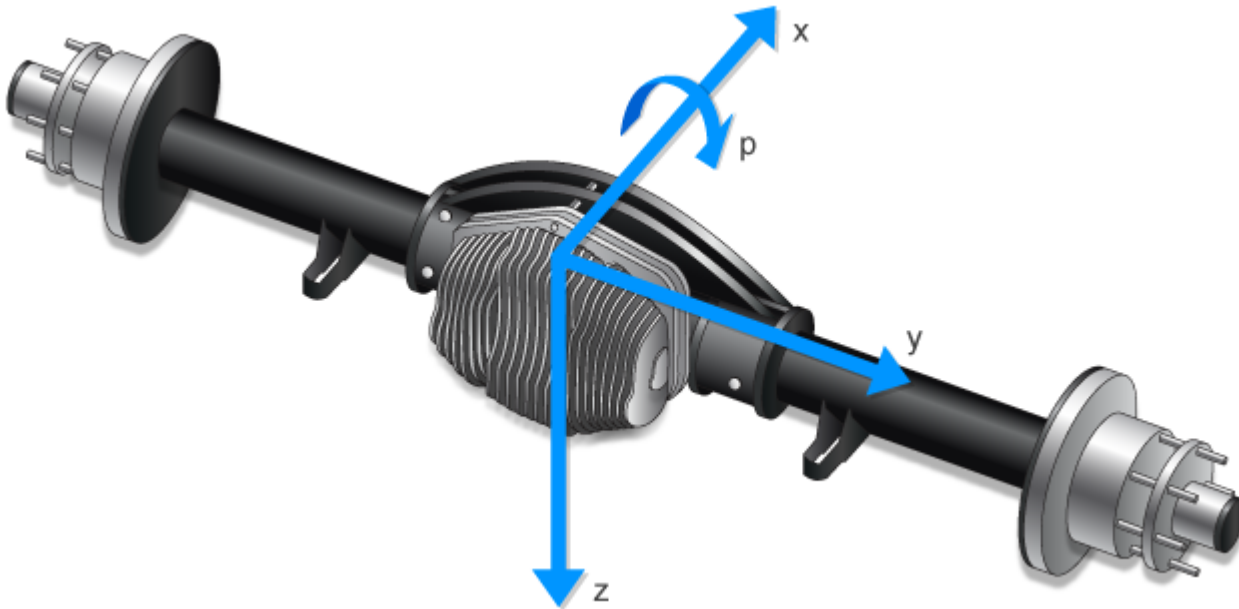
**Library:** Vehicle Dynamics Blockset / Suspension



## Description

The Solid Axle Suspension block implements a solid axle suspension for multiple axles with multiple tracks per axle.

The block models the suspension compliance, damping, and geometric effects as functions of the track positions and velocities, with axle-specific compliance and damping parameters. Using the track position and velocity, the block calculates the vertical track position and suspension forces on the vehicle and wheel. The block uses the Z-down (defined in SAE J670) and a solid axle coordinate system. The solid axle coordinate system, shown here, is aligned with the Z-down vehicle coordinate system, with the x-axis in the direction of forward vehicle motion.



For Each	You Can Specify
Axle	<ul style="list-style-type: none"> <li>• Multiple tracks.</li> <li>• Suspension parameters.</li> </ul>
Track	<ul style="list-style-type: none"> <li>• Steering angles.</li> </ul>

The block contains energy-storing spring elements and energy-dissipating damper elements. The block also stores energy via the axle roll angular acceleration and axle center of mass vertical and lateral acceleration.

This table summarizes the block parameter settings for a vehicle with:

- Two axles.
- Two tracks per axle.
- Steering angle input for both tracks on the front axle.

Parameter	Setting
Number of axles, NumAxl	2
Number of tracks by axle, NumTracksByAxl	[2 2]
Steered axle enable by axle, StrgEnByAxl	[1 0]

### Suspension Compliance and Damping

The block uses a linear spring and damper to model the vertical dynamic effects of the suspension system on the vehicle and wheel. Specifically, the block:

Uses	To Calculate
<ul style="list-style-type: none"> <li>• Longitudinal and lateral displacement and velocity of the vehicle.</li> <li>• Longitudinal and lateral displacement and velocity of the track.</li> <li>• Vertical wheel forces applied to the vehicle.</li> </ul>	<ul style="list-style-type: none"> <li>• Suspension forces applied to the axle center.</li> <li>• Vertical displacements and velocities of the vehicle and track.</li> <li>• Longitudinal, lateral and vertical suspension forces and moments applied to the vehicle.</li> <li>• Longitudinal, lateral and vertical suspension forces and moments applied to the wheel.</li> </ul>

To calculate the dynamics of the axle, the block implements these equations. The block neglects the effects of:

- Lateral and longitudinal translational velocity.
- Angular velocity about the vertical and lateral axes.

$$\begin{bmatrix} \ddot{x}_a \\ \ddot{y}_a \\ \ddot{z}_a \end{bmatrix} = \frac{1}{M_a} \begin{bmatrix} F_{xa} \\ F_{ya} \\ F_{za} \end{bmatrix} + \begin{bmatrix} \dot{x}_a \\ \dot{y}_a \\ \dot{z}_a \end{bmatrix} \times \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \frac{1}{M_a} \begin{bmatrix} 0 \\ 0 \\ F_{za} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{z}_a \end{bmatrix} \times \begin{bmatrix} p \\ q \\ r \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix} = \begin{bmatrix} 0 \\ p\dot{z}_a \\ \frac{F_{za}}{M_a} + g \end{bmatrix}$$

$$\begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix} - \begin{bmatrix} p \\ q \\ r \end{bmatrix} \times \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}^{-1}$$

$$= \begin{bmatrix} M_x \\ 0 \\ 0 \end{bmatrix} - \begin{bmatrix} p \\ q \\ 0 \end{bmatrix} \times \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} p \\ q \\ 0 \end{bmatrix} \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}^{-1} = \begin{bmatrix} \frac{M_x}{I_{xx}} \\ 0 \\ 0 \end{bmatrix}$$

The net vertical force on the axle center of mass is the sum of the wheel and suspension forces acting on the axle.

$$F_{za} = \sum_{t=1}^{Nta} \left( F_{wz_{a,t}} + F_{z0_a} + k_{z_a} (z_{v_{a,t}} - z_{s_{a,t}} + m_{hsteer_a} |\delta_{steer_{a,t}}|) + c_{z_a} (\dot{z}_{v_{a,t}} - \dot{z}_{s_{a,t}}) \right)$$

The net moment about the roll axis of the solid axle suspension accounts for the hardpoint coordinates of the suspension and tracks.

$$M_x = \sum_{t=1}^{Nta} \left( F_{wz_{a,t}} y_{w_t} + (F_{z0_a} + k_{z_a} (z_{v_{a,t}} - z_{s_{a,t}} + m_{hsteer_a} |\delta_{steer_{a,t}}|) + c_{z_a} (\dot{z}_{v_{a,t}} - \dot{z}_{s_{a,t}})) y_{s_t} \right) + M_{wx_{a,t}} \frac{I_{xx}}{I_{xx} + M_a y_{w_t}^2}$$

Block parameters provide the track and suspension hardpoints coordinates.

$$TC_t = \begin{bmatrix} x_{w1} & x_{w2} & \dots \\ y_{w1} & y_{w2} & \dots \\ z_{w1} & z_{w2} & \dots \end{bmatrix}$$

$$SC_t = \begin{bmatrix} x_{s1} & x_{s2} & \dots \\ y_{s1} & y_{s2} & \dots \\ z_{s1} & z_{s2} & \dots \end{bmatrix}$$

The block uses Euler angles to transform the track and suspension displacements, velocities, and accelerations to the vehicle coordinate system.

To calculate the suspension forces applied to the vehicle, the block implements this equation.

$$F_{vz_{a,t}} = - \left( F_{z0_a} + k_{z_a} (z_{v_{a,t}} - z_{s_{a,t}} + m_{hsteer_a} |\delta_{steer_{a,t}}|) + c_{z_a} (\dot{z}_{v_{a,t}} - \dot{z}_{s_{a,t}}) + F_{zhstop_{a,t}} \right)$$

The suspension forces and moments applied to the vehicle are equal to the suspension forces and moments applied to the wheel.

$$F_{vx_{a,t}} = F_{wx_{a,t}}$$

$$F_{vy_{a,t}} = F_{wy_{a,t}}$$

$$F_{vz_{a,t}} = - F_{wz_{a,t}}$$

$$M_{vx_{a,t}} = M_{wx_{a,t}} + F_{wy_{a,t}} (Re_{wy_{a,t}} + H_{a,t})$$

$$M_{vy_{a,t}} = M_{wy_{a,t}} + F_{wx_{a,t}} (Re_{wx_{a,t}} + H_{a,t})$$

$$M_{vz_{a,t}} = M_{wz_{a,t}}$$

To calculate the vertical force applied to the suspension at the track location, the block implements a stiff spring-damper.

$$F_{wz_{a,t}} = - F_{wa_{z0}} - k_{wa_z} (z_{w_{a,t}} - z_{s_{a,t}}) - c_{wa_z} (\dot{z}_{w_{a,t}} - \dot{z}_{s_{a,t}})$$



The equations use these variables.

$F_{wz_{a,t}}, M_{wz_{a,t}}$	Suspension force and moment applied to the wheel on axle $a$ , track $t$ along wheel-fixed $z$ -axis
$F_{wx_{a,t}}, M_{wx_{a,t}}$	Suspension force and moment applied to the wheel on axle $a$ , track $t$ along wheel-fixed $x$ -axis
$F_{wy_{a,t}}, M_{wy_{a,t}}$	Suspension force and moment applied to the wheel on axle $a$ , track $t$ along wheel-fixed $y$ -axis
$F_{vz_{a,t}}, M_{vz_{a,t}}$	Suspension force and moment applied to the vehicle on axle $a$ , track $t$ along wheel-fixed $z$ -axis
$F_{vx_{a,t}}, M_{vx_{a,t}}$	Suspension force and moment applied to the vehicle on axle $a$ , track $t$ along wheel-fixed $x$ -axis
$F_{vy_{a,t}}, M_{vy_{a,t}}$	Suspension force and moment applied to the vehicle on axle $a$ , track $t$ along wheel-fixed $y$ -axis
$F_{z0_a}$	Vertical suspension spring preload force applied to the wheels on axle $a$
$k_{z_a}$	Vertical spring constant applied to tracks on axle $a$
$m_{hsteer_a}$	Steering angle to vertical force slope applied at wheel carrier for tracks on axle $a$
$\delta_{steer_{a,t}}$	Steering angle input for axle $a$ , track $t$
$c_{z_a}$	Vertical damping constant applied to tracks on axle $a$
$Re_{w_{a,t}}$	Effective wheel radius for axle $a$ , track $t$
$F_{zhstop_{a,t}}$	Vertical hardstop force at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis
$F_{zaswy_{a,t}}$	Vertical anti-sway force at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis
$x_{v_{a,t}}, \dot{x}_{v_{a,t}}$	Vehicle displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $x$ -axis
$x_{w_{a,t}}, \dot{x}_{w_{a,t}}$	Track displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $x$ -axis
$y_{v_{a,t}}, \dot{y}_{v_{a,t}}$	Vehicle displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $y$ -axis
$y_{w_{a,t}}, \dot{y}_{w_{a,t}}$	Track displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $y$ -axis
$H_{a,t}$	Suspension height at axle $a$ , track $t$
$Re_{w_{a,t}}$	Effective wheel radius at axle $a$ , track $t$

### Hardstop Forces

The hardstop feedback force,  $F_{zhstop_{a,t}}$ , that the block applies depends on whether the suspension is compressing or extending. The block applies the force:

- In compression, when the suspension is compressed more than the maximum distance specified by the **Suspension maximum height, Hmax** parameter.
- In extension, when the suspension extension is greater than maximum extension specified by the **Suspension maximum height, Hmax** parameter.

To calculate the force, the block uses a stiffness based on a hyperbolic tangent and exponential scaling.

### Camber, Caster, and Toe Angles

To calculate the camber, caster, and toe angles, block uses linear functions of the suspension height and steering angle.

$$\begin{aligned}\xi_{a,t} &= \xi_{0a} + m_{hcamber_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{cambersteer_a}|\delta_{steer_{a,t}}| \\ \eta_{a,t} &= \eta_{0a} + m_{hcaster_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{castersteer_a}|\delta_{steer_{a,t}}| \\ \zeta_{a,t} &= \zeta_{0a} + m_{htoe_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{toesteer_a}|\delta_{steer_{a,t}}|\end{aligned}$$

The equations use these variables.

$\xi_{a,t}$	Camber angle of wheel on axle <b>a</b> , track <b>t</b>
$\eta_{a,t}$	Caster angle of wheel on axle <b>a</b> , track <b>t</b>
$\zeta_{a,t}$	Toe angle of wheel on axle <b>a</b> , track <b>t</b>
$\xi_{0a}, \eta_{0a}, \zeta_{0a}$	Nominal suspension axle <b>a</b> camber, caster, and toe angles, respectively, at zero steering angle
$m_{hcamber_a}, m_{hcaster_a}, m_{htoe_a}$	Camber, caster, and toe angles, respectively, versus suspension height slope for axle <b>a</b>
$m_{cambersteer_a}, m_{castersteer_a}, m_{toesteer_a}$	Camber, caster, and toe angles, respectively, versus steering angle slope for axle <b>a</b>
$m_{hsteer_a}$	Steering angle versus vertical force slope for axle <b>a</b>
$\delta_{steer_{a,t}}$	Steering angle input for axle <b>a</b> , track <b>t</b>
$z_{v_{a,t}}$	Vehicle displacement at axle <b>a</b> , track <b>t</b> , along the vehicle-fixed <i>z</i> -axis
$z_{w_{a,t}}$	Track displacement at axle <b>a</b> , track <b>t</b> , along the vehicle-fixed <i>z</i> -axis

### Steering Angles

Optionally, you can input steering angles for the tracks. To calculate the steering angles for the wheels, the block offsets the input steering angles with a linear function of the suspension height.

$$\delta_{whlsteer_{a,t}} = \delta_{steer_{a,t}} + m_{htoe_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{toesteer_a}|\delta_{steer_{a,t}}|$$

The equation uses these variables.

$m_{toesteer_a}$	Axle <b>a</b> toe angle versus steering angle slope
$m_{hsteer_a}$	Axle <b>a</b> steering angle versus vertical force slope
$m_{htoe_a}$	Axle <b>a</b> toe angle versus suspension height slope
$\delta_{whlsteer_{a,t}}$	Wheel steering angle for axle <b>a</b> , track <b>t</b>
$\delta_{steer_{a,t}}$	Steering angle input for axle <b>a</b> , track <b>t</b>
$z_{v_{a,t}}$	Vehicle displacement at axle <b>a</b> , track <b>t</b> , along the vehicle-fixed <i>z</i> -axis
$z_{w_{a,t}}$	Track displacement at axle <b>a</b> , track <b>t</b> , along the vehicle-fixed <i>z</i> -axis

### Power and Energy

The block calculates these suspension characteristics for each axle, **a**, track, **t**.

Calculation	Equation
Dissipated power, $P_{susp_{a,t}}$	$P_{susp_{a,t}} = F_{wzlookup_a}(\dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$
Absorbed energy, $E_{susp_{a,t}}$	$E_{susp_{a,t}} = F_{wzlookup_a}(z_{v_{a,t}} - z_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$
Suspension height, $H_{a,t}$	$H_{a,t} = -\left(z_{v_{a,t}} - z_{w_{a,t}} + \frac{F_{z0_a}}{k_{z_a}} + m_{hsteer_a} \delta_{steer_{a,t}} \right)$
Distance from wheel carrier center to tire/road interface	$z_{wtr_{a,t}} = Re_{w_{a,t}} + H_{a,t}$

The equations use these variables.

$m_{hsteer_a}$	Steering angle to vertical force slope applied at wheel carrier for tracks on axle a
$\delta_{steer_{a,t}}$	Steering angle input for axle a, track t
$Re_{w_{a,t}}$	Axle a, track t effective wheel radius from wheel carrier center to tire/road interface
$F_{z0_a}$	Vertical suspension spring preload force applied to the wheels on axle a
$z_{wtr_{a,t}}$	Distance from wheel carrier center to tire/road interface, along the vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along the vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along the vehicle-fixed z-axis

## Ports

### Input

#### WhlPz — Track z-axis displacement

array

Track displacement,  $z_w$ , along wheel-fixed z-axis, in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlPz:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlPz} = z_w = [z_{w1,1} \ z_{w1,2} \ z_{w2,1} \ z_{w2,2}]$$

Array Element	Axle	Track
WhlPz(1,1)	1	1
WhlPz(1,2)	1	2
WhlPz(1,3)	2	1
WhlPz(1,4)	2	2

#### WhlRe — Wheel effective radius

array

Effective wheel radius,  $Re_w$ , in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlRe:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlRe} = Re_w = [Re_{w1,1} \quad Re_{w1,2} \quad Re_{w2,1} \quad Re_{w2,2}]$$

Array Element	Axle	Track
WhlRe(1,1)	1	1
WhlRe(1,2)	1	2
WhlRe(1,3)	2	1
WhlRe(1,4)	2	2

**WhlVz — Track z-axis velocity**

array

Track velocity,  $\dot{z}_w$ , along wheel-fixed z-axis, in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlVz:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlVz} = \dot{z}_w = [\dot{z}_{w1,1} \quad \dot{z}_{w1,2} \quad \dot{z}_{w2,1} \quad \dot{z}_{w2,2}]$$

Array Element	Axle	Track
WhlVz(1,1)	1	1
WhlVz(1,2)	1	2
WhlVz(1,3)	2	1
WhlVz(1,4)	2	2

**WhlFx — Longitudinal wheel force on vehicle**

array

Longitudinal wheel force applied to vehicle,  $F_{wx}$ , along the vehicle-fixed x-axis. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlFx:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlFx} = F_{wx} = [F_{wx1,1} \quad F_{wx1,2} \quad F_{wx2,1} \quad F_{wx2,2}]$$

Array Element	Axle	Track
WhlFx(1,1)	1	1
WhlFx(1,2)	1	2
WhlFx(1,3)	2	1
WhlFx(1,4)	2	2

### WhlFy – Lateral wheel force on vehicle

array

Lateral wheel force applied to vehicle,  $F_{wy}$ , along the vehicle-fixed y-axis. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlFy:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlFy} = F_{wy} = [F_{wy1,1} \ F_{wy1,2} \ F_{wy2,1} \ F_{wy2,2}]$$

Array Element	Axle	Track
WhlFy(1,1)	1	1
WhlFy(1,2)	1	2
WhlFy(1,3)	2	1
WhlFy(1,4)	2	2

### WhlM – Suspension moment on wheel

array

Longitudinal, lateral, and vertical suspension moments at axle  $a$ , track  $t$ , applied to the wheel at the axle wheel carrier reference coordinate, in N·m. Array dimensions are 3 by the total number of tracks on the vehicle.

- WhlM(1, . . .) – Suspension moment applied to the wheel about the vehicle-fixed x-axis (longitudinal)
- WhlM(2, . . .) – Suspension moment applied to the wheel about the vehicle-fixed y-axis (lateral)
- WhlM(3, . . .) – Suspension moment applied to the wheel about the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the WhlM:

- Signal dimensions are [3x4].
- Signal contains suspension moments applied to four wheels according to their axle and track locations.

$$\text{WhlM} = M_w = \begin{bmatrix} M_{wx1,1} & M_{wx1,2} & M_{wx2,1} & M_{wx2,2} \\ M_{wy1,1} & M_{wy1,2} & M_{wy2,1} & M_{wy2,2} \\ M_{wz1,1} & M_{wz1,2} & M_{wz2,1} & M_{wz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Moment Axis
WhlM(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
WhlM(1,2)	1	2	
WhlM(1,3)	2	1	
WhlM(1,4)	2	2	
WhlM(2,1)	1	1	Vehicle-fixed y-axis (lateral)
WhlM(2,2)	1	2	
WhlM(2,3)	2	1	
WhlM(2,4)	2	2	
WhlM(3,1)	1	1	Vehicle-fixed z-axis (vertical)
WhlM(3,2)	1	2	
WhlM(3,3)	2	1	
WhlM(3,4)	2	2	

**VehP – Vehicle displacement**

array

Vehicle displacement from axle *a*, track *t* along vehicle-fixed coordinate system, in m. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehP(1, . . .) – Vehicle displacement from track,  $x_v$ , along the vehicle-fixed x-axis
- VehP(2, . . .) – Vehicle displacement from track,  $y_v$ , along the vehicle-fixed y-axis
- VehP(3, . . .) – Vehicle displacement from track,  $z_v$ , along the vehicle-fixed z-axis

For example, for a two-axle vehicle with two tracks per axle, the VehP:

- Signal dimensions are [3x4].
- Signal contains four track displacements according to their axle and track locations.

$$\text{VehP} = \begin{bmatrix} x_v \\ y_v \\ z_v \end{bmatrix} = \begin{bmatrix} x_{v1,1} & x_{v1,2} & x_{v2,1} & x_{v2,2} \\ y_{v1,1} & y_{v1,2} & y_{v2,1} & y_{v2,2} \\ z_{v1,1} & z_{v1,2} & z_{v2,1} & z_{v2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
VehP(1,1)	1	1	Vehicle-fixed x-axis
VehP(1,2)	1	2	
VehP(1,3)	2	1	
VehP(1,4)	2	2	
VehP(2,1)	1	1	Vehicle-fixed y-axis
VehP(2,2)	1	2	
VehP(2,3)	2	1	
VehP(2,4)	2	2	

Array Element	Axle	Track	Axis
VehP(3,1)	1	1	Vehicle-fixed z-axis
VehP(3,2)	1	2	
VehP(3,3)	2	1	
VehP(3,4)	2	2	

**VehV – Vehicle velocity**

array

Vehicle velocity at axle *a*, track *t* along vehicle-fixed coordinate system, in m. Input array dimensions are 3 by *a*\**t*.

- VehV(1, . . . ) – Vehicle velocity at track,  $x_v$ , along the vehicle-fixed x-axis
- VehV(2, . . . ) – Vehicle velocity at track,  $y_v$ , along the vehicle-fixed y-axis
- VehV(3, . . . ) – Vehicle velocity at track,  $z_v$ , along the vehicle-fixed z-axis

For example, for a two-axle vehicle with two tracks per axle, the VehV:

- Signal dimensions are [3x4].
- Signal contains 4 track velocities according to their axle and track locations.

$$\text{VehV} = \begin{bmatrix} \dot{x}_v \\ \dot{y}_v \\ \dot{z}_v \end{bmatrix} = \begin{bmatrix} \dot{x}_{v1,1} & \dot{x}_{v1,2} & \dot{x}_{v2,1} & \dot{x}_{v2,2} \\ \dot{y}_{v1,1} & \dot{y}_{v1,2} & \dot{y}_{v2,1} & \dot{y}_{v2,2} \\ \dot{z}_{v1,1} & \dot{z}_{v1,2} & \dot{z}_{v2,1} & \dot{z}_{v2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
VehV(1,1)	1	1	Vehicle-fixed x-axis
VehV(1,2)	1	2	
VehV(1,3)	2	1	
VehV(1,4)	2	2	
VehV(2,1)	1	1	Vehicle-fixed y-axis
VehV(2,2)	1	2	
VehV(2,3)	2	1	
VehV(2,4)	2	2	
VehV(3,1)	1	1	Vehicle-fixed z-axis
VehV(3,2)	1	2	
VehV(3,3)	2	1	
VehV(3,4)	2	2	

**StrgAng – Steering angle, optional**

array

Optional steering angle for each wheel,  $\delta$ . Input array dimensions are 1 by the number of steered tracks.

For example, for a two-axle vehicle with two tracks per axle, you can input steering angles for both wheels on the first axle.

- To create the `StrgAng` port, set **Steered axle enable by axle, `StrgEnByAxl`** to `[1 0]`. The input signal array dimensions are `[1x2]`.
- The `StrgAng` signal contains two steering angles according to their axle and track locations.

$$\text{StrgAng} = \delta_{steer} = [\delta_{steer1,1} \ \delta_{steer1,2}]$$

Array Element	Axle	Track
<code>StrgAng(1,1)</code>	1	1
<code>StrgAng(1,2)</code>	1	2

**Dependencies**

Setting an element of the **Steered axle enable by axle, `StrgEnByAxl`** vector to 1 creates:

- Input port `StrgAng`.
- Parameters:
  - **Toe angle vs steering angle slope, `ToeStrgSlp`**
  - **Caster angle vs steering angle slope, `CasterStrgSlp`**
  - **Camber angle vs steering angle slope, `CamberStrgSlp`**
  - **Suspension height vs steering angle slope, `StrgHgtSlp`**

**Output**

**Info — Bus signal**

bus

Bus signal containing block values. The signals are arrays that depend on the track location.

For example, here are the indices for a two-axle, two-track vehicle. The total number of tracks is four.

- 1D array signal (1-by-4)

Array Element	Axle	Track
<code>(1,1)</code>	1	1
<code>(1,2)</code>	1	2
<code>(1,3)</code>	2	1
<code>(1,4)</code>	2	2

- 3D array signal (3-by-4)

Array Element	Axle	Track
<code>(1,1)</code>	1	1
<code>(1,2)</code>	1	2
<code>(1,3)</code>	2	1
<code>(1,4)</code>	2	2



Array Element	Axle	Track
(2,1)	1	1
(2,2)	1	2
(2,3)	2	1
(2,4)	2	2
(3,1)	1	1
(3,2)	1	2
(3,3)	2	1
(3,4)	2	2

Signal	Description	Array Signal	Variable	Units
Camber	Wheel angles according to the axle.	1D	$WhlAng[1, \dots] = \xi = [\xi_{a,t}]$	rad
Caster			$WhlAng[2, \dots] = \eta = [\eta_{a,t}]$	
Toe			$WhlAng[3, \dots] = \zeta = [\zeta_{a,t}]$	
Height	Suspension height	1D	$H$	m
Power	Suspension power dissipation	1D	$P_{susp}$	W
Energy	Suspension absorbed energy	1D	$E_{susp}$	J
VehF	Suspension forces applied to the vehicle	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $VehF = F_v = \begin{bmatrix} F_{vx1,1} & F_{vx1,2} & F_{vx2,1} & F_{vx2,2} \\ F_{vy1,1} & F_{vy1,2} & F_{vy2,1} & F_{vy2,2} \\ F_{vz1,1} & F_{vz1,2} & F_{vz2,1} & F_{vz2,2} \end{bmatrix}$	N

Signal	Description	Array Signal	Variable	Units
VehM	Suspension moments applied to vehicle	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{VehM} = M_v =$ $\begin{bmatrix} M_{vx1,1} & M_{vx1,2} & M_{vx2,1} & M_{vx2,2} \\ M_{vy1,1} & M_{vy1,2} & M_{vy2,1} & M_{vy2,2} \\ M_{vz1,1} & M_{vz1,2} & M_{vz2,1} & M_{vz2,2} \end{bmatrix}$	N·m
WhlF	Suspension force applied to wheel	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlF} = F_w =$ $\begin{bmatrix} F_{wx1,1} & F_{wx1,2} & F_{wx2,1} & F_{wx2,2} \\ F_{wy1,1} & F_{wy1,2} & F_{wy2,1} & F_{wy2,2} \\ F_{wz1,1} & F_{wz1,2} & F_{wz2,1} & F_{wz2,2} \end{bmatrix}$	N
WhlP	Track displacement	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlP} = \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix} =$ $\begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{w2,2} \\ z_{wtr1,1} & z_{wtr1,2} & z_{wtr2,1} & z_{wtr2,2} \end{bmatrix}$	m

Signal	Description	Array Signal	Variable	Units
WhlV	Track velocity	3D	For a two-axle, two tracks per axle vehicle:  $\text{WhlV} = \begin{bmatrix} \dot{x}_w \\ \dot{y}_w \\ \dot{z}_w \end{bmatrix}$  =  $\begin{bmatrix} \dot{x}_{w1,1} & \dot{x}_{w1,2} & \dot{x}_{w2,1} & \dot{x}_{w2,2} \\ \dot{y}_{w1,1} & \dot{y}_{w1,2} & \dot{y}_{w2,1} & \dot{y}_{w2,2} \\ \dot{z}_{w1,1} & \dot{z}_{w1,2} & \dot{z}_{w2,1} & \dot{z}_{w2,2} \end{bmatrix}$	m/s
WhlAng	Wheel camber, caster, toe angles	3D	For a two-axle, two tracks per axle vehicle:  $\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix}$  =  $\begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$	rad

### VehF — Suspension force on vehicle

array

Longitudinal, lateral, and vertical suspension force at axle *a*, track *t*, applied to the vehicle at the suspension connection point, in N. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehF(1, . . .) — Suspension force applied to vehicle along the vehicle-fixed x-axis (longitudinal)
- VehF(2, . . .) — Suspension force applied to vehicle along the vehicle-fixed y-axis (lateral)
- VehF(3, . . .) — Suspension force applied to vehicle along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the VehF:

- Signal dimensions are [3x4].
- Signal contains suspension forces applied to the vehicle according to the axle and track locations.

$$\text{VehF} = F_v = \begin{bmatrix} F_{vx1,1} & F_{vx1,2} & F_{vx2,1} & F_{vx2,2} \\ F_{vy1,1} & F_{vy1,2} & F_{vy2,1} & F_{vy2,2} \\ F_{vz1,1} & F_{vz1,2} & F_{vz2,1} & F_{vz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
VehF(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
VehF(1,2)	1	2	
VehF(1,3)	2	1	
VehF(1,4)	2	2	
VehF(2,1)	1	1	Vehicle-fixed y-axis (lateral)
VehF(2,2)	1	2	
VehF(2,3)	2	1	
VehF(2,4)	2	2	
VehF(3,1)	1	1	Vehicle-fixed z-axis (vertical)
VehF(3,2)	1	2	
VehF(3,3)	2	1	
VehF(3,4)	2	2	

**VehM – Suspension moment on vehicle**

array

Longitudinal, lateral, and vertical suspension moment at axle *a*, track *t*, applied to the vehicle at the suspension connection point, in N·m. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehM(1, . . . ) – Suspension moment applied to the vehicle about the vehicle-fixed x-axis (longitudinal)
- VehM(2, . . . ) – Suspension moment applied to the vehicle about the vehicle-fixed y-axis (lateral)
- VehM(3, . . . ) – Suspension moment applied to the vehicle about the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the VehM:

- Signal dimensions are [3x4].
- Signal contains suspension moments applied to vehicle according to the axle and track locations.

$$VehM = M_v = \begin{bmatrix} M_{vx1,1} & M_{vx1,2} & M_{vx2,1} & M_{vx2,2} \\ M_{vy1,1} & M_{vy1,2} & M_{vy2,1} & M_{vy2,2} \\ M_{vz1,1} & M_{vz1,2} & M_{vz2,1} & M_{vz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Moment Axis
VehM(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
VehM(1,2)	1	2	
VehM(1,3)	2	1	
VehM(1,4)	2	2	
VehM(2,1)	1	1	Vehicle-fixed y-axis (lateral)
VehM(2,2)	1	2	

Array Element	Axle	Track	Moment Axis
VehM(2,3)	2	1	Vehicle-fixed z-axis (vertical)
VehM(2,4)	2	2	
VehM(3,1)	1	1	
VehM(3,2)	1	2	
VehM(3,3)	2	1	
VehM(3,4)	2	2	

### WhlF – Suspension force on wheel

array

Longitudinal, lateral, and vertical suspension forces at axle **a**, track **t**, applied to the wheel at the axle wheel carrier reference coordinate, in N. Array dimensions are 3 by the total number of tracks on the vehicle.

- WhlF(1, . . .) – Suspension force on wheel along the vehicle-fixed x-axis (longitudinal)
- WhlF(2, . . .) – Suspension force on wheel along the vehicle-fixed y-axis (lateral)
- WhlF(3, . . .) – Suspension force on wheel along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the WhlF:

- Signal dimensions are [3x4].
- Signal contains wheel forces applied to the vehicle according to the axle and track locations.

$$\text{WhlF} = F_w = \begin{bmatrix} F_{wx1,1} & F_{wx1,2} & F_{wx2,1} & F_{wx2,2} \\ F_{wy1,1} & F_{wy1,2} & F_{wy2,1} & F_{wy2,2} \\ F_{wz1,1} & F_{wz1,2} & F_{wz2,1} & F_{wz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
WhlF(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
WhlF(1,2)	1	2	
WhlF(1,3)	2	1	
WhlF(1,4)	2	2	
WhlF(2,1)	1	1	Vehicle-fixed y-axis (lateral)
WhlF(2,2)	1	2	
WhlF(2,3)	2	1	
WhlF(2,4)	2	2	
WhlF(3,1)	1	1	Vehicle-fixed z-axis (vertical)
WhlF(3,2)	1	2	
WhlF(3,3)	2	1	
WhlF(3,4)	2	2	

### WhlV – Track velocity

array

Longitudinal, lateral, and vertical track velocity at axle *a*, track *t*, in m/s. Array dimensions are 3 by the total number of tracks on the vehicle.

- $WhlV(1, \dots)$  — Track velocity along the vehicle-fixed x-axis (longitudinal)
- $WhlV(2, \dots)$  — Track velocity along the vehicle-fixed y-axis (lateral)
- $WhlV(3, \dots)$  — Track velocity along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the  $WhlV$ :

- Signal dimensions are [3x4].
- Signal contains wheel forces applied to the vehicle according to the axle and track locations.

$$WhlV = \begin{bmatrix} \dot{x}_w \\ \dot{y}_w \\ \dot{z}_w \end{bmatrix} = \begin{bmatrix} \dot{x}_{w1,1} & \dot{x}_{w1,2} & \dot{x}_{w2,1} & \dot{x}_{w2,2} \\ \dot{y}_{w1,1} & \dot{y}_{w1,2} & \dot{y}_{w2,1} & \dot{y}_{w2,2} \\ \dot{z}_{w1,1} & \dot{z}_{w1,2} & \dot{z}_{w2,1} & \dot{z}_{w2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
$WhlV(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$WhlV(1,2)$	1	2	
$WhlV(1,3)$	2	1	
$WhlV(1,4)$	2	2	
$WhlV(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$WhlV(2,2)$	1	2	
$WhlV(2,3)$	2	1	
$WhlV(2,4)$	2	2	
$WhlV(3,1)$	1	1	Vehicle-fixed z-axis (vertical)
$WhlV(3,2)$	1	2	
$WhlV(3,3)$	2	1	
$WhlV(3,4)$	2	2	

**WhlAng — Wheel camber, caster, toe angles**

array

Camber, caster, and toe angles at axle *a*, track *t*, in rad. Array dimensions are 3 by the total number of tracks on the vehicle.

- $WhlAng(1, \dots)$  — Camber angle
- $WhlAng(2, \dots)$  — Caster angle
- $WhlAng(3, \dots)$  — Toe angle

For example, for a two-axle vehicle with two tracks per axle, the  $WhlAng$ :

- Signal dimensions are [3x4].
- Signal contains wheel angles according to the axle and track locations.

$$\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix} = \begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$$

Array Element	Axle	Track	Angle
WhlAng(1,1)	1	1	Camber
WhlAng(1,2)	1	2	
WhlAng(1,3)	2	1	
WhlAng(1,4)	2	2	
WhlAng(2,1)	1	1	Caster
WhlAng(2,2)	1	2	
WhlAng(2,3)	2	1	
WhlAng(2,4)	2	2	
WhlAng(3,1)	1	1	Toe
WhlF(3,2)	1	2	
WhlF(3,3)	2	1	
WhlF(3,4)	2	2	

## Parameters

### Axles

#### Number of axles, NumAxl — Number of axles

2 (default) | scalar

Number of axles,  $N_a$ , dimensionless.

#### Number of tracks by axle, NumTracksByAxl — Number of tracks per axle

[2 2] (default) | vector

Number of tracks per axle,  $N_{t_a}$ , dimensionless. Vector is 1 by the number of vehicle axles,  $N_a$ . For example, [1, 2] represents one track on axle 1 and two tracks on axle 2.

#### Steered axle enable by axle, StrgEnByAxl — Boolean vector to enable axle steering

[1 0] (default) | vector

Boolean vector that enables axle steering,  $En_{steer}$ , dimensionless. Vector is 1 by the number of vehicle axles,  $N_a$ . For example:

- [1 0]—For a two-axle vehicle, enables axle 1 steering and disables axle 2 steering
- [1 1]—For a two-axle vehicle, enables axle 1 and axle 2 steering

### Dependencies

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1:

- Creates input port StrgAng.

- Creates these parameters
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

For example, for a two-axle vehicle with two tracks per axle, you can input steering angles for both wheels on the first axle.

- To create the StrgAng port, set **Steered axle enable by axle, StrgEnByAxl** to [1 0]. The input signal array dimensions are [1x2].
- The StrgAng signal contains two steering angles according to their axle and track locations.

$$\text{StrgAng} = \delta_{steer} = [\delta_{steer1,1} \ \delta_{steer1,2}]$$

Array Element	Axle	Track
StrgAng(1,1)	1	1
StrgAng(1,2)	1	2

**Axle and wheels lumped principal moments of inertia about longitudinal axis, AxlIxx – Inertia**

300 (default) | vector

Axle and wheels lumped principal moments of inertia about longitudinal axis, AxleIxx  $a$ , in kg\*m<sup>2</sup>.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Axle and wheels lumped mass, AxlM – Mass**

[2 2] (default) | vector

Axle and wheels lumped mass,  $a$ , in kg.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Track hardpoint coordinates relative to axle center, TrackCoords – Point**

[0 0 0 0; -1 1 -1 1; 0 0 0 0] (default) | array

Track hardpoint coordinates,  $Tc_t$ , along the solid axle x, y, and z-axes, in m.

For example, for a two-axle vehicle with two tracks per axle, the TrackCoords array:

- Dimensions are [3x4].
- Contains four track hardpoint coordinates according to their axle and track locations.

$$Tc_t = \begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{w2,2} \\ z_{w1,1} & z_{w1,2} & z_{w2,1} & z_{w2,2} \end{bmatrix}$$



Array Element	Axle	Track	Axis
TrackCoords (1, 1)	1	1	Solid axle x-axis
TrackCoords (1, 2)	1	2	
TrackCoords (1, 3)	2	1	
TrackCoords (1, 4)	2	2	
TrackCoords (2, 1)	1	1	Solid axle y-axis
TrackCoords (2, 2)	1	2	
TrackCoords (2, 3)	2	1	
TrackCoords (2, 4)	2	2	
TrackCoords (3, 1)	1	1	Solid axle z-axis
TrackCoords (3, 2)	1	2	
TrackCoords (3, 3)	2	1	
TrackCoords (3, 4)	2	2	

**Suspension hardpoint coordinates relative to axle center, SuspCoords – Point**  
`[0 0 0 0; -1 1 -1 1; 0 0 0 0]` (default) | array

Suspension hardpoint coordinates,  $Sc_t$ , along the solid axle x-, y-, and z-axes, in m.

For example, for a two-axle vehicle with two tracks per axle, the SuspCoords array:

- Dimensions are [3x4].
- Contains four track hardpoint coordinates according to their axle and track locations.

$$Sc_t = \begin{bmatrix} x_{s1,1} & x_{s1,2} & x_{s2,1} & x_{s2,2} \\ y_{s1,1} & y_{s1,2} & y_{s2,1} & y_{s2,2} \\ z_{s1,1} & z_{s1,2} & z_{s2,1} & z_{s2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
SuspCoords (1, 1)	1	1	Solid axle x-axis
SuspCoords (1, 2)	1	2	

Array Element	Axle	Track	Axis
SuspCoords(1,3)	2	1	
SuspCoords(1,4)	2	2	
SuspCoords(2,1)	1	1	Solid axle y-axis
SuspCoords(2,2)	1	2	
SuspCoords(2,3)	2	1	
SuspCoords(2,4)	2	2	
SuspCoords(3,1)	1	1	Solid axle z-axis
SuspCoords(3,2)	1	2	
SuspCoords(3,3)	2	1	
SuspCoords(3,4)	2	2	

**Wheel and axle interface compliance constant, KzWhlAxl – Spring rate**

6437000 (default) | scalar

Wheel and axle interface compliance constant,  $K_z$ , in N/m.

**Wheel and axle interface compliance preload, F0zWhlAxl – Spring rate**

9810 (default) | scalar

Wheel and axle interface compliance preload,  $F_{0z}$ , in N.

**Wheel and axle interface damping constant, CzWhlAxl – Damping**

10000 (default) | scalar

Wheel and axle interface damping constant,  $C_z$ , in m.

**Suspension**

**Compliance and Damping - Passive**

**Suspension spring constant, Kz – Suspension spring constant**

64370 (default) | scalar | vector

Linear vertical spring constant for independent suspension tracks on axle a,  $k_{z_a}$ , in N/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Suspension spring preload, F0z – Suspension spring preload**

9810 (default) | scalar | vector

Vertical preload spring force applied to the wheels on the axle at wheel carrier reference coordinates,  $F_{z0,a}$ , in N. Positive preload forces:

- Cause the vehicle to lift.
- Point along the negative vehicle-fixed  $z$ -axis.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

### **Suspension shock damping constant, Cz — Suspension shock damping constant**

10000 (default) | scalar | vector

Linear vertical damping constant for independent suspension tracks on axle  $a$ ,  $c_{z,a}$ , in Ns/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Dependencies**

To create this parameter, clear **Enable active damping**.

### **Suspension maximum height, Hmax — Height**

0.5 (default) | scalar | vector

Maximum suspension extension or minimum suspension compression height,  $H_{max}$ , for axle  $a$  before the suspension reaches a hardstop, in m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Geometry**

### **Toe angle at steering center, Toe — Toe angle**

0.0349 (default) | scalar

Nominal suspension toe angle at zero steering angle,  $\zeta_{0a}$ , in rad.

### **Roll steer vs suspension height slope, RollStrgSlp — Steer angle suspension slope**

-0.2269 (default) | scalar | vector

Roll steer angle versus suspension height,  $m_{htoe,a}$ , in rad/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

### **Toe angle vs steering angle slope, ToeStrgSlp — Toe angle steering slope**

0.01 (default) | scalar | vector

Toe angle versus steering angle slope,  $m_{toesteer,a}$ , dimensionless.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Dependencies**

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

**Caster angle at steering center, Caster – Caster angle at steering center**

0.0698 (default) | scalar

Nominal suspension caster angle at zero steering angle,  $\eta_{0a}$ , in rad.

**Caster angle vs suspension height slope, CasterHslp – Caster angle versus suspension height slope**

-0.2269 (default) | scalar | vector

Caster angle versus suspension height,  $m_{h_{caster,a}}$ , in rad/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Caster angle vs steering angle slope, CasterStrgSlp – Caster angle versus steering angle slope**

0.01 (default) | scalar | vector

Caster angle versus steering angle slope,  $m_{castersteer,a}$ , dimensionless.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Dependencies**

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

**Camber angle at steering center, Camber – Camber angle at steering center**

0.0698 (default) | scalar

Nominal suspension camber angle at zero steering angle,  $\xi_{0a}$ , in rad.

**Camber angle vs suspension height slope, CamberHslp – Camber angle versus suspension height slope**

-0.2269 (default) | scalar | vector

Camber angle versus suspension height,  $m_{h_{camber,a}}$ , in rad/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

### **Camber angle vs steering angle slope, CamberStrgSlp – Camber angle versus steering angle slope**

0.01 (default) | scalar | vector

Camber angle versus steering angle slope,  $m_{cambersteer_a}$ , dimensionless.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Dependencies**

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

### **Suspension height vs steering angle slope, StrgHgtSlp – Suspension height versus steering angle slope**

0.1432 (default) | scalar | vector

Steering angle to vertical force slope applied at suspension wheel carrier reference point,  $m_{hsteer_a}$ , in m/rad.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Dependencies**

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

## **References**

[1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers, 1992.

[2] Vehicle Dynamics Standards Committee. *Vehicle Dynamics Terminology*. SAE J670. Warrendale, PA: Society of Automotive Engineers, 2008.

[3] Technical Committee. *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*. ISO 8855:2011. Geneva, Switzerland: International Organization for Standardization, 2011.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

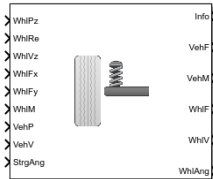
Solid Axle Suspension - Coil Spring | Solid Axle Suspension - Leaf Spring | Solid Axle Suspension - Mapped

**Introduced in R2018a**

## Solid Axle Suspension - Coil Spring

Solid axle suspension with coil spring

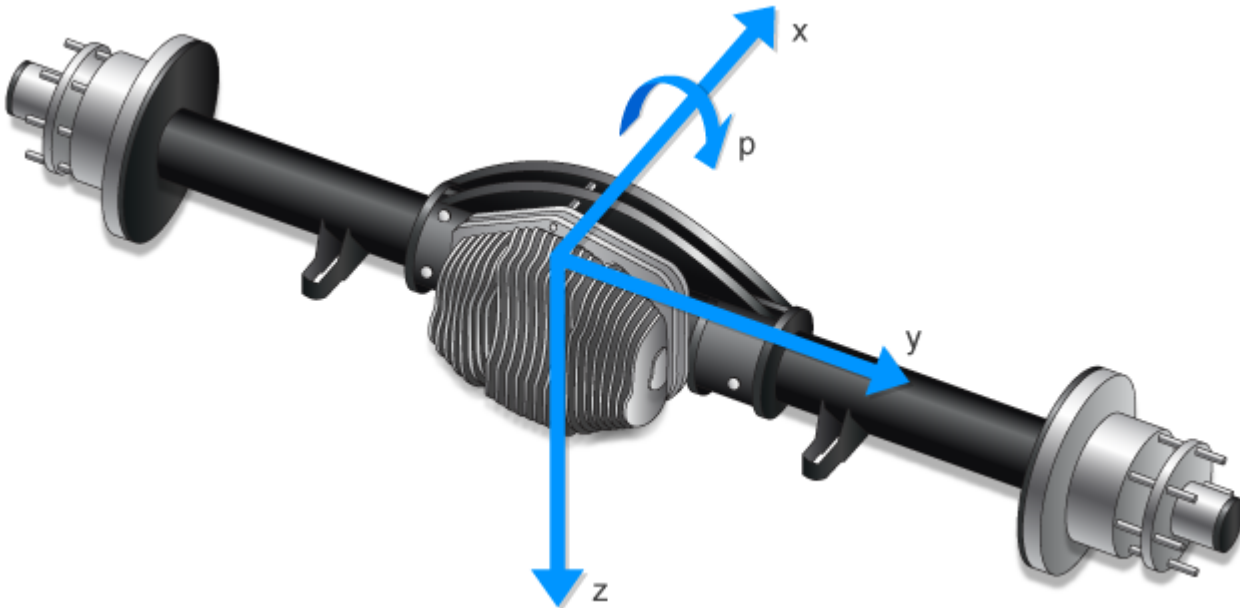
**Library:** Vehicle Dynamics Blockset / Suspension



### Description

The Solid Axle Suspension - Coil Spring block implements a solid axle suspension with a coil spring for multiple axles with multiple tracks per axle.

The block models the suspension compliance, damping, and geometric effects as functions of the track positions and velocities, with axle-specific compliance and damping parameters. Using the track position and velocity, the block calculates the vertical track position and suspension forces on the vehicle and wheel. The block uses the Z-down (defined in SAE J670) and a solid axle coordinate system. The solid axle coordinate system, shown here, is aligned with the Z-down vehicle coordinate system, with the x-axis in the direction of forward vehicle motion.



For Each	You Can Specify
Axle	<ul style="list-style-type: none"> <li>Multiple tracks.</li> <li>Suspension parameters.</li> </ul>
Track	<ul style="list-style-type: none"> <li>Steering angles.</li> </ul>

The block contains energy-storing spring elements and energy-dissipating damper elements. The block also stores energy via the axle roll angular acceleration and axle center of mass vertical and lateral acceleration.

This table summarizes the block parameter settings for a vehicle with:

- Two axles.
- Two tracks per axle.
- Steering angle input for both tracks on the front axle.

Parameter	Setting
Number of axles, NumAxl	2
Number of tracks by axle, NumTracksByAxl	[2 2]
Steered axle enable by axle, StrgEnByAxl	[1 0]

### Suspension Compliance and Damping

The block uses a linear spring and damper to model the vertical dynamic effects of the suspension system on the vehicle and wheel. Specifically, the block:

Uses	To Calculate
<ul style="list-style-type: none"> <li>• Longitudinal and lateral displacement and velocity of the vehicle.</li> <li>• Longitudinal and lateral displacement and velocity of the track.</li> <li>• Vertical wheel forces applied to the vehicle.</li> </ul>	<ul style="list-style-type: none"> <li>• Suspension forces applied to the axle center.</li> <li>• Vertical displacements and velocities of the vehicle and track.</li> <li>• Longitudinal, lateral and vertical suspension forces and moments applied to the vehicle.</li> <li>• Longitudinal, lateral and vertical suspension forces and moments applied to the wheel.</li> </ul>

To calculate the dynamics of the axle, the block implements these equations. The block neglects the effects of:

- Lateral and longitudinal translational velocity.
- Angular velocity about the vertical and lateral axes.

$$\begin{bmatrix} \ddot{x}_a \\ \ddot{y}_a \\ \ddot{z}_a \end{bmatrix} = \frac{1}{M_a} \begin{bmatrix} F_{xa} \\ F_{ya} \\ F_{za} \end{bmatrix} + \begin{bmatrix} \dot{x}_a \\ \dot{y}_a \\ \dot{z}_a \end{bmatrix} \times \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \frac{1}{M_a} \begin{bmatrix} 0 \\ 0 \\ F_{za} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{z}_a \end{bmatrix} \times \begin{bmatrix} p \\ q \\ r \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix} = \begin{bmatrix} 0 \\ p\dot{z}_a \\ \frac{F_{za}}{M_a} + g \end{bmatrix}$$

$$\begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix} - \begin{bmatrix} p \\ q \\ r \end{bmatrix} \times \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}^{-1}$$

$$= \begin{bmatrix} M_x \\ 0 \\ 0 \end{bmatrix} - \begin{bmatrix} p \\ q \\ 0 \end{bmatrix} \times \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} p \\ q \\ 0 \end{bmatrix} \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}^{-1} = \begin{bmatrix} \frac{M_x}{I_{xx}} \\ 0 \\ 0 \end{bmatrix}$$



The net vertical force on the axle center of mass is the sum of the wheel and suspension forces acting on the axle.

$$F_{za} = \sum_{t=1}^{Nta} \left( F_{wza,t} + F_{z0a} + k_{za}(z_{va,t} - z_{sa,t} + m_{hsteera}|\delta_{steera,t}|) + c_{za}(\dot{z}_{va,t} - \dot{z}_{sa,t}) \right)$$

The net moment about the roll axis of the solid axle suspension accounts for the hardpoint coordinates of the suspension and tracks.

$$M_x = \sum_{t=1}^{Nta} \left( F_{wza,t}y_{wt} + (F_{z0a} + k_{za}(z_{va,t} - z_{sa,t} + m_{hsteera}|\delta_{steera,t}|) + c_{za}(\dot{z}_{va,t} - \dot{z}_{sa,t}))y_{st} \right) + M_{wx_a,t} \frac{I_{xx}}{I_{xx} + M_a y_{wt}^2}$$

Block parameters provide the track and suspension hardpoints coordinates.

$$TC_t = \begin{bmatrix} x_{w1} & x_{w2} & \dots \\ y_{w1} & y_{w2} & \dots \\ z_{w1} & z_{w2} & \dots \end{bmatrix}$$

$$SC_t = \begin{bmatrix} x_{s1} & x_{s2} & \dots \\ y_{s1} & y_{s2} & \dots \\ z_{s1} & z_{s2} & \dots \end{bmatrix}$$

The block uses Euler angles to transform the track and suspension displacements, velocities, and accelerations to the vehicle coordinate system.

To calculate the suspension forces applied to the vehicle, the block implements this equation.

$$F_{vza,t} = - \left( F_{z0a} + k_{za}(z_{va,t} - z_{sa,t} + m_{hsteera}|\delta_{steera,t}|) + c_{za}(\dot{z}_{va,t} - \dot{z}_{sa,t}) + F_{zhstopa,t} \right)$$

The suspension forces and moments applied to the vehicle are equal to the suspension forces and moments applied to the wheel.

$$F_{vx_a,t} = F_{wx_a,t}$$

$$F_{vy_a,t} = F_{wy_a,t}$$

$$F_{vz_a,t} = -F_{wz_a,t}$$

$$M_{vx_a,t} = M_{wx_a,t} + F_{wy_a,t}(Re_{wy_a,t} + H_{a,t})$$

$$M_{vy_a,t} = M_{wy_a,t} + F_{wx_a,t}(Re_{wx_a,t} + H_{a,t})$$

$$M_{vz_a,t} = M_{wz_a,t}$$

To calculate the vertical force applied to the suspension at the track location, the block implements a stiff spring-damper.

$$F_{wza,t} = -Fwa_{z0} - k_{wa_z}(z_{wa,t} - z_{sa,t}) - c_{wa_z}(\dot{z}_{wa,t} - \dot{z}_{sa,t})$$

The equations use these variables.

$F_{wz_{a,t}}, M_{wz_{a,t}}$	Suspension force and moment applied to the wheel on axle <i>a</i> , track <i>t</i> along wheel-fixed <i>z</i> -axis
$F_{wx_{a,t}}, M_{wx_{a,t}}$	Suspension force and moment applied to the wheel on axle <i>a</i> , track <i>t</i> along wheel-fixed <i>x</i> -axis
$F_{wy_{a,t}}, M_{wy_{a,t}}$	Suspension force and moment applied to the wheel on axle <i>a</i> , track <i>t</i> along wheel-fixed <i>y</i> -axis
$F_{vz_{a,t}}, M_{vz_{a,t}}$	Suspension force and moment applied to the vehicle on axle <i>a</i> , track <i>t</i> along wheel-fixed <i>z</i> -axis
$F_{vx_{a,t}}, M_{vx_{a,t}}$	Suspension force and moment applied to the vehicle on axle <i>a</i> , track <i>t</i> along wheel-fixed <i>x</i> -axis
$F_{vy_{a,t}}, M_{vy_{a,t}}$	Suspension force and moment applied to the vehicle on axle <i>a</i> , track <i>t</i> along wheel-fixed <i>y</i> -axis
$F_{z0_a}$	Vertical suspension spring preload force applied to the wheels on axle <i>a</i>
$k_{z_a}$	Vertical spring constant applied to tracks on axle <i>a</i>
$m_{hsteer_a}$	Steering angle to vertical force slope applied at wheel carrier for tracks on axle <i>a</i>
$\delta_{steer_{a,t}}$	Steering angle input for axle <i>a</i> , track <i>t</i>
$c_{z_a}$	Vertical damping constant applied to tracks on axle <i>a</i>
$Re_{w_{a,t}}$	Effective wheel radius for axle <i>a</i> , track <i>t</i>
$F_{zhstop_{a,t}}$	Vertical hardstop force at axle <i>a</i> , track <i>t</i> , along the vehicle-fixed <i>z</i> -axis
$F_{zaswy_{a,t}}$	Vertical anti-sway force at axle <i>a</i> , track <i>t</i> , along the vehicle-fixed <i>z</i> -axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle <i>a</i> , track <i>t</i> , along the vehicle-fixed <i>z</i> -axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle <i>a</i> , track <i>t</i> , along the vehicle-fixed <i>z</i> -axis
$x_{v_{a,t}}, \dot{x}_{v_{a,t}}$	Vehicle displacement and velocity at axle <i>a</i> , track <i>t</i> , along the vehicle-fixed <i>x</i> -axis
$x_{w_{a,t}}, \dot{x}_{w_{a,t}}$	Track displacement and velocity at axle <i>a</i> , track <i>t</i> , along the vehicle-fixed <i>x</i> -axis
$y_{v_{a,t}}, \dot{y}_{v_{a,t}}$	Vehicle displacement and velocity at axle <i>a</i> , track <i>t</i> , along the vehicle-fixed <i>y</i> -axis
$y_{w_{a,t}}, \dot{y}_{w_{a,t}}$	Track displacement and velocity at axle <i>a</i> , track <i>t</i> , along the vehicle-fixed <i>y</i> -axis
$H_{a,t}$	Suspension height at axle <i>a</i> , track <i>t</i>
$Re_{w_{a,t}}$	Effective wheel radius at axle <i>a</i> , track <i>t</i>

### Hardstop Forces

The hardstop feedback force,  $F_{zhstop_{a,t}}$ , that the block applies depends on whether the suspension is compressing or extending. The block applies the force:

- In compression, when the suspension is compressed more than the maximum distance specified by the **Suspension maximum height, Hmax** parameter.
- In extension, when the suspension extension is greater than maximum extension specified by the **Suspension maximum height, Hmax** parameter.

To calculate the force, the block uses a stiffness based on a hyperbolic tangent and exponential scaling.

### Camber, Caster, and Toe Angles

To calculate the camber, caster, and toe angles, block uses linear functions of the suspension height and steering angle.

$$\begin{aligned}\xi_{a,t} &= \xi_{0a} + m_{hcamber_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{cambersteer_a}|\delta_{steer_{a,t}}| \\ \eta_{a,t} &= \eta_{0a} + m_{hcaster_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{castersteer_a}|\delta_{steer_{a,t}}| \\ \zeta_{a,t} &= \zeta_{0a} + m_{htoe_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{toesteer_a}|\delta_{steer_{a,t}}|\end{aligned}$$

The equations use these variables.

$\xi_{a,t}$	Camber angle of wheel on axle a, track t
$\eta_{a,t}$	Caster angle of wheel on axle a, track t
$\zeta_{a,t}$	Toe angle of wheel on axle a, track t
$\xi_{0a}, \eta_{0a}, \zeta_{0a}$	Nominal suspension axle a camber, caster, and toe angles, respectively, at zero steering angle
$m_{hcamber_a}, m_{hcaster_a}, m_{htoe_a}$	Camber, caster, and toe angles, respectively, versus suspension height slope for axle a
$m_{cambersteer_a}, m_{castersteer_a}, m_{toesteer_a}$	Camber, caster, and toe angles, respectively, versus steering angle slope for axle a
$m_{hsteer_a}$	Steering angle versus vertical force slope for axle a
$\delta_{steer_{a,t}}$	Steering angle input for axle a, track t
$z_{v_{a,t}}$	Vehicle displacement at axle a, track t, along the vehicle-fixed z-axis
$z_{w_{a,t}}$	Track displacement at axle a, track t, along the vehicle-fixed z-axis

### Steering Angles

Optionally, you can input steering angles for the tracks. To calculate the steering angles for the wheels, the block offsets the input steering angles with a linear function of the suspension height.

$$\delta_{whlsteer_{a,t}} = \delta_{steer_{a,t}} + m_{htoe_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{toesteer_a}|\delta_{steer_{a,t}}|$$

The equation uses these variables.

$m_{toesteer_a}$	Axle a toe angle versus steering angle slope
$m_{hsteer_a}$	Axle a steering angle versus vertical force slope
$m_{htoe_a}$	Axle a toe angle versus suspension height slope
$\delta_{whlsteer_{a,t}}$	Wheel steering angle for axle a, track t
$\delta_{steer_{a,t}}$	Steering angle input for axle a, track t
$z_{v_{a,t}}$	Vehicle displacement at axle a, track t, along the vehicle-fixed z-axis
$z_{w_{a,t}}$	Track displacement at axle a, track t, along the vehicle-fixed z-axis

### Power and Energy

The block calculates these suspension characteristics for each axle, a, track, t.

Calculation	Equation
Dissipated power, $P_{susp_{a,t}}$	$P_{susp_{a,t}} = F_{wzlookup_a}(\dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$
Absorbed energy, $E_{susp_{a,t}}$	$E_{susp_{a,t}} = F_{wzlookup_a}(z_{v_{a,t}} - z_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$
Suspension height, $H_{a,t}$	$H_{a,t} = - \left( z_{v_{a,t}} - z_{w_{a,t}} + \frac{F_{z0_a}}{k_{z_a}} + m_{hsteer_a}  \delta_{steer_{a,t}}  \right)$
Distance from wheel carrier center to tire/road interface	$z_{wtr_{a,t}} = Re_{w_{a,t}} + H_{a,t}$

The equations use these variables.

- $m_{hsteer_a}$  Steering angle to vertical force slope applied at wheel carrier for tracks on axle a
- $\delta_{steer_{a,t}}$  Steering angle input for axle a, track t
- $Re_{w_{a,t}}$  Axle a, track t effective wheel radius from wheel carrier center to tire/road interface
- $F_{z0_a}$  Vertical suspension spring preload force applied to the wheels on axle a
- $z_{wtr_{a,t}}$  Distance from wheel carrier center to tire/road interface, along the vehicle-fixed z-axis
- $z_{v_{a,t}}, \dot{z}_{v_{a,t}}$  Vehicle displacement and velocity at axle a, track t, along the vehicle-fixed z-axis
- $z_{w_{a,t}}, \dot{z}_{w_{a,t}}$  Track displacement and velocity at axle a, track t, along the vehicle-fixed z-axis

## Ports

### Input

#### WhlPz — Track z-axis displacement

array

Track displacement,  $z_w$ , along wheel-fixed z-axis, in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlPz:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlPz} = z_w = [z_{w1,1} \ z_{w1,2} \ z_{w2,1} \ z_{w2,2}]$$

Array Element	Axle	Track
WhlPz(1,1)	1	1
WhlPz(1,2)	1	2
WhlPz(1,3)	2	1
WhlPz(1,4)	2	2

#### WhlRe — Wheel effective radius

array

Effective wheel radius,  $Re_w$ , in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlRe:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlRe} = Re_w = [Re_{w1,1} \quad Re_{w1,2} \quad Re_{w2,1} \quad Re_{w2,2}]$$

Array Element	Axle	Track
WhlRe(1,1)	1	1
WhlRe(1,2)	1	2
WhlRe(1,3)	2	1
WhlRe(1,4)	2	2

### WhlVz — Track z-axis velocity

array

Track velocity,  $\dot{z}_w$ , along wheel-fixed z-axis, in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlVz:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlVz} = \dot{z}_w = [\dot{z}_{w1,1} \quad \dot{z}_{w1,2} \quad \dot{z}_{w2,1} \quad \dot{z}_{w2,2}]$$

Array Element	Axle	Track
WhlVz(1,1)	1	1
WhlVz(1,2)	1	2
WhlVz(1,3)	2	1
WhlVz(1,4)	2	2

### WhlFx — Longitudinal wheel force on vehicle

array

Longitudinal wheel force applied to vehicle,  $F_{wx}$ , along the vehicle-fixed x-axis. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlFx:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlFx} = F_{wx} = [F_{wx1,1} \quad F_{wx1,2} \quad F_{wx2,1} \quad F_{wx2,2}]$$

Array Element	Axle	Track
WhlFx(1,1)	1	1
WhlFx(1,2)	1	2
WhlFx(1,3)	2	1
WhlFx(1,4)	2	2

**WhlFy – Lateral wheel force on vehicle**

array

Lateral wheel force applied to vehicle,  $F_{wy}$ , along the vehicle-fixed y-axis. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlFy:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlFy} = F_{wy} = [F_{wy1,1} \ F_{wy1,2} \ F_{wy2,1} \ F_{wy2,2}]$$

Array Element	Axle	Track
WhlFy(1,1)	1	1
WhlFy(1,2)	1	2
WhlFy(1,3)	2	1
WhlFy(1,4)	2	2

**WhlM – Suspension moment on wheel**

array

Longitudinal, lateral, and vertical suspension moments at axle  $a$ , track  $t$ , applied to the wheel at the axle wheel carrier reference coordinate, in N·m. Array dimensions are 3 by the total number of tracks on the vehicle.

- WhlM(1, . . .) – Suspension moment applied to the wheel about the vehicle-fixed x-axis (longitudinal)
- WhlM(2, . . .) – Suspension moment applied to the wheel about the vehicle-fixed y-axis (lateral)
- WhlM(3, . . .) – Suspension moment applied to the wheel about the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the WhlM:

- Signal dimensions are [3x4].
- Signal contains suspension moments applied to four wheels according to their axle and track locations.

$$\text{WhlM} = M_w = \begin{bmatrix} M_{wx1,1} & M_{wx1,2} & M_{wx2,1} & M_{wx2,2} \\ M_{wy1,1} & M_{wy1,2} & M_{wy2,1} & M_{wy2,2} \\ M_{wz1,1} & M_{wz1,2} & M_{wz2,1} & M_{wz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Moment Axis
WhlM(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
WhlM(1,2)	1	2	
WhlM(1,3)	2	1	
WhlM(1,4)	2	2	
WhlM(2,1)	1	1	Vehicle-fixed y-axis (lateral)
WhlM(2,2)	1	2	
WhlM(2,3)	2	1	
WhlM(2,4)	2	2	
WhlM(3,1)	1	1	Vehicle-fixed z-axis (vertical)
WhlM(3,2)	1	2	
WhlM(3,3)	2	1	
WhlM(3,4)	2	2	

### VehP – Vehicle displacement

array

Vehicle displacement from axle  $a$ , track  $t$  along vehicle-fixed coordinate system, in m. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehP(1, . . .) – Vehicle displacement from track,  $x_v$ , along the vehicle-fixed x-axis
- VehP(2, . . .) – Vehicle displacement from track,  $y_v$ , along the vehicle-fixed y-axis
- VehP(3, . . .) – Vehicle displacement from track,  $z_v$ , along the vehicle-fixed z-axis

For example, for a two-axle vehicle with two tracks per axle, the VehP:

- Signal dimensions are [3x4].
- Signal contains four track displacements according to their axle and track locations.

$$\text{VehP} = \begin{bmatrix} x_v \\ y_v \\ z_v \end{bmatrix} = \begin{bmatrix} x_{v1,1} & x_{v1,2} & x_{v2,1} & x_{v2,2} \\ y_{v1,1} & y_{v1,2} & y_{v2,1} & y_{v2,2} \\ z_{v1,1} & z_{v1,2} & z_{v2,1} & z_{v2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
VehP(1,1)	1	1	Vehicle-fixed x-axis
VehP(1,2)	1	2	
VehP(1,3)	2	1	
VehP(1,4)	2	2	
VehP(2,1)	1	1	Vehicle-fixed y-axis
VehP(2,2)	1	2	
VehP(2,3)	2	1	
VehP(2,4)	2	2	

Array Element	Axle	Track	Axis
VehP(3,1)	1	1	Vehicle-fixed z-axis
VehP(3,2)	1	2	
VehP(3,3)	2	1	
VehP(3,4)	2	2	

**VehV – Vehicle velocity**

array

Vehicle velocity at axle *a*, track *t* along vehicle-fixed coordinate system, in m. Input array dimensions are 3 by *a*\**t*.

- VehV(1, . . . ) – Vehicle velocity at track, *x<sub>v</sub>*, along the vehicle-fixed x-axis
- VehV(2, . . . ) – Vehicle velocity at track, *y<sub>v</sub>*, along the vehicle-fixed y-axis
- VehV(3, . . . ) – Vehicle velocity at track, *z<sub>v</sub>*, along the vehicle-fixed z-axis

For example, for a two-axle vehicle with two tracks per axle, the VehV:

- Signal dimensions are [3x4].
- Signal contains 4 track velocities according to their axle and track locations.

$$\text{VehV} = \begin{bmatrix} \dot{x}_v \\ \dot{y}_v \\ \dot{z}_v \end{bmatrix} = \begin{bmatrix} \dot{x}_{v1,1} & \dot{x}_{v1,2} & \dot{x}_{v2,1} & \dot{x}_{v2,2} \\ \dot{y}_{v1,1} & \dot{y}_{v1,2} & \dot{y}_{v2,1} & \dot{y}_{v2,2} \\ \dot{z}_{v1,1} & \dot{z}_{v1,2} & \dot{z}_{v2,1} & \dot{z}_{v2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
VehV(1,1)	1	1	Vehicle-fixed x-axis
VehV(1,2)	1	2	
VehV(1,3)	2	1	
VehV(1,4)	2	2	
VehV(2,1)	1	1	Vehicle-fixed y-axis
VehV(2,2)	1	2	
VehV(2,3)	2	1	
VehV(2,4)	2	2	
VehV(3,1)	1	1	Vehicle-fixed z-axis
VehV(3,2)	1	2	
VehV(3,3)	2	1	
VehV(3,4)	2	2	

**StrgAng – Steering angle, optional**

array

Optional steering angle for each wheel, *δ*. Input array dimensions are 1 by the number of steered tracks.



For example, for a two-axle vehicle with two tracks per axle, you can input steering angles for both wheels on the first axle.

- To create the `StrgAng` port, set **Steered axle enable by axle, `StrgEnByAxl`** to `[1 0]`. The input signal array dimensions are `[1x2]`.
- The `StrgAng` signal contains two steering angles according to their axle and track locations.

$$\text{StrgAng} = \delta_{steer} = [\delta_{steer1,1} \ \delta_{steer1,2}]$$

Array Element	Axle	Track
<code>StrgAng(1,1)</code>	1	1
<code>StrgAng(1,2)</code>	1	2

### Dependencies

Setting an element of the **Steered axle enable by axle, `StrgEnByAxl`** vector to 1 creates:

- Input port `StrgAng`.
- Parameters:
  - **Toe angle vs steering angle slope, `ToeStrgSlp`**
  - **Caster angle vs steering angle slope, `CasterStrgSlp`**
  - **Camber angle vs steering angle slope, `CamberStrgSlp`**
  - **Suspension height vs steering angle slope, `StrgHgtSlp`**

### Output

#### Info — Bus signal

bus

Bus signal containing block values. The signals are arrays that depend on the track location.

For example, here are the indices for a two-axle, two-track vehicle. The total number of tracks is four.

- 1D array signal (1-by-4)

Array Element	Axle	Track
<code>(1,1)</code>	1	1
<code>(1,2)</code>	1	2
<code>(1,3)</code>	2	1
<code>(1,4)</code>	2	2

- 3D array signal (3-by-4)

Array Element	Axle	Track
<code>(1,1)</code>	1	1
<code>(1,2)</code>	1	2
<code>(1,3)</code>	2	1
<code>(1,4)</code>	2	2

Array Element	Axle	Track
(2,1)	1	1
(2,2)	1	2
(2,3)	2	1
(2,4)	2	2
(3,1)	1	1
(3,2)	1	2
(3,3)	2	1
(3,4)	2	2

Signal	Description	Array Signal	Variable	Units
Camber	Wheel angles according to the axle.	1D	$WhlAng[1, \dots] = \xi = [\xi_{a,t}]$	rad
Caster			$WhlAng[2, \dots] = \eta = [\eta_{a,t}]$	
Toe			$WhlAng[3, \dots] = \zeta = [\zeta_{a,t}]$	
Height	Suspension height	1D	$H$	m
Power	Suspension power dissipation	1D	$P_{susp}$	W
Energy	Suspension absorbed energy	1D	$E_{susp}$	J
VehF	Suspension forces applied to the vehicle	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $VehF = F_v = \begin{bmatrix} F_{vx1,1} & F_{vx1,2} & F_{vx2,1} & F_{vx2,2} \\ F_{vy1,1} & F_{vy1,2} & F_{vy2,1} & F_{vy2,2} \\ F_{vz1,1} & F_{vz1,2} & F_{vz2,1} & F_{vz2,2} \end{bmatrix}$	N

Signal	Description	Array Signal	Variable	Units
VehM	Suspension moments applied to vehicle	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{VehM} = M_v =$ $\begin{bmatrix} M_{vx1,1} & M_{vx1,2} & M_{vx2,1} & M_{vx2,2} \\ M_{vy1,1} & M_{vy1,2} & M_{vy2,1} & M_{vy2,2} \\ M_{vz1,1} & M_{vz1,2} & M_{vz2,1} & M_{vz2,2} \end{bmatrix}$	N·m
WhlF	Suspension force applied to wheel	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlF} = F_w =$ $\begin{bmatrix} F_{wx1,1} & F_{wx1,2} & F_{wx2,1} & F_{wx2,2} \\ F_{wy1,1} & F_{wy1,2} & F_{wy2,1} & F_{wy2,2} \\ F_{wz1,1} & F_{wz1,2} & F_{wz2,1} & F_{wz2,2} \end{bmatrix}$	N
WhlP	Track displacement	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlP} = \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix} =$ $\begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{w2,2} \\ z_{wtr1,1} & z_{wtr1,2} & z_{wtr2,1} & z_{wtr2,2} \end{bmatrix}$	m

Signal	Description	Array Signal	Variable	Units
WhlV	Track velocity	3D	For a two-axle, two tracks per axle vehicle:  $\text{WhlV} = \begin{bmatrix} \dot{x}_w \\ \dot{y}_w \\ \dot{z}_w \end{bmatrix}$  =  $\begin{bmatrix} \dot{x}_{w1,1} & \dot{x}_{w1,2} & \dot{x}_{w2,1} & \dot{x}_{w2,2} \\ \dot{y}_{w1,1} & \dot{y}_{w1,2} & \dot{y}_{w2,1} & \dot{y}_{w2,2} \\ \dot{z}_{w1,1} & \dot{z}_{w1,2} & \dot{z}_{w2,1} & \dot{z}_{w2,2} \end{bmatrix}$	m/s
WhlAng	Wheel camber, caster, toe angles	3D	For a two-axle, two tracks per axle vehicle:  $\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix}$  =  $\begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$	rad

**VehF — Suspension force on vehicle**

array

Longitudinal, lateral, and vertical suspension force at axle a, track t, applied to the vehicle at the suspension connection point, in N. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehF(1, . . .) — Suspension force applied to vehicle along the vehicle-fixed x-axis (longitudinal)
- VehF(2, . . .) — Suspension force applied to vehicle along the vehicle-fixed y-axis (lateral)
- VehF(3, . . .) — Suspension force applied to vehicle along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the VehF:

- Signal dimensions are [3x4].
- Signal contains suspension forces applied to the vehicle according to the axle and track locations.

$$\text{VehF} = F_v = \begin{bmatrix} F_{vx1,1} & F_{vx1,2} & F_{vx2,1} & F_{vx2,2} \\ F_{vy1,1} & F_{vy1,2} & F_{vy2,1} & F_{vy2,2} \\ F_{vz1,1} & F_{vz1,2} & F_{vz2,1} & F_{vz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
VehF(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
VehF(1,2)	1	2	
VehF(1,3)	2	1	
VehF(1,4)	2	2	
VehF(2,1)	1	1	Vehicle-fixed y-axis (lateral)
VehF(2,2)	1	2	
VehF(2,3)	2	1	
VehF(2,4)	2	2	
VehF(3,1)	1	1	Vehicle-fixed z-axis (vertical)
VehF(3,2)	1	2	
VehF(3,3)	2	1	
VehF(3,4)	2	2	

### VehM – Suspension moment on vehicle

array

Longitudinal, lateral, and vertical suspension moment at axle *a*, track *t*, applied to the vehicle at the suspension connection point, in N·m. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehM(1, . . .) – Suspension moment applied to the vehicle about the vehicle-fixed x-axis (longitudinal)
- VehM(2, . . .) – Suspension moment applied to the vehicle about the vehicle-fixed y-axis (lateral)
- VehM(3, . . .) – Suspension moment applied to the vehicle about the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the VehM:

- Signal dimensions are [3×4].
- Signal contains suspension moments applied to vehicle according to the axle and track locations.

$$\text{VehM} = M_v = \begin{bmatrix} M_{vx1,1} & M_{vx1,2} & M_{vx2,1} & M_{vx2,2} \\ M_{vy1,1} & M_{vy1,2} & M_{vy2,1} & M_{vy2,2} \\ M_{vz1,1} & M_{vz1,2} & M_{vz2,1} & M_{vz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Moment Axis
VehM(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
VehM(1,2)	1	2	
VehM(1,3)	2	1	
VehM(1,4)	2	2	
VehM(2,1)	1	1	Vehicle-fixed y-axis (lateral)
VehM(2,2)	1	2	

Array Element	Axle	Track	Moment Axis
VehM(2,3)	2	1	Vehicle-fixed z-axis (vertical)
VehM(2,4)	2	2	
VehM(3,1)	1	1	
VehM(3,2)	1	2	
VehM(3,3)	2	1	
VehM(3,4)	2	2	

**WhlF – Suspension force on wheel**

array

Longitudinal, lateral, and vertical suspension forces at axle **a**, track **t**, applied to the wheel at the axle wheel carrier reference coordinate, in N. Array dimensions are 3 by the total number of tracks on the vehicle.

- WhlF(1, . . .) – Suspension force on wheel along the vehicle-fixed x-axis (longitudinal)
- WhlF(2, . . .) – Suspension force on wheel along the vehicle-fixed y-axis (lateral)
- WhlF(3, . . .) – Suspension force on wheel along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the WhlF:

- Signal dimensions are [3x4].
- Signal contains wheel forces applied to the vehicle according to the axle and track locations.

$$WhlF = F_w = \begin{bmatrix} F_{wx1,1} & F_{wx1,2} & F_{wx2,1} & F_{wx2,2} \\ F_{wy1,1} & F_{wy1,2} & F_{wy2,1} & F_{wy2,2} \\ F_{wz1,1} & F_{wz1,2} & F_{wz2,1} & F_{wz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
WhlF(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
WhlF(1,2)	1	2	
WhlF(1,3)	2	1	
WhlF(1,4)	2	2	
WhlF(2,1)	1	1	Vehicle-fixed y-axis (lateral)
WhlF(2,2)	1	2	
WhlF(2,3)	2	1	
WhlF(2,4)	2	2	
WhlF(3,1)	1	1	Vehicle-fixed z-axis (vertical)
WhlF(3,2)	1	2	
WhlF(3,3)	2	1	
WhlF(3,4)	2	2	

**WhlV – Track velocity**

array

Longitudinal, lateral, and vertical track velocity at axle  $a$ , track  $t$ , in m/s. Array dimensions are 3 by the total number of tracks on the vehicle.

- $WhlV(1, \dots)$  — Track velocity along the vehicle-fixed x-axis (longitudinal)
- $WhlV(2, \dots)$  — Track velocity along the vehicle-fixed y-axis (lateral)
- $WhlV(3, \dots)$  — Track velocity along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the  $WhlV$ :

- Signal dimensions are [3x4].
- Signal contains wheel forces applied to the vehicle according to the axle and track locations.

$$WhlV = \begin{bmatrix} \dot{x}_w \\ \dot{y}_w \\ \dot{z}_w \end{bmatrix} = \begin{bmatrix} \dot{x}_{w1,1} & \dot{x}_{w1,2} & \dot{x}_{w2,1} & \dot{x}_{w2,2} \\ \dot{y}_{w1,1} & \dot{y}_{w1,2} & \dot{y}_{w2,1} & \dot{y}_{w2,2} \\ \dot{z}_{w1,1} & \dot{z}_{w1,2} & \dot{z}_{w2,1} & \dot{z}_{w2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
$WhlV(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$WhlV(1,2)$	1	2	
$WhlV(1,3)$	2	1	
$WhlV(1,4)$	2	2	
$WhlV(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$WhlV(2,2)$	1	2	
$WhlV(2,3)$	2	1	
$WhlV(2,4)$	2	2	
$WhlV(3,1)$	1	1	Vehicle-fixed z-axis (vertical)
$WhlV(3,2)$	1	2	
$WhlV(3,3)$	2	1	
$WhlV(3,4)$	2	2	

### **WhlAng — Wheel camber, caster, toe angles**

array

Camber, caster, and toe angles at axle  $a$ , track  $t$ , in rad. Array dimensions are 3 by the total number of tracks on the vehicle.

- $WhlAng(1, \dots)$  — Camber angle
- $WhlAng(2, \dots)$  — Caster angle
- $WhlAng(3, \dots)$  — Toe angle

For example, for a two-axle vehicle with two tracks per axle, the  $WhlAng$ :

- Signal dimensions are [3x4].
- Signal contains wheel angles according to the axle and track locations.

$$\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix} = \begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$$

Array Element	Axle	Track	Angle
WhlAng(1,1)	1	1	Camber
WhlAng(1,2)	1	2	
WhlAng(1,3)	2	1	
WhlAng(1,4)	2	2	
WhlAng(2,1)	1	1	Caster
WhlAng(2,2)	1	2	
WhlAng(2,3)	2	1	
WhlAng(2,4)	2	2	
WhlAng(3,1)	1	1	Toe
WhlF(3,2)	1	2	
WhlF(3,3)	2	1	
WhlF(3,4)	2	2	

## Parameters

### Axles

#### Number of axles, NumAxl — Number of axles

2 (default) | scalar

Number of axles,  $N_a$ , dimensionless.

#### Number of tracks by axle, NumTracksByAxl — Number of tracks per axle

[2 2] (default) | vector

Number of tracks per axle,  $N_{t_a}$ , dimensionless. Vector is 1 by the number of vehicle axles,  $N_a$ . For example, [1, 2] represents one track on axle 1 and two tracks on axle 2.

#### Steered axle enable by axle, StrgEnByAxl — Boolean vector to enable axle steering

[1 0] (default) | vector

Boolean vector that enables axle steering,  $En_{steer}$ , dimensionless. Vector is 1 by the number of vehicle axles,  $N_a$ . For example:

- [1 0]—For a two-axle vehicle, enables axle 1 steering and disables axle 2 steering
- [1 1]—For a two-axle vehicle, enables axle 1 and axle 2 steering

### Dependencies

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1:

- Creates input port StrgAng.



- Creates these parameters
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

For example, for a two-axle vehicle with two tracks per axle, you can input steering angles for both wheels on the first axle.

- To create the StrgAng port, set **Steered axle enable by axle, StrgEnByAxl** to [1 0]. The input signal array dimensions are [1x2].
- The StrgAng signal contains two steering angles according to their axle and track locations.

$$\text{StrgAng} = \delta_{steer} = [\delta_{steer1,1} \quad \delta_{steer1,2}]$$

Array Element	Axle	Track
StrgAng(1,1)	1	1
StrgAng(1,2)	1	2

#### **Axle and wheels lumped principal moments of inertia about longitudinal axis, AxlIxx – Inertia**

300 (default) | vector

Axle and wheels lumped principal moments of inertia about longitudinal axis, AxleIxx  $a$ , in kg\*m<sup>2</sup>.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Axle and wheels lumped mass, AxlM – Mass**

[2 2] (default) | vector

Axle and wheels lumped mass,  $a$ , in kg.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Track hardpoint coordinates relative to axle center, TrackCoords – Point**

[0 0 0 0; -1 1 -1 1; 0 0 0 0] (default) | array

Track hardpoint coordinates,  $Tc_t$ , along the solid axle  $x$ ,  $y$ , and  $z$ -axes, in m.

For example, for a two-axle vehicle with two tracks per axle, the TrackCoords array:

- Dimensions are [3x4].
- Contains four track hardpoint coordinates according to their axle and track locations.

$$Tc_t = \begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{w2,2} \\ z_{w1,1} & z_{w1,2} & z_{w2,1} & z_{w2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
TrackCoords (1, 1)	1	1	Solid axle x-axis
TrackCoords (1, 2)	1	2	
TrackCoords (1, 3)	2	1	
TrackCoords (1, 4)	2	2	
TrackCoords (2, 1)	1	1	Solid axle y-axis
TrackCoords (2, 2)	1	2	
TrackCoords (2, 3)	2	1	
TrackCoords (2, 4)	2	2	
TrackCoords (3, 1)	1	1	Solid axle z-axis
TrackCoords (3, 2)	1	2	
TrackCoords (3, 3)	2	1	
TrackCoords (3, 4)	2	2	

**Suspension hardpoint coordinates relative to axle center, SuspCoords – Point**  
`[0 0 0 0; -1 1 -1 1; 0 0 0 0]` (default) | array

Suspension hardpoint coordinates,  $Sc_t$ , along the solid axle x-, y-, and z-axes, in m.

For example, for a two-axle vehicle with two tracks per axle, the SuspCoords array:

- Dimensions are [3x4].
- Contains four track hardpoint coordinates according to their axle and track locations.

$$Sc_t = \begin{bmatrix} x_{s1,1} & x_{s1,2} & x_{s2,1} & x_{s2,2} \\ y_{s1,1} & y_{s1,2} & y_{s2,1} & y_{s2,2} \\ z_{s1,1} & z_{s1,2} & z_{s2,1} & z_{s2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
SuspCoords (1, 1)	1	1	Solid axle x-axis
SuspCoords (1, 2)	1	2	

Array Element	Axle	Track	Axis
SuspCoords(1,3)	2	1	
SuspCoords(1,4)	2	2	
SuspCoords(2,1)	1	1	Solid axle y-axis
SuspCoords(2,2)	1	2	
SuspCoords(2,3)	2	1	
SuspCoords(2,4)	2	2	
SuspCoords(3,1)	1	1	Solid axle z-axis
SuspCoords(3,2)	1	2	
SuspCoords(3,3)	2	1	
SuspCoords(3,4)	2	2	

**Wheel and axle interface compliance constant, KzWhlAxl – Spring rate**

6437000 (default) | scalar

Wheel and axle interface compliance constant,  $K_z$ , in N/m.**Wheel and axle interface compliance preload, F0zWhlAxl – Spring rate**

9810 (default) | scalar

Wheel and axle interface compliance preload,  $F_{0z}$ , in N.**Wheel and axle interface damping constant, CzWhlAxl – Damping**

10000 (default) | scalar

Wheel and axle interface damping constant,  $C_z$ , in m.**Suspension****Compliance and Damping - Passive****Suspension spring constant, Kz – Suspension spring constant**

64370 (default) | scalar | vector

Linear vertical spring constant for independent suspension tracks on axle a,  $k_{z_a}$ , in N/m.Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.**Suspension spring preload, F0z – Suspension spring preload**

9810 (default) | scalar | vector

Vertical preload spring force applied to the wheels on the axle at wheel carrier reference coordinates,  $F_{z0,a}$ , in N. Positive preload forces:

- Cause the vehicle to lift.
- Point along the negative vehicle-fixed  $z$ -axis.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

### **Suspension shock damping constant, Cz — Suspension shock damping constant**

10000 (default) | scalar | vector

Linear vertical damping constant for independent suspension tracks on axle  $a$ ,  $c_{z,a}$ , in Ns/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Dependencies**

To create this parameter, clear **Enable active damping**.

### **Suspension maximum height, Hmax — Height**

0.5 (default) | scalar | vector

Maximum suspension extension or minimum suspension compression height,  $H_{max}$ , for axle  $a$  before the suspension reaches a hardstop, in m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Geometry**

### **Toe angle at steering center, Toe — Toe angle**

0.0349 (default) | scalar

Nominal suspension toe angle at zero steering angle,  $\zeta_{0a}$ , in rad.

### **Roll steer vs suspension height slope, RollStrgSlp — Steer angle suspension slope**

-0.2269 (default) | scalar | vector

Roll steer angle versus suspension height,  $m_{htoe,a}$ , in rad/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

### **Toe angle vs steering angle slope, ToeStrgSlp — Toe angle steering slope**

0.01 (default) | scalar | vector

Toe angle versus steering angle slope,  $m_{toesteer,a}$ , dimensionless.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Dependencies**

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

**Caster angle at steering center, Caster – Caster angle at steering center**

0.0698 (default) | scalar

Nominal suspension caster angle at zero steering angle,  $\eta_{0a}$ , in rad.

**Caster angle vs suspension height slope, CasterHslp – Caster angle versus suspension height slope**

-0.2269 (default) | scalar | vector

Caster angle versus suspension height,  $m_{h_{caster,a}}$ , in rad/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Caster angle vs steering angle slope, CasterStrgSlp – Caster angle versus steering angle slope**

0.01 (default) | scalar | vector

Caster angle versus steering angle slope,  $m_{castersteer,a}$ , dimensionless.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Dependencies**

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

**Camber angle at steering center, Camber – Camber angle at steering center**

0.0698 (default) | scalar

Nominal suspension camber angle at zero steering angle,  $\xi_{0a}$ , in rad.

**Camber angle vs suspension height slope, CamberHslp – Camber angle versus suspension height slope**

-0.2269 (default) | scalar | vector

Camber angle versus suspension height,  $m_{h_{camber,a}}$ , in rad/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

### **Camber angle vs steering angle slope, CamberStrgSlp – Camber angle versus steering angle slope**

0.01 (default) | scalar | vector

Camber angle versus steering angle slope,  $m_{cambersteer_a}$ , dimensionless.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Dependencies**

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

### **Suspension height vs steering angle slope, StrgHgtSlp – Suspension height versus steering angle slope**

0.1432 (default) | scalar | vector

Steering angle to vertical force slope applied at suspension wheel carrier reference point,  $m_{hsteer_a}$ , in m/rad.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Dependencies**

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

## **References**

[1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers, 1992.

[2] Vehicle Dynamics Standards Committee. *Vehicle Dynamics Terminology*. SAE J670. Warrendale, PA: Society of Automotive Engineers, 2008.

[3] Technical Committee. *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*. ISO 8855:2011. Geneva, Switzerland: International Organization for Standardization, 2011.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

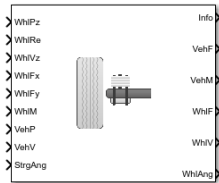
[Solid Axle Suspension](#) | [Solid Axle Suspension - Leaf Spring](#) | [Solid Axle Suspension - Mapped](#)

**Introduced in R2018a**

## Solid Axle Suspension - Leaf Spring

Solid axle suspension with leaf spring

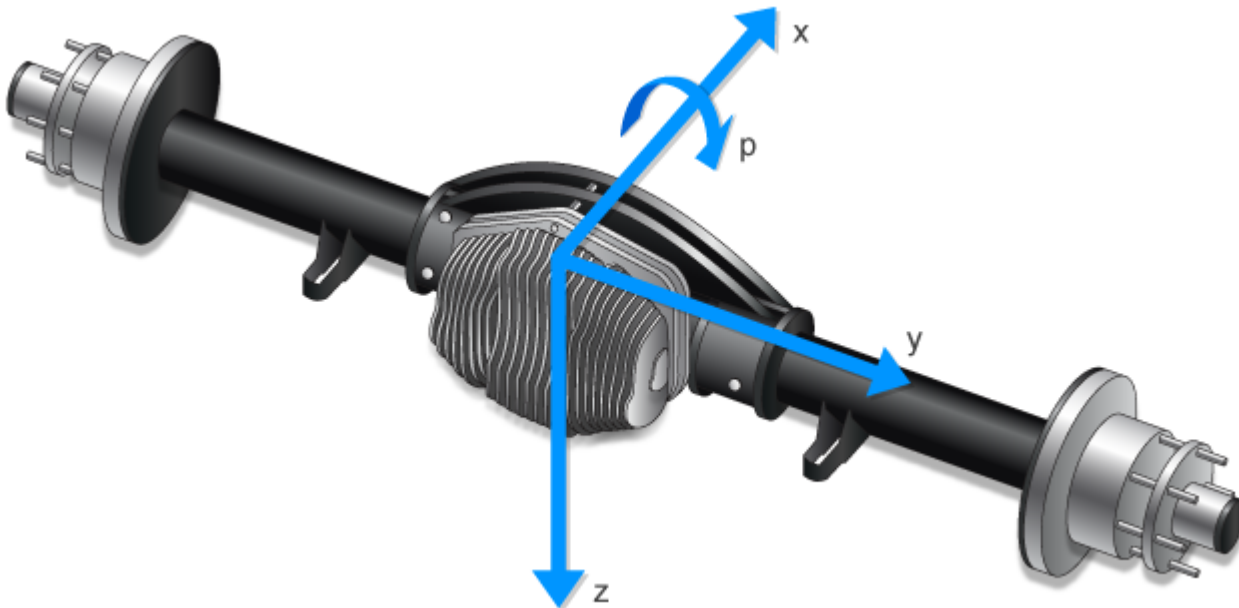
**Library:** Vehicle Dynamics Blockset / Suspension



### Description

The Solid Axle Suspension - Leaf Spring block implements a solid axle suspension with a coil spring for multiple axles with multiple tracks per axle.

The block models the suspension compliance, damping, and geometric effects as functions of the track positions and velocities, with axle-specific compliance and damping parameters. Using the track position and velocity, the block calculates the vertical track position and suspension forces on the vehicle and wheel. The block uses the Z-down (defined in SAE J670) and a solid axle coordinate system. The solid axle coordinate system, shown here, is aligned with the Z-down vehicle coordinate system, with the x-axis in the direction of forward vehicle motion.



For Each	You Can Specify
Axle	<ul style="list-style-type: none"> <li>Multiple tracks.</li> <li>Suspension parameters.</li> </ul>
Track	<ul style="list-style-type: none"> <li>Steering angles.</li> </ul>



The block contains energy-storing spring elements and energy-dissipating damper elements. The block also stores energy via the axle roll angular acceleration and axle center of mass vertical and lateral acceleration.

This table summarizes the block parameter settings for a vehicle with:

- Two axles.
- Two tracks per axle.
- Steering angle input for both tracks on the front axle.

Parameter	Setting
Number of axles, NumAxl	2
Number of tracks by axle, NumTracksByAxl	[2 2]
Steered axle enable by axle, StrgEnByAxl	[1 0]

### Suspension Compliance and Damping

The block uses a linear spring and damper to model the vertical dynamic effects of the suspension system on the vehicle and wheel. Specifically, the block:

Uses	To Calculate
<ul style="list-style-type: none"> <li>• Longitudinal and lateral displacement and velocity of the vehicle.</li> <li>• Longitudinal and lateral displacement and velocity of the track.</li> <li>• Vertical wheel forces applied to the vehicle.</li> </ul>	<ul style="list-style-type: none"> <li>• Suspension forces applied to the axle center.</li> <li>• Vertical displacements and velocities of the vehicle and track.</li> <li>• Longitudinal, lateral and vertical suspension forces and moments applied to the vehicle.</li> <li>• Longitudinal, lateral and vertical suspension forces and moments applied to the wheel.</li> </ul>

To calculate the dynamics of the axle, the block implements these equations. The block neglects the effects of:

- Lateral and longitudinal translational velocity.
- Angular velocity about the vertical and lateral axes.

$$\begin{bmatrix} \ddot{x}_a \\ \ddot{y}_a \\ \ddot{z}_a \end{bmatrix} = \frac{1}{M_a} \begin{bmatrix} F_{xa} \\ F_{ya} \\ F_{za} \end{bmatrix} + \begin{bmatrix} \dot{x}_a \\ \dot{y}_a \\ \dot{z}_a \end{bmatrix} \times \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \frac{1}{M_a} \begin{bmatrix} 0 \\ 0 \\ F_{za} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{z}_a \end{bmatrix} \times \begin{bmatrix} p \\ q \\ r \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix} = \begin{bmatrix} 0 \\ p\dot{z}_a \\ \frac{F_{za}}{M_a} + g \end{bmatrix}$$

$$\begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix} - \begin{bmatrix} p \\ q \\ r \end{bmatrix} \times \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}^{-1}$$

$$= \begin{bmatrix} M_x \\ 0 \\ 0 \end{bmatrix} - \begin{bmatrix} p \\ q \\ 0 \end{bmatrix} \times \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} p \\ q \\ 0 \end{bmatrix} \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}^{-1} = \begin{bmatrix} \frac{M_x}{I_{xx}} \\ 0 \\ 0 \end{bmatrix}$$

The net vertical force on the axle center of mass is the sum of the wheel and suspension forces acting on the axle.

$$F_{za} = \sum_{t=1}^{Nta} \left( F_{wz_{a,t}} + F_{z0_a} + k_{z_a} (z_{v_{a,t}} - z_{s_{a,t}} + m_{hsteer_a} |\delta_{steer_{a,t}}|) + c_{z_a} (\dot{z}_{v_{a,t}} - \dot{z}_{s_{a,t}}) \right)$$

The net moment about the roll axis of the solid axle suspension accounts for the hardpoint coordinates of the suspension and tracks.

$$M_x = \sum_{t=1}^{Nta} \left( F_{wz_{a,t}} y_{w_t} + (F_{z0_a} + k_{z_a} (z_{v_{a,t}} - z_{s_{a,t}} + m_{hsteer_a} |\delta_{steer_{a,t}}|) + c_{z_a} (\dot{z}_{v_{a,t}} - \dot{z}_{s_{a,t}})) y_{s_t} \right) + M_{wx_{a,t}} \frac{I_{xx}}{I_{xx} + M_a y_{w_t}^2}$$

Block parameters provide the track and suspension hardpoints coordinates.

$$TC_t = \begin{bmatrix} x_{w1} & x_{w2} & \dots \\ y_{w1} & y_{w2} & \dots \\ z_{w1} & z_{w2} & \dots \end{bmatrix}$$

$$SC_t = \begin{bmatrix} x_{s1} & x_{s2} & \dots \\ y_{s1} & y_{s2} & \dots \\ z_{s1} & z_{s2} & \dots \end{bmatrix}$$

The block uses Euler angles to transform the track and suspension displacements, velocities, and accelerations to the vehicle coordinate system.

To calculate the suspension forces applied to the vehicle, the block implements this equation.

$$F_{vz_{a,t}} = - \left( F_{z0_a} + k_{z_a} (z_{v_{a,t}} - z_{s_{a,t}} + m_{hsteer_a} |\delta_{steer_{a,t}}|) + c_{z_a} (\dot{z}_{v_{a,t}} - \dot{z}_{s_{a,t}}) + F_{zhstop_{a,t}} \right)$$

The suspension forces and moments applied to the vehicle are equal to the suspension forces and moments applied to the wheel.

$$F_{vx_{a,t}} = F_{wx_{a,t}}$$

$$F_{vy_{a,t}} = F_{wy_{a,t}}$$

$$F_{vz_{a,t}} = - F_{wz_{a,t}}$$

$$M_{vx_{a,t}} = M_{wx_{a,t}} + F_{wy_{a,t}} (Re_{wy_{a,t}} + H_{a,t})$$

$$M_{vy_{a,t}} = M_{wy_{a,t}} + F_{wx_{a,t}} (Re_{wx_{a,t}} + H_{a,t})$$

$$M_{vz_{a,t}} = M_{wz_{a,t}}$$

To calculate the vertical force applied to the suspension at the track location, the block implements a stiff spring-damper.

$$F_{wz_{a,t}} = - F_{wa_{z0}} - k_{wa_z} (z_{w_{a,t}} - z_{s_{a,t}}) - c_{wa_z} (\dot{z}_{w_{a,t}} - \dot{z}_{s_{a,t}})$$

The equations use these variables.

$F_{wz_{a,t}}, M_{wz_{a,t}}$	Suspension force and moment applied to the wheel on axle $a$ , track $t$ along wheel-fixed $z$ -axis
$F_{wx_{a,t}}, M_{wx_{a,t}}$	Suspension force and moment applied to the wheel on axle $a$ , track $t$ along wheel-fixed $x$ -axis
$F_{wy_{a,t}}, M_{wy_{a,t}}$	Suspension force and moment applied to the wheel on axle $a$ , track $t$ along wheel-fixed $y$ -axis
$F_{vz_{a,t}}, M_{vz_{a,t}}$	Suspension force and moment applied to the vehicle on axle $a$ , track $t$ along wheel-fixed $z$ -axis
$F_{vx_{a,t}}, M_{vx_{a,t}}$	Suspension force and moment applied to the vehicle on axle $a$ , track $t$ along wheel-fixed $x$ -axis
$F_{vy_{a,t}}, M_{vy_{a,t}}$	Suspension force and moment applied to the vehicle on axle $a$ , track $t$ along wheel-fixed $y$ -axis
$F_{z0_a}$	Vertical suspension spring preload force applied to the wheels on axle $a$
$k_{z_a}$	Vertical spring constant applied to tracks on axle $a$
$m_{hsteer_a}$	Steering angle to vertical force slope applied at wheel carrier for tracks on axle $a$
$\delta_{steer_{a,t}}$	Steering angle input for axle $a$ , track $t$
$c_{z_a}$	Vertical damping constant applied to tracks on axle $a$
$Re_{w_{a,t}}$	Effective wheel radius for axle $a$ , track $t$
$F_{zhstop_{a,t}}$	Vertical hardstop force at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis
$F_{zaswy_{a,t}}$	Vertical anti-sway force at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $z$ -axis
$x_{v_{a,t}}, \dot{x}_{v_{a,t}}$	Vehicle displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $x$ -axis
$x_{w_{a,t}}, \dot{x}_{w_{a,t}}$	Track displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $x$ -axis
$y_{v_{a,t}}, \dot{y}_{v_{a,t}}$	Vehicle displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $y$ -axis
$y_{w_{a,t}}, \dot{y}_{w_{a,t}}$	Track displacement and velocity at axle $a$ , track $t$ , along the vehicle-fixed $y$ -axis
$H_{a,t}$	Suspension height at axle $a$ , track $t$
$Re_{w_{a,t}}$	Effective wheel radius at axle $a$ , track $t$

### Hardstop Forces

The hardstop feedback force,  $F_{zhstop_{a,t}}$ , that the block applies depends on whether the suspension is compressing or extending. The block applies the force:

- In compression, when the suspension is compressed more than the maximum distance specified by the **Suspension maximum height, Hmax** parameter.
- In extension, when the suspension extension is greater than maximum extension specified by the **Suspension maximum height, Hmax** parameter.

To calculate the force, the block uses a stiffness based on a hyperbolic tangent and exponential scaling.

### Camber, Caster, and Toe Angles

To calculate the camber, caster, and toe angles, block uses linear functions of the suspension height and steering angle.

$$\begin{aligned}\xi_{a,t} &= \xi_{0a} + m_{hcamber_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{cambersteer_a}|\delta_{steer_{a,t}}| \\ \eta_{a,t} &= \eta_{0a} + m_{hcaster_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{castersteer_a}|\delta_{steer_{a,t}}| \\ \zeta_{a,t} &= \zeta_{0a} + m_{htoe_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{toesteer_a}|\delta_{steer_{a,t}}|\end{aligned}$$

The equations use these variables.

$\xi_{a,t}$	Camber angle of wheel on axle a, track t
$\eta_{a,t}$	Caster angle of wheel on axle a, track t
$\zeta_{a,t}$	Toe angle of wheel on axle a, track t
$\xi_{0a}, \eta_{0a}, \zeta_{0a}$	Nominal suspension axle a camber, caster, and toe angles, respectively, at zero steering angle
$m_{hcamber_a}, m_{hcaster_a}, m_{htoe_a}$	Camber, caster, and toe angles, respectively, versus suspension height slope for axle a
$m_{cambersteer_a}, m_{castersteer_a}, m_{toesteer_a}$	Camber, caster, and toe angles, respectively, versus steering angle slope for axle a
$m_{hsteer_a}$	Steering angle versus vertical force slope for axle a
$\delta_{steer_{a,t}}$	Steering angle input for axle a, track t
$z_{v_{a,t}}$	Vehicle displacement at axle a, track t, along the vehicle-fixed z-axis
$z_{w_{a,t}}$	Track displacement at axle a, track t, along the vehicle-fixed z-axis

### Steering Angles

Optionally, you can input steering angles for the tracks. To calculate the steering angles for the wheels, the block offsets the input steering angles with a linear function of the suspension height.

$$\delta_{whlsteer_{a,t}} = \delta_{steer_{a,t}} + m_{htoe_a}(z_{w_{a,t}} - z_{v_{a,t}} - m_{hsteer_a}|\delta_{steer_{a,t}}|) + m_{toesteer_a}|\delta_{steer_{a,t}}|$$

The equation uses these variables.

$m_{toesteer_a}$	Axle a toe angle versus steering angle slope
$m_{hsteer_a}$	Axle a steering angle versus vertical force slope
$m_{htoe_a}$	Axle a toe angle versus suspension height slope
$\delta_{whlsteer_{a,t}}$	Wheel steering angle for axle a, track t
$\delta_{steer_{a,t}}$	Steering angle input for axle a, track t
$z_{v_{a,t}}$	Vehicle displacement at axle a, track t, along the vehicle-fixed z-axis
$z_{w_{a,t}}$	Track displacement at axle a, track t, along the vehicle-fixed z-axis

### Power and Energy

The block calculates these suspension characteristics for each axle, a, track, t.

Calculation	Equation
Dissipated power, $P_{susp_{a,t}}$	$P_{susp_{a,t}} = F_{wzlookup_a}(\dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$
Absorbed energy, $E_{susp_{a,t}}$	$E_{susp_{a,t}} = F_{wzlookup_a}(z_{v_{a,t}} - z_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$
Suspension height, $H_{a,t}$	$H_{a,t} = - \left( z_{v_{a,t}} - z_{w_{a,t}} + \frac{F_{z0_a}}{k_{z_a}} + m_{hsteer_a}  \delta_{steer_{a,t}}  \right)$
Distance from wheel carrier center to tire/road interface	$z_{wtr_{a,t}} = Re_{w_{a,t}} + H_{a,t}$

The equations use these variables.

$m_{hsteer_a}$	Steering angle to vertical force slope applied at wheel carrier for tracks on axle a
$\delta_{steer_{a,t}}$	Steering angle input for axle a, track t
$Re_{w_{a,t}}$	Axle a, track t effective wheel radius from wheel carrier center to tire/road interface
$F_{z0_a}$	Vertical suspension spring preload force applied to the wheels on axle a
$z_{wtr_{a,t}}$	Distance from wheel carrier center to tire/road interface, along the vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along the vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along the vehicle-fixed z-axis

## Ports

### Input

#### WhlPz — Track z-axis displacement

array

Track displacement,  $z_w$ , along wheel-fixed z-axis, in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlPz:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlPz} = z_w = [z_{w1,1} \ z_{w1,2} \ z_{w2,1} \ z_{w2,2}]$$

Array Element	Axle	Track
WhlPz(1,1)	1	1
WhlPz(1,2)	1	2
WhlPz(1,3)	2	1
WhlPz(1,4)	2	2

#### WhlRe — Wheel effective radius

array

Effective wheel radius,  $Re_w$ , in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlRe:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlRe} = Re_w = [Re_{w1,1} \quad Re_{w1,2} \quad Re_{w2,1} \quad Re_{w2,2}]$$

Array Element	Axle	Track
WhlRe(1,1)	1	1
WhlRe(1,2)	1	2
WhlRe(1,3)	2	1
WhlRe(1,4)	2	2

**WhlVz — Track z-axis velocity**

array

Track velocity,  $\dot{z}_w$ , along wheel-fixed z-axis, in m. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlVz:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlVz} = \dot{z}_w = [\dot{z}_{w1,1} \quad \dot{z}_{w1,2} \quad \dot{z}_{w2,1} \quad \dot{z}_{w2,2}]$$

Array Element	Axle	Track
WhlVz(1,1)	1	1
WhlVz(1,2)	1	2
WhlVz(1,3)	2	1
WhlVz(1,4)	2	2

**WhlFx — Longitudinal wheel force on vehicle**

array

Longitudinal wheel force applied to vehicle,  $F_{wx}$ , along the vehicle-fixed x-axis. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlFx:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlFx} = F_{wx} = [F_{wx1,1} \quad F_{wx1,2} \quad F_{wx2,1} \quad F_{wx2,2}]$$

Array Element	Axle	Track
WhlFx(1,1)	1	1
WhlFx(1,2)	1	2
WhlFx(1,3)	2	1
WhlFx(1,4)	2	2

### WhlFy – Lateral wheel force on vehicle

array

Lateral wheel force applied to vehicle,  $F_{wy}$ , along the vehicle-fixed y-axis. Array dimensions are 1 by the total number of tracks on the vehicle.

For example, for a two-axle vehicle with two tracks per axle, the WhlFy:

- Signal array dimensions are [1x4].
- Array dimensions are axle by track.

$$\text{WhlFy} = F_{wy} = [F_{wy1,1} \ F_{wy1,2} \ F_{wy2,1} \ F_{wy2,2}]$$

Array Element	Axle	Track
WhlFy(1,1)	1	1
WhlFy(1,2)	1	2
WhlFy(1,3)	2	1
WhlFy(1,4)	2	2

### WhlM – Suspension moment on wheel

array

Longitudinal, lateral, and vertical suspension moments at axle  $a$ , track  $t$ , applied to the wheel at the axle wheel carrier reference coordinate, in N·m. Array dimensions are 3 by the total number of tracks on the vehicle.

- WhlM(1, . . .) – Suspension moment applied to the wheel about the vehicle-fixed x-axis (longitudinal)
- WhlM(2, . . .) – Suspension moment applied to the wheel about the vehicle-fixed y-axis (lateral)
- WhlM(3, . . .) – Suspension moment applied to the wheel about the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the WhlM:

- Signal dimensions are [3x4].
- Signal contains suspension moments applied to four wheels according to their axle and track locations.

$$\text{WhlM} = M_w = \begin{bmatrix} M_{wx1,1} & M_{wx1,2} & M_{wx2,1} & M_{wx2,2} \\ M_{wy1,1} & M_{wy1,2} & M_{wy2,1} & M_{wy2,2} \\ M_{wz1,1} & M_{wz1,2} & M_{wz2,1} & M_{wz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Moment Axis
WhlM(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
WhlM(1,2)	1	2	
WhlM(1,3)	2	1	
WhlM(1,4)	2	2	
WhlM(2,1)	1	1	Vehicle-fixed y-axis (lateral)
WhlM(2,2)	1	2	
WhlM(2,3)	2	1	
WhlM(2,4)	2	2	
WhlM(3,1)	1	1	Vehicle-fixed z-axis (vertical)
WhlM(3,2)	1	2	
WhlM(3,3)	2	1	
WhlM(3,4)	2	2	

**VehP – Vehicle displacement**

array

Vehicle displacement from axle *a*, track *t* along vehicle-fixed coordinate system, in m. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehP(1, . . .) – Vehicle displacement from track,  $x_v$ , along the vehicle-fixed x-axis
- VehP(2, . . .) – Vehicle displacement from track,  $y_v$ , along the vehicle-fixed y-axis
- VehP(3, . . .) – Vehicle displacement from track,  $z_v$ , along the vehicle-fixed z-axis

For example, for a two-axle vehicle with two tracks per axle, the VehP:

- Signal dimensions are [3x4].
- Signal contains four track displacements according to their axle and track locations.

$$\text{VehP} = \begin{bmatrix} x_v \\ y_v \\ z_v \end{bmatrix} = \begin{bmatrix} x_{v1,1} & x_{v1,2} & x_{v2,1} & x_{v2,2} \\ y_{v1,1} & y_{v1,2} & y_{v2,1} & y_{v2,2} \\ z_{v1,1} & z_{v1,2} & z_{v2,1} & z_{v2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
VehP(1,1)	1	1	Vehicle-fixed x-axis
VehP(1,2)	1	2	
VehP(1,3)	2	1	
VehP(1,4)	2	2	
VehP(2,1)	1	1	Vehicle-fixed y-axis
VehP(2,2)	1	2	
VehP(2,3)	2	1	
VehP(2,4)	2	2	



Array Element	Axle	Track	Axis
VehP(3,1)	1	1	Vehicle-fixed z-axis
VehP(3,2)	1	2	
VehP(3,3)	2	1	
VehP(3,4)	2	2	

**VehV – Vehicle velocity**

array

Vehicle velocity at axle *a*, track *t* along vehicle-fixed coordinate system, in m. Input array dimensions are 3 by *a*\**t*.

- VehV(1, . . . ) – Vehicle velocity at track,  $x_v$ , along the vehicle-fixed x-axis
- VehV(2, . . . ) – Vehicle velocity at track,  $y_v$ , along the vehicle-fixed y-axis
- VehV(3, . . . ) – Vehicle velocity at track,  $z_v$ , along the vehicle-fixed z-axis

For example, for a two-axle vehicle with two tracks per axle, the VehV:

- Signal dimensions are [3x4].
- Signal contains 4 track velocities according to their axle and track locations.

$$\text{VehV} = \begin{bmatrix} \dot{x}_v \\ \dot{y}_v \\ \dot{z}_v \end{bmatrix} = \begin{bmatrix} \dot{x}_{v1,1} & \dot{x}_{v1,2} & \dot{x}_{v2,1} & \dot{x}_{v2,2} \\ \dot{y}_{v1,1} & \dot{y}_{v1,2} & \dot{y}_{v2,1} & \dot{y}_{v2,2} \\ \dot{z}_{v1,1} & \dot{z}_{v1,2} & \dot{z}_{v2,1} & \dot{z}_{v2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
VehV(1,1)	1	1	Vehicle-fixed x-axis
VehV(1,2)	1	2	
VehV(1,3)	2	1	
VehV(1,4)	2	2	
VehV(2,1)	1	1	Vehicle-fixed y-axis
VehV(2,2)	1	2	
VehV(2,3)	2	1	
VehV(2,4)	2	2	
VehV(3,1)	1	1	Vehicle-fixed z-axis
VehV(3,2)	1	2	
VehV(3,3)	2	1	
VehV(3,4)	2	2	

**StrgAng – Steering angle, optional**

array

Optional steering angle for each wheel,  $\delta$ . Input array dimensions are 1 by the number of steered tracks.

For example, for a two-axle vehicle with two tracks per axle, you can input steering angles for both wheels on the first axle.

- To create the `StrgAng` port, set **Steered axle enable by axle, `StrgEnByAxl`** to `[1 0]`. The input signal array dimensions are `[1x2]`.
- The `StrgAng` signal contains two steering angles according to their axle and track locations.

$$\text{StrgAng} = \delta_{steer} = [\delta_{steer1,1} \ \delta_{steer1,2}]$$

Array Element	Axle	Track
<code>StrgAng(1,1)</code>	1	1
<code>StrgAng(1,2)</code>	1	2

### Dependencies

Setting an element of the **Steered axle enable by axle, `StrgEnByAxl`** vector to 1 creates:

- Input port `StrgAng`.
- Parameters:
  - **Toe angle vs steering angle slope, `ToeStrgSlp`**
  - **Caster angle vs steering angle slope, `CasterStrgSlp`**
  - **Camber angle vs steering angle slope, `CamberStrgSlp`**
  - **Suspension height vs steering angle slope, `StrgHgtSlp`**

### Output

#### Info — Bus signal

bus

Bus signal containing block values. The signals are arrays that depend on the track location.

For example, here are the indices for a two-axle, two-track vehicle. The total number of tracks is four.

- 1D array signal (1-by-4)

Array Element	Axle	Track
<code>(1,1)</code>	1	1
<code>(1,2)</code>	1	2
<code>(1,3)</code>	2	1
<code>(1,4)</code>	2	2

- 3D array signal (3-by-4)

Array Element	Axle	Track
<code>(1,1)</code>	1	1
<code>(1,2)</code>	1	2
<code>(1,3)</code>	2	1
<code>(1,4)</code>	2	2

Array Element	Axle	Track
(2,1)	1	1
(2,2)	1	2
(2,3)	2	1
(2,4)	2	2
(3,1)	1	1
(3,2)	1	2
(3,3)	2	1
(3,4)	2	2

Signal	Description	Array Signal	Variable	Units
Camber	Wheel angles according to the axle.	1D	$WhlAng[1, \dots] = \xi = [\xi_{a,t}]$	rad
Caster			$WhlAng[2, \dots] = \eta = [\eta_{a,t}]$	
Toe			$WhlAng[3, \dots] = \zeta = [\zeta_{a,t}]$	
Height	Suspension height	1D	$H$	m
Power	Suspension power dissipation	1D	$P_{susp}$	W
Energy	Suspension absorbed energy	1D	$E_{susp}$	J
VehF	Suspension forces applied to the vehicle	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $VehF = F_v =$ $\begin{bmatrix} F_{vx1,1} & F_{vx1,2} & F_{vx2,1} & F_{vx2,2} \\ F_{vy1,1} & F_{vy1,2} & F_{vy2,1} & F_{vy2,2} \\ F_{vz1,1} & F_{vz1,2} & F_{vz2,1} & F_{vz2,2} \end{bmatrix}$	N

Signal	Description	Array Signal	Variable	Units
VehM	Suspension moments applied to vehicle	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{VehM} = M_v =$ $\begin{bmatrix} M_{vx1,1} & M_{vx1,2} & M_{vx2,1} & M_{vx2,2} \\ M_{vy1,1} & M_{vy1,2} & M_{vy2,1} & M_{vy2,2} \\ M_{vz1,1} & M_{vz1,2} & M_{vz2,1} & M_{vz2,2} \end{bmatrix}$	N·m
WhlF	Suspension force applied to wheel	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlF} = F_w =$ $\begin{bmatrix} F_{wx1,1} & F_{wx1,2} & F_{wx2,1} & F_{wx2,2} \\ F_{wy1,1} & F_{wy1,2} & F_{wy2,1} & F_{wy2,2} \\ F_{wz1,1} & F_{wz1,2} & F_{wz2,1} & F_{wz2,2} \end{bmatrix}$	N
WhlP	Track displacement	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlP} = \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix} =$ $\begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{w2,2} \\ z_{wtr1,1} & z_{wtr1,2} & z_{wtr2,1} & z_{wtr2,2} \end{bmatrix}$	m

Signal	Description	Array Signal	Variable	Units
WhlV	Track velocity	3D	For a two-axle, two tracks per axle vehicle:  $\text{WhlV} = \begin{bmatrix} \dot{x}_w \\ \dot{y}_w \\ \dot{z}_w \end{bmatrix}$  =  $\begin{bmatrix} \dot{x}_{w1,1} & \dot{x}_{w1,2} & \dot{x}_{w2,1} & \dot{x}_{w2,2} \\ \dot{y}_{w1,1} & \dot{y}_{w1,2} & \dot{y}_{w2,1} & \dot{y}_{w2,2} \\ \dot{z}_{w1,1} & \dot{z}_{w1,2} & \dot{z}_{w2,1} & \dot{z}_{w2,2} \end{bmatrix}$	m/s
WhlAng	Wheel camber, caster, toe angles	3D	For a two-axle, two tracks per axle vehicle:  $\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix}$  =  $\begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$	rad

### VehF — Suspension force on vehicle

array

Longitudinal, lateral, and vertical suspension force at axle *a*, track *t*, applied to the vehicle at the suspension connection point, in N. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehF(1, . . .) — Suspension force applied to vehicle along the vehicle-fixed x-axis (longitudinal)
- VehF(2, . . .) — Suspension force applied to vehicle along the vehicle-fixed y-axis (lateral)
- VehF(3, . . .) — Suspension force applied to vehicle along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the VehF:

- Signal dimensions are [3x4].
- Signal contains suspension forces applied to the vehicle according to the axle and track locations.

$$\text{VehF} = F_v = \begin{bmatrix} F_{vx1,1} & F_{vx1,2} & F_{vx2,1} & F_{vx2,2} \\ F_{vy1,1} & F_{vy1,2} & F_{vy2,1} & F_{vy2,2} \\ F_{vz1,1} & F_{vz1,2} & F_{vz2,1} & F_{vz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
VehF(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
VehF(1,2)	1	2	
VehF(1,3)	2	1	
VehF(1,4)	2	2	
VehF(2,1)	1	1	Vehicle-fixed y-axis (lateral)
VehF(2,2)	1	2	
VehF(2,3)	2	1	
VehF(2,4)	2	2	
VehF(3,1)	1	1	Vehicle-fixed z-axis (vertical)
VehF(3,2)	1	2	
VehF(3,3)	2	1	
VehF(3,4)	2	2	

**VehM – Suspension moment on vehicle**

array

Longitudinal, lateral, and vertical suspension moment at axle *a*, track *t*, applied to the vehicle at the suspension connection point, in N·m. Array dimensions are 3 by the total number of tracks on the vehicle.

- VehM(1, . . .) – Suspension moment applied to the vehicle about the vehicle-fixed x-axis (longitudinal)
- VehM(2, . . .) – Suspension moment applied to the vehicle about the vehicle-fixed y-axis (lateral)
- VehM(3, . . .) – Suspension moment applied to the vehicle about the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the VehM:

- Signal dimensions are [3x4].
- Signal contains suspension moments applied to vehicle according to the axle and track locations.

$$VehM = M_v = \begin{bmatrix} M_{vx1,1} & M_{vx1,2} & M_{vx2,1} & M_{vx2,2} \\ M_{vy1,1} & M_{vy1,2} & M_{vy2,1} & M_{vy2,2} \\ M_{vz1,1} & M_{vz1,2} & M_{vz2,1} & M_{vz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Moment Axis
VehM(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
VehM(1,2)	1	2	
VehM(1,3)	2	1	
VehM(1,4)	2	2	
VehM(2,1)	1	1	Vehicle-fixed y-axis (lateral)
VehM(2,2)	1	2	

Array Element	Axle	Track	Moment Axis
VehM(2,3)	2	1	Vehicle-fixed z-axis (vertical)
VehM(2,4)	2	2	
VehM(3,1)	1	1	
VehM(3,2)	1	2	
VehM(3,3)	2	1	
VehM(3,4)	2	2	

**WhlF – Suspension force on wheel**

array

Longitudinal, lateral, and vertical suspension forces at axle **a**, track **t**, applied to the wheel at the axle wheel carrier reference coordinate, in N. Array dimensions are 3 by the total number of tracks on the vehicle.

- WhlF(1, . . .) – Suspension force on wheel along the vehicle-fixed x-axis (longitudinal)
- WhlF(2, . . .) – Suspension force on wheel along the vehicle-fixed y-axis (lateral)
- WhlF(3, . . .) – Suspension force on wheel along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the WhlF:

- Signal dimensions are [3x4].
- Signal contains wheel forces applied to the vehicle according to the axle and track locations.

$$\text{WhlF} = F_w = \begin{bmatrix} F_{wx1,1} & F_{wx1,2} & F_{wx2,1} & F_{wx2,2} \\ F_{wy1,1} & F_{wy1,2} & F_{wy2,1} & F_{wy2,2} \\ F_{wz1,1} & F_{wz1,2} & F_{wz2,1} & F_{wz2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
WhlF(1,1)	1	1	Vehicle-fixed x-axis (longitudinal)
WhlF(1,2)	1	2	
WhlF(1,3)	2	1	
WhlF(1,4)	2	2	
WhlF(2,1)	1	1	Vehicle-fixed y-axis (lateral)
WhlF(2,2)	1	2	
WhlF(2,3)	2	1	
WhlF(2,4)	2	2	
WhlF(3,1)	1	1	Vehicle-fixed z-axis (vertical)
WhlF(3,2)	1	2	
WhlF(3,3)	2	1	
WhlF(3,4)	2	2	

**WhlV – Track velocity**

array

Longitudinal, lateral, and vertical track velocity at axle *a*, track *t*, in m/s. Array dimensions are 3 by the total number of tracks on the vehicle.

- $WhlV(1, \dots)$  — Track velocity along the vehicle-fixed x-axis (longitudinal)
- $WhlV(2, \dots)$  — Track velocity along the vehicle-fixed y-axis (lateral)
- $WhlV(3, \dots)$  — Track velocity along the vehicle-fixed z-axis (vertical)

For example, for a two-axle vehicle with two tracks per axle, the  $WhlV$ :

- Signal dimensions are [3x4].
- Signal contains wheel forces applied to the vehicle according to the axle and track locations.

$$WhlV = \begin{bmatrix} \dot{x}_w \\ \dot{y}_w \\ \dot{z}_w \end{bmatrix} = \begin{bmatrix} \dot{x}_{w1,1} & \dot{x}_{w1,2} & \dot{x}_{w2,1} & \dot{x}_{w2,2} \\ \dot{y}_{w1,1} & \dot{y}_{w1,2} & \dot{y}_{w2,1} & \dot{y}_{w2,2} \\ \dot{z}_{w1,1} & \dot{z}_{w1,2} & \dot{z}_{w2,1} & \dot{z}_{w2,2} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
$WhlV(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$WhlV(1,2)$	1	2	
$WhlV(1,3)$	2	1	
$WhlV(1,4)$	2	2	
$WhlV(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$WhlV(2,2)$	1	2	
$WhlV(2,3)$	2	1	
$WhlV(2,4)$	2	2	
$WhlV(3,1)$	1	1	Vehicle-fixed z-axis (vertical)
$WhlV(3,2)$	1	2	
$WhlV(3,3)$	2	1	
$WhlV(3,4)$	2	2	

**WhlAng — Wheel camber, caster, toe angles**

array

Camber, caster, and toe angles at axle *a*, track *t*, in rad. Array dimensions are 3 by the total number of tracks on the vehicle.

- $WhlAng(1, \dots)$  — Camber angle
- $WhlAng(2, \dots)$  — Caster angle
- $WhlAng(3, \dots)$  — Toe angle

For example, for a two-axle vehicle with two tracks per axle, the  $WhlAng$ :

- Signal dimensions are [3x4].
- Signal contains wheel angles according to the axle and track locations.



$$\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix} = \begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$$

Array Element	Axle	Track	Angle
WhlAng(1,1)	1	1	Camber
WhlAng(1,2)	1	2	
WhlAng(1,3)	2	1	
WhlAng(1,4)	2	2	
WhlAng(2,1)	1	1	Caster
WhlAng(2,2)	1	2	
WhlAng(2,3)	2	1	
WhlAng(2,4)	2	2	
WhlAng(3,1)	1	1	Toe
WhlF(3,2)	1	2	
WhlF(3,3)	2	1	
WhlF(3,4)	2	2	

## Parameters

### Axles

#### Number of axles, NumAxl — Number of axles

2 (default) | scalar

Number of axles,  $N_a$ , dimensionless.

#### Number of tracks by axle, NumTracksByAxl — Number of tracks per axle

[2 2] (default) | vector

Number of tracks per axle,  $N_{t_a}$ , dimensionless. Vector is 1 by the number of vehicle axles,  $N_a$ . For example, [1, 2] represents one track on axle 1 and two tracks on axle 2.

#### Steered axle enable by axle, StrgEnByAxl — Boolean vector to enable axle steering

[1 0] (default) | vector

Boolean vector that enables axle steering,  $En_{steer}$ , dimensionless. Vector is 1 by the number of vehicle axles,  $N_a$ . For example:

- [1 0]—For a two-axle vehicle, enables axle 1 steering and disables axle 2 steering
- [1 1]—For a two-axle vehicle, enables axle 1 and axle 2 steering

### Dependencies

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1:

- Creates input port StrgAng.

- Creates these parameters
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

For example, for a two-axle vehicle with two tracks per axle, you can input steering angles for both wheels on the first axle.

- To create the StrgAng port, set **Steered axle enable by axle, StrgEnByAxl** to [1 0]. The input signal array dimensions are [1x2].
- The StrgAng signal contains two steering angles according to their axle and track locations.

$$\text{StrgAng} = \delta_{steer} = [\delta_{steer1,1} \ \delta_{steer1,2}]$$

Array Element	Axle	Track
StrgAng(1,1)	1	1
StrgAng(1,2)	1	2

**Axle and wheels lumped principal moments of inertia about longitudinal axis, AxlIxx – Inertia**

300 (default) | vector

Axle and wheels lumped principal moments of inertia about longitudinal axis, AxleIxx  $a$ , in kg\*m<sup>2</sup>.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Axle and wheels lumped mass, AxlM – Mass**

[2 2] (default) | vector

Axle and wheels lumped mass,  $a$ , in kg.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Track hardpoint coordinates relative to axle center, TrackCoords – Point**

[0 0 0 0; -1 1 -1 1; 0 0 0 0] (default) | array

Track hardpoint coordinates,  $Tc_t$ , along the solid axle  $x$ ,  $y$ , and  $z$ -axes, in m.

For example, for a two-axle vehicle with two tracks per axle, the TrackCoords array:

- Dimensions are [3x4].
- Contains four track hardpoint coordinates according to their axle and track locations.

$$Tc_t = \begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{w2,2} \\ z_{w1,1} & z_{w1,2} & z_{w2,1} & z_{w2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
TrackCoords (1, 1)	1	1	Solid axle x-axis
TrackCoords (1, 2)	1	2	
TrackCoords (1, 3)	2	1	
TrackCoords (1, 4)	2	2	
TrackCoords (2, 1)	1	1	Solid axle y-axis
TrackCoords (2, 2)	1	2	
TrackCoords (2, 3)	2	1	
TrackCoords (2, 4)	2	2	
TrackCoords (3, 1)	1	1	Solid axle z-axis
TrackCoords (3, 2)	1	2	
TrackCoords (3, 3)	2	1	
TrackCoords (3, 4)	2	2	

**Suspension hardpoint coordinates relative to axle center, SuspCoords – Point**  
`[0 0 0 0; -1 1 -1 1; 0 0 0 0]` (default) | array

Suspension hardpoint coordinates,  $Sc_t$ , along the solid axle x-, y-, and z-axes, in m.

For example, for a two-axle vehicle with two tracks per axle, the SuspCoords array:

- Dimensions are [3x4].
- Contains four track hardpoint coordinates according to their axle and track locations.

$$Sc_t = \begin{bmatrix} x_{s1,1} & x_{s1,2} & x_{s2,1} & x_{s2,2} \\ y_{s1,1} & y_{s1,2} & y_{s2,1} & y_{s2,2} \\ z_{s1,1} & z_{s1,2} & z_{s2,1} & z_{s2,2} \end{bmatrix}$$

Array Element	Axle	Track	Axis
SuspCoords (1, 1)	1	1	Solid axle x-axis
SuspCoords (1, 2)	1	2	

Array Element	Axle	Track	Axis
SuspCoords(1,3)	2	1	
SuspCoords(1,4)	2	2	
SuspCoords(2,1)	1	1	Solid axle y-axis
SuspCoords(2,2)	1	2	
SuspCoords(2,3)	2	1	
SuspCoords(2,4)	2	2	
SuspCoords(3,1)	1	1	Solid axle z-axis
SuspCoords(3,2)	1	2	
SuspCoords(3,3)	2	1	
SuspCoords(3,4)	2	2	

**Wheel and axle interface compliance constant, KzWhlAxl – Spring rate**  
6437000 (default) | scalar

Wheel and axle interface compliance constant,  $K_z$ , in N/m.

**Wheel and axle interface compliance preload, F0zWhlAxl – Spring rate**  
9810 (default) | scalar

Wheel and axle interface compliance preload,  $F_{0z}$ , in N.

**Wheel and axle interface damping constant, CzWhlAxl – Damping**  
10000 (default) | scalar

Wheel and axle interface damping constant,  $C_z$ , in m.

## Suspension

### Compliance and Damping - Passive

**Suspension spring constant, Kz – Suspension spring constant**  
64370 (default) | scalar | vector

Linear vertical spring constant for independent suspension tracks on axle a,  $k_{z_a}$ , in N/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Suspension spring preload, F0z – Suspension spring preload**  
9810 (default) | scalar | vector

Vertical preload spring force applied to the wheels on the axle at wheel carrier reference coordinates,  $F_{z0,a}$ , in N. Positive preload forces:

- Cause the vehicle to lift.
- Point along the negative vehicle-fixed  $z$ -axis.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

### **Suspension shock damping constant, Cz — Suspension shock damping constant**

10000 (default) | scalar | vector

Linear vertical damping constant for independent suspension tracks on axle  $a$ ,  $c_{z,a}$ , in Ns/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Dependencies**

To create this parameter, clear **Enable active damping**.

### **Suspension maximum height, Hmax — Height**

0.5 (default) | scalar | vector

Maximum suspension extension or minimum suspension compression height,  $H_{max}$ , for axle  $a$  before the suspension reaches a hardstop, in m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Geometry**

### **Toe angle at steering center, Toe — Toe angle**

0.0349 (default) | scalar

Nominal suspension toe angle at zero steering angle,  $\zeta_{0a}$ , in rad.

### **Roll steer vs suspension height slope, RollStrgSlp — Steer angle suspension slope**

-0.2269 (default) | scalar | vector

Roll steer angle versus suspension height,  $m_{htoe,a}$ , in rad/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

### **Toe angle vs steering angle slope, ToeStrgSlp — Toe angle steering slope**

0.01 (default) | scalar | vector

Toe angle versus steering angle slope,  $m_{toesteer,a}$ , dimensionless.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Dependencies**

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

**Caster angle at steering center, Caster – Caster angle at steering center**

0.0698 (default) | scalar

Nominal suspension caster angle at zero steering angle,  $\eta_{0a}$ , in rad.

**Caster angle vs suspension height slope, CasterHslp – Caster angle versus suspension height slope**

-0.2269 (default) | scalar | vector

Caster angle versus suspension height,  $m_{h_{caster,a}}$ , in rad/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Caster angle vs steering angle slope, CasterStrgSlp – Caster angle versus steering angle slope**

0.01 (default) | scalar | vector

Caster angle versus steering angle slope,  $m_{castersteer,a}$ , dimensionless.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

**Dependencies**

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

**Camber angle at steering center, Camber – Camber angle at steering center**

0.0698 (default) | scalar

Nominal suspension camber angle at zero steering angle,  $\xi_{0a}$ , in rad.

**Camber angle vs suspension height slope, CamberHslp – Camber angle versus suspension height slope**

-0.2269 (default) | scalar | vector

Camber angle versus suspension height,  $m_{h_{camber,a}}$ , in rad/m.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

### **Camber angle vs steering angle slope, CamberStrgSlp – Camber angle versus steering angle slope**

0.01 (default) | scalar | vector

Camber angle versus steering angle slope,  $m_{cambersteer_a}$ , dimensionless.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Dependencies**

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

### **Suspension height vs steering angle slope, StrgHgtSlp – Suspension height versus steering angle slope**

0.1432 (default) | scalar | vector

Steering angle to vertical force slope applied at suspension wheel carrier reference point,  $m_{hsteer_a}$ , in m/rad.

Vector is 1 by the number of vehicle axles,  $N_a$ . If you provide a scalar value, the block uses that value for all axles.

#### **Dependencies**

Setting an element of the **Steered axle enable by axle, StrgEnByAxl** vector to 1 creates:

- Input port StrgAng.
- Parameters:
  - **Toe angle vs steering angle slope, ToeStrgSlp**
  - **Caster angle vs steering angle slope, CasterStrgSlp**
  - **Camber angle vs steering angle slope, CamberStrgSlp**
  - **Suspension height vs steering angle slope, StrgHgtSlp**

## **References**

[1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers, 1992.

[2] Vehicle Dynamics Standards Committee. *Vehicle Dynamics Terminology*. SAE J670. Warrendale, PA: Society of Automotive Engineers, 2008.

[3] Technical Committee. *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*. ISO 8855:2011. Geneva, Switzerland: International Organization for Standardization, 2011.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Solid Axle Suspension | Solid Axle Suspension - Coil Spring | Solid Axle Suspension - Mapped

**Introduced in R2018a**



# Drivetrain Blocks

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## Rotational Inertia

Ideal mechanical rotational inertia

**Library:** Powertrain Blockset / Drivetrain / Couplings  
Vehicle Dynamics Blockset / Powertrain / Drivetrain / Couplings



### Description

The Rotational Inertia block implements an ideal mechanical rotational inertia.

### Power Accounting

For the power accounting, the block implements these equations.

Bus Signal		Description	Variable	Equations	
PwrInfo	PwrTrnsfrd — Power transferred between blocks  <ul style="list-style-type: none"> <li>Positive signals indicate flow into block</li> <li>Negative signals indicate flow out of block</li> </ul>	PwrR	Mechanical power from base shaft	$P_{TR}$	$P_{TR} = T_R\omega$
		PwrC	Mechanical power from follower shaft	$P_{TC}$	$P_{TC} = T_C\omega$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred  <ul style="list-style-type: none"> <li>Positive signals indicate an input</li> <li>Negative signals indicate a loss</li> </ul>	PwrDampLoss	Power loss due to damping	$P_d$	$P_d = -b \omega ^2$
	PwrStored — Stored energy rate of change  <ul style="list-style-type: none"> <li>Positive signals indicate an increase</li> <li>Negative signals indicate a decrease</li> </ul>	PwrStoredShft	Rate change of stored internal torsional energy	$P_s$	$P_s = \omega\dot{\omega}J$

The equations use these variables.

$T_R$	Input torque
$T_C$	Output torque
$\omega$	Driveshaft angular velocity
$J$	Rotational inertia
$b$	Rotational viscous damping
$P_d$	Power loss due to damping
$P_s$	Rate change of stored internal torsional energy

## Ports

### Input

#### RTrq — Input torque

scalar

Applied input driveshaft torque,  $T_R$ , in N·m.

#### Dependencies

To enable this port, for **Port Configuration**, select Simulink.

#### CTrq — Output torque

scalar

Load driveshaft torque,  $T_C$ , in N·m.

#### Dependencies

To enable this port, for **Port Configuration**, select Simulink.

#### R — Angular velocity and torque

two-way connector port

Angular velocity in rad/s. Torque is in N·m.

#### Dependencies

To enable this port, for **Port Configuration**, select Two-way connection.

#### Inertia — Input

scalar

Rotational inertia, in kg·m<sup>2</sup>.

#### Dependencies

To create the Inertia port, select **External inertia input**.

### Output

#### Info — Bus signal

bus

Bus signal containing these block calculations.

Signal		Description	Variable	Units	
Trq	R	Applied input driveshaft torque	$T_R$	N·m	
	C	Output driveshaft torque	$T_C$	N·m	
	Damp	Damping torque	$T_d=b\omega$	N·m	
Spd		Angular driveshaft speed	$\omega$	rad/s	
PwrInfo	PwrTrnsfrd	PwrR	Mechanical power from base shaft	$P_{TR}$	W
		PwrC	Mechanical power from follower shaft	$P_{TC}$	W
	PwrNotTrnsfrd	PwrDampLoss	Power loss due to damping	$P_d$	W
	PwrStored	PwrStoredShft	Rate change of stored internal torsional energy	$P_s$	W

**Dependencies**

To enable this port, select **Output Info bus**.

**Spd — Driveshaft speed**

scalar

Angular driveshaft speed,  $\omega$ , in rad/s.

**Dependencies**

To enable this port, for **Port Configuration**, select Simulink.

**C — Angular velocity and torque**

two-way connector port

Angular velocity in rad/s. Torque is in N·m.

**Dependencies**

To enable this port, for **Port Configuration**, select Two-way connection.

**Parameters**

**Block Options**

**Port Configuration — Specify configuration**

Simulink (default) | Two-way connection

Specify the port configuration.

**Dependencies**

Specifying Simulink creates these ports:

- RTrq
- CTrq
- Spd

Specifying **Two-way** connection creates these ports:

- R
- C

### Output Info bus – Selection

off (default) | on

Select to create the Info output port.

### External inertia input – Input rotational inertia

off (default) | on

#### Dependencies

To create the Inertia port, select **External inertia input**.

#### Parameters

### Rotational inertia, J – Inertia

.01 (default) | scalar

Rotational inertia, in  $\text{kg}\cdot\text{m}^2$ .

#### Dependencies

To enable this parameter, clear **Input rotational inertia**.

### Torsional damping, b – Damping

.001 (default) | scalar

Torsional damping, in  $\text{N}\cdot\text{m}\cdot\text{s}/\text{rad}$ .

### Initial velocity, omega\_o – Angular

0 (default) | scalar

Initial angular velocity, in rad/s.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

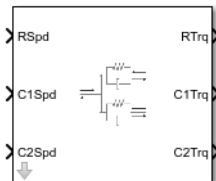
Split Torsional Compliance | Torsional Compliance

### Introduced in R2017a

## Split Torsional Compliance

Split torsional coupler

**Library:** Powertrain Blockset / Drivetrain / Couplings  
Vehicle Dynamics Blockset / Powertrain / Drivetrain / Couplings



### Description

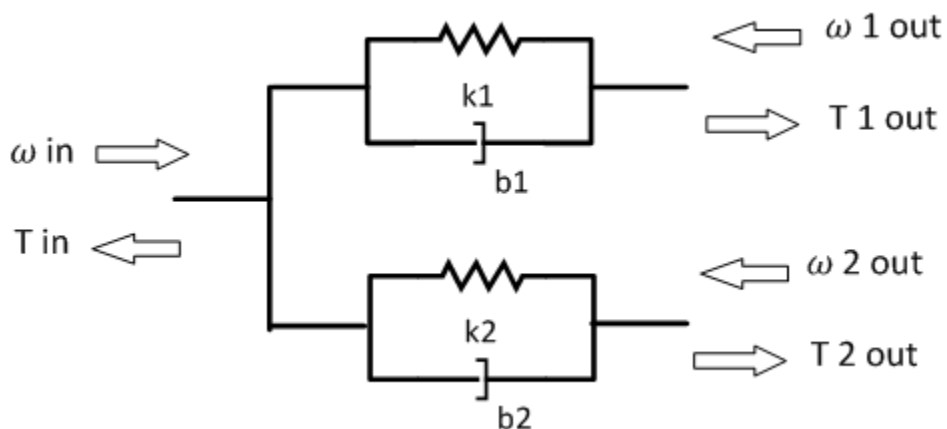
The Split Torsional Compliance block implements parallel spring-damper coupling between shafts. You can specify the type of coupling by selecting one of the **Coupling Configuration** parameters:

- Shaft `split` — Single input shaft coupled to two output shafts
- Shaft `merge` — Two input shafts coupled to a single output shaft

In fuel economy and emissions studies, you can use the Split Torsional Compliance block to model mechanical rotational compliance between common driveline elements such as motors, planetary gears, and clutches. For example, use the `Shaft split` configuration to couple a motor and two planetary gear sets. Use the `Shaft merge` configuration to couple a dual clutch transmission to an output shaft.

### Shaft Split

For the `Shaft split` configuration, the block implements this schematic and equations.



$$T_{in} = -(\omega_{in} - \omega_{1out})b_1 - (\omega_{in} - \omega_{2out})b_2 - \theta_1 k_1 - \theta_2 k_2$$

$$T_{1out} = (\omega_{in} - \omega_{1out})b_1 + \theta_1 k_1$$

$$T_{2out} = (\omega_{in} - \omega_{2out})b_2 + \theta_2 k_2$$

$$\dot{\theta}_1 = (\omega_{in} - \omega_{1out})$$

$$\dot{\theta}_2 = (\omega_{in} - \omega_{2out})$$

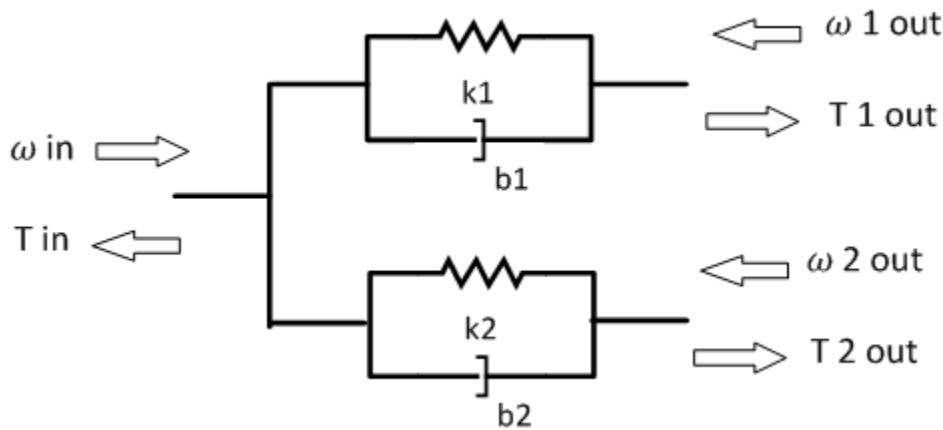
To account for frequency-dependent damping, both damping terms incorporate a low-pass filter.

The equations use these variables.

$T_{in}$	Resulting applied input reaction torque
$\omega_{in}$	Input shaft rotational velocity
$T_{1out}$	Resulting applied torque to first output shaft
$\omega_{1out}$	First output shaft rotational velocity
$T_{2out}$	Resulting applied torque to second output shaft
$\omega_{2out}$	Second output shaft rotational velocity
$\theta_1, \theta_2$	First, second shaft rotation, respectively
$b_1, b_2$	First, second shaft viscous damping, respectively
$k_1, k_2$	First, second shaft torsional stiffness, respectively

### Shaft Merge

For the Shaft merge configuration, the block implements this schematic and equations.



$$T_{out} = (-\omega_{out} + \omega_{1in})b_1 + (-\omega_{out} + \omega_{2in})b_2 + \theta_1 k_1 + \theta_2 k_2$$

$$T_{1out} = (\omega_{out} - \omega_{1in})b_1 - \theta_1 k_1$$

$$T_{2out} = (\omega_{out} - \omega_{2in})b_2 - \theta_2 k_2$$

$$\dot{\theta}_1 = (\omega_{1in} - \omega_{out})$$

$$\dot{\theta}_2 = (\omega_{2in} - \omega_{out})$$

To account for frequency-dependent damping, both damping terms incorporate a low-pass filter.

The equations use these variables.

$T_{out}$	Resulting applied output torque
$\omega_{out}$	Output shaft rotational velocity
$T_{1in}$	Resulting reaction torque to first input shaft
$\omega_{1in}$	First input shaft rotational velocity
$T_{2in}$	Resulting reaction torque to second input shaft
$\omega_{2in}$	Second input shaft rotational velocity
$\theta_1, \theta_2$	First, second shaft rotation, respectively
$b_1, b_2$	First, second shaft viscous damping, respectively
$k_1, k_2$	First, second shaft torsional stiffness, respectively

### Power Accounting

For the power accounting, the block implements these equations.

Bus Signal		Description	Variable	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks <ul style="list-style-type: none"> <li>• Positive signals indicate flow into block</li> <li>• Negative signals indicate flow out of block</li> </ul>	PwrR	For the Shaft split configuration, mechanical power from input shaft	$P_{TR} = -T_R\omega_R$
		PwrC1	For the Shaft split configuration, mechanical power from first output shaft	$P_{TC1} = -T_{C1}\omega_{C1}$
		PwrC2	For the Shaft split configuration, mechanical power from second output shaft	$P_{TC2} = -T_{C2}\omega_{C2}$
		PwrC	For the Shaft merge configuration, mechanical power from output shaft	$P_{TC} = T_C\omega_C$



Bus Signal		Description	Variable	Equations
	PwrR1	For the Shaft merge configuration, mechanical power from first input shaft	$P_{TR1}$	$P_{TR1} = T_{R1}\omega_{R1}$
	PwrR2	For the Shaft merge configuration, mechanical power from second input shaft	$P_{TR2}$	$P_{TR2} = T_{R2}\omega_{R2}$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred  <ul style="list-style-type: none"> <li>• Positive signals indicate an input</li> <li>• Negative signals indicate a loss</li> </ul>	PwrDampLoss	Mechanical damping loss	$P_d = -\left(b_1 \dot{\theta}_1 ^2 + b_2 \dot{\theta}_2 ^2\right)$
	PwrStored — Stored energy rate of change  <ul style="list-style-type: none"> <li>• Positive signals indicate an increase</li> <li>• Negative signals indicate a decrease</li> </ul>	PwrStoredShft	Rate change in spring energy	$P_s = \left(k_1\theta_1\dot{\theta}_1 + k_2\theta_2\dot{\theta}_2\right)$

The equations use these variables.

$T_R$	Shaft R torque
$T_C$	Shaft C torque
$\omega_R$	Shaft R angular velocity
$\omega_C$	Shaft C angular velocity
$\theta$	Coupled shaft rotation
$k$	Shaft torsional stiffness
$b$	Rotational viscous damping
$P_t$	Total mechanical power
$P_d$	Power loss due to damping
$P_s$	Rate change of stored spring energy

## Ports

### Input

#### **RSpd — Input shaft speed**

scalar

Input shaft rotational velocity,  $\omega_{in}$ , in rad/s.

#### **Dependencies**

To enable this port, set both of these parameters:

- **Port Configuration** to Simulink
- **Coupling Configuration** to Shaft split

#### **C1Spd — First output shaft speed**

scalar

First output shaft rotational velocity,  $\omega_{1out}$ , in rad/s.

#### **Dependencies**

To enable this port, set both of these parameters:

- **Port Configuration** to Simulink
- **Coupling Configuration** to Shaft split

#### **C2Spd — Second output shaft speed**

scalar

Second output shaft rotational velocity,  $\omega_{2out}$ , in rad/s.

#### **Dependencies**

To enable this port, set both of these parameters:

- **Port Configuration** to Simulink
- **Coupling Configuration** to Shaft split

#### **CSpd — Input speed**

scalar

Output shaft rotational velocity,  $\omega_{out}$ , in rad/s.

#### **Dependencies**

To enable this port, set both of these parameters:

- **Port Configuration** to Simulink
- **Coupling Configuration** to Shaft merge

#### **R1Spd — First input shaft speed**

scalar

First input shaft rotational velocity,  $\omega_{1in}$ , in rad/s.

**Dependencies**

To enable this port, set both of these parameters:

- **Port Configuration** to Simulink
- **Coupling Configuration** to Shaft merge

**R2Spd – Second input shaft speed**

scalar

Second input shaft rotational velocity,  $\omega_{2in}$ , in rad/s.

**Dependencies**

To enable this port, set both of these parameters:

- **Port Configuration** to Simulink
- **Coupling Configuration** to Shaft merge

**R – Input shaft angular velocity and torque**

two-way connector port

Input shaft angular velocity,  $\omega_{in}$ , in rad/s and torque,  $T_{in}$ , in N·m.

**Dependencies**

To enable this port, select:

- **Port Configuration**>Two-way connection
- **Coupling Configuration**>Shaft split

**R1 – First input shaft angular velocity and torque**

two-way connector port

First input shaft angular velocity,  $\omega_{1in}$ , in rad/s and torque,  $T_{1in}$ , in N·m.

**Dependencies**

To enable this port, select:

- **Port Configuration**>Two-way connection
- **Coupling Configuration**>Shaft merge

**R2 – Second input shaft angular velocity and torque**

two-way connector port

Second input shaft angular velocity,  $\omega_{2in}$ , in rad/s and torque,  $T_{2in}$ , in N·m.

**Dependencies**

To enable this port, select:

- **Port Configuration**>Two-way connection
- **Coupling Configuration**>Shaft merge

**Output**

**Info – Bus signal**

bus

If you set **Coupling Configuration** to Shaft split, the Info bus contains these signals.

Signal		Description	Variable	Units	
Trq	R	Input shaft torque	$T_{in}$	N·m	
	C1	First output shaft torque	$T_{1out}$	N·m	
	C2	Second output shaft torque	$T_{2out}$	N·m	
	Damp	C1	First output shaft damping torque	$b_1\omega_{1out}$	N·m
		C2	Second output shaft damping torque	$b_2\omega_{2out}$	N·m
	Spring	C1	First output shaft spring torque	$k_1\theta_1$	N·m
C2		Second output shaft spring torque	$k_2\theta_2$	N·m	
Spd	R	Input shaft angular velocity	$\omega_{in}$	rad/s	
	C1	First output shaft angular velocity	$\omega_{1out}$	rad/s	
	C2	Second output shaft angular velocity	$\omega_{2out}$	rad/s	
	deltadot1	Difference in input and first output shaft angular velocity	$\dot{\theta}_1$	rad/s	
	deltadot2	Difference in input and second output shaft angular velocity	$\dot{\theta}_2$	rad/s	
PwrInfo	PwrTrnsfrd	PwrR	Mechanical power from input shaft	$P_{TR}$	W
		PwrC1	Mechanical power from first output shaft	$P_{TC1}$	W
		PwrC2	Mechanical power from second output shaft	$P_{TC2}$	W
	PwrNotTrnsfrd	PwrDampLoss	Mechanical damping loss	$P_d$	W
	PwrStored	PwrStoredShft	Rate change of stored internal torsional energy	$P_s$	W

If you set **Coupling Configuration** to Shaft merge, the Info bus contains these signals.

Signal		Description	Variable	Units
Trq	C	Output shaft torque	$T_{out}$	N·m
	R1	First input shaft torque	$T_{1in}$	N·m
	R2	Second input shaft torque	$T_{2in}$	N·m

Signal			Description	Variable	Units
	Damp	R1	First input shaft damping torque	$b_1\omega_{1in}$	N·m
		R2	Second in shaft damping torque	$b_2\omega_{2in}$	N·m
	Spring	R1	First input shaft spring torque	$k_1\theta_1$	N·m
		R2	Second in shaft spring torque	$k_2\theta_2$	N·m
Spd	C		Output shaft angular velocity	$\omega_{out}$	rad/s
	R1		First input shaft angular velocity	$\omega_{1in}$	rad/s
	R2		Second input shaft angular velocity	$\omega_{2in}$	rad/s
	deltadot1		Difference in first input and output shaft angular velocity	$\dot{\theta}_1$	rad/s
	deltadot2		Difference in second input and output shaft angular velocity	$\dot{\theta}_2$	rad/s
PwrInfo	PwrTrnsfrd	PwrC	Mechanical power from output shaft	$P_{TC}$	W
		PwrR1	Mechanical power from first input shaft	$P_{TR1}$	W
		PwrR2	Mechanical power from second input shaft	$P_{TR2}$	W
	PwrNotTrnsfrd	PwrDampLoss	Mechanical damping loss	$P_d$	W
	PwrStored	PwrStoredShft	Rate change of stored internal torsional energy	$P_s$	W

### Dependencies

To enable this port, select **Output Info bus**.

### RTrq – Input shaft torque

scalar

Input shaft torque,  $T_{in}$ , in N·m.

### Dependencies

To enable this port, set both of these parameters:

- **Port Configuration** to Simulink
- **Coupling Configuration** to Shaft split

### C1Trq – First output shaft torque

scalar

First output shaft torque,  $T_{1out}$ , in N·m.

### Dependencies

To enable this port, set both of these parameters:

- **Port Configuration** to Simulink
- **Coupling Configuration** to Shaft split

**C2Trq — Second output shaft torque**

scalar

Second output shaft torque,  $T_{2out}$ , in N·m.**Dependencies**

To enable this port, set both of these parameters:

- **Port Configuration** to Simulink
- **Coupling Configuration** to Shaft split

**CTrq — Output shaft torque**

scalar

Output shaft torque,  $T_{out}$ , in N·m.**Dependencies**

To enable this port, set both of these parameters:

- **Port Configuration** to Simulink
- **Coupling Configuration** to Shaft merge

**R1Trq — First input shaft torque**

scalar

First input shaft torque,  $T_{1in}$ , in N·m.**Dependencies**

To enable this port, set both of these parameters:

- **Port Configuration** to Simulink
- **Coupling Configuration** to Shaft merge

**R2Trq — Second input shaft torque**

scalar

Second input shaft torque,  $T_{2in}$ , in N·m.**Dependencies**

To enable this port, set both of these parameters:

- **Port Configuration** to Simulink
- **Coupling Configuration** to Shaft merge

**C1 — First output shaft angular velocity and torque**

two-way connector port

First output shaft angular velocity,  $\omega_{1out}$ , in rad/s and torque,  $T_{1out}$ , in N·m.

**Dependencies**

To enable this port, select:

- **Port Configuration**>Two-way connection
- **Coupling Configuration**>Shaft split

**C2 — Second output shaft angular velocity and torque**

two-way connector port

Second output shaft angular velocity,  $\omega_{2out}$ , in rad/s and torque,  $T_{2out}$ , in N·m.

**Dependencies**

To enable this port, select:

- **Port Configuration**>Two-way connection
- **Coupling Configuration**>Shaft split

**C — Output shaft angular velocity and torque**

two-way connector port

Output shaft angular velocity,  $\omega_{out}$ , in rad/s and torque,  $T_{out}$ , in N·m.

**Dependencies**

To enable this port, select:

- **Port Configuration**>Two-way connection
- **Coupling Configuration**>Shaft merge

**Parameters****Block Options****Port Configuration — Specify configuration**

Simulink (default) | Two-way connection

Specify the port configuration.

**Coupling Configuration — Specify configuration**

Shaft split (default) | Shaft merge

Specify the coupling type.

**Output Info bus — Selection**

off (default) | on

Select to create the Info output port.

**Coupling 1****Torsional stiffness, k1 — Stiffness**

5e4 (default) | scalar

Rotational inertia,  $k_1$ , in N·m/rad.

**Torsional damping, b1 — Damping**

1e2 (default) | scalar

Torsional damping,  $b_1$ , in N·m· s/rad.

**Damping cutoff frequency, omega1\_c — Frequency**

3000 (default) | scalar

Damping cutoff frequency, in rad/s.

**Coupling 2**

**Torsional stiffness, k2 — Stiffness**

5e4 (default) | scalar

Rotational inertia,  $k_2$ , in N·m/rad.

**Torsional damping, b2 — Damping**

1e2 (default) | scalar

Torsional damping,  $b_2$ , in N·m· s/rad.

**Damping cutoff frequency, omega2\_c — Frequency**

3000 (default) | scalar

Damping cutoff frequency, in rad/s.

**Extended Capabilities**

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Rotational Inertia | Torsional Compliance

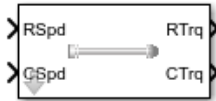
**Introduced in R2017b**



# Torsional Compliance

Parallel spring-damper

**Library:** Powertrain Blockset / Drivetrain / Couplings  
Vehicle Dynamics Blockset / Powertrain / Drivetrain / Couplings



## Description

The Torsional Compliance block implements a parallel spring-damper to couple two rotating driveshafts. The block uses the driveshaft angular velocities, torsional stiffness, and torsional damping to determine the torques.

$$T_R = -(\omega_R - \omega_C)b - \theta k$$

$$T_C = (\omega_R - \omega_C)b + \theta k$$

$$\dot{\theta} = (\omega_R - \omega_C)$$

## Power Accounting

For the power accounting, the block implements these equations.

Bus Signal	Description	Variable	Equations	
PwrInfo	PwrTrnsfrd — Power transferred between blocks	PwrR	Mechanical power from driveshaft R	$P_{TR} = T_R \omega_R$
	<ul style="list-style-type: none"> <li>Positive signals indicate flow into block</li> <li>Negative signals indicate flow out of block</li> </ul>	PwrC	Mechanical power from driveshaft C	$P_{TC} = T_C \omega_C$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred	PwrDampLoss	Mechanical damping loss	$P_d = -b \dot{\theta} ^2$
	<ul style="list-style-type: none"> <li>Positive signals indicate an input</li> <li>Negative signals indicate a loss</li> </ul>			

Bus Signal		Description	Variable	Equations	
	PwrStored — Stored energy rate of change <ul style="list-style-type: none"> <li>Positive signals indicate an increase</li> <li>Negative signals indicate a decrease</li> </ul>	PwrStoredShft	Rate change in spring energy	$P_s$	$P_s = -\theta k \dot{\theta}$

The equations use these variables.

$T_R$	Driveshaft R torque
$T_C$	Driveshaft C torque
$\omega_R$	Driveshaft R angular velocity
$\omega_C$	Driveshaft C angular velocity
$\theta$	Coupled driveshaft rotation
$k$	Driveshaft torsional stiffness
$b$	Rotational viscous damping
$P_d$	Power loss due to damping
$P_s$	Rate change of stored spring energy

## Ports

### Input

#### RSpd — Driveshaft R angular velocity

scalar

Input driveshaft angular velocity, in rad/s.

#### Dependencies

To enable this port, for **Port Configuration**, select Simulink.

#### CSpd — Driveshaft C angular velocity

scalar

Output driveshaft angular velocity, in rad/s.

#### Dependencies

To enable this port, for **Port Configuration**, select Simulink.

#### R — Angular velocity and torque

two-way connector port

Angular velocity in rad/s. Torque is in N·m.

#### Dependencies

To enable this port, for **Port Configuration**, select Two-way connection.

## Output

### Info — Bus signal

bus

Bus signal containing these block calculations.

Signal		Description	Variable	Units	
Trq	R	Input driveshaft torque	$T_R$	N·m	
	C	Output driveshaft torque	$T_C$	N·m	
	Damp	Damping torque	$T_s = b\dot{\theta}$	N·m	
	Spring	Spring torque	$T_d = k\theta$	N·m	
Spd	R	Input driveshaft angular velocity	$\omega_R$	rad/s	
	C	Output driveshaft angular velocity	$\omega_C$	rad/s	
	deltadot	Difference in input and output driveshaft angular velocity	$\dot{\theta}$	rad/s	
PwrInfo	PwrTrnsfrd	PwrR	Mechanical power from driveshaft R	$P_{TR}$	W
		PwrC	Mechanical power from driveshaft C	$P_{TC}$	W
	PwrNotTrnsfrd	PwrDampLoss	Power loss due to damping	$P_d$	W
	PwrStored	PwrStoredShft	Rate change of stored internal kinetic energy	$P_s$	W

### Dependencies

To enable this port, select **Output Info bus**.

### RTrq — Driveshaft R torque

scalar

Input drive shaft torque, in N·m.

### Dependencies

To enable this port, for **Port Configuration**, select Simulink.

### CTrq — Driveshaft C torque

scalar

Applied output driveshaft torque, in N·m.

### Dependencies

To enable this port, for **Port Configuration**, select Simulink.

**C – Angular velocity and torque**

two-way connector port

Angular velocity in rad/s. Torque is in N·m.

**Dependencies**To enable this port, for **Port Configuration**, select `Two-way` connection.**Parameters****Block Options****Port Configuration – Specify configuration**Simulink (default) | `Two-way` connection

Specify the port configuration.

**Dependencies**Specifying `Simulink` creates these ports:

- `RSpd`
- `CSpd`
- `RTrq`
- `CTrq`

Specifying `Two-way` connection creates these ports:

- `R`
- `C`

**Output Info bus – Selection**`off` (default) | `on`Select to create the `Info` output port.**Torsional stiffness, k – Inertia**`1e4` (default) | `scalar`

Torsional stiffness, in N·m/rad.

**Torsional damping, b – Damping**`1e2` (default) | `scalar`

Torsional damping, in N·m·s/rad.

**Initial deflection, theta\_o – Angular**`0` (default) | `scalar`

Initial deflection, in rad.

**Initial velocity difference, domega\_o – Angular**`0` (default) | `scalar`

Initial velocity difference, in rad/s.

**Damping cut-off frequency, omega\_c — Frequency**

3000 (default) | scalar

Damping cut-off frequency, in rad/s.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

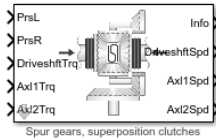
Rotational Inertia | Split Torsional Compliance

**Introduced in R2017a**

## Active Differential

Spur or planetary active differential gear

**Library:** Vehicle Dynamics Blockset / Powertrain / Drivetrain / Final Drive Unit



### Description

The Active Differential block implements an active differential to account for the power transfer from the driveshaft to the axles. The block models the active differential as an open differential coupled to either a spur or planetary differential gear set. The block uses external pressure signals to regulate the clutch pressure to either speed up or slow down each axle rotation.

Use the block in hardware-in-the-loop (HIL) and optimization workflows to dynamically couple the driveshaft to the wheel axles when you want to direct the transmission torque to a specific axle. For detailed front wheel driving studies, use the block to couple the driveshaft to universal joints. The block is suitable to use in system-level closed-loop control studies, for example, yaw stability and torque vectoring. All the parameters are tunable.

To specify the active differential, open the **Active Differential** parameters and specify **Active differential type**.

Setting	Block Implementation
Spur gears, superposition clutches	Clutches are in superposition through a three-gang gear system and a differential case
Double planetary gears, stationary clutches	Clutches are fixed to the carrier and axles through double planetary gear sets

Use the **Open Differential** parameter **Crown wheel (ring gear) located** to specify the open differential location, either to the left or right of the center-line.

Depending on the available data, to specify the method to couple the different torques applied to the axles, use the **Slip Coupling** parameter **Coupling type**.

Setting	Block Implementation
Pre-loaded ideal clutch	Torque modeled as a dry clutch with constant friction coefficients
Slip speed dependent torque data	Torque determined from a lookup table that is a function of slip-speed and clutch pressure

The Active Differential block does not include a controller or external clutch actuator dynamics. Use this information to control the input clutch pressure. The info bus contains the slip speeds at clutch 1,  $\Delta\omega_{cl1}$ , and clutch 2,  $\Delta\omega_{cl2}$ .

Input Axle Torque	$\Delta\omega_{cl1}$	$\Delta\omega_{cl2}$	Input Clutch Pressure
Positive axle 1 torque	$> 0$	N/A	Increase clutch 1 pressure
Positive axle 1 torque	$< 0$	N/A	Disengage clutch 1 and 2
Positive axle 2 torque	N/A	$> 0$	Increase clutch 1 pressure
Positive axle 2 torque	N/A	$< 0$	Disengage clutch 1 and 2

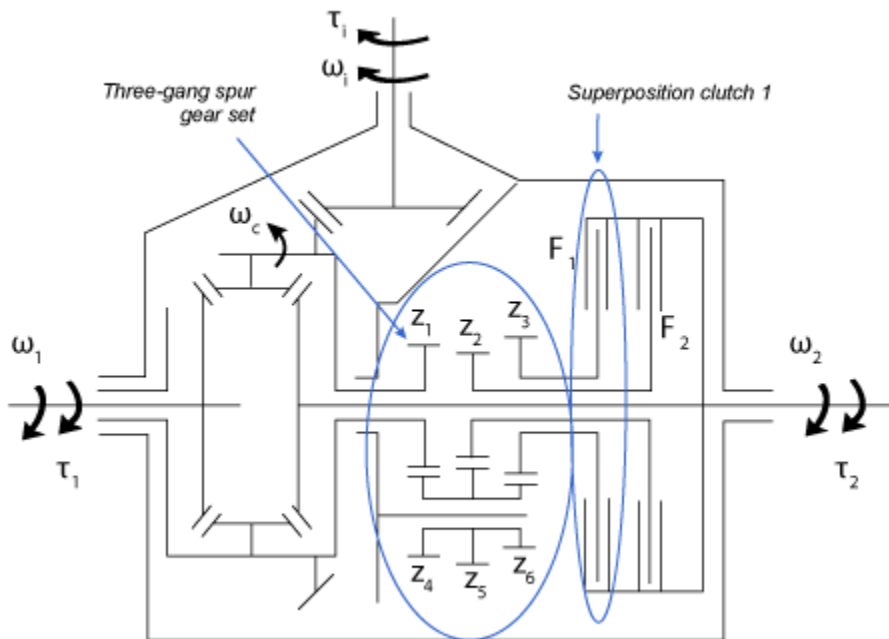
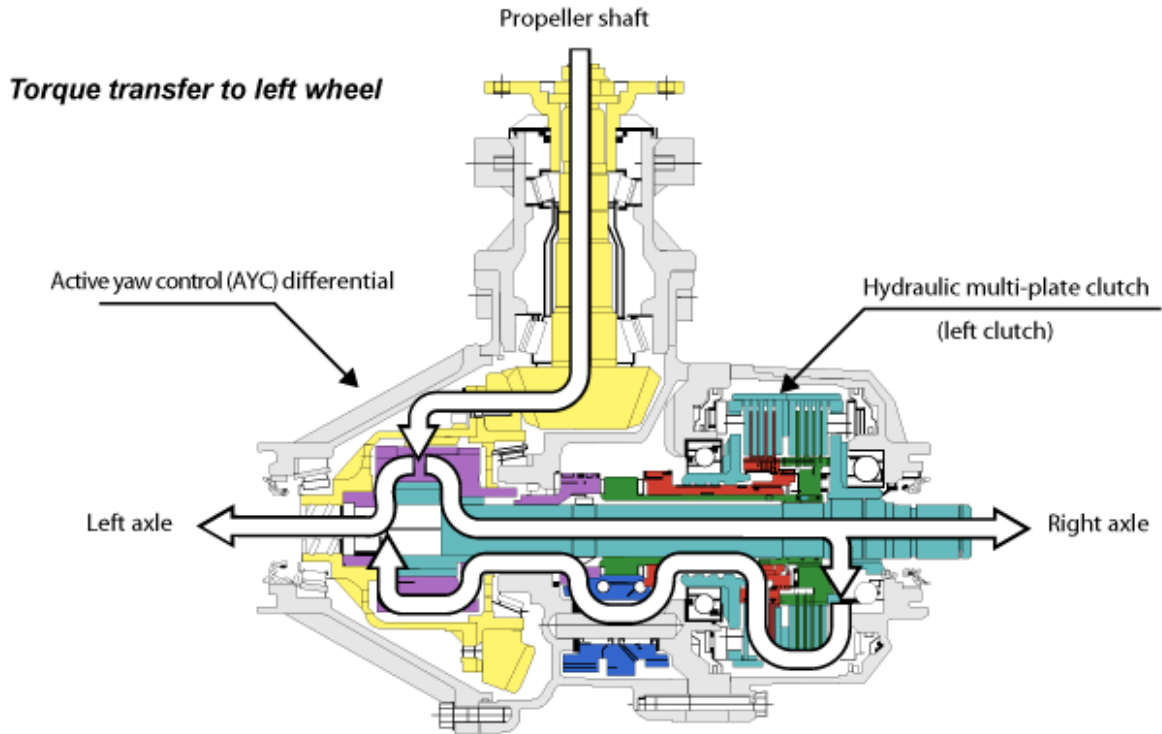
### Differentials

The Active Differential block implements these equations to represent the mechanical dynamic response for the superposition and stationary clutch configurations. To determine the gear ratios, the block uses the clutch speed and the number of teeth for each gear pair. The allowable wheel speed difference (AWSD) limits the wheel speed difference for positive torque.

Mechanical Dynamic Response	Equations	
	Superposition Clutches and Spur Gearing	Stationary Clutches and Planetary Gearing
Crown gear	$\dot{\omega}_d(J_d + J_{gs}) = T_d - \omega_d b_d - T_i$	$\dot{\omega}_d(J_d + J_{s1} + J_{s2}) = T_d - \omega_d b_d - T_i$
Axle 1	$\dot{\omega}_1 J_1 = \eta T_1 - \omega_1 b_1 - T_{i1}$	$\dot{\omega}_1(J_1 + J_{r1}) = T_1 - \omega_1 b_1 - T_{i1}$
Axle 2	$\dot{\omega}_2 J_2 = \eta T_2 - \omega_2 b_2 - T_{i2}$	$\dot{\omega}_2(J_{axle2} + J_{r1}) = T_2 - \omega_2 b_2 - T_{i2}$
Gear ratios	$\frac{\omega_{cl1}}{\omega_d} = N_{s1} = \frac{z_1 z_6}{z_4 z_3}$ $\frac{\omega_{cl2}}{\omega_d} = N_{s2} = \frac{z_1 z_5}{z_4 z_2}$	$\frac{\omega_{cl1}}{\omega_d} = N_{p1} = \frac{z_1 z_6}{z_4 z_3}$ $\frac{\omega_{cl2}}{\omega_d} = N_{p2} = \frac{z_1 z_5}{z_4 z_2}$
Rigid Coupling Constraints	$T_1 = \frac{NT_i}{2} - \frac{N_{s2}}{2} T_{cl2} + \frac{N_{s1}}{2} T_{cl1}$ $T_2 = \frac{NT_i}{2} + (1 - \frac{N_{s2}}{2}) T_{cl2} - (1 - \frac{N_{s1}}{2}) T_{cl1}$ $\omega_d = \frac{N}{2}(\omega_1 + \omega_2)$	$T_1 = \frac{NT_i}{2} - \frac{N_{p2}}{(N_{p2} - 1)2} T_{cl2} + \frac{(2 - N_{p1})}{(N_{p1} - 1)2} T_{cl1}$ $T_2 = \frac{NT_i}{2} + \frac{(2 - N_{p2})}{(N_{p2} - 1)2} T_{cl2} - \frac{N_{p1}}{(N_{p1} - 1)2} T_{cl1}$ $\omega_d = \frac{N}{2}(\omega_1 + \omega_2)$
Allowable wheel speed difference (AWSD)	$\overline{\Delta\omega}_{max} = (N_{s2} - N_{s1}) \cdot 100\%$	$\overline{\Delta\omega}_{max} = (N_{p1,2} - 1) \cdot 100\%$

### Superposition Clutches and Spur Gearing

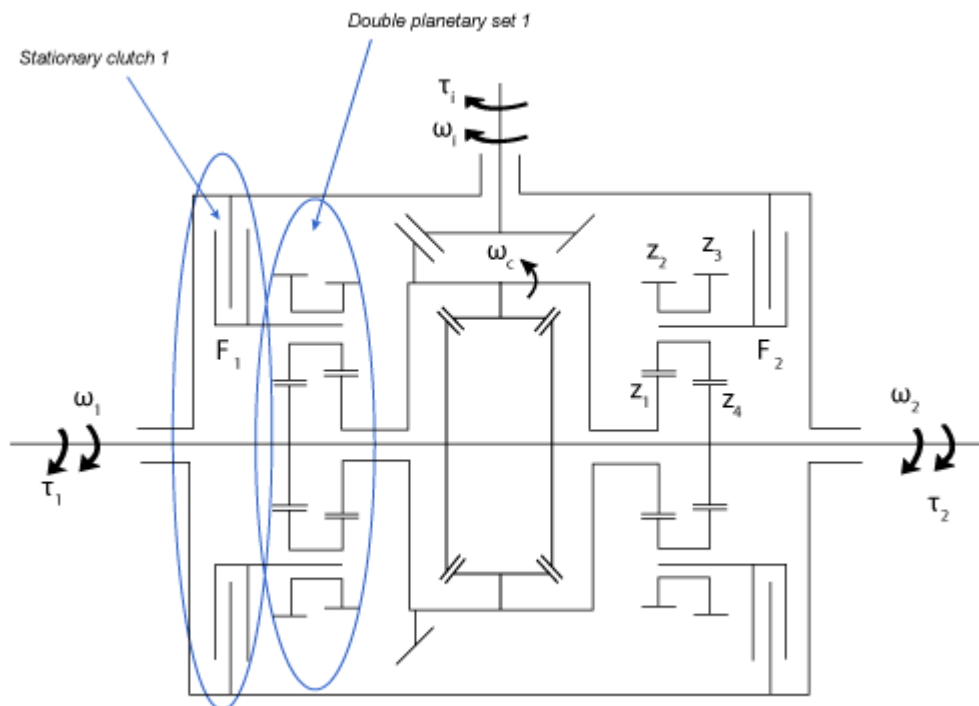
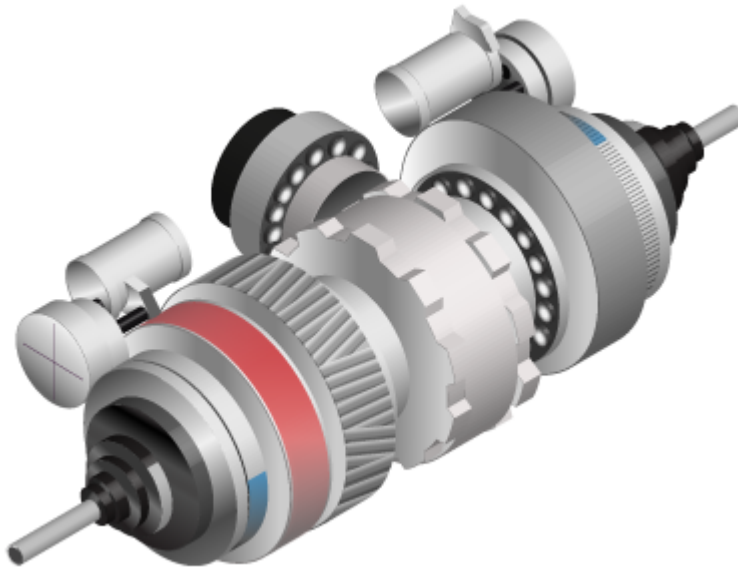
These superposition clutch illustrations show the clutch configuration and schematic for torque transfer to the left wheel.





### Stationary Clutches and Planetary Gearing

The illustrations show the stationary clutch configuration and schematic.



### Slip Coupling

For both the ideal clutch and slip-speed configurations, the slip coupling is a function of the slip-speed and clutch pressure. The slip-speed depends on the slip velocity at each of the clutch interfaces.

$$\bar{\omega} = [\Delta\omega_{c1}, \Delta\omega_{c2}]$$

#### Ideal Clutch

The ideal clutch coupling model uses the axle slip speed, clutch pressure, and friction to calculate the clutch torque. The friction coefficient is a function of the slip speed.

$$T_C = F_T N_d \mu(|\bar{\omega}|) R_{eff} \tanh(4\bar{\omega})$$

To calculate the total clutch force, the block uses the effective radius, clutch pressure, and clutch preload force.

$$F_T = F_C + P_{1,2} A_{eff}, \quad F_T \geq 0$$

The disc radii determine the effective clutch radius over which the clutch force acts.

$$R_{eff} = \frac{2(R_o^3 - R_i^3)}{3(R_o^2 - R_i^2)}$$

#### Slip-Speed

To calculate the clutch torque, the slip speed coupling model uses torque data that is a function of slip speed and clutch pressure. The angular velocities of the axles determine the slip speed.

$$T_C = T_C(\bar{\omega}, P_{1,2})$$

The equations use these variables.

$A_{eff}$	Effective clutch pressure area
$b_d$	Crown gear linear viscous damping
$b_1, b_2$	Axle 1 and 2 linear viscous damping, respectively
$F_c, F_T$	Clutch preload force and total force, respectively
$J_d$	Carrier rotational inertia
$J_{gc}$	Three-gang gear rotational inertia
$J_{c1}, J_{c2}$	Planetary carrier 1 and 2 rotational inertia, respectively
$J_{r1}, J_{r2}$	Planetary ring gear 1 and 2 rotational inertia, respectively
$J_{s1}, J_{s2}$	Planetary sun gear 1 and 2 rotational inertia, respectively
$J_1, J_2$	Axle 1 and 2 rotational inertia, respectively
$N$	Carrier-to-drive shaft gear ratio
$N_d$	Number of disks
$N_{s1}, N_{s2}$	Clutch 1 and 2 carrier-to-spur gear ratio, respectively
$N_{p1}, N_{p2}$	Planetary 1 and 2 carrier-to-axle gear ratio, respectively
$P_1, P_2$	Clutch 1 and 2 pressure, respectively

$R_{eff}$	Effective clutch radius
$R_i, R_o$	Annular disk inner and outer radius, respectively
$T_c$	Clutch torque
$T_{cl1}, T_{cl2}$	Clutch 1 and 2 coupling torque, respectively
$T_d$	Driveshaft torque
$T_1, T_2$	Axle 1 and 2 torque, respectively
$T_i$	Axle internal resistance torque
$T_{i1}, T_{i2}$	Axle 1 and 2 internal resistance torque
$\omega_d$	Driveshaft angular velocity
$\bar{\omega}$	Slip speed
$\omega_1, \omega_2$	Axle 1 and 2 angular velocity, respectively
$\Delta\omega_{cl1}, \Delta\omega_{cl2}$	Clutch 1 and 2 slip speed at interface, respectively
$\omega_{cl1}, \omega_{cl2}$	Clutch 1 and 2 angular velocity, respectively
$\mu$	Clutch coefficient of friction
$z_i$	Number of teeth on gear $i$

## Ports

### Inputs

#### Prs1 – Clutch 1 pressure

scalar

Clutch 1 pressure,  $P_1$ , in Pa.

#### Prs2 – Clutch 2 pressure

scalar

Clutch 2 pressure,  $P_2$ , in Pa.

#### DriveshaftTrq – Driveshaft torque

scalar

Applied input torque,  $T_d$ , typically from the engine driveshaft, in N·m.

#### Axl1Trq – Torque

scalar

Axle 1 torque,  $T_1$ , in N·m.

#### Axl2Trq – Torque

scalar

Axle 2 torque,  $T_2$ , in N·m.

### Output

#### Info – Bus signal

bus

Bus signal containing these block calculations.

Signal		Description	Units
Driveshft	DriveshftTrq	Drive shaft torque	N·m
	DriveshftSpd	Drive shaft angular velocity	rad/s
Axl1	Axl1Trq	Axle 1 torque	N·m
	Axl1Spd	Axle 1 angular velocity	rad/s
Axl2	Axl2Trq	Axle 2 torque	N·m
	Axl2Spd	Axle 2 angular velocity	rad/s
Cplng	CplngTrq1	Clutch 1 coupling torque	N·m
	CplngTrq2	Clutch 2 coupling torque	N·m
	CplngSlipSpd1	Clutch 1 slip speed	rad/s
	CplngSlipSpd2	Clutch 2 slip speed	rad/s
	CplngPrs1	Clutch 1 input pressure	Pa
	CplngPrs2	Clutch 2 input pressure	Pa

**DriveshftSpd – Angular velocity**

scalar

Driveshaft angular velocity,  $\omega_d$ , in rad/s.

**Axl1Spd – Angular velocity**

scalar

Axle 1 angular velocity,  $\omega_1$ , in rad/s.

**Axl2Spd – Angular velocity**

scalar

Axle 2 angular velocity,  $\omega_2$ , in rad/s.

**Parameters**

**Active Differential**

**Active differential type – Differential**

Spur gears, superposition clutches (default) | Double planetary gears, stationary clutches

Specify the type of active differential.

Setting	Block Implementation
Spur gears, superposition clutches	Clutches are in superposition through a three-gang gear system and a differential case
Double planetary gears, stationary clutches	Clutches are fixed to the carrier and axles through double planetary gear sets

**Clutch 1 to differential case gear ratio,  $N_{s1}$  — Clutch 1-spur gear ratio**

.875 (default) | scalar

Clutch 1-to-carrier spur gear ratio,  $N_{s1}$ , dimensionless.**Dependencies**To enable the spur gear parameters, select Spur gears, superposition clutches for the **Active differential type** parameter.**Clutch 2 to differential case gear ratio,  $N_{s2}$  — Clutch 2-spur gear ratio**

1.125 (default) | scalar

Clutch 2-to-carrier spur gear ratio,  $N_{s2}$ , dimensionless.**Dependencies**To enable the spur gear parameters, select Spur gears, superposition clutches for the **Active differential type** parameter.**Three-gang gear inertia,  $J_{gc}$  — Rotational inertia**

.003 (default) | scalar

Three-gang gear rotational inertia,  $J_{gc}$ , in  $\text{kg}\cdot\text{m}^2$ .**Dependencies**To enable the spur gear parameters, select Spur gears, superposition clutches for the **Active differential type** parameter.**Axle 1 planetary carrier to axle gear ratio,  $N_{p1}$  — Planetary 1 carrier gear ratio**

1.125 (default) | scalar

Planetary 1 carrier-to-axle gear ratio,  $N_{p1}$ , dimensionless.**Dependencies**To enable the planetary gear parameters, select Double planetary gears, stationary clutches for the **Active differential type** parameter.**Axle 1 sun gear inertia,  $J_{s1}$  — Planetary 1 sun gear inertia**

.001 (default) | scalar

Planetary 1 sun gear inertia,  $J_{s1}$ , in  $\text{kg}\cdot\text{m}^2$ .**Dependencies**To enable the planetary gear parameters, select Double planetary gears, stationary clutches for the **Active differential type** parameter.**Axle 1 carrier inertia,  $J_{c1}$  — Planetary 1 carrier inertia**

.001 (default) | scalar

Planetary 1 carrier inertia,  $J_{c1}$ , in  $\text{kg}\cdot\text{m}^2$ .**Dependencies**To enable the planetary gear parameters, select Double planetary gears, stationary clutches for the **Active differential type** parameter.

**Axle 1 ring inertia, Jr1 – Planetary 1 ring gear inertia**

.002 (default) | scalar

Planetary 1 ring gear inertia,  $J_{r1}$ , kg·m<sup>2</sup>.

**Dependencies**

To enable the planetary gear parameters, select **Double planetary gears, stationary clutches** for the **Active differential type** parameter.

**Axle 2 planetary carrier to axle gear ratio, Np2 – Planetary 2 carrier gear ratio**

1.125 (default) | scalar

Planetary 2 carrier-to-axle gear ratio,  $N_{p2}$ , dimensionless.

**Dependencies**

To enable the planetary gear parameters, select **Double planetary gears, stationary clutches** for the **Active differential type** parameter.

**Axle 2 sun gear inertia, Js2 – Planetary 2 sun gear inertia**

.001 (default) | scalar

Planetary 2 sun gear inertia,  $J_{s2}$ , in kg·m<sup>2</sup>.

**Dependencies**

To enable the planetary gear parameters, select **Double planetary gears, stationary clutches** for the **Active differential type** parameter.

**Axle 2 carrier inertia, Jc2 – Planetary 2 carrier inertia**

.001 (default) | scalar

Planetary 2 carrier inertia,  $J_{c2}$ , in kg·m<sup>2</sup>.

**Dependencies**

To enable the planetary gear parameters, select **Double planetary gears, stationary clutches** for the **Active differential type** parameter.

**Axle 2 ring inertia, Jr2 – Planetary 2 ring gear inertia**

.002 (default) | scalar

Planetary 2 ring gear inertia,  $J_{r2}$ , in kg·m<sup>2</sup>.

**Dependencies**

To enable the planetary gear parameters, select **Double planetary gears, stationary clutches** for the **Active differential type** parameter.

**Open Differential****Crown wheel (ring gear) located – Specify crown wheel connection**

To the left of center-line (default) | To the right of center-line

Specify the crown wheel connection to the drive shaft.

**Carrier to drive shaft ratio, NC/ND – Ratio**

4 (default) | scalar

Carrier-to-drive shaft gear ratio,  $N$ .**Carrier inertia, Jd – Inertia**

.1 (default) | scalar

Rotational inertia of the crown gear assembly,  $J_d$ , in  $\text{kg}\cdot\text{m}^2$ . You can include the drive shaft inertia.**Carrier damping, bd – Damping**

1e-3 (default) | scalar

Crown gear linear viscous damping,  $b_d$ , in  $\text{N}\cdot\text{m}\cdot\text{s}/\text{rad}$ .**Axle 1 inertia, Jw1 – Inertia**

.1 (default) | scalar

Axle 1 rotational inertia,  $J_1$ , in  $\text{kg}\cdot\text{m}^2$ .**Axle 1 damping, bw1 – Damping**

1e-3 (default) | scalar

Axle 1 linear viscous damping,  $b_1$ , in  $\text{N}\cdot\text{m}\cdot\text{s}/\text{rad}$ .**Axle 2 inertia, Jw2 – Inertia**

.1 (default) | scalar

Axle 2 rotational inertia,  $J_2$ , in  $\text{kg}\cdot\text{m}^2$ .**Axle 2 damping, bw2 – Damping**

1e-3 (default) | scalar

Axle 2 linear viscous damping,  $b_2$ , in  $\text{N}\cdot\text{m}\cdot\text{s}/\text{rad}$ .**Axle 1 initial velocity, omegaw1o – Angular velocity**

0 (default) | scalar

Axle 1 initial velocity,  $\omega_{o1}$ , in  $\text{rad}/\text{s}$ .**Axle 2 initial velocity, omegaw2o – Angular velocity**

0 (default) | scalar

Axle 2 initial velocity,  $\omega_{o2}$ , in  $\text{rad}/\text{s}$ .**Slip Coupling****Coupling type – Torque coupling**

Ideal pre-loaded clutch (default) | Slip speed dependent torque data | Input torque dependent torque data

Specify the type of torque coupling.

Setting	Block Implementation
Pre-loaded ideal clutch	Torque modeled as a wet clutch with a constant velocity

Setting	Block Implementation
Slip speed dependent torque data	Torque determined from a lookup table that is a function of slip-speed and clutch pressure

**Effective applied pressure area – Pressure area**

0.01 (default) | scalar

Effective applied pressure area, in N/m<sup>2</sup>.

**Dependencies**

To enable the clutch parameters, select `Ideal pre-loaded clutch` for the **Coupling type** parameter.

**Number of disks, Ndisks – Torque coupling**

4 (default) | scalar

Number of disks.

**Dependencies**

To enable the clutch parameters, select `Ideal pre-loaded clutch` for the **Coupling type** parameter.

**Effective radius, Reff – Radius**

.20 (default) | scalar

The effective radius,  $R_{eff}$ , used with the applied clutch friction force to determine the friction force. The effective radius is defined as:

$$R_{eff} = \frac{2(R_o^3 - R_i^3)}{3(R_o^2 - R_i^2)}$$

The equation uses these variables.

$R_o$             Annular disk outer radius

$R_i$             Annular disk inner radius

**Dependencies**

To enable the clutch parameters, select `Ideal pre-loaded clutch` for the **Coupling type** parameter.

**Nominal preload force, Fc – Force**

500 (default) | scalar

Nominal preload force, in N.

**Dependencies**

To enable the clutch parameters, select `Ideal pre-loaded clutch` for the **Coupling type** parameter.

**Friction coefficient vector, mu – Friction**

[.16 0.13 0.115 0.11 0.105 0.1025 0.10125 .10125] (default) | vector



Friction coefficient vector.

#### Dependencies

To enable the clutch parameters, select `Ideal pre-loaded clutch` for the **Coupling type** parameter.

#### Slip speed vector, $dw$ — Angular velocity

[0 10 20 40 60 80 100 500] (default) | vector

Slip speed vector, in rad/s.

To enable the clutch parameters, select `Ideal pre-loaded clutch` for the **Coupling type** parameter.

#### Torque - slip speed matrix, $TdPdw$ — Clutch torque

[-1000, -500, -90, -50, -5, 0, 5, 50, 90, 500, 1000].\*ones(11) (default) | matrix

Torque matrix,  $T_c$ , in N·m.

#### Dependencies

To enable the slip speed parameters, select `Slip speed dependent torque data` for the **Coupling type** parameter.

#### Clutch pressure vector, $pT$ — Clutch pressure breakpoints

[0 1e3 5e3 7e3 1e4 2e4 5e4 1e5 5e5 1e6 5e6] (default) | vector

Clutch pressure breakpoints vector,  $P_{1,2}$ , in Pa.

#### Dependencies

To enable the slip speed parameters, select `Slip speed dependent torque data` for the **Coupling type** parameter.

#### Slip speed vector, $dwT$ — Slip speed breakpoints

[-500 -200, -175, -100, - 50, 0, 50, 100, 175, 200, 500] (default) | vector

Slip speed breakpoints vector,  $\omega$ , in rad/s.

#### Dependencies

To enable the slip speed parameters, select `Slip speed dependent torque data` for the **Coupling type** parameter.

#### Coupling time constant, $\tau_c$ — Constant

.01 (default) | scalar

Coupling time constant, in s.

## References

- [1] Deur, J., Ivanović, V., Hancock, M., and Assadian, F. "Modeling of Active Differential Dynamics." In ASME proceedings. *Transportation Systems*. Vol. 17, pp: 427-436.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

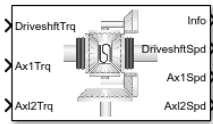
Limited Slip Differential | Open Differential

**Introduced in R2018b**

# Limited Slip Differential

Limited differential as a planetary bevel gear

**Library:** Powertrain Blockset / Drivetrain / Final Drive Unit  
 Vehicle Dynamics Blockset / Powertrain / Drivetrain / Final Drive Unit



## Description

The Limited Slip Differential block implements a differential as a planetary bevel gear train. The block matches the driveshaft bevel gear to the crown (ring) bevel gear. You can specify:

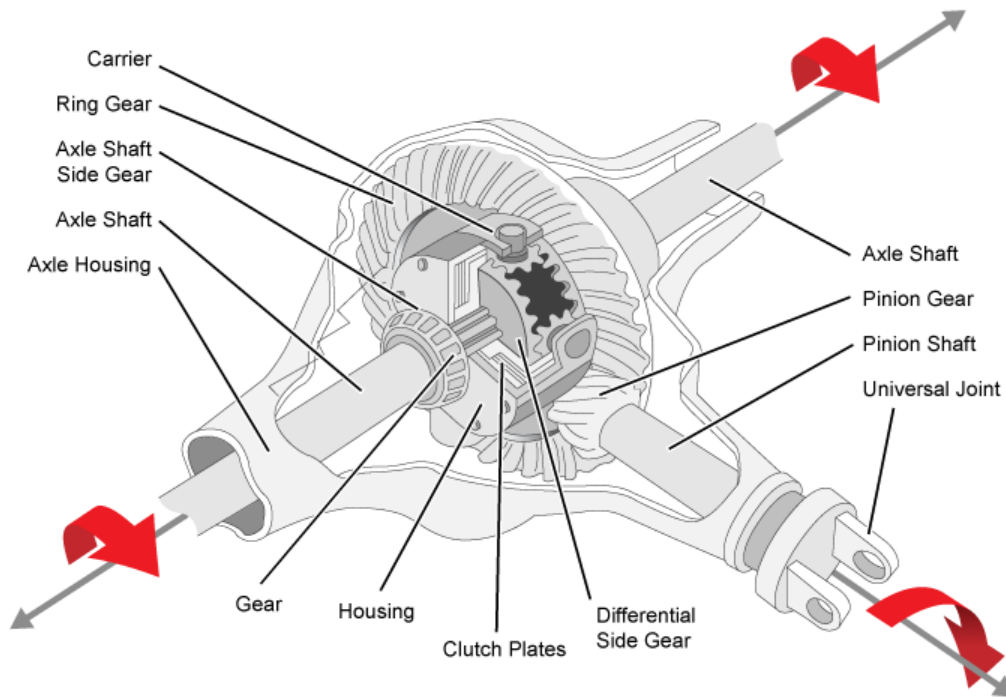
- Carrier-to-driveshaft ratio
- Crown wheel location
- Viscous and damping coefficients for the axles and carrier
- Type of slip coupling

Use the block in system-level driveline analysis to account for the power transfer from the transmission to the wheels. The block is suitable for use in hardware-in-the-loop (HIL) and optimization workflows. All the parameters are tunable.

In a limited slip differential, to prevent one of the wheels from slipping, the differential splits the torque applied to the left and right axles. With different torque applied to the axles, the wheels can move at different angular velocities, preventing slip. The block implements three methods for coupling the different torques applied to the axes:

- Pre-loaded ideal clutch
- Slip speed-dependent torque data
- Input torque dependent torque data

The block uses a coordinate system that produces positive tire and vehicle motion for standard engine, transmission, and differential configurations. The arrows indicate positive motion.



### Efficiency

To account for the block efficiency, use the **Efficiency factors** parameter. This table summarizes the block implementation for each setting.

Setting	Implementation
Constant	Constant efficiency that you can set with the <b>Constant efficiency factor, eta</b> parameter.
Driveshaft torque, temperature and speed	<p>Efficiency as a function of base gear input torque, air temperature, and driveshaft speed. Use these parameters to specify the lookup table and breakpoints:</p> <ul style="list-style-type: none"> <li>• <b>Efficiency lookup table, eta_tbl</b></li> <li>• <b>Efficiency torque breakpoints, Trq_bpts</b></li> <li>• <b>Efficiency speed breakpoints, omega_bpts</b></li> <li>• <b>Efficiency temperature breakpoints, Temp_bpts</b></li> </ul> <p>For the air temperature, you can either:</p> <ul style="list-style-type: none"> <li>• Select <b>Input temperature</b> to create an input port.</li> <li>• Set a <b>Ambient temperature, Tamb</b> parameter value.</li> </ul> <p>To select the interpolation method, use the <b>Interpolation method</b> parameter. For more information, see “Interpolation Methods”.</p>

## Power Accounting

For the power accounting, the block implements these equations.

Bus Signal		Description	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks	PwrDriveshft	Mechanical power from driveshaft $\eta T_d \omega_d$
	<ul style="list-style-type: none"> <li>Positive signals indicate flow into block</li> <li>Negative signals indicate flow out of block</li> </ul>	PwrAxl1	Mechanical power from axle 1 $\eta T_1 \omega_1$
		PwrAxl2	Mechanical power from axle 2 $\eta T_2 \omega_2$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred <ul style="list-style-type: none"> <li>Positive signals indicate an input</li> <li>Negative signals indicate a loss</li> </ul>	PwrMechLoss	Total power loss $\dot{W}_{loss} = -(P_t + P_d + P_c) + P_s$ $P_t = \eta(T_d \omega_d + T_1 \omega_1 + T_2 \omega_2)$
		PwrDampLoss	Power loss due to damping $P_d = -(b_1  \omega_1  + b_2  \omega_2  + b_d  \omega_d )$
		PwrCplngLoss	Power loss due to clutch $P_c = T_c  \bar{\omega} $
PwrStored — Stored energy rate of change <ul style="list-style-type: none"> <li>Positive signals indicate an increase</li> <li>Negative signals indicate a decrease</li> </ul>	PwrStoredShft	Rate change of stored internal energy $P_s = -(\omega_1 \dot{\omega}_1 J_1 + \omega_2 \dot{\omega}_2 J_2 + \omega_d \dot{\omega}_d J_d)$	

## Dynamics

The Limited Slip Differential block implements these differential equations to represent the mechanical dynamic response for the crown gear, left axle, and right axle.

Mechanical Dynamic Response	Differential Equation
Crown Gear	$\dot{\omega}_d J_d = \eta T_d - \omega_d b_d - T_i$
Left Axle	$\dot{\omega}_1 J_1 = \eta T_1 - \omega_1 b_1 - T_{i1}$
Right Axle	$\dot{\omega}_2 J_2 = \eta T_2 - \omega_2 b_2 - T_{i2}$

The block assumes rigid coupling between the crown gear and axles. These constraint equations apply.

$$\eta T_1 = \frac{N}{2} T_i - \frac{1}{2} T_c$$

$$\eta T_2 = \frac{N}{2} T_i + \frac{1}{2} T_c$$

$$\omega_d = \frac{N}{2}(\omega_1 + \omega_2)$$

The equations use these variables.

$N$	Carrier-to-driveshaft gear ratio
$J_d$	Rotational inertia of the crown gear assembly
$b_d$	Crown gear linear viscous damping
$\omega_d$	Driveshaft angular speed
$\varpi$	Slip speed
$J_1$	Axle 1 rotational inertia
$b_1$	Axle 1 linear viscous damping
$\omega_1$	Axle 1 speed
$J_2$	Axle 2 rotational inertia
$b_2$	Axle 2 linear viscous damping
$\omega_2$	Axle 2 angular speed
$\eta$	Efficiency
$T_d$	Driveshaft torque
$T_1$	Axle 1 torque
$T_2$	Axle 2 torque
$T_i$	Axle internal resistance torque
$T_{i1}$	Axle 1 internal resistance torque
$T_{i2}$	Axle 2 internal resistance torque
$\mu$	Coefficient of friction
$R_{eff}$	Effective clutch radius
$R_o$	Annular disk outer radius
$R_i$	Annular disk inner radius
$F_c$	Clutch force
$T_c$	Clutch torque
$\mu$	Coefficient of friction

Table blocks in the Limited Slip Differential have these parameter settings:

- **Interpolation method** – Linear
- **Extrapolation method** – Clip

#### Ideal Clutch Coupling

The ideal clutch coupling model uses the axle slip speed and friction to calculate the clutch torque. The friction coefficient is a function of the slip speed.

$$T_c = F_c N \mu(|\varpi|) R_{eff} \tanh(4|\varpi|)$$

The disc radii determine the effective clutch radius over which the clutch force acts.

$$R_{eff} = \frac{2(R_o^3 - R_i^3)}{3(R_o^2 - R_i^2)}$$

The angular velocities of the axles determine the slip speed.

$$\varpi = \omega_1 - \omega_2$$

### Slip Speed Coupling

To calculate the clutch torque, the slip speed coupling model uses torque data that is a function of slip speed. The angular velocities of the axles determine the slip speed.

$$\varpi = \omega_1 - \omega_2$$

### Input Torque Coupling

To calculate the clutch torque, the input torque coupling model uses torque data that is a function of input torque.

The Open Differential block assumes rigid coupling between the crown gear and axles. These constraint equations apply.

$$\eta T_1 = \eta T_2 = \frac{N}{2} T_i$$

$$\omega_d = \frac{N}{2} (\omega_1 + \omega_2)$$

## Ports

### Inputs

#### DriveshaftTrq — Torque

scalar

Applied input torque, typically from the engine crankshaft, in N·m.

#### Axl1Trq — Torque

scalar

Axle 1 torque,  $T_1$ , in N·m.

#### Axl2Trq — Torque

scalar

Axle 2 torque,  $T_2$ , in N·m.

#### Temp — Temperature

scalar

Temperature, in K.

### Dependencies

To enable this port:

- Set **Efficiency factors** to Driveshaft torque, speed and temperature.
- Select **Input temperature**.

**Output**

**Info – Bus signal**

bus

Bus signal containing these block calculations.

Signal		Description	Units	
Driveshft	DriveshftTrq	Driveshaft torque	N·m	
	DriveshftSpd	Driveshaft speed	rad/s	
Axl1	Axl1Trq	Axle 1 torque	N·m	
	Axl1Spd	Axle 1 speed	rad/s	
Axl2	Axl2Trq	Axle 2 torque	N·m	
	Axl2Spd	Axle 2 speed	rad/s	
Cplng	CplngTrq	Torque coupling	N·m	
	CplngSlipSpd	Slip speed	rad/s	
PwrInfo	PwrTrnsfrd	PwrDriveshft	Mechanical power from driveshaft	W
		PwrAxl1	Mechanical power from axle 1	W
		PwrAxl2	Mechanical power from axle 2	W
	PwrNotTrnsfrd	PwrMechLoss	Total power loss	W
		PwrDampLoss	Power loss due to damping	W
		PwrCplngLoss	Power loss due to clutch	W
	PwrStoredShft	PwrStoredShft	Rate change of stored internal energy	W

**DriveshftSpd – Angular speed**

scalar

Driveshaft angular speed,  $\omega_d$ , in rad/s.

**Axl1Spd – Angular speed**

scalar

Axle 1 angular speed,  $\omega_1$ , in rad/s.

**Axl2Spd – Angular speed**

scalar

Axle 2 angular speed,  $\omega_2$ , in rad/s.



## Parameters

### Block Options

#### Efficiency factors — Specify configuration

Constant (default) | Driveshaft torque, speed and temperature

To account for the block efficiency, use the **Efficiency factors** parameter. This table summarizes the block implementation for each setting.

Setting	Implementation
Constant	Constant efficiency that you can set with the <b>Constant efficiency factor, eta</b> parameter.
Driveshaft torque, temperature and speed	<p>Efficiency as a function of base gear input torque, air temperature, and driveshaft speed. Use these parameters to specify the lookup table and breakpoints:</p> <ul style="list-style-type: none"> <li>• <b>Efficiency lookup table, eta_tbl</b></li> <li>• <b>Efficiency torque breakpoints, Trq_bpts</b></li> <li>• <b>Efficiency speed breakpoints, omega_bpts</b></li> <li>• <b>Efficiency temperature breakpoints, Temp_bpts</b></li> </ul> <p>For the air temperature, you can either:</p> <ul style="list-style-type: none"> <li>• Select <b>Input temperature</b> to create an input port.</li> <li>• Set a <b>Ambient temperature, Tamb</b> parameter value.</li> </ul> <p>To select the interpolation method, use the <b>Interpolation method</b> parameter. For more information, see “Interpolation Methods”.</p>

#### Interpolation method — Method

Flat | Nearest | Linear point-slope | Linear Lagrange | Cubic spline

For more information, see “Interpolation Methods”.

### Dependencies

To enable this parameter, set **Efficiency factors** to Driveshaft torque, speed and temperature.

#### Input temperature — Create input port

off (default) | on

Select to create input port Temp for the temperature.

### Dependencies

To enable this parameter, set **Efficiency factors** to Driveshaft torque, speed and temperature.

### Open Differential

#### Crown wheel (ring gear) located — Specify crown wheel connection

To the left of center-line (default) | To the right of center-line

Specify the crown wheel connection to the driveshaft.

**Carrier to drive shaft ratio, NC/ND – Ratio**

4 (default) | scalar

Carrier-to-driveshaft gear ratio,  $N$ .

**Carrier inertia, Jd – Inertia**

.1 (default) | scalar

Rotational inertia of the crown gear assembly,  $J_d$ , in  $\text{kg}\cdot\text{m}^2$ . You can include the driveshaft inertia.

**Carrier damping, bd – Damping**

1e-3 (default) | scalar

Crown gear linear viscous damping,  $b_d$ , in  $\text{N}\cdot\text{m}\cdot\text{s}/\text{rad}$ .

**Axle 1 inertia, Jw1 – Inertia**

.1 (default) | scalar

Axle 1 rotational inertia,  $J_1$ , in  $\text{kg}\cdot\text{m}^2$ .

**Axle 1 damping, bw1 – Damping**

1e-3 (default) | scalar

Axle 1 linear viscous damping,  $b_1$ , in  $\text{N}\cdot\text{m}\cdot\text{s}/\text{rad}$ .

**Axle 2 inertia, Jw2 – Inertia**

.1 (default) | scalar

Axle 2 rotational inertia,  $J_2$ , in  $\text{kg}\cdot\text{m}^2$ .

**Axle 2 damping, bw2 – Damping**

1e-3 (default) | scalar

Axle 2 linear viscous damping,  $b_2$ , in  $\text{N}\cdot\text{m}\cdot\text{s}/\text{rad}$ .

**Axle 1 initial velocity, omegaw1o – Angular velocity**

0 (default) | scalar

Axle 1 initial velocity,  $\omega_{o1}$ , in  $\text{rad}/\text{s}$ .

**Axle 2 initial velocity, omegaw2o – Angular velocity**

0 (default) | scalar

Axle 2 initial velocity,  $\omega_{o2}$ , in  $\text{rad}/\text{s}$ .

**Constant efficiency factor, eta – Efficiency**

1 (default) | scalar

Constant efficiency,  $\eta$ .

**Dependencies**

To enable this parameter, set **Efficiency factors** to Constant.

**Efficiency lookup table, eta\_tbl — Lookup table**

M-by-N-by-L array

Dimensionless array of values for efficiency as a function of:

- M input torques
- N input speed
- L air temperatures

Each value specifies the efficiency for a specific combination of torque, speed, and temperature. The array size must match the dimensions defined by the torque, speed, and temperature breakpoint vectors.

**Dependencies**

To enable this parameter, set **Efficiency factors** to Driveshaft torque, speed and temperature.

**Efficiency torque breakpoints, Trq\_bpts — Torque breakpoints**

[25, 50, 75, 100, 150, 200, 250] (default) | 1-by-M vector

Vector of input torque, breakpoints for efficiency, in N·m.

**Dependencies**

To enable this parameter, set **Efficiency factors** to Driveshaft torque, speed and temperature.

**Efficiency speed breakpoints, omega\_bpts — Speed breakpoints**

[52.4 78.5 105 131 157 183 209 262 314 419 524] (default) | 1-by-N vector

Vector of speed, breakpoints for efficiency, in rad/s.

**Dependencies**

To enable this parameter, set **Efficiency factors** to Driveshaft torque, speed and temperature.

**Efficiency temperature breakpoints, Temp\_bpts — Temperature breakpoints**

[290 358] (default) | 1-by-L vector

Vector of ambient temperature breakpoints for efficiency, in K.

**Dependencies**

To enable this parameter, set **Efficiency factors** to Driveshaft torque, speed and temperature.

**Ambient temperature, Tamb — Ambient temperature**

297.15 (default) | scalar

Ambient air temperature,  $T_{air}$ , in K.

**Dependencies**

To enable this parameter:

- Set **Efficiency factors** to Driveshaft torque, speed and temperature.
- Clear **Input temperature**.

### Slip Coupling

#### Coupling type – Torque coupling

Pre-loaded ideal clutch (default) | Slip speed dependent torque data | Input torque dependent torque data

Specify the type of torque coupling.

#### Number of disks, Ndisks – Torque coupling

4 (default) | scalar

Number of disks.

#### Dependencies

To enable the ideal clutch parameters, select Pre-loaded ideal clutch for the **Coupling type** parameter.

#### Effective radius, Reff – Radius

.20 (default) | scalar

The effective radius,  $R_{eff}$ , used with the applied clutch friction force to determine the friction force. The effective radius is defined as:

$$R_{eff} = \frac{2(R_o^3 - R_i^3)}{3(R_o^2 - R_i^2)}$$

The equation uses these variables.

$R_o$  Annular disk outer radius

$R_i$  Annular disk inner radius

#### Dependencies

To enable the clutch parameters, select Pre-loaded ideal clutch for the **Coupling type** parameter.

#### Nominal preload force, Fc – Force

500 (default) | scalar

Nominal preload force, in N.

#### Dependencies

To enable the clutch parameters, select Pre-loaded ideal clutch for the **Coupling type** parameter.

#### Friction coefficient vector, muc – Friction

[.16 0.13 0.115 0.11 0.105 0.1025 0.10125] (default) | vector

Friction coefficient vector.

**Dependencies**

To enable the clutch parameters, select Pre-loaded ideal clutch for the **Coupling type** parameter.

**Slip speed vector,  $d\omega$  — Angular velocity**

[0 10 20 40 60 80 100] (default) | vector

Slip speed vector, in rad/s.

**Dependencies**

To enable the clutch parameters, select Pre-loaded ideal clutch for the **Coupling type** parameter.

**Torque - slip speed vector,  $T_{dw}$  — Torque**

[-100, -90, -50, -5, 0, 5, 50, 90, 100] (default) | vector

Torque vector, in N·m.

**Dependencies**

To enable the slip speed parameters, select Slip speed dependent torque data for the **Coupling type** parameter.

**Slip speed vector,  $d\omega_T$  — Angular velocity**

[-200, -175, -100, -50, 0, 50, 100, 175, 200] (default) | vector

Slip speed vector, in rad/s.

**Dependencies**

To enable the slip speed parameters, select Slip speed dependent torque data for the **Coupling type** parameter.

**Torque - input torque vector,  $T_{Tin}$  — Torque**

[-200 -175 -100 -50 0 50 100 175 200] (default) | vector

Torque vector, in N·m.

**Dependencies**

To enable the input torque parameters, select Input torque dependent torque data for the **Coupling type** parameter.

**Input torque vector,  $T_{in}$  — Torque**

[-200 -175 -100 -50 0 50 100 175 200] (default) | vector

Torque vector, in N·m.

**Dependencies**

To enable the input torque parameters, select Input torque dependent torque data for the **Coupling type** parameter.

**Coupling time constant,  $\tau_C$  — Constant**

.01 (default) | scalar

Coupling time constant, in s.

## References

- [1] Deur, J., Ivanović, V., Hancock, M., and Assadian, F. "Modeling of Active Differential Dynamics." In ASME proceedings. *Transportation Systems*. Vol. 17, pp: 427-436.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

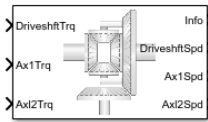
Open Differential

**Introduced in R2017a**

# Open Differential

Differential as a planetary bevel gear

**Library:** Powertrain Blockset / Drivetrain / Final Drive Unit  
 Vehicle Dynamics Blockset / Powertrain / Drivetrain / Final Drive Unit



## Description

The Open Differential block implements a differential as a planetary bevel gear train. The block matches the driveshaft bevel gear to the crown (ring) bevel gear. You can specify:

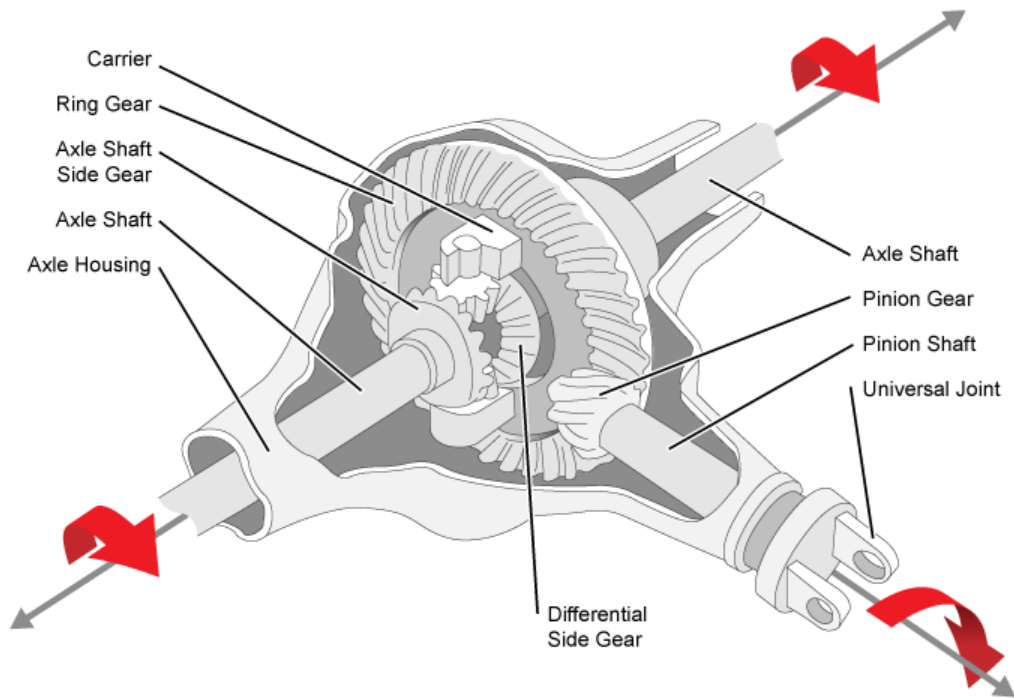
- Carrier-to-driveshaft ratio
- Crown wheel location
- Viscous and damping coefficients for the axles and carrier

Use the Open Differential block to:

- Dynamically couple the post-transmission driveshaft to the wheel axles or universal joints
- Model simplified or older drivetrains when optimal traction control does not require passive or active torque vectoring
- Model mechanical power splitting in generic gearbox and drive line scenarios

The block is suitable for use in hardware-in-the-loop (HIL) and optimization workflows. All the parameters are tunable.

The block uses a coordinate system that produces positive tire and vehicle motion for standard engine, transmission, and differential configurations. The arrows indicate positive motion.



### Efficiency

To account for the block efficiency, use the **Efficiency factors** parameter. This table summarizes the block implementation for each setting.

Setting	Implementation
Constant	Constant efficiency that you can set with the <b>Constant efficiency factor, eta</b> parameter.
Driveshaft torque, temperature and speed	<p>Efficiency as a function of base gear input torque, air temperature, and driveshaft speed. Use these parameters to specify the lookup table and breakpoints:</p> <ul style="list-style-type: none"> <li>• <b>Efficiency lookup table, eta_tbl</b></li> <li>• <b>Efficiency torque breakpoints, Trq_bpts</b></li> <li>• <b>Efficiency speed breakpoints, omega_bpts</b></li> <li>• <b>Efficiency temperature breakpoints, Temp_bpts</b></li> </ul> <p>For the air temperature, you can either:</p> <ul style="list-style-type: none"> <li>• Select <b>Input temperature</b> to create an input port.</li> <li>• Set a <b>Ambient temperature, Tamb</b> parameter value.</li> </ul> <p>To select the interpolation method, use the <b>Interpolation method</b> parameter. For more information, see “Interpolation Methods”.</p>



## Power Accounting

For the power accounting, the block implements these equations.

Bus Signal		Description	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks	PwrDriveshft	Mechanical power from driveshaft $\eta T_d \omega_d$
	<ul style="list-style-type: none"> <li>Positive signals indicate flow into block</li> <li>Negative signals indicate flow out of block</li> </ul>	PwrAxl1	Mechanical power from axle 1 $\eta T_1 \omega_1$
		PwrAxl2	Mechanical power from axle 2 $\eta T_2 \omega_2$
PwrNotTrnsfrd — Power crossing the block boundary, but not transferred	<ul style="list-style-type: none"> <li>Positive signals indicate an input</li> <li>Negative signals indicate a loss</li> </ul>	PwrMechLoss	Total power loss $\dot{W}_{loss} = -(P_t + P_d) + P_s$
		PwrDampLoss	Power loss due to damping $P_d = -(b_1 \omega_1  + b_2 \omega_2  + b_d \omega_d )$
PwrStored — Stored energy rate of change	<ul style="list-style-type: none"> <li>Positive signals indicate an increase</li> <li>Negative signals indicate a decrease</li> </ul>	PwrStoredShft	Rate change of stored internal energy $P_s = -(\omega_1 \dot{\omega}_1 J_1 + \omega_2 \dot{\omega}_2 J_2 + \omega_d \dot{\omega}_d J_d)$

## Dynamics

The Open Differential block implements these differential equations to represent the mechanical dynamic response for the crown gear, left axle, and right axle.

Mechanical Dynamic Response	Differential Equation
Crown Gear	$\dot{\omega}_d J_d = \eta T_d - \omega_d b_d - T_i$
Left Axle	$\dot{\omega}_1 J_1 = \eta T_1 - \omega_1 b_1 - T_{i1}$
Right Axle	$\dot{\omega}_2 J_2 = \eta T_2 - \omega_2 b_2 - T_{i2}$

The Open Differential block assumes rigid coupling between the crown gear and axles. These constraint equations apply.

$$\eta T_1 = \eta T_2 = \frac{N}{2} T_i$$

$$\omega_d = \frac{N}{2} (\omega_1 + \omega_2)$$

The equations use these variables.

$N$	Carrier-to-driveshaft gear ratio
$J_d$	Rotational inertia of the crown gear assembly
$b_d$	Crown gear linear viscous damping
$\omega_d$	Driveshaft angular speed
$\eta$	Differential efficiency
$J_1$	Axle 1 rotational inertia
$b_1$	Axle 1 linear viscous damping
$\omega_1$	Axle 1 speed
$J_2$	Axle 2 rotational inertia
$b_2$	Axle 2 linear viscous damping
$\omega_2$	Axle 2 angular speed
$T_d$	Driveshaft torque
$T_1$	Axle 1 torque
$T_2$	Axle 2 torque
$T_i$	Driveshaft internal resistance torque
$T_{i1}$	Axle 1 internal resistance torque
$T_{i2}$	Axle 2 internal resistance torque

## Ports

### Inputs

#### **DriveshaftTrq — Torque**

scalar

Applied input torque, typically from the engine crankshaft, in N·m.

#### **Ax11Trq — Torque**

scalar

Axle 1 torque,  $T_1$ , in N·m.

#### **Ax12Trq — Torque**

scalar

Axle 2 torque,  $T_2$ , in N·m.

#### **Temp — Temperature**

scalar

Temperature, in K.

### Dependencies

To enable this port:

- Set **Efficiency factors** to Driveshaft torque, speed and temperature.
- Select **Input temperature**.

## Output

### Info – Bus signal

bus

Bus signal containing these block calculations.

Signal			Description	Units
Driveshft	DriveshftTrq		Driveshaft torque	N·m
	DriveshftSpd		Driveshaft speed	rad/s
Axl1	Axl1Trq		Axle 1 torque	N·m
	Axl1Spd		Axle 1 speed	rad/s
Axl2	Axl2Trq		Axle 2 torque	N·m
	Axl2Spd		Axle 2 speed	rad/s
PwrInfo	PwrTrnsfrd	PwrDriveshft	Mechanical power from driveshaft	W
		PwrAxl1	Mechanical power from axle 1	W
		PwrAxl2	Mechanical power from axle 2	W
	PwrTrnsfrd	PwrMechLoss	Total power loss	W
		PwrDampLoss	Power loss due to damping	W
	PwrStored	PwrStoredShft	Rate change of stored internal energy	W

### DriveshftSpd – Angular speed

scalar

Driveshaft angular speed,  $\omega_d$ , in rad/s.

### Axl1Spd – Angular speed

scalar

Axle 1 angular speed,  $\omega_1$ , in rad/s.

### Axl2Spd – Angular speed

scalar

Axle 2 angular speed,  $\omega_2$ , in rad/s.

## Parameters

### Block Options

#### Efficiency factors — Specify configuration

Constant (default) | Driveshaft torque, speed and temperature

To account for the block efficiency, use the **Efficiency factors** parameter. This table summarizes the block implementation for each setting.

Setting	Implementation
Constant	Constant efficiency that you can set with the <b>Constant efficiency factor, eta</b> parameter.
Driveshaft torque, temperature and speed	<p>Efficiency as a function of base gear input torque, air temperature, and driveshaft speed. Use these parameters to specify the lookup table and breakpoints:</p> <ul style="list-style-type: none"> <li>• <b>Efficiency lookup table, eta_tbl</b></li> <li>• <b>Efficiency torque breakpoints, Trq_bpts</b></li> <li>• <b>Efficiency speed breakpoints, omega_bpts</b></li> <li>• <b>Efficiency temperature breakpoints, Temp_bpts</b></li> </ul> <p>For the air temperature, you can either:</p> <ul style="list-style-type: none"> <li>• Select <b>Input temperature</b> to create an input port.</li> <li>• Set a <b>Ambient temperature, Tamb</b> parameter value.</li> </ul> <p>To select the interpolation method, use the <b>Interpolation method</b> parameter. For more information, see “Interpolation Methods”.</p>

#### Interpolation method — Method

Flat | Nearest | Linear point-slope | Linear Lagrange | Cubic spline

For more information, see “Interpolation Methods”.

### Dependencies

To enable this parameter, set **Efficiency factors** to Driveshaft torque, speed and temperature.

#### Input temperature — Create input port

off (default) | on

Select to create input port Temp for the temperature.

### Dependencies

To enable this parameter, set **Efficiency factors** to Driveshaft torque, speed and temperature.

#### Crown wheel (ring gear) located — Specify crown wheel connection

To the left of center-line (default) | To the right of center-line

Specify the crown wheel connection to the driveshaft.

**Carrier to drive shaft ratio, Ndiff – Ratio**

4 (default) | scalar

Carrier-to-driveshaft gear ratio,  $N$ , dimensionless.**Carrier inertia, Jd – Inertia**

.1 (default) | scalar

Rotational inertia of the crown gear assembly,  $J_d$ , in  $\text{kg}\cdot\text{m}^2$ . You can include the driveshaft inertia.**Carrier damping, bd – Damping**

1e-3 (default) | scalar

Crown gear linear viscous damping,  $b_d$ , in  $\text{N}\cdot\text{m}\cdot\text{s}/\text{rad}$ .**Axle 1 inertia, Jw1 – Inertia**

.1 (default) | scalar

Axle 1 rotational inertia,  $J_1$ , in  $\text{kg}\cdot\text{m}^2$ .**Axle 1 damping, bw1 – Damping**

1e-3 (default) | scalar

Axle 1 linear viscous damping,  $b_1$ , in  $\text{N}\cdot\text{m}\cdot\text{s}/\text{rad}$ .**Axle 2 inertia, Jw2 – Inertia**

.1 (default) | scalar

Axle 2 rotational inertia,  $J_2$ , in  $\text{kg}\cdot\text{m}^2$ .**Axle 2 damping, bw2 – Damping**

1e-3 (default) | scalar

Axle 2 linear viscous damping,  $b_2$ , in  $\text{N}\cdot\text{m}\cdot\text{s}/\text{rad}$ .**Axle 1 initial velocity, omegaw1o – Angular velocity**

0 (default) | scalar

Axle 1 initial velocity,  $\omega_{o1}$ , in  $\text{rad}/\text{s}$ .**Axle 2 initial velocity, omegaw2o – Angular velocity**

0 (default) | scalar

Axle 2 initial velocity,  $\omega_{o2}$ , in  $\text{rad}/\text{s}$ .**Efficiency****Constant efficiency factor, eta – Efficiency**

1 (default) | scalar

Constant efficiency,  $\eta$ .**Dependencies**To enable this parameter, set **Efficiency factors** to Constant.

**Efficiency lookup table, eta\_tbl — Lookup table**

M-by-N-by-L array

Dimensionless array of values for efficiency as a function of:

- M input torques
- N input speed
- L air temperatures

Each value specifies the efficiency for a specific combination of torque, speed, and temperature. The array size must match the dimensions defined by the torque, speed, and temperature breakpoint vectors.

**Dependencies**

To enable this parameter, set **Efficiency factors** to Driveshaft torque, speed and temperature.

**Efficiency torque breakpoints, Trq\_bpts — Torque breakpoints**

[25, 50, 75, 100, 150, 200, 250] (default) | 1-by-M vector

Vector of input torque, breakpoints for efficiency, in N·m.

**Dependencies**

To enable this parameter, set **Efficiency factors** to Driveshaft torque, speed and temperature.

**Efficiency speed breakpoints, omega\_bpts — Speed breakpoints**

[52.4 78.5 105 131 157 183 209 262 314 419 524] (default) | 1-by-N vector

Vector of speed, breakpoints for efficiency, in rad/s.

**Dependencies**

To enable this parameter, set **Efficiency factors** to Driveshaft torque, speed and temperature.

**Efficiency temperature breakpoints, Temp\_bpts — Temperature breakpoints**

[290 358] (default) | 1-by-L vector

Vector of ambient temperature breakpoints for efficiency, in K.

**Dependencies**

To enable this parameter, set **Efficiency factors** to Driveshaft torque, speed and temperature.

**Ambient temperature, Tamb — Ambient temperature**

297.15 (default) | scalar

Ambient air temperature,  $T_{air}$ , in K.

**Dependencies**

To enable this parameter:

- Set **Efficiency factors** to Driveshaft torque, speed and temperature.
- Clear **Input temperature**.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

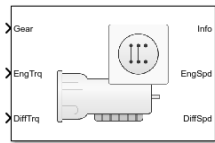
Limited Slip Differential

**Introduced in R2017a**

## Ideal Fixed Gear Transmission

Ideal fixed gear transmission without clutch or synchronization

**Library:** Powertrain Blockset / Transmission / Transmission Systems  
Vehicle Dynamics Blockset / Powertrain / Transmission



### Description

The Ideal Fixed Gear Transmission implements an idealized fixed-gear transmission without a clutch or synchronization. Use the block to model the overall gear ratio and power loss when you do not need a detailed transmission model, for example, in component-sizing, fuel economy, and emission studies. The block implements a transmission model with minimal parameterization or computational cost.

To specify the block efficiency calculation, for **Efficiency factors**, select either of these options.

Setting	Block Implementation
Gear only	Efficiency determined from a 1D lookup table that is a function of the gear.
Gear, input torque, input speed, and temperature	Efficiency determined from a 4D lookup table that is a function of: <ul style="list-style-type: none"> <li>• Gear</li> <li>• Input torque</li> <li>• Input speed</li> <li>• Oil temperature</li> </ul>

The block uses this equation to determine the transmission dynamics:

$$\dot{\omega}_i \frac{J_N}{N^2} = \eta_N \left( \frac{T_o}{N} + T_i \right) - \frac{\omega_i}{N^2} b_N$$

$$\omega_i = N \omega_o$$

The block filters the gear command signal:

$$\frac{G}{G_{cmd}}(s) = \frac{1}{\tau_s s + 1}$$

### Neutral Gear

When **Initial gear number, G\_o** is equal to 0, the initial gear is neutral. The block uses these parameters to decouple the input flywheel from the downstream gearing.

- **Initial input velocity, omega\_o**
- **Initial neutral input velocity, omegainN\_o**



The block uses these equations for the neutral gear speed and flywheel.

$$\dot{\omega}_{neutral} \frac{J_N}{N^2} = \eta_N \frac{T_o}{N} - \frac{\omega_{neutral}}{N^2} b_N$$

$$\omega_{neutral} = N\omega_o$$

$$\dot{\omega}_1 J_F = \eta_{@N} = 0 T_i - b_{@N} = 0 \omega_i$$

$$J_F = J_{@N} = 1 - J_{@N} = 0$$

**Power Accounting**

For the power accounting, the block implements these equations.

Bus Signal		Description	Variable	Equations	
PwrIn fo	PwrTrnsfrd — Power transferred between blocks  • Positive signals indicate flow into block • Negative signals indicate flow out of block	PwrEng	Engine power	$P_{eng}$	$\omega_i T_i$
		PwrDiffrntl	Differential power	$P_{diff}$	$\omega_o T_o$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred  • Positive signals indicate an input • Negative signals indicate a loss	PwrEffLoss	Mechanical power loss	$P_{effloss}$	$\omega_o T_o (\eta_N - 1)$
		PwrDampLoss	Mechanical damping loss	$P_{damploss}$	For $G=0$ : $-\frac{b_N \omega_i^2}{ N^2 }$ For $G \neq 0$ : $-b_N \omega_i^2 - \frac{b_N \omega_{neutral}^2}{ N^2 }$
PwrStored — Stored energy rate of change  • Positive signals indicate an increase • Negative signals indicate a decrease	PwrStoredTrns	Rate change in rotational kinetic energy	$P_{str}$	For $G=0$ : $\frac{J_N}{N^2} \dot{\omega}_i \omega_i$ For $G \neq 0$ : $J_F \dot{\omega}_i \omega_i + \frac{J_N}{N^2} \dot{\omega}_{neutral} \omega_{neutral}$	

The equations use these variables.

- $b_N$  Engaged gear viscous damping
- $J_N$  Engaged gear rotational inertia
- $J_F$  Flywheel rotational inertia
- $\eta_N$  Engaged gear efficiency
- $G$  Engaged gear number
- $G_{cmd}$  Gear number to engage
- $N$  Engaged gear ratio

$T_i$	Applied input torque, typically from the engine crankshaft or dual mass flywheel damper
$T_o$	Applied load torque, typically from the differential or drive shaft
$\omega_o$	Initial input drive shaft rotational velocity
$\omega_i, \dot{\omega}_i$	Applied drive shaft angular speed and acceleration
$\omega_{No}$	Initial neutral gear input rotational velocity
$\omega_{neutral}$	Neutral gear drive shaft rotational velocity
$\tau_s$	Shift time constant

## Ports

### Inputs

#### **Gear — Gear number to engage**

scalar

Integer value of gear number to engage,  $G_{cmd}$ .

#### **EngTrq — Applied input torque**

scalar

Applied input torque,  $T_i$ , typically from the engine crankshaft or dual mass flywheel damper, in N·m.

#### **DiffTrq — Applied load torque**

scalar

Applied load torque,  $T_o$ , typically from the differential, in N·m.

#### **Temp — Oil temperature**

scalar

Oil temperature, in K. To determine the efficiency, the block uses a 4D lookup table that is a function of:

- Gear
- Input torque
- Input speed
- Oil temperature

### Dependencies

To enable this port, set **Efficiency factors** to Gear, input torque, input speed, and temperature.

### Output

#### **Info — Bus signal**

bus

Bus signal containing these block calculations.

Signal		Description	Variable	Units	
Eng	EngTrq	Applied input torque, typically from the engine crankshaft or dual mass flywheel damper	$T_i$	N·m	
	EngSpd	Applied drive shaft angular speed input	$\omega_i$	rad/s	
Diff	DiffTrq	Applied load torque, typically from the differential	$T_o$	N·m	
	DiffSpd	Drive shaft angular speed output	$\omega_o$	rad/s	
Trans	TransSpdRatio	Input to output speed ratio at time t	$\Phi(t)$	N/A	
	TransEta	Ratio of output power to input power	$\eta_N$	N/A	
	TransGearCmd	Commanded gear	$N_{cmd}$	N/A	
	TransGear	Engaged gear	$N$	N/A	
PwrInfo	PwrTrnsfrd	PwrEng	Engine power	$P_{eng}$	W
		PwrDiffrentl	Differential power	$P_{diff}$	W
	PwrNotTrnsfrd	PwrEffLoss	Mechanical power loss	$P_{effloss}$	W
		PwrDampLoss	Mechanical damping loss	$P_{damploss}$	W
	PwrStored	PwrStoredTrans	Rate change in rotational kinetic energy	$P_{str}$	W

**EngSpd — Angular speed**

scalar

Applied drive shaft angular speed input,  $\omega_i$ , in rad/s.**DiffSpd — Angular speed**

scalar

Drive shaft angular speed output,  $\omega_o$ , in rad/s.

## Parameters

### Efficiency factors – Specify efficiency calculation

Gear only (default) | Gear, input torque, input speed, and temperature

To specify the block efficiency calculation, for **Efficiency factors**, select either of these options.

Setting	Block Implementation
Gear only	Efficiency determined from a 1D lookup table that is a function of the gear.
Gear, input torque, input speed, and temperature	Efficiency determined from a 4D lookup table that is a function of: <ul style="list-style-type: none"> <li>• Gear</li> <li>• Input torque</li> <li>• Input speed</li> <li>• Oil temperature</li> </ul>

### Dependencies

Setting Parameter To	Enables
Gear only	<b>Efficiency vector, eta</b>
Gear, input torque, input speed, and temperature	<b>Efficiency torque breakpoints, Trq_bpts</b> <b>Efficiency speed breakpoints, omega_bpts</b> <b>Efficiency temperature breakpoints, Temp_bpts</b> <b>Efficiency lookup table, eta_tbl</b>

### Gear property interpolation method – Interpolation

Nearest (default) | Linear | Flat | Cubic spline

Method that the block uses to switch the gear ratio during gear shifting.

### Transmission

#### Gear number vector, G – Specify number of transmission speeds

[-1,0,1,2,3,4,5] (default) | vector

Vector of integer gear commands used to specify the number of transmission speeds. Neutral gear is 0. For example, you can set these parameter values.

To Specify	Set Gear number, G To
Four transmission speeds, including neutral	[0, 1, 2, 3, 4]
Three transmission speeds, including neutral and reverse	[-1, 0, 1, 2, 3]
Five transmission speeds, including neutral and reverse	[-1, 0, 1, 2, 3, 4, 5]

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Inertia vector**, **Damping vector**, and **Efficiency vector** parameters must be equal.

#### **Efficiency torque breakpoints, Trq\_bpts – Breakpoints**

[25,50,75,100,150,200,250] (default) | vector

Torque breakpoints for efficiency table.

#### **Dependencies**

To enable this parameter, set **Efficiency factors** to Gear, input torque, input speed, and temperature.

#### **Efficiency speed breakpoints, omega\_bpts – Breakpoints**

[52.4 78.5 105 131 157 183 209 262 314 419 524] (default) | vector

Speed breakpoints for efficiency table.

#### **Dependencies**

To enable this parameter, set **Efficiency factors** to Gear, input torque, input speed, and temperature.

#### **Efficiency temperature breakpoints, Temp\_bpts – Breakpoints**

[313 358] (default) | vector

Temperature breakpoints for efficiency table.

#### **Dependencies**

To enable this parameter, set **Efficiency factors** to Gear, input torque, input speed, and temperature.

#### **Gear ratio vector, N – Ratio of input speed to output speed**

[-4.47,4.47,4.47,2.47,1.47,1,0.8] (default) | vector

Vector of gear ratios (that is, input speed to output speed) with indices corresponding to the ratios specified in **Gear number, G**. For neutral, set the gear ratio to 1. For example, you can set these parameter values.

To Specify Gear Ratios For	Set Gear number, G To	Set Gear ratio, N To
Four transmission speeds, including neutral	[0, 1, 2, 3, 4]	[1, 4.47, 2.47, 1.47, 1]
Five transmission speeds, including neutral and reverse	[-1, 0, 1, 2, 3, 4, 5]	[-4.47, 1, 4.47, 2.47, 1.47, 1, 0.8]

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Inertia vector**, **Damping vector**, and **Efficiency vector** parameters must be equal.

#### **Inertia vector, Jout – Gear rotational inertia**

[0.128 0.01 0.128 0.1 0.062 0.028 0.01] (default) | vector

Vector of gear rotational inertias,  $J_N$ , with indices corresponding to the inertias specified in **Gear number, G**, in  $\text{kg}\cdot\text{m}^2$ . For example, you can set these parameter values.

To Specify Inertia For	Set Gear number, G To	Set Inertia, J To
Four gears, including neutral	[0, 1, 2, 3, 4]	[0.01, 2.28, 2.04, 0.32, 0.028]
Inertia for five gears, including reverse and neutral	[-1, 0, 1, 2, 3, 4, 5]	[2.28, 0.01, 2.28, 2.04, 0.32, 0.028, 0.01]

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Inertia vector**, **Damping vector**, and **Efficiency vector** parameters must be equal.

**Damping vector, *bout* – Gear viscous damping coefficient**

[.003 .001 .003 .0025 .002 .001 .001] (default) | vector

Vector of gear viscous damping coefficients,  $b_N$ , with indices corresponding to the coefficients specified in **Gear number**, **G**, in N·m·s/rad. For example, you can set these parameter values.

To Specify Damping For	Set Gear number, G To	Set Damping, b To
Four gears, including neutral	[0, 1, 2, 3, 4]	[0.001, 0.003, 0.0025, 0.002, 0.001]
Five gears, including reverse and neutral	[-1, 0, 1, 2, 3, 4, 5]	[0.003, 0.001, 0.003, 0.0025, 0.002, 0.001, 0.001]

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Inertia vector**, **Damping vector**, and **Efficiency vector** parameters must be equal.

**Efficiency vector, *eta* – Gear efficiency**

[0.9, 0.9, 0.9, 0.9, 0.9, 0.95, 0.95] (default) | vector

Vector of gear mechanical efficiency,  $\eta_N$ , with indices corresponding to the efficiencies specified in **Gear number**, **G**. For example, you can set these parameter values.

To Specify Efficiency For	Set Gear number, G To	Set Efficiency, eta To
Four gears, including neutral	[0, 1, 2, 3, 4]	[0.9, 0.9, 0.9, 0.9, 0.95]
Five gears, including reverse and neutral	[-1, 0, 1, 2, 3, 4, 5]	[0.9, 0.9, 0.9, 0.9, 0.9, 0.95, 0.95]

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Inertia vector**, **Damping vector**, and **Efficiency vector** parameters must be equal.

**Dependencies**

To enable this parameter, set **Efficiency factors** to Gear only.

**Efficiency lookup table, *eta\_tbl* – Gear efficiency**

array

Table of gear mechanical efficiency,  $\eta_N$  as a function of gear, input torque, input speed, and temperature.

**Dependencies**

To enable this parameter, set **Efficiency factors** to Gear, input torque, input speed, and temperature.

**Initial gear number, G\_o – Gear**

0 (default) | scalar

Initial gear number,  $G_o$ , dimensionless.**Initial output velocity, omega\_o – Output speed**

0 (default) | scalar

Transmission initial output rotational velocity,  $\omega_o$ , in rad/s.**Initial neutral input velocity, omegainN\_o – Neutral gear input speed**

0 (default) | scalar

Initial neutral gear input rotational velocity,  $\omega_{No}$ , in rad/s.**Shift time constant, tau\_s – Time**

.01 (default) | scalar

Shift time constant,  $\tau_s$ , in s.**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Limited Slip Differential | Open Differential

**Introduced in R2017a**





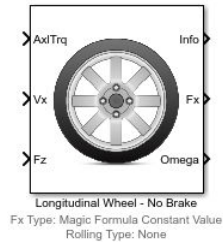
# Wheel and Tire Blocks

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## Longitudinal Wheel

Longitudinal wheel with disc, drum, or mapped brake

**Library:** Powertrain Blockset / Drivetrain / Wheels  
Vehicle Dynamics Blockset / Wheels and Tires



### Description

The Longitudinal Wheel block implements the longitudinal behavior of an ideal wheel. You can specify the longitudinal force and rolling resistance calculation method, and brake type. Use the block in driveline and longitudinal vehicle simulations where low frequency tire-road and braking forces are required to determine vehicle acceleration, braking, and wheel-rolling resistance. For example, you can use the block to determine the torque and power requirements for a specified drive cycle or braking event. The block is not suitable for applications that require combined lateral slip.

There are four types of Longitudinal Wheel blocks. Each block implements a different brake type.

Block Name	Brake Type Setting	Brake Implementation
Longitudinal Wheel - No Brake	None	None
Longitudinal Wheel - Disc Brake	Disc	Brake that converts the brake cylinder pressure into a braking force.
Longitudinal Wheel - Drum Brake	Drum	Simplex drum brake that converts the applied force and brake geometry into a net braking torque.
Longitudinal Wheel - Mapped Brake	Mapped	Lookup table that is a function of the wheel speed and applied brake pressure.

The block models longitudinal force as a function of wheel slip relative to the road surface. To calculate the longitudinal force, specify one of these **Longitudinal Force** parameters.

Setting	Block Implementation
Magic Formula constant value	Magic Formula with constant coefficient for stiffness, shape, peak, and curvature.
Magic Formula pure longitudinal slip	Magic Formula with load-dependent coefficients that implement equations 4.E9 through 4.E18 in <i>Tire and Vehicle Dynamics</i> .
Mapped force	Lookup table that is a function of the normal force and wheel slip ratio.

To calculate the rolling resistance torque, specify one of these **Rolling Resistance** parameters.

Setting	Block Implementation
None	None
Pressure and velocity	Method in <i>Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance</i> . The rolling resistance is a function of tire pressure, normal force, and velocity.
ISO 28580	Method specified in ISO 28580:2018, <i>Passenger car, truck and bus tyre rolling resistance measurement method – Single point test and correlation of measurement results</i> .
Magic Formula	Magic formula equations from 4.E70 in <i>Tire and Vehicle Dynamics</i> . The magic formula is an empirical equation based on fitting coefficients.
Mapped torque	Lookup table that is a function of the normal force and spin axis longitudinal velocity.

To calculate vertical motion, specify one of these **Vertical Motion** parameters.

Setting	Block Implementation
None	Block passes the applied chassis forces directly through to the rolling resistance and longitudinal force calculations.
Mapped stiffness and damping	Vertical motion depends on wheel stiffness and damping. Stiffness is a function of tire sidewall displacement and pressure. Damping is a function of tire sidewall velocity and pressure.

### Rotational Wheel Dynamics

The block calculates the inertial response of the wheel subject to:

- Axle losses
- Brake and drive torque
- Tire rolling resistance
- Ground contact through the tire-road interface

The input torque is the summation of the applied axle torque, braking torque, and moment arising from the combined tire torque.

$$T_i = T_a - T_b + T_d$$

For the moment arising from the combined tire torque, the block implements tractive wheel forces and rolling resistance with first order dynamics. The rolling resistance has a time constant parameterized in terms of a relaxation length.

$$T_d(s) = \frac{1}{\frac{|\omega| R_e}{L_e} s + 1} (F_x R_e + M_y)$$

To calculate the rolling resistance torque, you can specify one of these **Rolling Resistance** parameters.

Setting	Block Implementation
None	Block sets rolling resistance, $M_y$ , to zero.
Pressure and velocity	Block uses the method in SAE <i>Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance</i> . The rolling resistance is a function of tire pressure, normal force, and velocity. Specifically, $M_y = R_e \{ a + b V_x  + cV_x^2 \} \{ F_z \beta p_i a \} \tanh(4V_x)$
ISO 28580	Block uses the method specified in ISO 28580:2018, <i>Passenger car, truck and bus tyre rolling resistance measurement method – Single point test and correlation of measurement results</i> . The method accounts for normal load, parasitic loss, and thermal corrections from test conditions. Specifically, $M_y = R_e \left( \frac{F_z C_r}{1 + K_t(T_{amb} - T_{meas})} - F_{pl} \right) \tanh(\omega)$
Magic Formula	Block calculates the rolling resistance, $M_y$ , using the Magic Formula equations from 4.E70 in <i>Tire and Vehicle Dynamics</i> . The magic formula is an empirical equation based on fitting coefficients.
Mapped torque	For the rolling resistance, $M_y$ , the block uses a lookup table that is a function of the normal force and spin axis longitudinal velocity.

If the brakes are enabled, the block determines the braking locked or unlocked condition based on an idealized dry clutch friction model. Based on the lock-up condition, the block implements these friction and dynamic models.

If	Lock-Up Condition	Friction Model	Dynamic Model
$\omega \neq 0$ or $T_S <  T_i + T_f - \omega b $	Unlocked	$T_f = T_k$ where, $T_k = F_c R_{eff} \mu_k \tanh[4(-\omega_d)]$ $T_s = F_c R_{eff} \mu_s$ $R_{eff} = \frac{2(R_o^3 - R_i^3)}{3(R_o^2 - R_i^2)}$	$\dot{\omega} J = -\omega b + T_i + T_o$
$\omega = 0$ and $T_S \geq  T_i + T_f - \omega b $	Locked	$T_f = T_s$	$\omega = 0$

The equations use these variables.

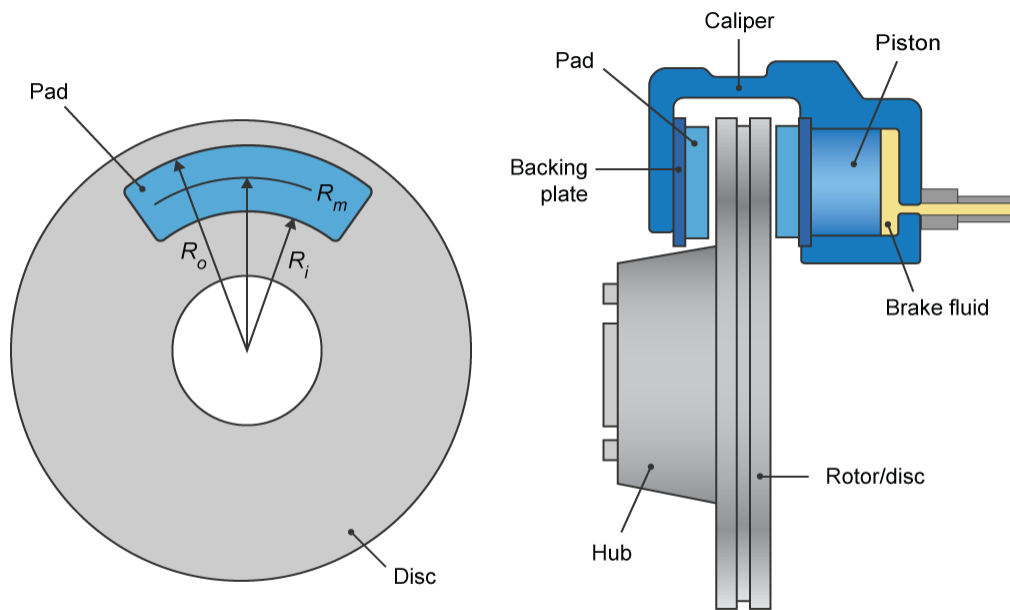
- $\omega$  Wheel angular velocity
- $a$  Velocity-independent force component
- $b$  Linear velocity force component
- $c$  Quadratic velocity force component
- $L_e$  Tire relaxation length
- $J$  Moment of inertia

$M_y$	Rolling resistance torque
$T_a$	Applied axle torque
$T_b$	Braking torque
$T_d$	Combined tire torque
$T_f$	Frictional torque
$T_i$	Net input torque
$T_k$	Kinetic frictional torque
$T_o$	Net output torque
$T_s$	Static frictional torque
$F_c$	Applied clutch force
$F_x$	Longitudinal force developed by the tire road interface due to slip
$R_{eff}$	Effective clutch radius
$R_o$	Annular disk outer radius
$R_i$	Annular disk inner radius
$R_e$	Effective tire radius while under load and for a given pressure
$V_x$	Longitudinal axle velocity
$F_z$	Vehicle normal force
$C_r$	Rolling resistance constant
$T_{amb}$	Ambient temperature
$T_{meas}$	Measured temperature for rolling resistance constant
$F_{pl}$	Parasitic force loss
$K_t$	Thermal correction factor
$\alpha$	Tire pressure exponent
$\beta$	Normal force exponent
$p_i$	Tire pressure
$\mu_s$	Coefficient of static friction
$\mu_k$	Coefficient of kinetic friction

## Brakes

### Disc

If you specify the **Brake Type** parameter `Disc`, the block implements a disc brake. This figure shows the side and front views of a disc brake.



A disc brake converts brake cylinder pressure from the brake cylinder into force. The disc brake applies the force at the brake pad mean radius.

The block uses these equations to calculate brake torque for the disc brake.

$$T = \begin{cases} \frac{\mu P \pi B_a^2 R_m N_{pads}}{4} & \text{when } N \neq 0 \\ \frac{\mu_{static} P \pi B_a^2 R_m N_{pads}}{4} & \text{when } N = 0 \end{cases}$$

$$R_m = \frac{R_o + R_i}{2}$$

The equations use these variables.

$T$	Brake torque
$P$	Applied brake pressure
$N$	Wheel speed
$N_{pads}$	Number of brake pads in disc brake assembly
$\mu_{static}$	Disc pad-rotor coefficient of static friction
$\mu$	Disc pad-rotor coefficient of kinetic friction
$B_a$	Brake actuator bore diameter
$R_m$	Mean radius of brake pad force application on brake rotor
$R_o$	Outer radius of brake pad

$R_i$  Inner radius of brake pad

### Drum

If you specify the **Brake Type** parameter Drum, the block implements a static (steady-state) simplex drum brake. A simplex drum brake consists of a single two-sided hydraulic actuator and two brake shoes. The brake shoes do not share a common hinge pin.

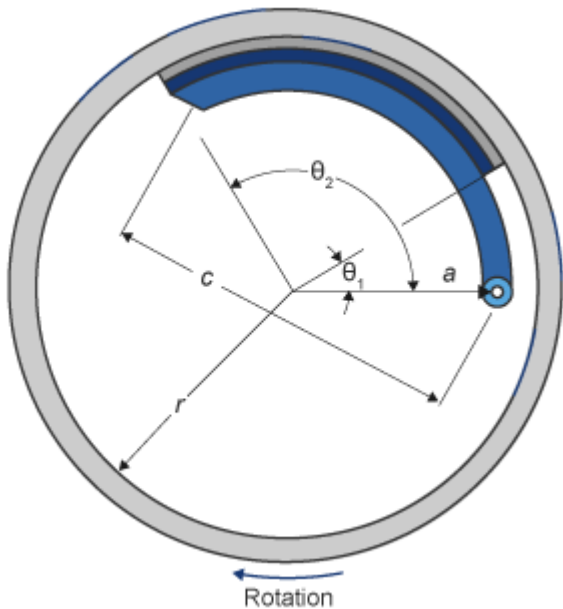
The simplex drum brake model uses the applied force and brake geometry to calculate a net torque for each brake shoe. The drum model assumes that the actuators and shoe geometry are symmetrical for both sides, allowing a single set of geometry and friction parameters to be used for both shoes.

The block implements equations that are derived from these equations in *Fundamentals of Machine Elements*.

$$T_{rshoe} = \left( \frac{\pi \mu c r (\cos \theta_2 - \cos \theta_1) B a^2}{2 \mu (2r (\cos \theta_2 - \cos \theta_1) + a (\cos^2 \theta_2 - \cos^2 \theta_1)) + ar (2\theta_1 - 2\theta_2 + \sin 2\theta_2 - \sin 2\theta_1)} \right) P$$

$$T_{lshoe} = \left( \frac{\pi \mu c r (\cos \theta_2 - \cos \theta_1) B a^2}{-2 \mu (2r (\cos \theta_2 - \cos \theta_1) + a (\cos^2 \theta_2 - \cos^2 \theta_1)) + ar (2\theta_1 - 2\theta_2 + \sin 2\theta_2 - \sin 2\theta_1)} \right) P$$

$$T = \begin{cases} T_{rshoe} + T_{lshoe} & \text{when } N \neq 0 \\ (T_{rshoe} + T_{lshoe}) \frac{\mu_{static}}{\mu} & \text{when } N = 0 \end{cases}$$



The equations use these variables.

$T$  Brake torque  
 $P$  Applied brake pressure  
 $N$  Wheel speed

$\mu_{static}$	Disc pad-rotor coefficient of static friction
$\mu$	Disc pad-rotor coefficient of kinetic friction
$T_{rshoe}$	Right shoe brake torque
$T_{lshoe}$	Left shoe brake torque
$a$	Distance from drum center to shoe hinge pin center
$c$	Distance from shoe hinge pin center to brake actuator connection on brake shoe
$r$	Drum internal radius
$B_a$	Brake actuator bore diameter
$\theta_1$	Angle from shoe hinge pin center to start of brake pad material on shoe
$\theta_2$	Angle from shoe hinge pin center to end of brake pad material on shoe

**Mapped**

If you specify the **Brake Type** parameter Mapped, the block uses a lookup table to determine the brake torque.

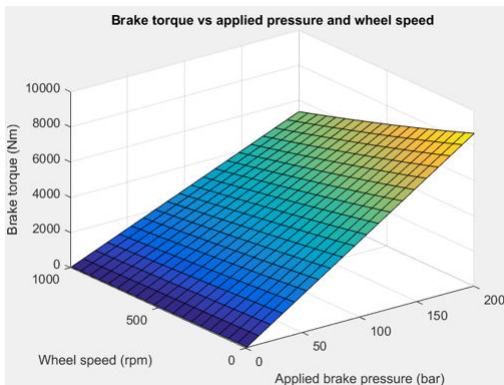
$$T = \begin{cases} f_{brake}(P, N) & \text{when } N \neq 0 \\ \left(\frac{\mu_{static}}{\mu}\right)f_{brake}(P, N) & \text{when } N = 0 \end{cases}$$

The equations use these variables.

$T$	Brake torque
$f_{brake}(P, N)$	Brake torque lookup table
$P$	Applied brake pressure
$N$	Wheel speed
$\mu_{static}$	Friction coefficient of drum pad-face interface under static conditions
$\mu$	Friction coefficient of disc pad-rotor interface

The lookup table for the brake torque,  $f_{brake}(P, N)$ , is a function of applied brake pressure and wheel speed, where:

- $T$  is brake torque, in N·m.
- $P$  is applied brake pressure, in bar.
- $N$  is wheel speed, in rpm.





## Longitudinal Force

To model the Longitudinal Wheel block longitudinal forces, you can use the Magic Formula. The model provides a steady-state *tire characteristic function*  $F_x = f(\kappa, F_z)$ , the longitudinal force  $F_x$  on the tire, based on:

- Vertical load  $F_z$
- Wheel slip  $\kappa$



The Magic Formula model uses these variables.

$\Omega$	Wheel angular velocity
$r_w$	Wheel radius
$V_x$	Wheel hub longitudinal velocity
$r_w\Omega$	Tire tread longitudinal velocity
$V_{sx} = r_w\Omega - V_x$	Wheel slip velocity
$\kappa = V_{sx}/ V_x $	Wheel slip
$F_z, F_{z0}$	Vertical load and nominal vertical load on tire
$F_x = f(\kappa, F_z)$	Longitudinal force exerted on the tire at the contact point. Also a characteristic function $f$ of the tire.

### Magic Formula Constant Value

If you set **Longitudinal Force** to **Magic Formula constant value**, the block implements the Magic Formula as a specific form of the tire characteristic function, characterized by four dimensionless coefficients ( $B, C, D, E$ ), or stiffness, shape, peak, and curvature:

$$F_x = f(\kappa, F_z) = F_z D \sin\left(C \tan^{-1}\left[\left\{B\kappa - E\left[B\kappa - \tan^{-1}(B\kappa)\right]\right\}\right]\right)$$

The slope of  $f$  at  $\kappa = 0$  is  $BCD \cdot F_z$ .

The coefficients are based on empirical tire data. These values are typical sets of constant Magic Formula coefficients for common road conditions.

Surface	B	C	D	E
Dry tarmac	10	1.9	1	0.97
Wet tarmac	12	2.3	0.82	1
Snow	5	2	0.3	1
Ice	4	2	0.1	1

### Magic Formula Pure Longitudinal Slip

If you set **Longitudinal Force** to Magic Formula pure longitudinal slip, the block implements a more general Magic Formula using dimensionless coefficients that are functions of the tire load. The block implements the longitudinal force equations in Chapter 4 of *Tire and Vehicle Dynamics*, including 4.E9 through 4.E18:

$$F_{x0} = D_x \sin\left(C_x \tan^{-1}\left[\left\{B_x K_x - E_x [B_x K_x - \tan^{-1}(B_x K_x)]\right\}\right]\right) + S_{Vx}$$

where:

$$K_x = \kappa + S_{Hx}$$

$$C_x = p_{Cx1} \lambda_{Cx}$$

$$D_x = \mu_x F_z \zeta_1$$

$$\mu_x = (p_{Dx1} + p_{Dx2} df_z)(1 + p_{px3} dp_i + p_{px4} dp_i^2)(1 - p_{Dx3} v^2) \lambda_{\mu x}^*$$

$$E_x = (p_{Ex1} + p_{Ex2} df_z + p_{Ex3} df_z^2)[1 - p_{Ex4} \text{sgn}(\kappa_x)] \lambda_{Ex}$$

$$K_{xx} = F_z (p_{Kx1} + p_{Kx2} df_z) \exp(p_{Kx3} df_z)(1 + p_{px1} dp_i + p_{px2} dp_i^2)$$

$$B_x = K_{xx} / (C_x D_x + \varepsilon_x)$$

$$S_{Hx} = p_{Hx1} + p_{Hx2} df_z$$

$$S_{Vx} = F_z \cdot (p_{Vx1} + p_{Vx2} df_z) \lambda_{Vx} \lambda_{\mu x} \zeta_1$$

$S_{Hx}$  and  $S_{Vx}$  represent offsets to the slip and longitudinal force in the force-slip function, or horizontal and vertical offsets if the function is plotted as a curve.  $\mu_x$  is the longitudinal load-dependent friction coefficient.  $\varepsilon_x$  is a small number inserted to prevent division by zero as  $F_z$  approaches zero.

### Vertical Dynamics

If you select no vertical degrees-of-freedom by setting **Vertical Motion** to None, the block passes the applied chassis forces directly through to the rolling resistance and longitudinal force calculations.

If you set **Vertical Motion** to Mapped stiffness and damping, the vertical motion depends on wheel stiffness and damping. Stiffness is a function of tire sidewall displacement and pressure. Damping is a function of tire sidewall velocity and pressure.

$$F_{ztire}(z, \dot{z}, P_{tire}) = F_{zk}(z, P_{tire}) + F_{zb}(\dot{z}, P_{tire})$$

The block determines the vertical response using this differential equation.

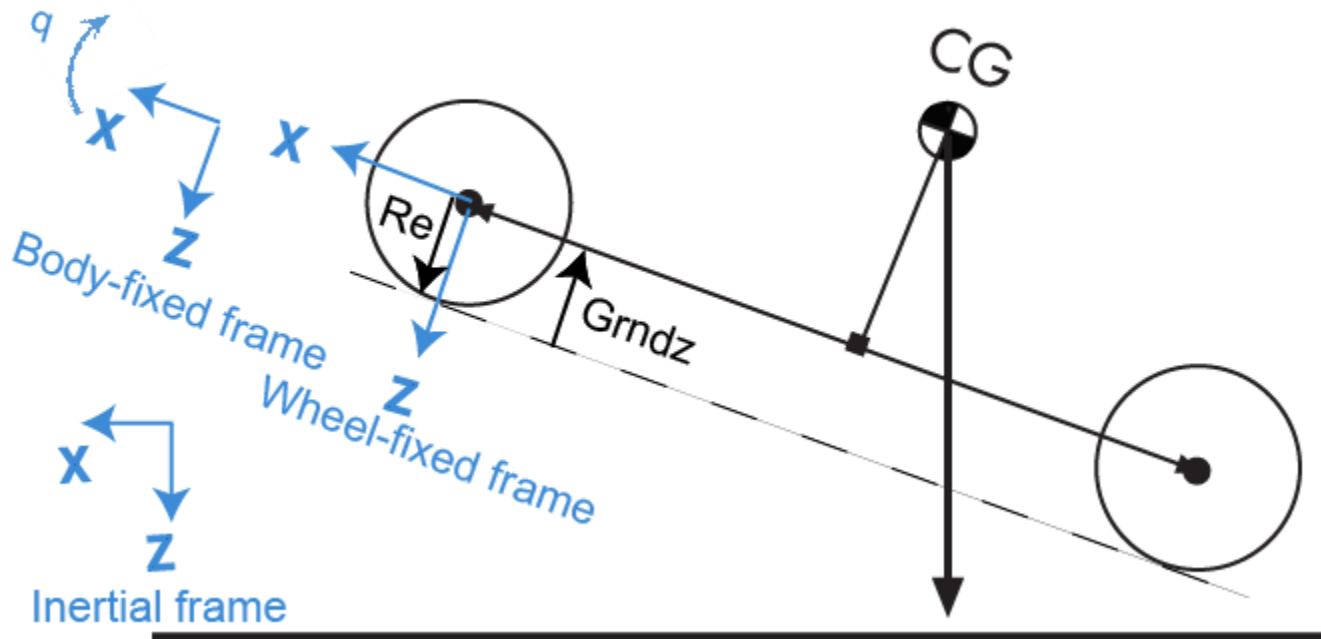
$$\ddot{z}m = F_{ztire} - F_z - mg$$

When you disable the vertical degree-of-freedom, the input normal force from the vehicle passes directly to the longitudinal and rolling force calculations.

$$\ddot{z} = \dot{z} = m = 0$$

$$F_{ztire} = mg$$

The block uses the wheel-fixed frame to resolve the vertical forces.



The equations use these variables.

$F_{ztire}$	Tire normal force along the wheel-fixed z-axis
$m$	Axle mass
$F_{zk}$	Tire normal force due to wheel stiffness along the wheel-fixed z-axis
$F_{zb}$	Tire normal force due to wheel damping along the wheel-fixed z-axis
$F_z$	Suspension or vehicle normal force along the wheel-fixed z-axis
$P_{Tire}$	Tire pressure
$z, \dot{z}, \ddot{z}$	Tire displacement, velocity, and acceleration, respectively, along the wheel-fixed z-axis

### Power Accounting

For the power accounting, the block implements these equations.

Bus Signal		Description	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks	PwrRoad	Tractive power applied from the axle $P_{road} = F_x V_x$
		PwrAxlTrq	External torque applied by the axle to the wheel $P_T = T\omega$

Bus Signal	Description	Equations
<ul style="list-style-type: none"> <li>Positive signals indicate flow into block</li> <li>Negative signals indicate flow out of block</li> </ul>	PwrFz	Vertical force applied to the wheel by the vehicle or suspension $P_{Fz} = F_z \dot{z}$
PwrNotTrnsfrd — Power crossing the block boundary, but not transferred  <ul style="list-style-type: none"> <li>Positive signals indicate an input</li> <li>Negative signals indicate a loss</li> </ul>	PwrSlip	Tractive power loss $P_K = F_x V_x + (-F_{cp} R_e + M_y) \omega$
	PwrMyRoll	Rolling resistance power $P_{My} = M_y \omega$
	PwrMyBrk	Braking power $P_{brk} = M_{brk} \omega$
	PwrMyb	Rolling viscous damping loss $P_b = -b \omega^2$
	PwrFzDamp	Vertical damping power $P_{Fzb} = F_{zb} \dot{z}$
PwrStored — Stored energy rate of change  <ul style="list-style-type: none"> <li>Positive signals indicate an increase</li> <li>Negative signals indicate a decrease</li> </ul>	PwrStoredzdot	Rate of change of vertical kinetic energy $P_z = m \dot{z} \dot{z}$
	PwrStoredq	Rate of change of rotational kinetic energy $P_\omega = I_{yy} \dot{\omega} \omega$
	PwrStoredFsFzSprng	Rate of change of stored sidewall potential energy $P_{Fzk} = F_{zk} \dot{x}$
	PwrStoredGrvty	Rate of change of gravitational potential energy $P_g = -mg \dot{z}$

The equations use these variables.

- $\omega$  Wheel angular velocity
- $b$  Linear velocity force component
- $F_x$  Longitudinal force developed by the tire road interface due to slip
- $F_{cp}$  Tire slip force at contact patch
- $F_z$  Vehicle normal force
- $F_{zb}$  Tire normal force due to wheel damping
- $F_{zk}$  Tire normal force due to wheel stiffness
- $I_{yy}$  Wheel rotational inertia
- $M_{brk}$  Braking moment
- $M_y$  Rolling resistance torque
- $R_e$  Effective tire radius while under load and for a given pressure
- $T$  Axle torque applied on wheel
- $V_x$  Longitudinal axle velocity

$z, \dot{z}, \ddot{z}$	Tire displacement, velocity, and acceleration, respectively
$\omega$	Wheel angular velocity
$\dot{z}$	Vehicle vertical velocity along the vehicle-fixed z-axis

## Ports

### Input

#### **BrkPrs — Brake pressure**

scalar

Brake pressure, in Pa.

#### **Dependencies**

To enable this port, for the **Brake Type** parameter, specify one of these types:

- Disc
- Drum
- Mapped

#### **AxLTrq — Axle torque**

scalar

Axle torque,  $T_a$ , about wheel spin axis, in N·m.

#### **Vx — Velocity**

scalar

Axle longitudinal velocity along vehicle(body)-fixed x-axis, in m/s.

#### **Fz — Normal force**

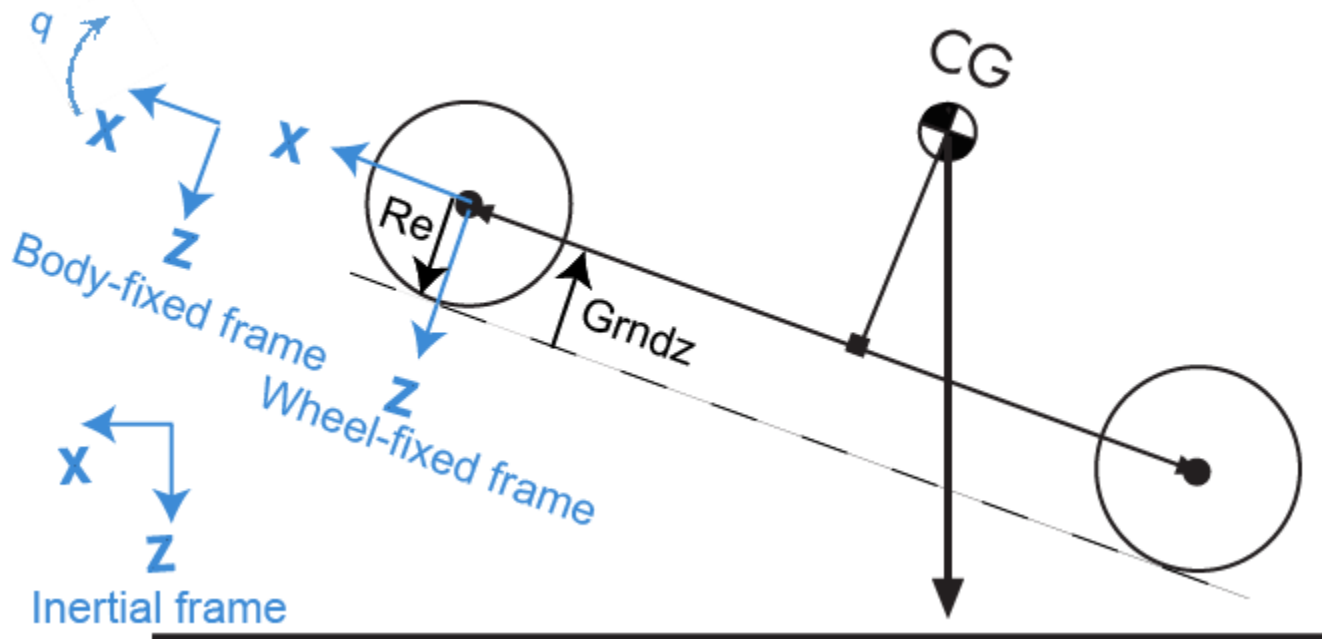
scalar

Absolute value of suspension or vehicle normal force along body-fixed z-axis, in N.

#### **Gnd — Ground displacement**

scalar

Ground displacement,  $G_{ndz}$ , along negative wheel-fixed z-axis, in m.



**Dependencies**

To create Gnd:

- Set **Vertical Motion** to Mapped stiffness and damping.
- On the **Vertical** pane, select **Input ground displacement**.

**lam\_mux – Friction scaling factor**

scalar

Longitudinal friction scaling factor, dimensionless.

**Dependencies**

To enable this port, select **Input friction scale factor**.

**TirePrs – Tire pressure**

scalar

Tire pressure, in Pa.

**Dependencies**

To enable this port:

- Set one of these parameters:
  - **Longitudinal Force** to Magic Formula pure longitudinal slip.
  - **Rolling Resistance** to Pressure and velocity or Magic Formula.
  - **Vertical Motion** to Mapped stiffness and damping.

- On the **Wheel Dynamics** pane, select **Input tire pressure**.

### Tamb — Ambient temperature

scalar

Ambient temperature,  $T_{amb}$ , in K.

#### Dependencies

To enable this port:

- 1 Set **Rolling Resistance** to ISO 28580.
- 2 On the **Rolling Resistance** pane, select to **Input ambient temperature**.

#### Output

### Info — Bus signal

bus

Bus signal containing these block calculations.

Signal	Description	Units
AxlTrq	Axle torque about body-fixed y-axis	N·m
Omega	Wheel angular velocity about body-fixed y-axis	rad/s
Omegadot	Wheel angular acceleration about body-fixed y-axis	rad/s <sup>2</sup>
Fx	Longitudinal vehicle force along body-fixed x-axis	N
Fz	Vertical vehicle force along body-fixed z-axis	N
Fzb	Tire normal force due to wheel damping along the wheel-fixed z-axis	N
Fzk	Tire normal force due to wheel stiffness along the wheel-fixed z-axis	N
My	Rolling resistance torque about body-fixed y-axis	N·m
Myb	Rolling resistance torque due to damping about body-fixed y-axis	N·m
Kappa	Slip ratio	NA
Vx	Vehicle longitudinal velocity along body-fixed x-axis	m/s
Re	Wheel effective radius along wheel-fixed z-axis	m

Signal		Description	Units	
BrkTrq		Brake torque about body-fixed y-axis	N·m	
BrkPrs		Brake pressure	Pa	
z		Wheel vertical deflection along wheel-fixed z-axis	m	
zdot		Wheel vertical velocity along wheel-fixed z-axis	m/s	
zddot		Wheel vertical acceleration along wheel-fixed z-axis	m/s <sup>2</sup>	
Gndz		Ground displacement along negative of wheel-fixed z-axis (positive input produces wheel lift)	m	
GndFz		Vertical wheel force on ground along negative of wheel-fixed z-axis	N	
TirePrs		Tire pressure	Pa	
Fpatch		Tractive power applied from the axle		
PwrInfo	PwrTrnsfrd	PwrRoad	External torque applied by the axle to the wheel	W
		PwrAxlTrq	Vertical force applied to the wheel by the vehicle or suspension	W
		PwrFz	Tractive power loss	W
	PwrNotTrnsfrd	PwrSlip	Rolling resistance power	W
		PwrMyRoll	Braking power	W
		PwrMyBrk	Rolling viscous damping loss	W
		PwrMyb	Vertical damping power	W
		PwrFzDamp	Rate of change of vertical kinetic energy	W
	PwrStored	PwrStoredzdot	Rate of change of rotational kinetic energy	W
		PwrStoredq	Rate of change of stored sidewall potential energy	W
		PwrStoredFsFzSprng	Rate of change of gravitational potential energy	W
		PwrStoredGrvty	Tractive power applied from the axle	W

**Fx — Longitudinal axle force**  
scalar



Longitudinal force acting on axle, along body-fixed x-axis, in N. Positive force acts to move the vehicle forward.

**Omega – Wheel angular velocity**

scalar

Wheel angular velocity, about body-fixed y-axis, in rad/s.

**z – Wheel vertical deflection**

scalar

Wheel vertical deflection along wheel-fixed z-axis, in m.

**Dependencies**

To enable this port, set **Vertical Motion** to Mapped stiffness and damping.

**zdot – Wheel vertical velocity**

scalar

Wheel vertical velocity along wheel-fixed z-axis, in m/s.

**Dependencies**

To enable this port, set **Vertical Motion** to Mapped stiffness and damping.

**Parameters**

**Block Options**

**Longitudinal Force – Select type**

Magic Formula constant value (default) | Magic Formula pure longitudinal slip | Mapped force

The block models longitudinal force as a function of wheel slip relative to the road surface. To calculate the longitudinal force, specify one of these **Longitudinal Force** parameters.

Setting	Block Implementation
Magic Formula constant value	Magic Formula with constant coefficient for stiffness, shape, peak, and curvature.
Magic Formula pure longitudinal slip	Magic Formula with load-dependent coefficients that implement equations 4.E9 through 4.E18 in <i>Tire and Vehicle Dynamics</i> .
Mapped force	Lookup table that is a function of the normal force and wheel slip ratio.

**Dependencies**

<b>Selecting</b>	<b>Enables These Parameters</b>
Magic Formula constant value	<b>Pure longitudinal peak factor, Dx</b> <b>Pure longitudinal shape factor, Cx</b> <b>Pure longitudinal stiffness factor, Bx</b> <b>Pure longitudinal curvature factor, Ex</b>

Selecting	Enables These Parameters
Magic Formula pure longitudinal slip	<p>Cfx shape factor, PCX1</p> <p>Longitudinal friction at nominal normal load, PDX1</p> <p>Frictional variation with load, PDX2</p> <p>Frictional variation with camber, PDX3</p> <p>Longitudinal curvature at nominal normal load, PEX1</p> <p>Variation of curvature factor with load, PEX2</p> <p>Variation of curvature factor with square of load, PEX3</p> <p>Longitudinal curvature factor with slip, PEX4</p> <p>Longitudinal slip stiffness at nominal normal load, PKX1</p> <p>Variation of slip stiffness with load, PKX2</p> <p>Slip stiffness exponent factor, PKX3</p> <p>Horizontal shift in slip ratio at nominal normal load, PHX1</p> <p>Variation of horizontal slip ratio with load, PHX2</p> <p>Vertical shift in load at nominal normal load, PVX1</p> <p>Variation of vertical shift with load, PVX2</p> <p>Linear variation of longitudinal slip stiffness with tire pressure, PPX1</p> <p>Quadratic variation of longitudinal slip stiffness with tire pressure, PPX2</p> <p>Linear variation of peak longitudinal friction with tire pressure, PPX3</p> <p>Quadratic variation of peak longitudinal friction with tire pressure, PPX4</p> <p>Linear variation of longitudinal slip stiffness with tire pressure, PPX1</p> <p>Slip speed decay function scaling factor, lam_muV</p> <p>Brake slip stiffness scaling factor, lam_Kxkappa</p> <p>Longitudinal shape scaling factor, lam_Cx</p> <p>Longitudinal curvature scaling factor, lam_Ex</p>

Selecting	Enables These Parameters
	<b>Longitudinal horizontal shift scaling factor, lam_Hx</b> <b>Longitudinal vertical shift scaling factor, lam_Vx</b>
Mapped force	<b>Slip ratio breakpoints, kappaFx</b> <b>Normal force breakpoints, FzFx</b> <b>Longitudinal force map, FxMap</b>

### Rolling Resistance – Select type

None (default) | Pressure and velocity | ISO 28580 | Magic Formula | Mapped torque

To calculate the rolling resistance torque, specify one of these **Rolling Resistance** parameters.

Setting	Block Implementation
None	None
Pressure and velocity	Method in <i>Stepwise Cooldown Methodology for Measuring Tire Rolling Resistance</i> . The rolling resistance is a function of tire pressure, normal force, and velocity.
ISO 28580	Method specified in ISO 28580:2018, <i>Passenger car, truck and bus tyre rolling resistance measurement method – Single point test and correlation of measurement results</i> .
Magic Formula	Magic formula equations from 4.E70 in <i>Tire and Vehicle Dynamics</i> . The magic formula is an empirical equation based on fitting coefficients.
Mapped torque	Lookup table that is a function of the normal force and spin axis longitudinal velocity.

### Dependencies

Selecting	Parameters
Pressure and velocity	<b>Velocity independent force coefficient, aMy</b> <b>Linear velocity force component, bMy</b> <b>Quadratic velocity force component, cMy</b> <b>Tire pressure exponent, alphaMy</b> <b>Normal force exponent, betaMy</b>

Selecting	Parameters
ISO 28580	<b>Parasitic losses force, Fpl</b> <b>Rolling resistance constant, Cr</b> <b>Thermal correction factor, Kt</b> <b>Measured temperature, Tmeas</b> <b>Parasitic losses force, Fpl</b> <b>Ambient temperature, Tamb</b>
Magic Formula	<b>Rolling resistance torque coefficient, QSY</b> <b>Longitudinal force rolling resistance coefficient, QSY2</b> <b>Linear rotational speed rolling resistance coefficient, QSY3</b> <b>Quartic rotational speed rolling resistance coefficient, QSY4</b> <b>Camber squared rolling resistance torque, QSY5</b> <b>Load based camber squared rolling resistance torque, QSY6</b> <b>Normal load rolling resistance coefficient, QSY7</b> <b>Pressure load rolling resistance coefficient, QSY8</b> <b>Rolling resistance scaling factor, lam_My</b>
Mapped torque	<b>Spin axis velocity breakpoints, VxMy</b> <b>Normal force breakpoints, FzMy</b> <b>Rolling resistance torque map, MyMap</b>

### Brake Type – Select type

None | Disc | Drum | Mapped

There are four types of Longitudinal Wheel blocks. Each block implements a different brake type.

Block Name	Brake Type Setting	Brake Implementation
Longitudinal Wheel - No Brake	None	None
Longitudinal Wheel - Disc Brake	Disc	Brake that converts the brake cylinder pressure into a braking force.
Longitudinal Wheel - Drum Brake	Drum	Simplex drum brake that converts the applied force and brake geometry into a net braking torque.

Block Name	Brake Type Setting	Brake Implementation
Longitudinal Wheel - Mapped Brake	Mapped	Lookup table that is a function of the wheel speed and applied brake pressure.

**Vertical Motion – Select type**

None (default) | Mapped stiffness and damping

To calculate vertical motion, specify one of these **Vertical Motion** parameters.

Setting	Block Implementation
None	Block passes the applied chassis forces directly through to the rolling resistance and longitudinal force calculations.
Mapped stiffness and damping	Vertical motion depends on wheel stiffness and damping. Stiffness is a function of tire sidewall displacement and pressure. Damping is a function of tire sidewall velocity and pressure.

Selecting	Enables These Parameters	Creates These Output Ports
Mapped stiffness and damping	<p><b>Wheel and unsprung mass, m</b></p> <p><b>Initial deflection, z<sub>0</sub></b></p> <p><b>Initial velocity, z<sub>dot0</sub></b></p> <p><b>Gravitational acceleration, g</b></p> <p><b>Vertical deflection breakpoints, zFz</b></p> <p><b>Pressure breakpoints, pFz</b></p> <p><b>Force due to deflection, Fzz</b></p> <p><b>Vertical velocity breakpoints, zdotFz</b></p> <p><b>Force due to velocity, Fzzdot</b></p> <p><b>Ground displacement, Gndz</b></p> <p><b>Input ground displacement</b></p>	<p>z</p> <p>zdot</p>

**Longitudinal scaling factor, lam\_x – Friction scaling factor**

1 (default)

Longitudinal friction scaling factor, dimensionless.

**Dependencies**

To enable this parameter, clear **Input friction scale factor**.

**Input friction scale factor – Selection**

Off (default)

Create input port for longitudinal friction scaling factor.

**Dependencies**

Selecting this parameter:

- Creates input port `lam_mux`.
- Disables parameter **Longitudinal scaling factor, lam\_x**.

**Wheel Dynamics****Axle viscous damping coefficient, br – Damping**

0.001 (default) | scalar

Axle viscous damping coefficient,  $br$ , in N·m·s/rad.

**Wheel inertia, Iyy – Inertia**

0.8 (default) | scalar

Wheel inertia, in kg·m<sup>2</sup>.

**Wheel initial angular velocity, omegao – Wheel speed**

0 (default) | scalar

Initial angular velocity of wheel, along body-fixed y-axis, in rad/s.

**Relaxation length, Lrel – Relaxation length**

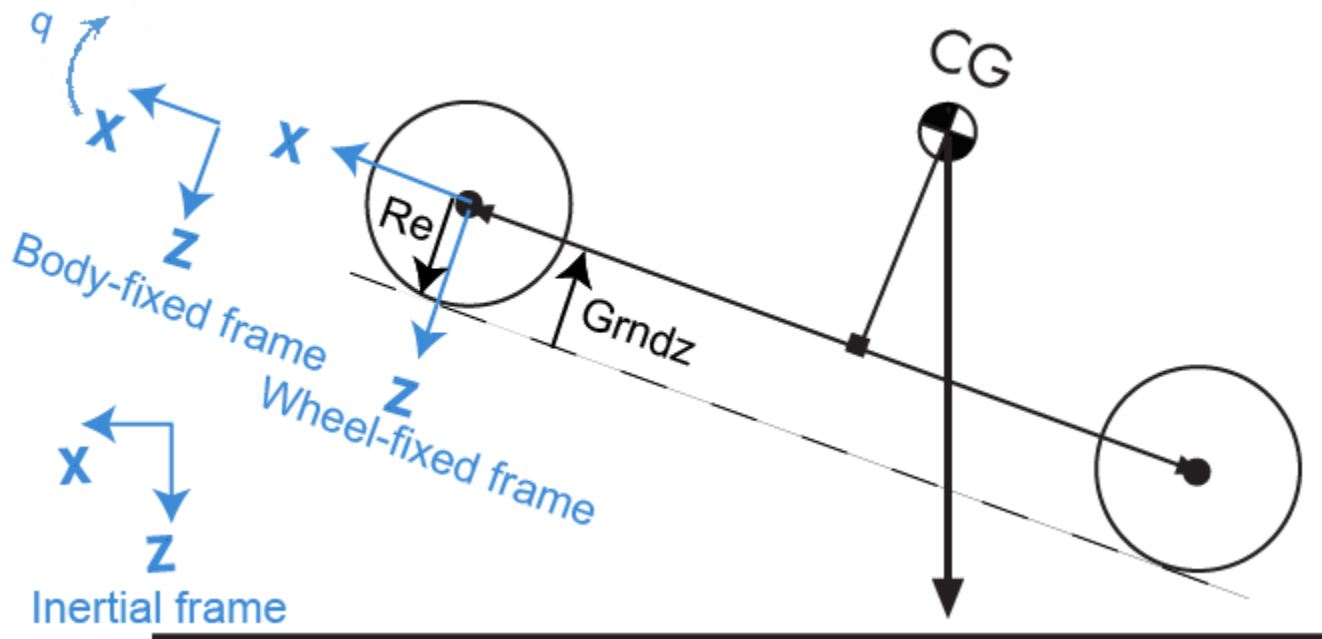
0.5 (default) | scalar

Wheel relaxation length, in m.

**Loaded radius, Re – Loaded radius**

0.3 (default) | scalar

Loaded wheel radius,  $Re$ , in m.



**Unloaded radius, UNLOADED\_RADIUS – Unloaded radius**

0.4 (default) | scalar

Unloaded wheel radius, in m.

**Dependencies**

To create this parameter, set **Rolling Resistance** to Pressure and velocity or Magic Formula.

**Nominal longitudinal speed, LONGVL – Speed**

16 (default) | scalar

Nominal longitudinal speed along body-fixed x-axis, in m/s.

**Dependencies**

To enable this parameter, set **Longitudinal Force** to Magic Formula pure longitudinal slip.

**Nominal camber angle, gamma – Camber**

0 (default) | scalar

Nominal camber angle, in rad.

**Dependencies**

To enable this parameter, set either:

- **Longitudinal Force** to Magic Formula pure longitudinal slip.
- **Rolling Resistance** to Magic Formula.



**Nominal pressure, NOMPRES – Pressure**

220000 (default) | scalar

Nominal pressure, in Pa.

**Dependencies**

To enable this parameter, set either:

- **Longitudinal Force** to Magic Formula pure longitudinal slip.
- **Rolling Resistance** to Magic Formula.

**Pressure, press – Pressure**

220000 (default) | scalar

Pressure, in Pa.

**Dependencies**

To enable this parameter:

- Set one of these:
  - **Longitudinal Force** to Magic Formula pure longitudinal slip.
  - **Rolling Resistance** to Pressure and velocity or Magic Formula.
  - **Vertical Motion** to Mapped stiffness and damping.
- On the **Wheel Dynamics** pane, clear **Input tire pressure**.

**Longitudinal**

**Magic Formula Constant Value**

**Pure longitudinal peak factor, Dx – Factor**

1 (default) | scalar

Pure longitudinal peak factor, dimensionless.

The coefficients are based on empirical tire data. These values are typical sets of constant Magic Formula coefficients for common road conditions.

Surface	B	C	D	E
Dry tarmac	10	1.9	1	0.97
Wet tarmac	12	2.3	0.82	1
Snow	5	2	0.3	1
Ice	4	2	0.1	1

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula constant value.

**Pure longitudinal shape factor, Cx – Factor**

1.65 (default) | scalar

Pure longitudinal shape factor, dimensionless.

The coefficients are based on empirical tire data. These values are typical sets of constant Magic Formula coefficients for common road conditions.

Surface	B	C	D	E
Dry tarmac	10	1.9	1	0.97
Wet tarmac	12	2.3	0.82	1
Snow	5	2	0.3	1
Ice	4	2	0.1	1

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula constant value.

**Pure longitudinal stiffness factor, Bx – Factor**

10 (default) | scalar

Pure longitudinal stiffness factor, dimensionless.

The coefficients are based on empirical tire data. These values are typical sets of constant Magic Formula coefficients for common road conditions.

Surface	B	C	D	E
Dry tarmac	10	1.9	1	0.97
Wet tarmac	12	2.3	0.82	1
Snow	5	2	0.3	1
Ice	4	2	0.1	1

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula constant value.

**Pure longitudinal curvature factor, Ex – Factor**

0.01 (default) | scalar

Pure longitudinal curvature factor, dimensionless.

The coefficients are based on empirical tire data. These values are typical sets of constant Magic Formula coefficients for common road conditions.

Surface	B	C	D	E
Dry tarmac	10	1.9	1	0.97
Wet tarmac	12	2.3	0.82	1
Snow	5	2	0.3	1
Ice	4	2	0.1	1

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula constant value.

**Magic Formula Pure Longitudinal Slip****Cfx shape factor, PCX1 – Factor**

1.6 (default) | scalar

Cfx shape factor, PCX1, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Longitudinal friction at nominal normal load, PDX1 – Factor**

1 (default) | scalar

Longitudinal friction at nominal normal load, PDX1, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Frictional variation with load, PDX2 – Factor**

-0.08 (default) | scalar

Frictional variation with load, PDX2, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Frictional variation with camber, PDX3 – Factor**

0 (default) | scalar

Frictional variation with camber, PDX3, 1/rad<sup>2</sup>.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Longitudinal curvature at nominal normal load, PEX1 – Factor**

0.112 (default) | scalar

Longitudinal curvature at nominal normal load, PEX1, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Variation of curvature factor with load, PEX2 – Factor**

0.313 (default) | scalar

Variation of curvature factor with load, PEX2, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Variation of curvature factor with square of load, PEX3 – Factor**

0 (default) | scalar

Variation of curvature factor with square of load, PEX3, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Longitudinal curvature factor with slip, PEX4 – Factor**

0.0016 (default) | scalar

Longitudinal curvature factor with slip, PEX4, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Longitudinal slip stiffness at nominal normal load, PKX1 – Factor**

21.7 (default) | scalar

Longitudinal slip stiffness at nominal normal load, PKX1, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Variation of slip stiffness with load, PKX2 – Factor**

13.77 (default) | scalar

Variation of slip stiffness with load, PKX2, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Slip stiffness exponent factor, PKX3 – Factor**

-0.412 (default) | scalar

Slip stiffness exponent factor, PKX3, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Horizontal shift in slip ratio at nominal normal load, PHX1 – Factor**

2.1585E-4 (default) | scalar

Horizontal shift in slip ratio at nominal normal load, PHX1, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Variation of horizontal slip ratio with load, PHX2 – Factor**

0.00115 (default) | scalar

Variation of horizontal slip ratio with load, PHX2, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Vertical shift in load at nominal normal load, PVX1 – Factor**

1.5973E-5 (default) | scalar

Vertical shift in load at nominal normal load, PVX1, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Variation of vertical shift with load, PVX2 – Factor**

1.043E-4 (default) | scalar

Variation of vertical shift with load, PVX2, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Linear variation of longitudinal slip stiffness with tire pressure, PPX1 – Factor**

-0.3489 (default) | scalar

Linear variation of longitudinal slip stiffness with tire pressure, PPX1, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Quadratic variation of longitudinal slip stiffness with tire pressure, PPX2 – Factor**

0.382 (default) | scalar

Quadratic variation of longitudinal slip stiffness with tire pressure, PPX2, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Linear variation of peak longitudinal friction with tire pressure, PPX3 – Factor**

-0.09634 (default) | scalar

Linear variation of peak longitudinal friction with tire pressure, PPX3, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Quadratic variation of peak longitudinal friction with tire pressure, PPX4 – Factor**

0.06447 (default) | scalar

Quadratic variation of peak longitudinal friction with tire pressure, PPX4, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Slip speed decay function scaling factor, lam\_muV – Factor**

1 (default) | scalar

Slip speed decay function scaling factor, lam\_muV, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Brake slip stiffness scaling factor, lam\_Kxkappa – Factor**

1 (default) | scalar

Brake slip stiffness scaling factor, lam\_Kxkappa, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Longitudinal shape scaling factor, lam\_Cx – Factor**

1 (default) | scalar

Longitudinal shape scaling factor, lam\_Cx, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Longitudinal curvature scaling factor, lam\_Ex — Factor**

0 (default) | scalar

Longitudinal curvature scaling factor, lam\_Ex, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Longitudinal horizontal shift scaling factor, lam\_Hx — Factor**

1 (default) | scalar

Longitudinal horizontal shift scaling factor, lam\_Hx, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Longitudinal vertical shift scaling factor, lam\_Vx — Factor**

1 (default) | scalar

Longitudinal vertical shift scaling factor, lam\_Vx, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

**Mapped Force****Slip ratio breakpoints, kappaFx — Breakpoints**

vector

Slip ratio breakpoints, dimensionless.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Mapped force.

**Normal force breakpoints, FzFx — Breakpoints**

vector

Normal force breakpoints, N.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Mapped force.

**Longitudinal force map, FxMap — Lookup table**

array

Longitudinal force versus slip ratio and normal force, N.

**Dependencies**

To create this parameter, select the **Longitudinal Force** parameter Mapped force.

### Rolling Resistance

#### Pressure and Velocity

##### Velocity independent force coefficient, $a_{My}$ – Force coefficient

8e-4 (default) | scalar

Velocity-independent force coefficient,  $a$ , in s/m.

##### Dependencies

To create this parameter, select the **Rolling Resistance** parameter Pressure and velocity.

##### Linear velocity force component, $b_{My}$ – Force component

.001 (default) | scalar

Linear velocity force component,  $b$ , in s/m.

##### Dependencies

To create this parameter, select the **Rolling Resistance** parameter Pressure and velocity.

##### Quadratic velocity force component, $c_{My}$ – Force component

1.6e-4 (default) | scalar

Quadratic velocity force component,  $c$ , in  $s^2/m^2$ .

##### Dependencies

To create this parameter, select the **Rolling Resistance** parameter Pressure and velocity.

##### Tire pressure exponent, $\alpha_{My}$ – Pressure exponent

-0.003 (default) | scalar

Tire pressure exponent,  $\alpha$ , dimensionless.

##### Dependencies

To create this parameter, select the **Rolling Resistance** parameter Pressure and velocity.

##### Normal force exponent, $\beta_{My}$ – Force exponent

0.97 (default) | scalar

Normal force exponent,  $\beta$ , dimensionless.

##### Dependencies

To create this parameter, select the **Rolling Resistance** parameter Pressure and velocity.

#### ISO 28580

##### Parasitic losses force, $F_{pl}$ – Force loss

10 (default) | scalar

Parasitic force loss,  $F_{pl}$ , in N.

##### Dependencies

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.



**Rolling resistance constant, Cr – Constant**

1e-3 (default) | scalar

Rolling resistance constant,  $C_r$ , in N/kN. ISO 28580 specifies the rolling resistance unit as one newton of tractive resistance for every kilonewtons of normal load.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

**Thermal correction factor, Kt – Correction factor**

.008 (default) | scalar

Thermal correction factor,  $K_t$ , in 1/degC.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

**Measured temperature, Tmeas – Temperature**

298.15 (default) | scalar

Measured temperature,  $T_{meas}$ , in K.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

**Ambient temperature, Tamb – Temperature**

298.15 (default) | scalar

Measured temperature,  $T_{amb}$ , in K.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

**Input ambient temperature – Selection**

off (default) | on

Select to create input port Tamb.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

**Magic Formula****Rolling resistance torque coefficient, QSY1 – Torque coefficient**

0.007 (default) | scalar

Rolling resistance torque coefficient, dimensionless.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

**Longitudinal force rolling resistance coefficient, QSY2 – Force resistance coefficient**

0 (default) | scalar

Longitudinal force rolling resistance coefficient, dimensionless.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

**Linear rotational speed rolling resistance coefficient, QSY3 – Linear speed coefficient**

0.0015 (default) | scalar

Linear rotational speed rolling resistance coefficient, dimensionless.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

**Quartic rotational speed rolling resistance coefficient, QSY4 – Quartic speed coefficient**

8.5e-05 (default) | scalar

Quartic rotational speed rolling resistance coefficient, dimensionless.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

**Camber squared rolling resistance torque, QSY5 – Camber resistance torque**

0 (default) | scalar

Camber squared rolling resistance torque, in 1/rad<sup>2</sup>.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

**Load based camber squared rolling resistance torque, QSY6 – Load resistance torque**

0 (default) | scalar

Load based camber squared rolling resistance torque, in 1/rad<sup>2</sup>.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

**Normal load rolling resistance coefficient, QSY7 – Normal resistance coefficient**

0.9 (default) | scalar

Normal load rolling resistance coefficient, dimensionless.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

**Pressure load rolling resistance coefficient, QSY8 – Pressure resistance coefficient**

-0.4 (default) | scalar

Pressure load rolling resistance coefficient, dimensionless.

**Dependencies**To create this parameter, select the **Rolling Resistance** parameter Magic Formula.**Rolling resistance scaling factor, lam\_My – Scale**

1 (default) | scalar

Rolling resistance scaling factor, dimensionless.

**Dependencies**To create this parameter, select the **Rolling Resistance** parameter Magic Formula.**Mapped****Spin axis velocity breakpoints, VxMy – Breakpoints**

-20:1:20 (default) | vector

Spin axis velocity breakpoints, in m/s.

**Dependencies**To create this parameter, select the **Rolling Resistance** parameter Mapped torque.**Normal force breakpoints, FzMy – Breakpoints**

0:200:1e4 (default) | vector

Normal force breakpoints, in N.

**Dependencies**To create this parameter, select the **Rolling Resistance** parameter Mapped torque.**Rolling resistance torque map, MyMap – Lookup table**

array

Rolling resistance torque versus axle speed and normal force, in N·m.

**Dependencies**To create this parameter, select the **Rolling Resistance** parameter Mapped torque.**Brake****Static friction coefficient, mu\_static – Static friction**

.3 (default) | scalar

Static friction coefficient, dimensionless.

**Dependencies**To enable this parameter, for the **Brake Type** parameter, specify one of these types:

- Disc
- Drum
- Mapped

**Kinetic friction coefficient, mu\_kinetic — Kinetic friction**

.2 (default) | scalar

Kinematic friction coefficient, dimensionless.

**Dependencies**

To enable this parameter, for the **Brake Type** parameter, specify one of these types:

- Disc
- Drum
- Mapped

**Disc**

**Disc brake actuator bore, disc\_abore — Bore distance**

.05 (default) | scalar

Disc brake actuator bore, in m.

**Dependencies**

To enable the disc brake parameters, select Disc for the **Brake Type** parameter.

**Brake pad mean radius, Rm — Radius**

.177 (default) | scalar

Brake pad mean radius, in m.

**Dependencies**

To enable the disc brake parameters, select Disc for the **Brake Type** parameter.

**Number of brake pads, num\_pads — Count**

2 (default) | scalar

Number of brake pads.

**Dependencies**

To enable the disc brake parameters, select Disc for the **Brake Type** parameter.

**Drum**

**Drum brake actuator bore, disc\_abore — Bore distance**

0.0508 (default) | scalar

Drum brake actuator bore, in m.

**Dependencies**

To enable the drum brake parameters, select Drum for the **Brake Type** parameter.

**Shoe pin to drum center distance, drum\_a – Distance**

0.123 (default) | scalar

Shoe pin to drum center distance, in m.

**Dependencies**To enable the drum brake parameters, select Drum for the **Brake Type** parameter.**Shoe pin center to force application point distance, drum\_c – Distance**

0.212 (default) | scalar

Shoe pin center to force application point distance, in m.

**Dependencies**To enable the drum brake parameters, select Drum for the **Brake Type** parameter.**Drum internal radius, drum\_r – Radius**

0.15 (default) | scalar

Drum internal radius, in m.

**Dependencies**To enable the drum brake parameters, select Drum for the **Brake Type** parameter.**Shoe pin to pad start angle, drum\_theta1 – Angle**

0 (default) | scalar

Shoe pin to pad start angle, in deg.

**Dependencies**To enable the drum brake parameters, select Drum for the **Brake Type** parameter.**Shoe pin to pad end angle, drum\_theta2 – Angle**

126 (default) | scalar

Shoe pin to pad end angle, in deg.

**Dependencies**To enable the drum brake parameters, select Drum for the **Brake Type** parameter.**Mapped****Brake actuator pressure breakpoints, brake\_p\_bpt – Breakpoints**

vector

Brake actuator pressure breakpoints, in bar.

**Dependencies**To enable the mapped brake parameters, select Mapped for the **Brake Type** parameter.**Wheel speed breakpoints, brake\_n\_bpt – Breakpoints**

vector

Wheel speed breakpoints, in rpm.

#### Dependencies

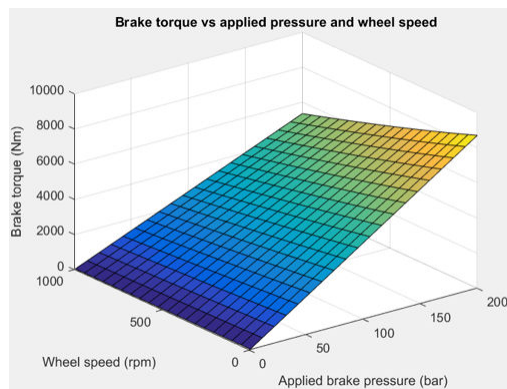
To enable the mapped brake parameters, select Mapped for the **Brake Type** parameter.

#### Brake torque map, $f_{brake\_t}$ – Lookup table

array

The lookup table for the brake torque,  $f_{brake}(P, N)$ , is a function of applied brake pressure and wheel speed, where:

- $T$  is brake torque, in N·m.
- $P$  is applied brake pressure, in bar.
- $N$  is wheel speed, in rpm.



#### Dependencies

To enable the mapped brake parameters, select Mapped for the **Brake Type** parameter.

#### Vertical

#### Nominal normal force, $FNOMIN$ – Force

2000 (default) | scalar

Nominal rated wheel load along wheel-fixed z-axis, in N.

#### Dependencies

To enable this parameter, set either:

- **Longitudinal Force** to Magic Formula pure longitudinal slip.
- **Rolling Resistance** to Magic Formula.

#### Nominal rated load scaling factor, $\lambda_{m\_Fz0}$ – Factor

1 (default) | scalar

Nominal rated load scaling factor, dimensionless. Used to scale the normal for specific applications and load conditions.

#### Dependencies

To enable this parameter, set **Longitudinal Force** to Magic Formula pure longitudinal slip.

**Wheel and unsprung mass,  $m$  – Mass** $10$  (default) | scalar

Wheel and unsprung mass, in kg. Used in the vertical motion calculations.

**Dependencies**

To enable this parameter, set **Vertical Motion** to Mapped stiffness and damping.

**Initial deflection,  $z_0$  – Deflection** $0$  (default) | scalar

Initial axle displacement along wheel-fixed  $z$ -axis, in m.

**Dependencies**

To enable this parameter, set **Vertical Motion** to Mapped stiffness and damping.

**Initial velocity,  $\dot{z}_0$  – Velocity** $0$  (default) | scalar

Initial axle velocity along wheel-fixed  $z$ -axis, in m.

**Dependencies**

To enable this parameter, set **Vertical Motion** to Mapped stiffness and damping.

**Gravitational acceleration,  $g$  – Gravity** $9.81$  (default) | scalar

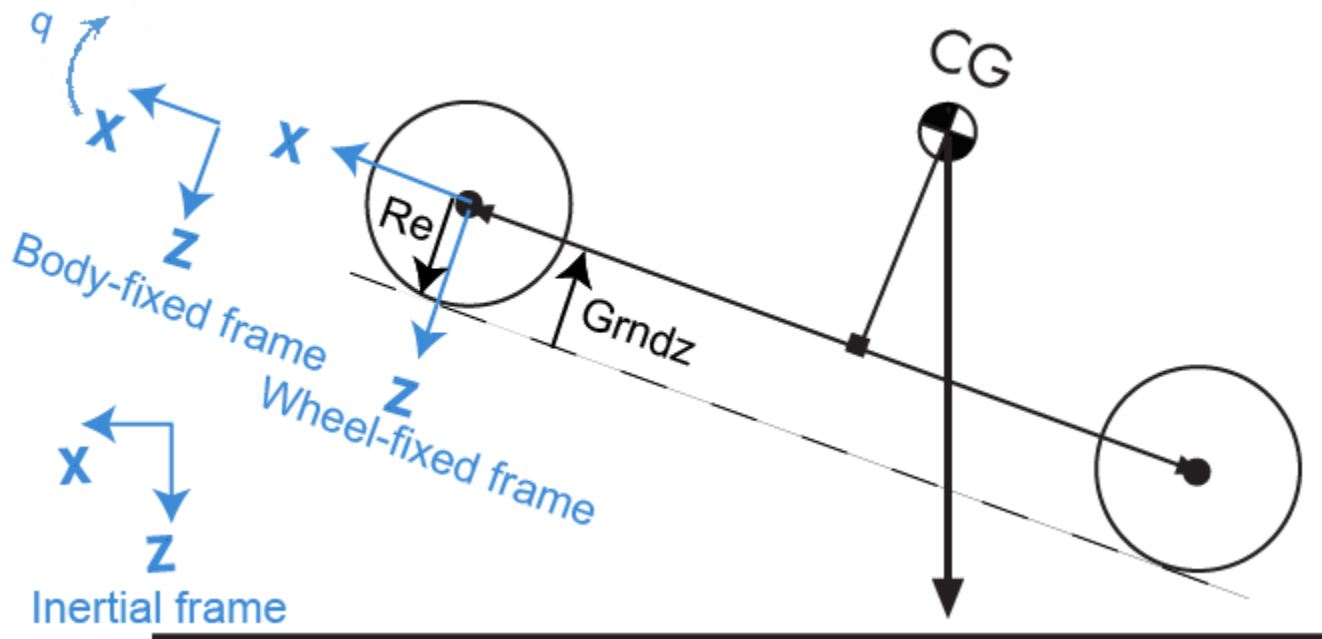
Gravitational acceleration, in  $\text{m/s}^2$ .

**Dependencies**

To enable this parameter, set **Vertical Motion** to Mapped stiffness and damping.

**Ground displacement,  $G_{ndz}$  – Displacement** $0$  (default) | scalar

Ground displacement,  $G_{rndz}$ , along negative wheel-fixed  $z$ -axis, in m.



**Dependencies**

To enable this parameter, set **Vertical Motion** to Mapped stiffness and damping.

**Mapped Stiffness and Damping**

**Vertical deflection breakpoints, zFz – Breakpoints**

[0 .01 .1] (default) | vector

Vector of sidewall deflection breakpoints corresponding to the force table, in m.

**Dependencies**

To enable this parameter, set **Vertical Motion** to Mapped stiffness and damping.

**Pressure breakpoints, pFz – Breakpoints**

[10000 1000000] (default) | vector

Vector of pressure data points corresponding to the force table, in Pa.

**Dependencies**

To enable this parameter, set **Vertical Motion** to Mapped stiffness and damping.

**Force due to deflection, Fzz – Force**

[0 1e3 1e4; 0 1e4 1e5] (default) | vector

Force due to sidewall deflection and pressure along wheel-fixed z-axis, in N.

**Dependencies**

To enable this parameter, set **Vertical Motion** to Mapped stiffness and damping.



**Vertical velocity breakpoints, zdotFz – Breakpoints**

[-20 0 20] (default) | scalar

Vector of sidewall velocity breakpoints corresponding to the force due to velocity table, in m.

**Dependencies**

To enable this parameter, set **Vertical Motion** to Mapped stiffness and damping.

**Force due to velocity, Fzzdot – Force**

[500 0 -500;250 0 -250] (default) | array

Force due to sidewall velocity and pressure along wheel-fixed z-axis, in N.

**Dependencies**

To enable this parameter, set **Vertical Motion** to Mapped stiffness and damping.

**Simulation Setup****Minimum normal force, FZMIN – Force**

0 (default) | scalar

Minimum normal force, in N. Used with all vertical force calculations.

**Maximum normal force, FZMAX – Force**

10000 (default) | scalar

Maximum normal force, in N. Used with all vertical force calculations.

**Max allowable slip ratio (absolute), kappamax – Ratio**

1.5 (default) | scalar

Maximum allowable absolute slip ratio, dimensionless.

**Velocity tolerance used to handle low velocity situations, VXL0W – Tolerance**

1 (default) | scalar

Velocity tolerance used to handle low-velocity situations, in m/s.

**Minimum ambient temperature, TMIN – Tmin**

0 (default) | scalar

Minimum ambient temperature,  $T_{MIN}$ , in K.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

**Maximum ambient temperature, TMAX – Tmax**

400 (default) | scalar

Maximum ambient temperature,  $T_{MAX}$ , in K.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

## References

- [1] Highway Tire Committee. *Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance*. Standard J2452\_199906. Warrendale, PA: SAE International, June 1999.
- [2] Pacejka, H. B. *Tire and Vehicle Dynamics*. 3rd ed. Oxford, United Kingdom: SAE and Butterworth-Heinemann, 2012.
- [3] Schmid, Steven R., Bernard J. Hamrock, and Bo O. Jacobson. "Chapter 18: Brakes and Clutches." *Fundamentals of Machine Elements, SI Version*. 3rd ed. Boca Raton, FL: CRC Press, 2014.
- [4] Shigley, Joseph E., and Larry Mitchel. *Mechanical Engineering Design*. 4th ed. New York, NY: McGraw Hill, 1983.
- [5] ISO 28580:2018. *Passenger car, truck and bus tyre rolling resistance measurement method -- Single point test and correlation of measurement results*. ISO (International Organization for Standardization), 2018.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

### See Also

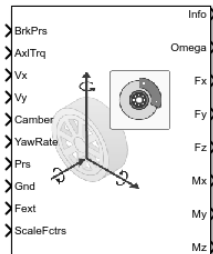
Combined Slip Wheel 2DOF | Drive Cycle Source | Longitudinal Driver

### Introduced in R2017a

## Combined Slip Wheel 2DOF

Combined slip 2DOF wheel with disc, drum, or mapped brake

**Library:** Vehicle Dynamics Blockset / Wheels and Tires



### Description

The Combined Slip Wheel 2DOF block implements the longitudinal and lateral behavior of a wheel characterized by the Magic Formula<sup>[1] and [2]</sup>. Use the block in driveline and vehicle simulations where low frequency tire-road and braking forces are required to determine vehicle acceleration, braking, and wheel-rolling resistance. The block is suitable for applications that require combined lateral slip, for example, in lateral motion and yaw stability studies.

Based on the driveline torque, brake pressure, road height, wheel camber angle, and inflation pressure, the block determines the wheel rotation rate, vertical motion, forces, and moments in all six degrees of freedom (DOF). Use the vertical DOF to study tire-suspension resonances from road profiles or chassis motion.

To implement the Magic Formula, the block uses empirical equations<sup>[1] and [2]</sup>. The equations use fitting coefficients that correspond to the block parameters.

To update the block parameters with fitting coefficients from a file:

- 1 On the **Wheel and Tire Parameters > Tire** pane, select **Select file**.
- 2 Select the tire coefficient file.
- 3 Select **Update mask values from file**. In the dialog box that prompts you for confirmation, click **OK**. The block updates the parameters.
- 4 Select **Apply**.

Use the **Brake Type** parameter to select the brake.

Brake Type Setting	Brake Implementation
None	None
Disc	Brake that converts the brake cylinder pressure into a braking force
Drum	Simplex drum brake that converts the applied force and brake geometry into a net braking torque
Mapped	Lookup table that is a function of the wheel speed and applied brake pressure

**Rotational Wheel Dynamics**

The block calculates the inertial response of the wheel subject to:

- Axle losses
- Brake and drive torque
- Tire rolling resistance
- Ground contact through the tire-road interface

To implement the Magic Formula, the block uses these equations.

Calculation	Equations
Longitudinal force	<i>Tire and Vehicle Dynamics</i> <sup>[2]</sup> equations 4.E9 through 4.E57
Lateral force - pure sideslip	<i>Tire and Vehicle Dynamics</i> <sup>[2]</sup> equations 4.E19 through 4.E30
Lateral force - combined slip	<i>Tire and Vehicle Dynamics</i> <sup>[2]</sup> equations 4.E58 through 4.E67
Vertical dynamics	<i>Tire and Vehicle Dynamics</i> <sup>[2]</sup> equations 4.E68, 4.E1, 4.E2a, and 4.E2b
Overturning couple	<i>Tire and Vehicle Dynamics</i> <sup>[2]</sup> equation 4.E69
Rolling resistance	<ul style="list-style-type: none"> <li>• <i>An improved Magic Formula/Swift tyre model that can handle inflation pressure changes</i><sup>[1]</sup> equation 6.1.2</li> <li>• <i>Tire and Vehicle Dynamics</i><sup>[2]</sup> equation 4.E70</li> </ul>
Aligning moment	<i>Tire and Vehicle Dynamics</i> <sup>[2]</sup> equation 4.E31 through 4.E49
Aligning torque - combined slip	<i>Tire and Vehicle Dynamics</i> <sup>[2]</sup> equation 4.E71 through 4.E78

The input torque is the summation of the applied axle torque, braking torque, and moment arising from the combined tire torque.

$$T_i = T_a - T_b + T_d$$

For the moment arising from the combined tire torque, the block implements tractive wheel forces and rolling resistance with first-order dynamics. The rolling resistance has a time constant parameterized in terms of a relaxation length.

$$T_d(s) = \frac{1}{\frac{|\omega| R_e}{L_e} s + 1} (F_x R_e + M_y)$$

If the brakes are enabled, the block determines the braking locked or unlocked condition based on an idealized dry clutch friction model. Based on the lockup condition, the block implements these friction and dynamic models.

If	Lockup Condition	Friction Model	Dynamic Model
$\omega \neq 0$ or $T_S <  T_i + T_f - \omega b $	Unlocked	$T_f = T_k$ where, $T_k = F_c R_{eff} \mu_k \tanh[4(-\omega_d)]$ $T_s = F_c R_{eff} \mu_s$ $R_{eff} = \frac{2(R_o^3 - R_i^3)}{3(R_o^2 - R_i^2)}$	$\dot{\omega} J = -\omega b + T_i + T_o$
$\omega = 0$ and $T_S \geq  T_i + T_f - \omega b $	Locked	$T_f = T_s$	$\omega = 0$

The equations use these variables.

$\omega$	Wheel angular velocity
$a$	Velocity independent force component
$b$	Linear velocity force component
$c$	Quadratic velocity force component
$L_e$	Tire relaxation length
$J$	Moment of inertia
$M_y$	Rolling resistance torque
$T_a$	Applied axle torque about wheel spin axis
$T_b$	Braking torque
$T_d$	Combined tire torque
$T_f$	Frictional torque
$T_i$	Net input torque
$T_k$	Kinetic frictional torque
$T_o$	Net output torque
$T_s$	Static frictional torque
$F_c$	Applied clutch force
$F_x$	Longitudinal force developed by the tire road interface due to slip
$R_{eff}$	Effective clutch radius
$R_o$	Annular disk outer radius
$R_i$	Annular disk inner radius
$R_e$	Effective tire radius while under load and for a given pressure
$V_x$	Longitudinal axle velocity
$F_z$	Vehicle normal force
$\alpha$	Tire pressure exponent
$\beta$	Normal force exponent

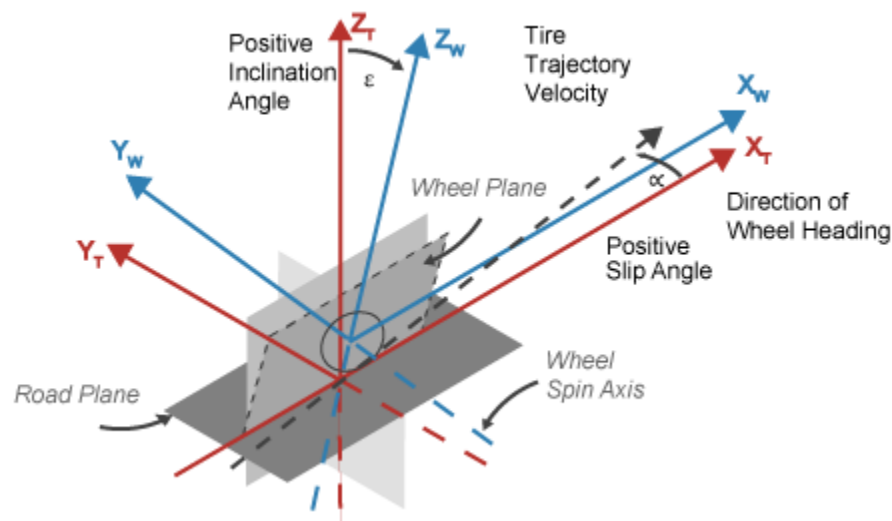
$p_i$	Tire pressure
$\mu_s$	Coefficient of static friction
$\mu_k$	Coefficient of kinetic friction

#### Tire and Wheel Coordinate Systems

To resolve the forces and moments, the block uses the Z-Up orientation of the tire and wheel coordinate systems.

- Tire coordinate system axes ( $X_T, Y_T, Z_T$ ) are fixed in a reference frame attached to the tire. The origin is at the tire contact with the ground.
- Wheel coordinate system axes ( $X_W, Y_W, Z_W$ ) are fixed in a reference frame attached to the wheel. The origin is at the wheel center.

#### Z-Up Orientation<sup>1</sup>

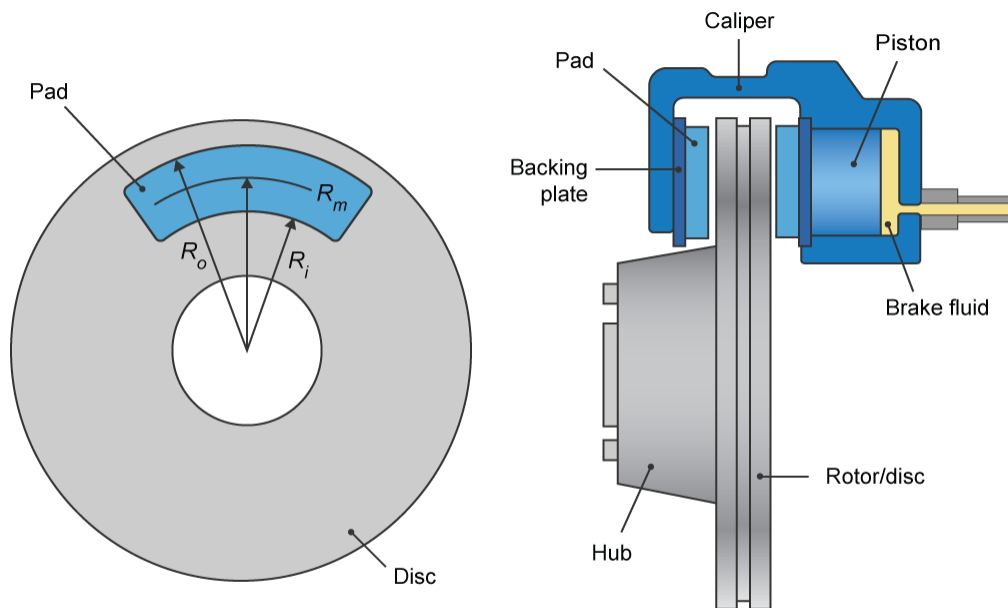


#### Brakes

##### Disc

If you specify the **Brake Type** parameter Disc, the block implements a disc brake. This figure shows the side and front views of a disc brake.

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A disc brake converts brake cylinder pressure from the brake cylinder into force. The disc brake applies the force at the brake pad mean radius.

The block uses these equations to calculate brake torque for the disc brake.

$$T = \begin{cases} \frac{\mu P \pi B_a^2 R_m N_{pads}}{4} & \text{when } N \neq 0 \\ \frac{\mu_{static} P \pi B_a^2 R_m N_{pads}}{4} & \text{when } N = 0 \end{cases}$$

$$R_m = \frac{R_o + R_i}{2}$$

The equations use these variables.

$T$	Brake torque
$P$	Applied brake pressure
$N$	Wheel speed
$N_{pads}$	Number of brake pads in disc brake assembly
$\mu_{static}$	Disc pad-rotor coefficient of static friction
$\mu$	Disc pad-rotor coefficient of kinetic friction
$B_a$	Brake actuator bore diameter
$R_m$	Mean radius of brake pad force application on brake rotor
$R_o$	Outer radius of brake pad

$R_i$  Inner radius of brake pad

**Drum**

If you specify the **Brake Type** parameter Drum, the block implements a static (steady-state) simplex drum brake. A simplex drum brake consists of a single two-sided hydraulic actuator and two brake shoes. The brake shoes do not share a common hinge pin.

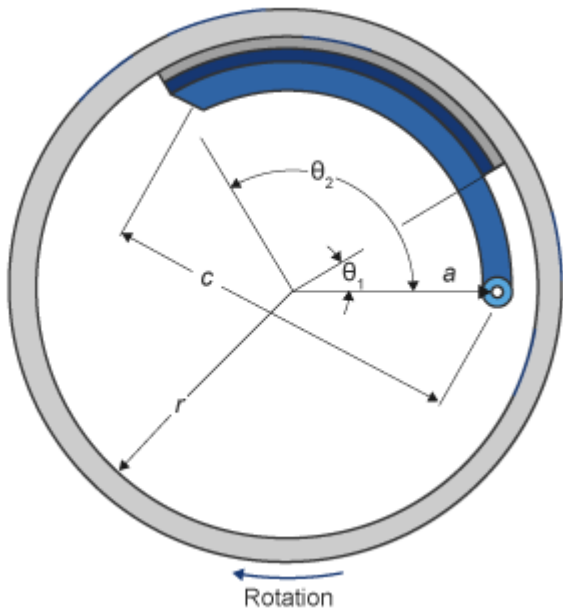
The simplex drum brake model uses the applied force and brake geometry to calculate a net torque for each brake shoe. The drum model assumes that the actuators and shoe geometry are symmetrical for both sides, allowing a single set of geometry and friction parameters to be used for both shoes.

The block implements equations that are derived from these equations in *Fundamentals of Machine Elements*.

$$T_{rshoe} = \left( \frac{\pi\mu cr(\cos\theta_2 - \cos\theta_1)B_a^2}{2\mu(2r(\cos\theta_2 - \cos\theta_1) + a(\cos^2\theta_2 - \cos^2\theta_1)) + ar(2\theta_1 - 2\theta_2 + \sin 2\theta_2 - \sin 2\theta_1)} \right) P$$

$$T_{lshoe} = \left( \frac{\pi\mu cr(\cos\theta_2 - \cos\theta_1)B_a^2}{-2\mu(2r(\cos\theta_2 - \cos\theta_1) + a(\cos^2\theta_2 - \cos^2\theta_1)) + ar(2\theta_1 - 2\theta_2 + \sin 2\theta_2 - \sin 2\theta_1)} \right) P$$

$$T = \begin{cases} T_{rshoe} + T_{lshoe} & \text{when } N \neq 0 \\ (T_{rshoe} + T_{lshoe}) \frac{\mu_{static}}{\mu} & \text{when } N = 0 \end{cases}$$



The equations use these variables.

- $T$  Brake torque
- $P$  Applied brake pressure
- $N$  Wheel speed



$\mu_{static}$	Disc pad-rotor coefficient of static friction
$\mu$	Disc pad-rotor coefficient of kinetic friction
$T_{rshoe}$	Right shoe brake torque
$T_{lshoe}$	Left shoe brake torque
$a$	Distance from drum center to shoe hinge pin center
$c$	Distance from shoe hinge pin center to brake actuator connection on brake shoe
$r$	Drum internal radius
$B_a$	Brake actuator bore diameter
$\theta_1$	Angle from shoe hinge pin center to start of brake pad material on shoe
$\theta_2$	Angle from shoe hinge pin center to end of brake pad material on shoe

### Mapped

If you specify the **Brake Type** parameter Mapped, the block uses a lookup table to determine the brake torque.

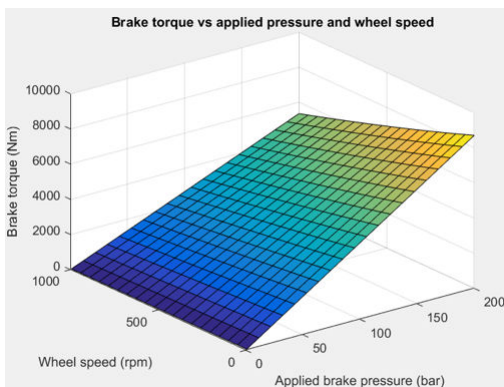
$$T = \begin{cases} f_{brake}(P, N) & \text{when } N \neq 0 \\ \left(\frac{\mu_{static}}{\mu}\right)f_{brake}(P, N) & \text{when } N = 0 \end{cases}$$

The equations use these variables.

$T$	Brake torque
$f_{brake}(P, N)$	Brake torque lookup table
$P$	Applied brake pressure
$N$	Wheel speed
$\mu_{static}$	Friction coefficient of drum pad-face interface under static conditions
$\mu$	Friction coefficient of disc pad-rotor interface

The lookup table for the brake torque,  $f_{brake}(P, N)$ , is a function of applied brake pressure and wheel speed, where:

- $T$  is brake torque, in N·m.
- $P$  is applied brake pressure, in bar.
- $N$  is wheel speed, in rpm.



## Ports

### Input

#### **BrkPrs — Brake pressure**

scalar | N-by-1 vector

Brake pressure, in Pa.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

#### **Dependencies**

To enable this port, for the **Brake Type** parameter, specify one of these types:

- Disc
- Drum
- Mapped

#### **AxlTrq — Axle torque**

scalar | N-by-1 vector

Axle torque,  $T_a$ , about wheel spin axis, in N·m.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

#### **Vx — Longitudinal velocity**

scalar | N-by-1 vector

Axle longitudinal velocity,  $V_x$ , along tire-fixed x-axis, in m/s.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

#### **Vy — Lateral velocity**

scalar | N-by-1 vector

Axle lateral velocity,  $V_y$ , along tire-fixed y-axis, in m/s.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

#### **Camber — Camber angle**

scalar | N-by-1 vector

Camber angle,  $\gamma$ , in rad.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

#### **YawRate — Tire angular velocity**

scalar | N-by-1 vector

Tire angular velocity,  $r$ , about the tire-fixed z-axis (yaw rate), in rad/s.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

**Prs – Tire inflation pressure**

scalar | N-by-1 vector

Tire inflation pressure,  $p_i$ , in Pa.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

**Gnd – Ground displacement**

scalar | N-by-1 vector

Ground displacement along tire-fixed  $z$ -axis, in m. Positive input produces wheel lift.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

**Fext – Axle force applied to tire**

scalar | N-by-1 vector

Axle force applied to tire,  $F_{ext}$ , along vehicle-fixed  $z$ -axis (positive input compresses the tire), in N·m.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

**ScaleFctrs – Scale factors**

27-by-N array

Magic Formula scale factor array. Array dimensions are 27 by the number of wheels,  $N$ .

The Magic Formula equations use scale factors to account for static or simulation run-time variations. Nominally, most are set to 1.

Array Element	Variable	Scale Factor
ScaleFctrs(1,1)	lam_Fzo	Nominal load
ScaleFctrs(2,1)	lam_mux	Longitudinal peak friction coefficient
ScaleFctrs(3,1)	lam_muy	Lateral peak friction coefficient
ScaleFctrs(4,1)	lam_muV	Slip speed Vs decaying friction
ScaleFctrs(5,1)	lam_Kxkappa	Brake slip stiffness
ScaleFctrs(6,1)	lam_Kyalpha	Cornering stiffness
ScaleFctrs(7,1)	lam_Cx	Longitudinal shape factor
ScaleFctrs(8,1)	lam_Cy	Lateral shape factor
ScaleFctrs(9,1)	lam_Ex	Longitudinal curvature factor
ScaleFctrs(10,1)	lam_Ey	Lateral curvature factor
ScaleFctrs(11,1)	lam_Hx	Longitudinal horizontal shift
ScaleFctrs(12,1)	lam_Hy	Lateral horizontal shift
ScaleFctrs(13,1)	lam_Vx	Longitudinal vertical shift

Array Element	Variable	Scale Factor
ScaleFctrs(14,1)	lam_Vy	Lateral vertical shift
ScaleFctrs(15,1)	lam_Kygamma	Camber force stiffness
ScaleFctrs(16,1)	lam_Kzgamma	Camber torque stiffness
ScaleFctrs(17,1)	lam_t	Pneumatic trail (effecting aligning torque stiffness)
ScaleFctrs(18,1)	lam_Mr	Residual torque
ScaleFctrs(19,1)	lam_xalpha	Alpha influence on $F_x$ (kappa)
ScaleFctrs(20,1)	lam_ykappa	Kappa influence on $F_y$ (alpha)
ScaleFctrs(21,1)	lam_Vykappa	Induced ply steer $F_y$
ScaleFctrs(22,1)	lam_s	Moment arm of $F_x$
ScaleFctrs(23,1)	lam_Cz	Radial tire stiffness
ScaleFctrs(24,1)	lam_Mx	Overturning couple stiffness
ScaleFctrs(25,1)	lam_VMx	Overturning couple vertical shift
ScaleFctrs(26,1)	lam_My	Rolling resistance moment
ScaleFctrs(27,1)	lam_Mphi	Parking torque $M_z$

**Output**

**Info – Block data**

bus

Block data, returned as a bus signal containing these block values.

Signal	Description	Units
AxlTrq	Axle torque about wheel-fixed $y$ -axis	N·m
Omega	Wheel angular velocity about wheel-fixed $y$ -axis	rad/s
Fx	Longitudinal vehicle force along tire-fixed $x$ -axis	N
Fy	Lateral vehicle force along tire-fixed $y$ -axis	N
Fz	Vertical vehicle force along tire-fixed $z$ -axis	N
Mx	Overturning moment about tire-fixed $x$ -axis	N·m
My	Rolling resistance torque about tire-fixed $y$ -axis	N·m
Mz	Aligning moment about tire-fixed $z$ -axis	N·m
Vx	Vehicle longitudinal velocity along tire-fixed $x$ -axis	m/s
Vy	Vehicle lateral velocity along tire-fixed $y$ -axis	m/s
Re	Loaded effective radius	m
Kappa	Longitudinal slip ratio	NA
Alpha	Side slip angle	rad
a	Contact patch half length	m
b	Contact patch half width	m

Signal	Description	Units
Gamma	Camber angle	rad
psidot	Tire angular velocity about the tire-fixed z-axis (yaw rate)	rad/s
BrkTrq	Brake torque about vehicle-fixed y-axis	N·m
BrkPrs	Brake pressure	Pa
z	Axle vertical displacement along tire-fixed z-axis	m
zdot	Axle vertical velocity along tire-fixed z-axis	m/s
Gnd	Ground displacement along tire-fixed z-axis (positive input produces wheel lift)	m
GndFz	Vertical sidewall force on ground along tire-fixed z-axis	N
Prs	Tire inflation pressure	Pa

### Omega — Wheel angular velocity

scalar | N-by-1 vector

Wheel angular velocity,  $\omega$ , about wheel-fixed y-axis, in rad/s.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

### Fx — Longitudinal axle force

scalar | N-by-1 vector

Longitudinal force acting on axle,  $F_x$ , along tire-fixed x-axis, in N. Positive force acts to move the vehicle forward.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

### Fy — Lateral axle force

scalar | N-by-1 vector

Lateral force acting on axle,  $F_y$ , along tire-fixed y-axis, in N.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

### Fz — Vertical axle force

scalar | N-by-1 vector

Vertical force acting on axle,  $F_z$ , along tire-fixed z-axis, in N.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

### Mx — Overturning moment

scalar | N-by-1 vector

Longitudinal moment acting on axle,  $M_x$ , about tire-fixed x-axis, in N·m.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

**My – Rolling resistive moment**

scalar | N-by-1 vector

Lateral moment acting on axle,  $M_y$ , about tire-fixed  $y$ -axis, in N·m.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

**Mz – Aligning moment**

scalar | N-by-1 vector

Vertical moment acting on axle,  $M_z$ , about tire-fixed  $z$ -axis, in N·m.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

**Parameters**

**Block Options**

**Brake Type – Select type**

None | Disc | Drum | Mapped

Use the **Brake Type** parameter to select the brake.

Brake Type Setting	Brake Implementation
None	None
Disc	Brake that converts the brake cylinder pressure into a braking force
Drum	Simplex drum brake that converts the applied force and brake geometry into a net braking torque
Mapped	Lookup table that is a function of the wheel speed and applied brake pressure

**Brake**

**Static friction coefficient, mu\_static – Static friction**

.3 (default) | scalar

Static friction coefficient, dimensionless.

**Dependencies**

To enable this parameter, for the **Brake Type** parameter, specify one of these types:

- Disc
- Drum
- Mapped

**Kinetic friction coefficient, mu\_kinetic – Kinetic friction**

.2 (default) | scalar

Kinematic friction coefficient, dimensionless.

**Dependencies**To enable this parameter, for the **Brake Type** parameter, specify one of these types:

- Disc
- Drum
- Mapped

**Disc****Disc brake actuator bore, disc\_abore – Bore distance**

.05 (default) | scalar

Disc brake actuator bore, in m.

**Dependencies**To enable the disc brake parameters, select Disc for the **Brake Type** parameter.**Brake pad mean radius, Rm – Radius**

.177 (default) | scalar

Brake pad mean radius, in m.

**Dependencies**To enable the disc brake parameters, select Disc for the **Brake Type** parameter.**Number of brake pads, num\_pads – Count**

2 (default) | scalar

Number of brake pads.

**Dependencies**To enable the disc brake parameters, select Disc for the **Brake Type** parameter.**Drum****Drum brake actuator bore, disc\_abore – Bore distance**

0.0508 (default) | scalar

Drum brake actuator bore, in m.

**Dependencies**To enable the drum brake parameters, select Drum for the **Brake Type** parameter.**Shoe pin to drum center distance, drum\_a – Distance**

0.123 (default) | scalar

Shoe pin to drum center distance, in m.

**Dependencies**

To enable the drum brake parameters, select Drum for the **Brake Type** parameter.

**Shoe pin center to force application point distance, drum\_c – Distance**

0.212 (default) | scalar

Shoe pin center to force application point distance, in m.

**Dependencies**

To enable the drum brake parameters, select Drum for the **Brake Type** parameter.

**Drum internal radius, drum\_r – Radius**

0.15 (default) | scalar

Drum internal radius, in m.

**Dependencies**

To enable the drum brake parameters, select Drum for the **Brake Type** parameter.

**Shoe pin to pad start angle, drum\_theta1 – Angle**

0 (default) | scalar

Shoe pin to pad start angle, in deg.

**Dependencies**

To enable the drum brake parameters, select Drum for the **Brake Type** parameter.

**Shoe pin to pad end angle, drum\_theta2 – Angle**

126 (default) | scalar

Shoe pin to pad end angle, in deg.

**Dependencies**

To enable the drum brake parameters, select Drum for the **Brake Type** parameter.

**Mapped****Brake actuator pressure breakpoints, brake\_p\_bpt – Breakpoints**

vector

Brake actuator pressure breakpoints, in bar.

**Dependencies**

To enable the mapped brake parameters, select Mapped for the **Brake Type** parameter.

**Wheel speed breakpoints, brake\_n\_bpt – Breakpoints**

vector

Wheel speed breakpoints, in rpm.

**Dependencies**

To enable the mapped brake parameters, select Mapped for the **Brake Type** parameter.

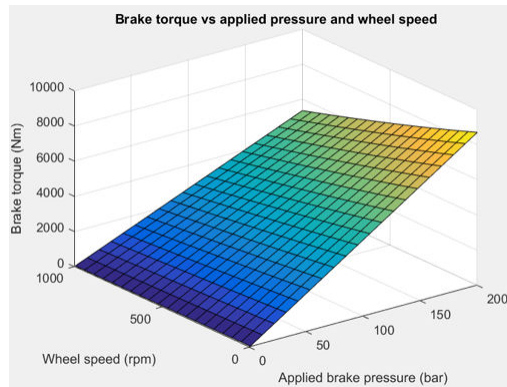


**Brake torque map,  $f_{brake\_t}$  – Lookup table**

array

The lookup table for the brake torque,  $f_{brake}(P, N)$ , is a function of applied brake pressure and wheel speed, where:

- $T$  is brake torque, in N·m.
- $P$  is applied brake pressure, in bar.
- $N$  is wheel speed, in rpm.

**Dependencies**

To enable the mapped brake parameters, select Mapped for the **Brake Type** parameter.

**Tire****Tire file or object,  $tireParamSet$  – Tire file**

`vdynPassCar.mat` (default) | `.tir` | `.txt`

Tire file `.tir` or object containing empirical data to model tire longitudinal and lateral behavior with the Magic Formula. If you provide an `.txt` file, make sure the file contains names that correspond to the block parameters.

To update the block parameters with fitting coefficients from a file:

- 1 On the **Wheel and Tire Parameters > Tire** pane, select **Select file**.
- 2 Select the tire coefficient file.
- 3 Select **Update mask values from file**. In the dialog box that prompts you for confirmation, click **OK**. The block updates the parameters.
- 4 Select **Apply**.

**Simulation****Maximum pressure,  $PRESMAX$  – Pressure**

1003118 (default) | scalar

Maximum pressure,  $PRESMAX$ , in Pa.

**Minimum pressure,  $PRESMIN$  – Pressure**

9982 (default) | scalar

Minimum pressure, *PRESMIN*, in Pa.

**Maximum normal force, FZMAX — Force**  
10000 (default) | scalar

Maximum normal force, *FZMAX*, in N.

**Minimum normal force, FZMIN — Force**  
100 (default) | scalar

Minimum normal force, *FZMIN*, in N.

**Velocity tolerance used to handle low velocity situations, VXL0W — Tolerance**  
0.1 (default) | scalar

Velocity tolerance used to handle low velocity situations, *VXL0W*, in m/s.

**Max allowable slip ratio (absolute), KPUMAX — Ratio**  
1.5 (default) | scalar

Max allowable slip ratio (absolute), *KPUMAX*, dimensionless.

**Minimum allowable slip ratio (absolute), KPUMIN — Ratio**  
-1.5 (default) | scalar

Minimum allowable slip ratio (absolute), *KPUMIN*, dimensionless.

**Max allowable slip angle (absolute), ALPMAX — Angle**  
1.5708 (default) | scalar

Max allowable slip angle (absolute), *ALPMAX*, in rad.

**Minimum allowable slip angle (absolute), ALPMIN — Angle**  
-1.5708 (default) | scalar

Minimum allowable slip angle (absolute), *ALPMIN*, in rad.

**Maximum allowable camber angle, CAMMAX — Angle**  
0.173 (default) | scalar

Maximum allowable camber angle *CAMMAX*, in rad.

**Minimum allowable camber angle, CAMMIN — Angle**  
-0.173 (default) | scalar

Minimum allowable camber angle, *CAMMIN*, in rad.

**Nominal longitudinal speed, LONGVL — Speed**  
16.7 (default) | scalar

Nominal longitudinal speed, *LONGVL*, in m/s.

### **Wheel**

**Initial rotational velocity, omegao — Velocity**  
0 (default) | scalar

Initial rotational velocity, in rad/s.

**Rotational damping, *br* – Damping**

1e-3 (default) | scalar

Rotational damping, *br*, in N·m·s/rad.

**Unloaded radius, UNLOADED\_RADIUS – Radius**

0.309 (default) | scalar

Unloaded radius, *UNLOADED\_RADIUS*, in m.

**Nominal pressure, NOMPRES – Pressure**

224006 (default) | scalar

Nominal pressure, *NOMPRES*, in Pa.

**Nominal normal force, FNOMIN – Force**

4025 (default) | scalar

Nominal normal force, *FNOMIN*, in N.

**Wheel width, WIDTH – Width**

0.209 (default) | scalar

Wheel width, *WIDTH*, in m.

**Rim radius, RIM\_RADIUS – Radius**

.19 (default) | scalar

Rim radius, *RIM\_RADIUS*, in m.

**Inertial**

**Wheel mass, MASS – Mass**

9.465 (default) | scalar

Wheel mass, *MASS*, in kg.

**Rotational inertia (rolling axis), IYY – Inertia**

0.74 (default) | scalar

Rotational inertia (rolling axis), *IYY*, in kg·m<sup>2</sup>.

**Gravity, GRAVITY – Gravity**

-9.81 (default) | scalar

Gravity, *GRAVITY*, in m/s<sup>2</sup>.

**Vertical**

**Initial tire deflection, zo – Deflection**

0 (default) | scalar

Initial tire deflection, *zo*, in m.

**Initial wheel vertical velocity (wheel fixed frame),  $z_{dot0}$  – Velocity**  
0 (default) | scalar

Initial wheel vertical velocity (wheel fixed frame),  $z_{dot0}$ , in m/s.

**Effective rolling radius at low load stiffness,  $BREFF$  – Stiffness**  
8.25094594147963 (default) | scalar

Effective rolling radius at low load stiffness,  $BREFF$ , dimensionless.

**Effective rolling radius peak value,  $DREFF$  – Radius**  
0.260468730454265 (default) | scalar

Effective rolling radius peak value,  $DREFF$ , dimensionless.

**Effective rolling radius at high load stiffness,  $FREFF$  – Radius**  
0.0735298544471851 (default) | scalar

Effective rolling radius at high load stiffness,  $FREFF$ , dimensionless.

**Unloaded to nominal rolling radius ratio,  $Q_{RE0}$  – Ratio**  
1.00866439868088 (default) | scalar

Unloaded to nominal rolling radius ratio,  $Q_{RE0}$ , dimensionless.

**Radius rotational speed dependence,  $Q_{V1}$  – Speed**  
0.000760413786224011 (default) | scalar

Radius rotational speed dependence,  $Q_{V1}$ , dimensionless.

**Stiffness rotational speed dependence,  $Q_{V2}$  – Speed**  
0.0463384792019201 (default) | scalar

Stiffness rotational speed dependence,  $Q_{V2}$ , dimensionless.

**Linear load change with deflection,  $Q_{FZ1}$  – Load change**  
0 (default) | scalar

Linear load change with deflection,  $Q_{FZ1}$ , dimensionless.

**Quadratic load change with deflection,  $Q_{FZ2}$  – Load change**  
15.6870832810226 (default) | scalar

Quadratic load change with deflection,  $Q_{FZ2}$ , dimensionless.

**Linear load change with deflection and quadratic camber,  $Q_{FZ3}$  – Load change**  
0 (default) | scalar

Linear load change with deflection and quadratic camber,  $Q_{FZ3}$ , dimensionless.

**Load response to longitudinal force,  $Q_{FCX}$  – Force**  
0.138643970247602 (default) | scalar

Load response to longitudinal force,  $Q_{FCX}$ , dimensionless.

**Load response to lateral force, Q\_FCY – Force**

0.10843499565426 (default) | scalar

Load response to lateral force, *Q\_FCY*, dimensionless.**Vertical stiffness change due to lateral load dependency on lateral stiffness, Q\_FCY2 – Stiffness**

-0.465763352339538 (default) | scalar

Vertical stiffness change due to lateral load dependency on lateral stiffness, *Q\_FCY2*, dimensionless.**Stiffness response to pressure, PFZ1 – Stiffness**

0.69958166705601 (default) | scalar

Stiffness response to pressure, *PFZ1*, dimensionless.**Vertical tire stiffness, VERTICAL\_STIFFNESS – Stiffness**

207885.061134007 (default) | scalar

Vertical tire stiffness, *VERTICAL\_STIFFNESS*, in N/m.**Vertical tire damping, VERTICAL\_DAMPING – Damping**

494.649255786991 (default) | scalar

Vertical tire damping, *VERTICAL\_DAMPING*, in N·s/m.**Rim bottoming out offset, BOTTOM\_OFFST – Offset**

.01 (default) | scalar

Rim bottoming out offset, *BOTTOM\_OFFST*, in m.**Bottoming out stiffness, BOTTOM\_STIFF – Stiffness**

2e6 (default) | scalar

Bottoming out stiffness, *BOTTOM\_STIFF*, in N/m.**Structural****Longitudinal stiffness, LONGITUDINAL\_STIFFNESS – Stiffness**

388714.175879854 (default) | scalar

Longitudinal stiffness, *LONGITUDINAL\_STIFFNESS*, in N/m.**Lateral stiffness, LATERAL\_STIFFNESS – Stiffness**

157087.404633332 (default) | scalar

Longitudinal stiffness, *LATERAL\_STIFFNESS*, in N/m.**Linear vertical deflection influence on longitudinal stiffness, PCFX1 – Deflection influence**

0.18539229191199 (default) | scalar

Linear vertical deflection influence on longitudinal stiffness, *PCFX1*, dimensionless.

**Quadratic vertical deflection influence on longitudinal stiffness, PCFX2 – Deflection influence**

0 (default) | scalar

Quadratic vertical deflection influence on longitudinal stiffness, *PCFX2*, dimensionless.

**Pressure dependency on longitudinal stiffness, PCFX3 – Pressure dependency**

0 (default) | scalar

Pressure dependency on longitudinal stiffness, *PCFX3*, dimensionless.

**Linear vertical deflection influence on lateral stiffness, PCFY1 – Deflection influence**

0.163183345037677 (default) | scalar

Linear vertical deflection influence on lateral stiffness, *PCFY1*, dimensionless.

**Quadratic vertical deflection influence on lateral stiffness, PCFY2 – Deflection influence**

0 (default) | scalar

Quadratic vertical deflection influence on lateral stiffness, *PCFY2*, dimensionless.

**Pressure dependency on longitudinal stiffness, PCFY3 – Pressure dependency**

0.249094918231954 (default) | scalar

Pressure dependency on longitudinal stiffness, *PCFY3*, dimensionless.

**Contact Patch**

**Contact length square root term, Q\_RA1 – Length term**

0.675942571700787 (default) | scalar

Contact length square root term, *Q\_RA1*, dimensionless.

**Contact length linear term, Q\_RA2 – Length term**

0.73800463546164 (default) | scalar

Contact length linear term, *Q\_RA2*, dimensionless.

**Contact width root term, Q\_RB1 – Width term**

1.04487486456705 (default) | scalar

Contact width root term, *Q\_RB1*, dimensionless.

**Contact width linear term, Q\_RB2 – Width term**

-1.191763806629 (default) | scalar

Contact width linear term *Q\_RB2*, dimensionless.

**Longitudinal**

**Cfx shape factor, PCX1 – Shape factor**

1.58523057950359 (default) | scalar

Shape factor,  $C_{fx}$ , *PCX1*, dimensionless.

**Longitudinal friction at nominal normal load, PDX1 — Friction**

1.0239116238178 (default) | scalar

Longitudinal friction at nominal normal load, *PDX1*, dimensionless.**Frictional variation with load, PDX2 — Friction variation**

-0.0842405110022724 (default) | scalar

Frictional variation with load, *PDX2*, dimensionless.**Frictional variation with camber, PDX3 — Friction variation**

0 (default) | scalar

Frictional variation with camber, *PDX3*, in  $1/\text{rad}^2$ .**Longitudinal curvature at nominal normal load, PEX1 — Curvature**

0.110312777158455 (default) | scalar

Longitudinal curvature at nominal normal load, *PEX1*, dimensionless.**Variation of curvature factor with load, PEX2 — Curvature variation**

0.313468516038146 (default) | scalar

Variation of curvature factor with load, *PEX2*, dimensionless.**Variation of curvature factor with square of load, PEX3 — Curvature variation**

0 (default) | scalar

Variation of curvature factor with square of load, *PEX3*, dimensionless.**Longitudinal curvature factor with slip, PEX4 — Curvature**

0.0016060905760045 (default) | scalar

Longitudinal curvature factor with slip, *PEX4*, dimensionless.**Longitudinal slip stiffness at nominal normal load, PKX1 — Stiffness**

21.3872544684023 (default) | scalar

Longitudinal slip stiffness at nominal normal load, *PKX1*, dimensionless.**Variation of slip stiffness with load, PKX2 — Stiffness variation**

14.0006541873175 (default) | scalar

Variation of slip stiffness with load, *PKX1*, dimensionless.**Slip stiffness exponent factor, PKX3 — Slip stiffness**

-0.405326109653452 (default) | scalar

Slip stiffness exponent factor, *PKX3*, dimensionless.**Horizontal shift in slip ratio at nominal normal load, PHX1 — Slip ratio shift**

0.000212599305364818 (default) | scalar

Horizontal shift in slip ratio at nominal normal load, *PHX1*, dimensionless.

**Variation of horizontal slip ratio with load, PHX2 — Slip variation**

0.00115950515263055 (default) | scalar

Variation of horizontal slip ratio with load, *PHX2*, dimensionless.**Vertical shift in load at nominal normal load, PVX1 — Load shift**

(default) | scalar | 1.59236164471432e-05

Vertical shift in load at nominal normal load, *PVX1*, dimensionless.**Variation of vertical shift with load, PVX2 — Load variation**

0.000104321112127671 (default) | scalar

Variation of vertical shift with load, *PVX2*, dimensionless.**Linear variation of longitudinal slip stiffness with tire pressure, PPX1 — Stiffness variation**

-0.349461321276586 (default) | scalar

Linear variation of longitudinal slip stiffness with tire pressure, *PPX1*, dimensionless.**Quadratic variation of longitudinal slip stiffness with tire pressure, PPX2 — Stiffness variation**

0.387840040616429 (default) | scalar

Quadratic variation of longitudinal slip stiffness with tire pressure, *PPX2*, dimensionless.**Linear variation of peak longitudinal friction with tire pressure, PPX3 — Friction variation**

-0.0969947336569324 (default) | scalar

Linear variation of peak longitudinal friction with tire pressure, *PPX3*, dimensionless.**Quadratic variation of peak longitudinal friction with tire pressure, PPX4 — Friction variation**

0.0632271859795801 (default) | scalar

Quadratic variation of peak longitudinal friction with tire pressure, *PPX4*, dimensionless.**Combined slip  $F_x$  slope factor reduction, RBX1 — Combined slip longitudinal force slope factor reduction**

12.7633329850276 (default) | scalar

Combined slip longitudinal force,  $F_x$ , slope factor reduction, *RBX1*, dimensionless.**Slip ratio  $F_x$  slope reduction variation, RBX2 — Slip ratio longitudinal force slope reduction variation**

9.5787123658471 (default) | scalar

Slip ratio longitudinal force,  $F_x$ , slope reduction variation, *RBX2*, dimensionless.**Camber influence on combined slip  $F_x$  stiffness, RBX3 — Camber influence on combined slip longitudinal force stiffness**

0 (default) | scalar

Camber influence on combined slip longitudinal force,  $F_x$ , stiffness, *RBX3*, dimensionless.



**Shape factor for combined slip  $F_x$  reduction, RCX1 – Shape factor for combined slip longitudinal force reduction**

1.02796280922059 (default) | scalar

Shape factor for combined slip longitudinal force,  $F_x$ , reduction,  $RCX1$ , dimensionless.**Combined  $F_x$  curvature factor, REX1 – Combined longitudinal force curvature factor**

-0.45202516851367 (default) | scalar

Combined longitudinal force,  $F_x$ , curvature factor,  $REX1$ , dimensionless.**Combined  $F_x$  curvature factor with load, REX2 – Combined longitudinal force curvature factor**

-0.47304886171176 (default) | scalar

Combined longitudinal force,  $F_x$ , curvature factor with load,  $REX2$ , dimensionless.**Combined slip  $F_x$  shift factor reduction, RHX1 – Combined slip longitudinal force slip factor**

0.000233272373115809 (default) | scalar

Combined slip longitudinal force,  $F_x$ , shift factor reduction,  $RHX1$ , dimensionless.**Overturning****Vertical shift of overturning moment, QSX1 – Overturning moment**

-0.00788307788961443 (default) | scalar

Vertical shift of overturning moment,  $QSX1$ , dimensionless.**Overturning moment due to camber, QSX2 – Overturning moment due to camber**

0.954629515459396 (default) | scalar

Overturning moment due to camber,  $QSX2$ , dimensionless.**Overturning moment due to  $F_y$ , QSX3 – Overturning moment due to lateral force**

0.0155855777667025 (default) | scalar

Overturning moment due to lateral force,  $QSX3$ , dimensionless. **$M_x$  combined lateral force load and camber, QSX4 – Overturning moment**

0.125904607142414 (default) | scalar

Overturning moment,  $M_x$ , moment combined lateral force load and camber,  $QSX4$ , dimensionless. **$M_x$  load effect due to lateral force and camber, QSX5 – Overturning moment**

1.01110069703963 (default) | scalar

Overturning moment,  $M_x$ , load effect due to lateral force and camber,  $QSX5$ , dimensionless. **$M_x$  load effect due to B-factor, QSX6 – Overturning moment**

20.1938577118433 (default) | scalar

Overturning moment,  $M_x$ , load effect due to B-factor,  $QSX6$ , dimensionless.

**Mx due to camber and load, QSX7 – Overturning moment**

0.310818120717083 (default) | scalar

Overturning moment,  $M_x$ , due to camber and load, *QSX7*, dimensionless.**Mx due to lateral force and load, QSX8 – Overturning moment**

-0.0430823751139655 (default) | scalar

Overturning moment,  $M_x$ , due to lateral force and load, *QSX8*, dimensionless.**Mx due to B-factor of lateral force and load, QSX9 – Overturning moment**

0.636494404888216 (default) | scalar

Overturning moment,  $M_x$ , due to B-factor of lateral force and load, *QSX9*, dimensionless.**Mx due to vertical force and camber, QSX10 – Overturning moment**

0.142438060591663 (default) | scalar

Overturning moment,  $M_x$ , due to vertical force and camber, *QSX10*, dimensionless.**Mx due to B-factor of vertical force and camber, QSX11 – Overturning moment**

0.346766530036373 (default) | scalar

Overturning moment,  $M_x$ , due to B-factor of vertical force and camber, *QSX11*, dimensionless.**Mx due to squared camber, QSX12 – Overturning moment**

0 (default) | scalar

Overturning moment,  $M_x$ , due to squared camber, *QSX12*, dimensionless.**Mx due to lateral force, QSX13 – Overturning moment**

0 (default) | scalar

Overturning moment,  $M_x$ , due to lateral force, *QSX13*, dimensionless.**Mx due to lateral force with camber, QSX14 – Overturning moment**

0 (default) | scalar

Overturning moment,  $M_x$ , due to lateral force with camber, *QSX14*, dimensionless.**Mx due to inflation pressure, PPMX1 – Overturning moment due to pressure**

0 (default) | scalar

Overturning moment,  $M_x$ , due to inflation pressure, *PPMX1*, dimensionless.**Lateral****Cfy shape factor for lateral force, PCY1 – Lateral force shape factor**

1.34299950037631 (default) | scalar

Shape factor for lateral force,  $C_{fy}$ , *PCY1*, dimensionless.**Lateral friction  $\mu_y$ , PDY1 – Lateral friction**

0.878267729082195 (default) | scalar

Lateral friction,  $\mu_y$ , *PDY1*, dimensionless.

**Lateral friction variation of  $\mu_y$  with load, PDY2 – Lateral friction variation**

-0.0644597923147385 (default) | scalar

Variation of lateral friction,  $\mu_y$ , with load, *PDY2*, dimensionless.**Lateral friction variation of  $\mu_y$  with squared camber, PDY3 – Lateral friction variation**

0 (default) | scalar

Variation of lateral friction,  $\mu_y$ , with squared camber, *PDY3*, dimensionless.**Efy lateral curvature at nominal force FZNOM, PEY1 – Lateral curvature at nominal force**

-0.809776534470972 (default) | scalar

Lateral curvature,  $Ef_y$ , at nominal force,  $F_{ZNOM}$ , *PEY1*, dimensionless.**Efy curvature variation with load PEY2 – Lateral curvature variation**

-0.600180598867198 (default) | scalar

Lateral curvature,  $Ef_y$ , variation with load, *PEY2*, dimensionless.**Efy curvature constant camber dependency, PEY3 – Lateral curvature constant**

0.0991732552633487 (default) | scalar

Lateral curvature,  $Ef_y$ , constant camber dependency, *PEY3*, dimensionless.**Efy curvature variation with camber, PEY4 – Lateral curvature variation**

-6.5577974035573 (default) | scalar

Lateral curvature,  $Ef_y$ , variation with camber, *PEY4*, dimensionless.**Efy curvature variation with camber squared, PEY5 – Lateral curvature variation**

0 (default) | scalar

Lateral curvature,  $Ef_y$ , variation with camber squared, *PEY5*, dimensionless.**Maximum KFy/FZNOM stiffness, PKY1 – Maximum stiffness**

-15.5714726518315 (default) | scalar

Maximum lateral force stiffness,  $KF_y$ , to nominal force,  $F_{ZNOM}$ , ratio, *PKY1*, dimensionless.**Load at maximum KFy/FZNOM stiffness, PKY2 – Load**

1.73126522291751 (default) | scalar

Load at maximum lateral force stiffness,  $KF_y$ , to nominal force,  $F_{ZNOM}$ , ratio, *PKY2*, dimensionless.**KFy/FZNOM stiffness variation with camber, PKY3 – Stiffness variation**

0.365349873517229 (default) | scalar

Lateral force stiffness,  $KF_y$ , to nominal force,  $F_{ZNOM}$ , stiffness variation with camber, *PKY3*, dimensionless.**KFy curvature, PKY4 – Lateral force stiffness curvature**

1.98176755955416 (default) | scalar

Lateral force stiffness,  $KF_y$ , curvature,  $PKY4$ , dimensionless.

**Variation of peak stiffness with squared camber, PKY5 — Stiffness variation**  
0 (default) | scalar

Variation of peak stiffness with squared camber,  $PKY5$ , dimensionless.

**Fy camber stiffness factor, PKY6 — Lateral force camber stiffness factor**  
-0.884005199550313 (default) | scalar

Lateral force,  $F_y$ , camber stiffness factor,  $PKY6$ , dimensionless.

**Camber stiffness vertical load dependency, PKY7 — Stiffness**  
-0.237259727611847 (default) | scalar

Camber stiffness vertical load dependency,  $PKY7$ , dimensionless.

**SHY horizontal shift at FZNOM, PHY1 — Horizontal shift at nominal force**  
-0.00183370557235628 (default) | scalar

Horizontal shift,  $S_{HY}$ , at nominal force,  $F_{ZNOM}$ ,  $PHY1$ , dimensionless.

**SHY variation with load, PHY2 — Horizontal shift variation**  
0.00346401302716671 (default) | scalar

Horizontal shift,  $S_{HY}$ , variation with load,  $PHY2$ , dimensionless.

**Svy/Fz vertical shift at FZNOM, PVY1 — Vertical shift at nominal force**  
-0.00675427560163264 (default) | scalar

Vertical shift,  $S_{vy}$ , at nominal force,  $F_{ZNOM}$ ,  $PVY1$ , dimensionless.

**Svy/Fz variation with load, PVY2 — Vertical shift variation with load**  
0.036379218103843 (default) | scalar

Vertical shift,  $S_{vy}$ , variation with load,  $PVY2$ , dimensionless.

**Svy/Fz variation with camber, PVY3 — Vertical shift variation with camber**  
-0.163543984089166 (default) | scalar

Vertical shift,  $S_{vy}$ , variation with camber,  $PVY3$ , dimensionless.

**Svy/Fz variation with load and camber, PVY4 — Vertical shift variation with load and camber**  
-0.491003349625726 (default) | scalar

Vertical shift,  $S_{vy}$ , variation with load and camber,  $PVY4$ , dimensionless.

**Cornering stiffness variation with inflation pressure, PPY1 — Stiffness variation with pressure**  
-0.62059646553185 (default) | scalar

Cornering stiffness variation with inflation pressure,  $PPY1$ , dimensionless.

**Cornering stiffness variation with inflation pressure induced nominal load dependency, PPY2 – Stiffness variation with pressure**

-0.0647824842338686 (default) | scalar

Cornering stiffness variation with inflation pressure induced nominal load dependency, *PPY2*, dimensionless.**Linear inflation pressure on peak lateral friction, PPY3 – Pressure**

-0.164648843290686 (default) | scalar

Linear inflation pressure on peak lateral friction, *PPY3*, dimensionless.**Quadratic inflation pressure on peak lateral friction, PPY4 – Pressure**

0.283193909060098 (default) | scalar

Quadratic inflation pressure on peak lateral friction, *PPY4*, dimensionless.**Inflation pressure effect on camber stiffness, PPY5 – Pressure**

0 (default) | scalar

Inflation pressure effect on camber stiffness, *PPY5*, dimensionless.**Combined  $F_y$  reduction slope factor, RBY1 – Combined lateral force reduction slope factor**

10.7588809173639 (default) | scalar

Combined lateral force,  $F_y$ , reduction slope factor, *RBY1*, dimensionless. **$F_y$  slope reduction with slip angle, RBY2 – Lateral force slope reduction with slip angle**

7.70420065295029 (default) | scalar

Lateral force,  $F_y$ , slope reduction with slip angle, *RBY2*, dimensionless. **$F_y$  shift reduction with slip angle, RBY3 – Lateral force shift reduction with slip angle**

3.40283755070691e-06 (default) | scalar

Lateral force,  $F_y$ , shift reduction with slip angle, *RBY3*, dimensionless. **$F_y$  combined stiffness variation from camber, RBY4 – Lateral force combined stiffness variation from camber**

0 (default) | scalar

Lateral force,  $F_y$ , combined stiffness variation from camber, *RBY4*, dimensionless. **$F_y$  combined reduction shape factor, RCY1 – Lateral force combined reduction shape factor**

1.06691874059059 (default) | scalar

Lateral force,  $F_y$ , combined reduction shape factor, *RCY1*, dimensionless. **$F_y$  combined curvature factor, REY1 – Lateral force combined curvature factor**

0.308244924574305 (default) | scalar

Lateral force,  $F_y$ , combined curvature factor, *REY1*, dimensionless.

**Fy combined curvature factor with load, REY2 – Lateral force combined curvature factor with load**

7.48775032604508e-06 (default) | scalar

Lateral force,  $F_y$ , combined curvature factor with load,  $REY2$ , dimensionless.

**Fy combined reduction shift factor, RHY1 – Lateral force combined reduction shift factor**

0.0118479204960415 (default) | scalar

Lateral force,  $F_y$ , combined reduction shift factor,  $RHY1$ , dimensionless.

**Fy combined reduction shift factor with load, RHY2 – Lateral force combined reduction shift factor with load**

7.63650177161071e-06 (default) | scalar

Lateral force,  $F_y$ , combined reduction shift factor with load,  $RHY2$ , dimensionless.

**Slip ratio side force  $S_{vyk}/\mu_{ty} * F_z$  at  $F_{ZNOM}$ , RVY1 – Slip ratio side force at nominal force**

0.0560024425050078 (default) | scalar

Slip ratio side force at nominal force,  $F_{ZNOM}$ ,  $RVY1$ , dimensionless.

**Side force  $S_{vyk}/\mu_{ty} * F_z$  variation with load, RVY2 – Side force variation with load**

7.48487127056197e-06 (default) | scalar

Side force variation with load,  $RVY2$ , dimensionless.

**Side force  $S_{vyk}/\mu_{ty} * F_z$  variation with camber, RVY3 – Side force variation with camber**

0 (default) | scalar

Side force variation with camber,  $RVY3$ , dimensionless.

**Side force  $S_{vyk}/\mu_{ty} * F_z$  variation with slip angle, RVY4 – Side force variation with slip angle**

98.4047026517149 (default) | scalar

Side force variation with slip angle,  $RVY4$ , dimensionless.

**Side force  $S_{vyk}/\mu_{ty} * F_z$  variation with slip ratio, RVY5 – Side force variation with slip ratio**

2.02759273900054 (default) | scalar

Side force variation with slip ratio,  $RVY5$ , dimensionless.

**Side force  $S_{vyk}/\mu_{ty} * F_z$  variation with slip ratio arctangent, RVY6 – Side force variation with slip ratio arctangent**

15.7623064923347 (default) | scalar

Side force variation with slip ratio arctangent,  $RVY6$ , dimensionless.

**Rolling****Torque resistance coefficient, QSY1 — Torque resistance**

0.00699077564863536 (default) | scalar

Torque resistance coefficient,  $QSY1$ , dimensionless.**Torque resistance due to  $F_x$ , QSY2 — Torque resistance due to longitudinal force**

0 (default) | scalar

Torque resistance due to longitudinal force,  $F_x$ ,  $QSY2$ , dimensionless.**Torque resistance due to speed, QSY3 — Torque resistance due to speed**

(default) | scalar | 0.00153535478298811

Torque resistance due to speed,  $QSY3$ , dimensionless.**Torque resistance due to speed<sup>4</sup>, QSY4 — Torque resistance due to speed**

8.55710322455322e-05 (default) | scalar

Torque resistance due to speed<sup>4</sup>,  $QSY4$ , dimensionless.**Torque resistance due to square of camber, QSY5 — Torque resistance due to camber**

0 (default) | scalar

Torque resistance due to square of camber,  $QSY5$ , dimensionless.**Torque resistance due to square of camber and load, QSY6 — Torque resistance due to camber and load**

0 (default) | scalar

Torque resistance due to square of camber and load,  $QSY6$ , dimensionless.**Torque resistance due to load, QSY7 — Torque resistance due to load**

0.89443879773793 (default) | scalar

Torque resistance due to load,  $QSY7$ , dimensionless.**Torque resistance due to pressure, QSY8 — Torque resistance due to pressure**

-0.403227641260894 (default) | scalar

Torque resistance due to pressure,  $QSY8$ , dimensionless.**Aligning****Trail slope factor for trail Bpt at FZNOM, QBZ1 — Trail slope factor at nominal force**

11.666656027484 (default) | scalar

Trail slope factor for trail Bpt at nominal force,  $F_{ZNOM}$ ,  $QBZ1$ , dimensionless.**Bpt slope variation with load, QBZ2 — Slope variation with load**

-1.30355438574485 (default) | scalar

Slope variation with load,  $QBZ2$ , dimensionless.

**Bpt slope variation with square of load, QBZ3 — Slope variation with load**  
0 (default) | scalar

Slope variation with square of load, *QBZ3*, dimensionless.

**Bpt slope variation with camber, QBZ4 — Slope variation with camber**  
0.177918305399071 (default) | scalar

Slope variation with camber, *QBZ4*, dimensionless.

**Bpt slope variation with absolute value of camber, QBZ5 — Slope variation with camber**  
-0.162481135068033 (default) | scalar

Slope variation with absolute value of camber, *QBZ5*, dimensionless.

**Bpt slope variation with square of camber, QBZ6 — Slope variation with camber**  
0 (default) | scalar

Slope variation with square of camber, *QBZ6*, dimensionless.

**Br of Mzr slope scaling factor, QBZ9 — Slope scaling factor**  
30.1445534682089 (default) | scalar

Slope scaling factor, *QBZ9*, dimensionless.

**Br of Mzr cornering stiffness factor, QBZ10 — Cornering stiffness factor**  
0 (default) | scalar

Br of Mzr cornering stiffness factor, *QBZ10*, dimensionless.

**Cpt pneumatic trail shape factor, QCZ1 — Pneumatic trail shape factor**  
1.29026978207574 (default) | scalar

Pneumatic trail shape factor,  $C_{pt}$ , *QCZ1*, dimensionless.

**Dpt peak trail, QDZ1 — Peak trail**  
0.0886972644991399 (default) | scalar

Peak trail,  $D_{pt}$ , *QDZ1*, dimensionless.

**Dpt peak trail variation with load, QDZ2 — Peak trail variation with load**  
-0.0058634820161856 (default) | scalar

Peak trail,  $D_{pt}$ , variation with load, *QDZ2*, dimensionless.

**Dpt peak trail variation with camber, QDZ3 — Peak trail variation with camber**  
0.3805597481383 (default) | scalar

Peak trail,  $D_{pt}$ , variation with camber, *QDZ3*, dimensionless.

**Dpt peak trail variation with square of camber, QDZ4 — Peak trail variation with camber**  
0 (default) | scalar

Peak trail,  $D_{pt}$ , variation with square of camber, *QDZ4*, dimensionless.



**Dmr peak residual torque, QDZ6 — Peak residual torque**

0.00160914918118959 (default) | scalar

Peak residual torque,  $D_{mr}$ , QDZ6, dimensionless.**Dmr peak residual torque variation with load, QDZ7 — Peak residual torque variation with load**

-0.00211036330862154 (default) | scalar

Peak residual torque,  $D_{mr}$ , variation with load, QDZ7, dimensionless.**Dmr peak residual torque variation with camber, QDZ8 — Peak residual torque variation with camber**

-0.13921904912557 (default) | scalar

Peak residual torque,  $D_{mr}$ , variation with camber, QDZ8, dimensionless.**Dmr peak residual torque variation with camber and load, QDZ9 — Peak residual torque variation with camber and load**

0.00816585550028243 (default) | scalar

Peak residual torque,  $D_{mr}$ , variation with camber and load, QDZ9, dimensionless.**Dmr peak residual torque variation with square of camber, QDZ10 — Peak residual torque variation with camber**

0 (default) | scalar

Peak residual torque,  $D_{mr}$ , variation with square of camber, QDZ10, dimensionless.**Dmr peak residual torque variation with square of load, QDZ11 — Peak residual torque variation with load**

0 (default) | scalar

Peak residual torque,  $D_{mr}$ , variation with square of load, QDZ11, dimensionless.**Ept trail curvature at FZNOM, QEZ1 — Trail curvature at nominal force**

-2.19802254534746 (default) | scalar

Trail curvature,  $E_{pt}$ , at nominal force,  $F_{ZNOM}$ , QEZ1, dimensionless.**Ept variation with load, QEZ2 — Trail curvature variation with load**

1.01850535789165 (default) | scalar

Trail curvature,  $E_{pt}$  variation with load, QEZ2, dimensionless.**Ept variation with square of load, QEZ3 — Trail curvature variation with load**

0 (default) | scalar

Trail curvature,  $E_{pt}$  variation with square of load, QEZ3, dimensionless.**Ept variation with sign of alpha-t, QEZ4 — Trail curvature variation**

0.278379679112054 (default) | scalar

Trail curvature,  $E_{pt}$  variation with sign of alpha-t, QEZ4, dimensionless.

**Ept variation with sign of alpha-t and camber, QEZ5 – Variation**

-0.548414722765386 (default) | scalar

Trail curvature,  $E_{pt}$  variation with sign of alpha-t and camber, *QEZ5*, dimensionless.

**Sht horizontal trail shift at FZNOM, QHZ1 – Horizontal trail shift at nominal load**

0.00148361198869669 (default) | scalar

Horizontal trail shift,  $Sh_t$ , at nominal load,  $F_{ZNOM}$ , *QHZ1*, dimensionless.

**Sht variation with load, QHZ2 – Horizontal trail shift variation with load**

0.00202017567585904 (default) | scalar

Horizontal trail shift,  $Sh_t$ , variation with load, *QHZ2*, dimensionless.

**Sht variation with camber, QHZ3 – Horizontal trail shift variation with camber**

0.240316641332066 (default) | scalar

Horizontal trail shift,  $Sh_t$ , variation with camber, *QHZ3*, dimensionless.

**Sht variation with load and camber, QHZ4 – Horizontal trail shift variation with load and camber**

-0.210114035738085 (default) | scalar

Horizontal trail shift,  $Sh_t$ , variation with load and camber, *QHZ4*, dimensionless.

**Inflation pressure influence on trail length, PPZ1 – Pressure influence on trail length**

-0.443927982388615 (default) | scalar

Inflation pressure influence on trail length, *PPZ1*, dimensionless.

**Inflation pressure influence on residual aligning torque, PPZ2 – Pressure influence on aligning torque**

0 (default) | scalar

Inflation pressure influence on residual aligning torque, *PPZ2*, dimensionless.

**Nominal value of s/R0: effect of Fx on Mz, SSZ1 – Effect of longitudinal force on aligning torque**

0.00914999585397887 (default) | scalar

Nominal value of s/R0: effect of longitudinal force,  $F_x$ , on aligning torque,  $M_z$ , *SSZ1*, dimensionless.

**s/R0 variation with lateral to nominal force ratio, SSZ2 – Variation with lateral to nominal force ratio**

0.0389830656052735 (default) | scalar

Variation with lateral to nominal force ratio, *SSZ2*, dimensionless.

**s/R0 variation with camber, SSZ3 – Variation with camber**

0 (default) | scalar

Variation with camber, *SSZ3*, dimensionless.

**s/R0 variation with camber and load, SSZ4 – Variation with camber and load**

0 (default) | scalar

Variation with camber and load, *SSZ4*, dimensionless.**Turnslip****Fx peak reduction due to spin, PDXP1 – Longitudinal force peak reduction due to spin**

0.396718274678791 (default) | scalar

Longitudinal force,  $F_x$ , peak reduction due to spin, *PDXP1*, dimensionless.**Fx peak reduction due to spin with varying load, PDXP2 – Longitudinal force peak reduction due to spin**

0 (default) | scalar

Longitudinal force,  $F_x$ , peak reduction due to spin with varying load, *PDXP2*, dimensionless.**Fx peak reduction due to spin with slip ratio, PDXP3 – Longitudinal force peak reduction due to spin**

0 (default) | scalar

Longitudinal force,  $F_x$ , peak reduction due to spin with slip ratio, *PDXP3*, dimensionless.**Cornering stiffness reduction due to spin, PKYP1 – Stiffness reduction due to spin**

1.00587060633573 (default) | scalar

Cornering stiffness reduction due to spin, *PKYP1*, dimensionless.**Fy peak reduction due to spin, PDYP1 – Lateral force peak reduction due to spin**

0.40483048923438 (default) | scalar

Lateral force,  $F_y$ , peak reduction due to spin, *PDYP1*, dimensionless.**Fy peak reduction due to spin with varying load, PDYP2 – Lateral force peak reduction due to spin**

0 (default) | scalar

Lateral force,  $F_y$ , peak reduction due to spin with varying load, *PDYP2*, dimensionless.**Fy peak reduction due to spin with slip angle, PDYP3 – Lateral force peak reduction due to spin**

0 (default) | scalar

Lateral force,  $F_y$ , peak reduction due to spin with slip angle, *PDYP3*, dimensionless.**Fy peak reduction due to square root of spin, PDYP4 – Lateral force peak reduction due to spin**

0 (default) | scalar

Lateral force,  $F_y$ , peak reduction due to square root of spin, *PDYP4*, dimensionless.**Fy vs. slip angle response lateral shift limit, PHYP1 – Lateral force versus slip angle response**

0.992731942067188 (default) | scalar

Lateral force,  $F_y$ , versus slip angle response lateral shift limit, *PHYP1*, dimensionless.

**Fy vs. slip angle response max lateral shift limit, PHYP2 – Lateral force versus slip angle response**

0.150352945499914 (default) | scalar

Lateral force,  $F_y$ , versus slip angle response max lateral shift limit, *PHYP2*, dimensionless.

**Fy vs. slip angle response max lateral shift limit with load, PHYP3 – Lateral force versus slip angle response**

0 (default) | scalar

Lateral force,  $F_y$ , versus slip angle response max lateral shift limit with load, *PHYP3*, dimensionless.

**Fy vs. slip angle response lateral shift curvature factor, PHYP4 – Lateral force versus slip angle response**

-3.98988682633674 (default) | scalar

Lateral force,  $F_y$ , versus slip angle response lateral shift curvature factor, *PHYP4*, dimensionless.

**Camber stiffness reduction due to spin, PECP1 – Camber stiffness reduction**

0.502379254513503 (default) | scalar

Camber stiffness reduction due to spin, *PECP1*, dimensionless.

**Camber stiffness reduction due to spin with load, PECP2 – Camber stiffness reduction**

0 (default) | scalar

Camber stiffness reduction due to spin with load, *PECP2*, dimensionless.

**Turn slip pneumatic trail reduction factor, QDTP1 – Turn slip pneumatic trail reduction factor**

10.0178654287947 (default) | scalar

Turn slip pneumatic trail reduction factor, *QDTP1*, dimensionless.

**Turn moment for constant turning and zero longitudinal speed, QCRP1 – Turn moment for constant turning**

0.200627747200702 (default) | scalar

Turn moment for constant turning and zero longitudinal speed, *QCRP1*, dimensionless.

**Turn slip moment increase with spin at 90deg slip angle, QCRP2 – Turn slip moment**

0.0995735881599772 (default) | scalar

Turn slip moment increase with spin at 90-degree slip angle, *QCRP2*, dimensionless.

**Residual spin torque reduction from side slip, QBRP1 – Residual spin torque reduction**

0.0997107127960717 (default) | scalar

Residual spin torque reduction from side slip, *QBRP1*, dimensionless.

**Turn slip moment peak magnitude, QDRP1 — Turn slip moment peak magnitude**

1.01432910167423 (default) | scalar

Turn slip moment peak magnitude, *QDRP1*, dimensionless.**Turn slip moment curvature, QDRP2 — Turn slip moment curvature**

0 (default) | scalar

Turn slip moment curvature, *QDRP2*, dimensionless.**References**

- [1] Besselink, I. J. M., A. J. C. Schmeitz, and H. B. Pacejka. "An improved Magic Formula/Swift tyre model that can handle inflation pressure changes." *Vehicle System Dynamics - International Journal of Vehicle Mechanics and Mobility*. Vol. 48, 2010. doi: 10.1080/00423111003748088.
- [2] Pacejka, H. B. *Tire and Vehicle Dynamics*. 3rd ed. Oxford, United Kingdom: SAE and Butterworth-Heinemann, 2012.
- [3] Schmid, Steven R., Bernard J. Hamrock, and Bo O. Jacobson. "Chapter 18: Brakes and Clutches." *Fundamentals of Machine Elements, SI Version*. 3rd ed. Boca Raton, FL: CRC Press, 2014.

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Longitudinal Wheel

**Topics**

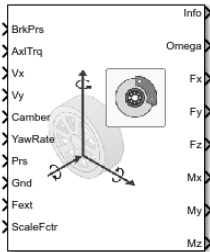
"Coordinate Systems in Vehicle Dynamics Blockset"

**Introduced in R2018a**

## Fiala Wheel 2DOF

Fiala wheel 2DOF wheel with disc, drum, or mapped brake

**Library:** Vehicle Dynamics Blockset / Wheels and Tires



### Description

The Fiala Wheel 2DOF block implements a simplified tire with lateral and longitudinal slip capability based on the E. Fiala model<sup>[1]</sup>. The block uses a translational friction model to calculate the forces and moments during combined longitudinal and lateral slip, requiring fewer parameters than the Combined Slip Wheel 2DOF block. If you do not have the tire coefficients needed by the Magic Formula, consider using this block for studies that do not involve extensive nonlinear combined lateral slip or lateral dynamics. If your study does require nonlinear combined slip or lateral dynamics, consider using the Combined Slip Wheel 2DOF block.

The block determines the wheel rotation rate, vertical motion, and forces and moments in all six degrees-of-freedom (DOFs) based on the driveline torque, brake pressure, road height, wheel camber angle, and inflation pressure. You can use this block for these types of analyses:

- Driveline and vehicle simulations that require low frequency tire-road and braking forces for vehicle acceleration, braking, and wheel rolling resistance calculations with minimal tire parameters.
- Wheel interaction with an idealized road surface.
- Ride and handling maneuvers for vehicles undergoing mild combined slip. For this analysis, you can connect the block to driveline and chassis components such as differentials, suspension, and vehicle body systems.
- Yaw stability. For this analyses, you can connect this block to more detailed braking system models.
- Tire stiffness and unsprung mass interactions with ground variations, load transfer, or chassis motion using the block vertical DOF.

The block integrates rotational wheel, vertical mass, and braking dynamics models. For the slip-dependent tire forces and moments, the block implements the Fiala tire model.

Use the **Brake Type** parameter to select the brake.

Brake Type Setting	Brake Implementation
None	None
Disc	Brake that converts the brake cylinder pressure into a braking force

Brake Type Setting	Brake Implementation
Drum	Simplex drum brake that converts the applied force and brake geometry into a net braking torque
Mapped	Lookup table that is a function of the wheel speed and applied brake pressure

To calculate the rolling resistance torque, specify one of these **Rolling Resistance** parameters.

Setting	Block Implementation
None	None
Pressure and velocity	Method in <i>Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance</i> . The rolling resistance is a function of tire pressure, normal force, and velocity.
ISO 28580	Method specified in ISO 28580:2018, <i>Passenger car, truck and bus tyre rolling resistance measurement method – Single point test and correlation of measurement results</i> .
Magic Formula	Magic formula equations from 4.E70 in <i>Tire and Vehicle Dynamics</i> . The magic formula is an empirical equation based on fitting coefficients.
Mapped torque	Lookup table that is a function of the normal force and spin axis longitudinal velocity.

To calculate vertical motion, specify one of these **Vertical Motion** parameters.

Setting	Block Implementation
None	Block passes the applied chassis forces directly through to the rolling resistance and longitudinal force calculations.
Mapped stiffness and damping	Vertical motion depends on wheel stiffness and damping. Stiffness is a function of tire sidewall displacement and pressure. Damping is a function of tire sidewall velocity and pressure.

### Rotational Wheel Dynamics

The block calculates the inertial response of the wheel subject to:

- Axle losses
- Brake and drive torque
- Tire rolling resistance
- Ground contact through the tire-road interface

The input torque is the summation of the applied axle torque, braking torque, and moment arising from the combined tire torque.

$$T_i = T_a - T_b + T_d$$

For the moment arising from the combined tire torque, the block implements tractive wheel forces and rolling resistance with first-order dynamics. The rolling resistance has a time constant parameterized in terms of a relaxation length.

$$T_d(s) = \frac{1}{\frac{|\omega| R_e}{L_e} s + 1} (F_x R_e + M_y)$$

To calculate the rolling resistance torque, you can specify one of these **Rolling Resistance** parameters.

Setting	Block Implementation
None	Block sets rolling resistance, $M_y$ , to zero.
Pressure and velocity	Block uses the method in SAE <i>Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance</i> . The rolling resistance is a function of tire pressure, normal force, and velocity. Specifically, $M_y = R_e \{ a + b V_x  + cV_x^2 \} \{ F_z \beta p_i^a \} \tanh(4V_x)$
ISO 28580	Block uses the method specified in ISO 28580:2018, <i>Passenger car, truck and bus tyre rolling resistance measurement method – Single point test and correlation of measurement results</i> . The method accounts for normal load, parasitic loss, and thermal corrections from test conditions. Specifically, $M_y = R_e \left( \frac{F_z C_r}{1 + K_t(T_{amb} - T_{meas})} - F_{pl} \right) \tanh(\omega)$
Magic Formula	Block calculates the rolling resistance, $M_y$ , using the Magic Formula equations from 4.E70 in <i>Tire and Vehicle Dynamics</i> . The magic formula is an empirical equation based on fitting coefficients.
Mapped torque	For the rolling resistance, $M_y$ , the block uses a lookup table that is a function of the normal force and spin axis longitudinal velocity.

If the brakes are enabled, the block determines the braking locked or unlocked condition based on an idealized dry clutch friction model. Based on the lock-up condition, the block implements these friction and dynamic models.

If	Lock-Up Condition	Friction Model	Dynamic Model
$\omega \neq 0$ or $T_S <  T_i + T_f - \omega b $	Unlocked	$T_f = T_k$ where, $T_k = F_c R_{eff} \mu_k \tanh[4(-\omega_d)]$ $T_s = F_c R_{eff} \mu_s$ $R_{eff} = \frac{2(R_o^3 - R_i^3)}{3(R_o^2 - R_i^2)}$	$\dot{\omega} J = -\omega b + T_i + T_o$
$\omega = 0$ and $T_S \geq  T_i + T_f - \omega b $	Locked	$T_f = T_s$	$\omega = 0$

The equations use these variables.

- $\omega$  Wheel angular velocity
- $a$  Velocity-independent force component



$b$	Linear velocity force component
$c$	Quadratic velocity force component
$L_e$	Tire relaxation length
$J$	Moment of inertia
$M_y$	Rolling resistance torque
$T_a$	Applied axle torque
$T_b$	Braking torque
$T_d$	Combined tire torque
$T_f$	Frictional torque
$T_i$	Net input torque
$T_k$	Kinetic frictional torque
$T_o$	Net output torque
$T_s$	Static frictional torque
$F_c$	Applied clutch force
$F_x$	Longitudinal force developed by the tire road interface due to slip
$R_{eff}$	Effective clutch radius
$R_o$	Annular disk outer radius
$R_i$	Annular disk inner radius
$R_e$	Effective tire radius while under load and for a given pressure
$V_x$	Longitudinal axle velocity
$F_z$	Vehicle normal force
$C_r$	Rolling resistance constant
$T_{amb}$	Ambient temperature
$T_{meas}$	Measured temperature for rolling resistance constant
$F_{pl}$	Parasitic force loss
$K_t$	Thermal correction factor
$\alpha$	Tire pressure exponent
$\beta$	Normal force exponent
$p_i$	Tire pressure
$\mu_s$	Coefficient of static friction
$\mu_k$	Coefficient of kinetic friction

### Longitudinal Force

The block implements the longitudinal force as a function of wheel slip relative to the road surface using these equations.

Calculation	Equation
Critical slip	$K'_{Critical} = \left  \frac{\mu F_z}{2C_K} \right $

Calculation	Equation
Longitudinal force	$F_x = \begin{cases} C_k \kappa' & \text{when }  \kappa'  \leq \kappa'_{Critical} \\ \tanh(4\kappa') \left( \mu  F_z  - \left  \frac{(\mu F_z)^2}{4\kappa' C_k} \right  \right) & \text{when }  \kappa'  > \kappa'_{Critical} \end{cases}$
Friction coefficient	$\mu = (\mu_s - (\mu_s - \mu_k) \kappa_{ka}) \lambda_\mu$
Slip coefficient	$\kappa_{ka} = \sqrt{\kappa'^2 + \tan^2(\alpha')}$

The equations use these variables.

- $\kappa'$  Slip state
- $F_x$  Longitudinal force acting on axle along tire-fixed x-axis,
- $C_k$  Longitudinal stiffness
- $F_z$  Vertical contact patch normal force along tire-fixed z-axis,
- $\mu$  Friction coefficient
- $\mu_s$  Coefficient of static friction
- $\mu_k$  Coefficient of kinetic friction
- $\kappa_{ka}$  Comprehensive slip coefficient
- $\alpha'$  Slip angle state
- $\lambda_\mu$  Friction scaling

### Lateral Force

The block implements the lateral force as a function of wheel slip angle state using these equations.

Calculation	Equation
Critical slip angle	$\alpha'_{Critical} = \text{atan}\left(\frac{3\mu F_z }{C_a}\right)$
Lateral force	$F_y = \begin{cases} -\tanh(4\alpha')\mu F_z  & \text{when }  \alpha'  > \alpha'_{Critical} \\ -\tanh(4\alpha')\mu F_z (1 - \xi^3) + \gamma C_\gamma & \text{when }  \alpha'  \leq \alpha'_{Critical} \end{cases}$ $\xi = 1 - \frac{C_a  \tan(\alpha') }{3\mu F_z }$

The equations use these variables.

- $\alpha'$  Slip angle state
- $F_y$  Lateral force acting on axle along tire-fixed y-axis,
- $F_z$  Vertical contact patch normal force along tire-fixed z-axis
- $C_\gamma$  Camber stiffness
- $C_a$  Lateral stiffness per slip angle
- $\mu$  Friction coefficient

## Vertical Dynamics

For the vertical dynamics, the block implements these equations.

Calculation	Equation
Vertical response	$\ddot{z}m = F_{ztire} + mg - F_z$
Tire normal force	$F_{ztire} = \rho_z k - b\dot{z}$
Vertical sidewall deflection	$\rho_z = z_{gnd} - z, z \geq 0$

The equations use these variables.

$z$	Tire deflection along tire-fixed $z$ -axis
$z_{gnd}$	Ground displacement along tire-fixed $z$ -axis
$F_{ztire}$	Tire normal force along tire-fixed $z$ -axis
$F_z$	Vertical force acting on axle along tire-fixed $z$ -axis
$\rho_z$	Vertical sidewall deflection along tire-fixed $z$ -axis
$k$	Vertical sidewall stiffness
$b$	Vertical sidewall damping

## Overturning, Aligning, and Scaling

This table summarizes the overturning, aligning, and scaling implementation.

Calculation	Implementation
Overturning moment	The Fiala model does not define an overturning moment. The block implements this equation, requiring minimal parameters. $M_x = F_y R_e \cos(\gamma)$
Aligning moment	The block implements the aligning moment as a combination of yaw rate damping and slip angle state. $M_z = \begin{cases} \dot{\psi} b_{M_z} & \text{when }  \alpha'  > \alpha'_{Critical} \\ \tanh(4\alpha') w \mu  F_z  (1 - \xi) \xi^3 + \dot{\psi} b_{M_z} & \text{when }  \alpha'  \leq \alpha'_{Critical} \end{cases}$ $\xi = 1 - \frac{C_d  \tan(\alpha') }{3\mu  F_z }$
Friction scaling	To vary the coefficient of friction, use the <code>ScaleFctr</code> input port.

The equations use these variables.

$M_x$	Overturning moment acting on axle about tire-fixed $x$ -axis
$M_z$	Aligning moment acting on axle about tire-fixed $z$ -axis
$R_e$	Effective contact patch to wheel carrier radial distance
$\gamma$	Camber angle
$k$	Vertical sidewall stiffness

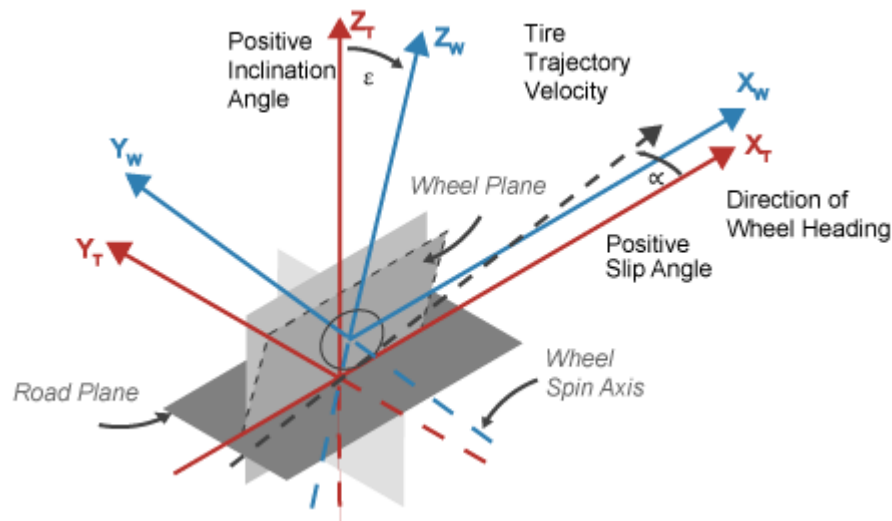
$b$	Vertical sidewall damping
$\dot{\psi}$	Tire angular velocity about the tire-fixed $z$ -axis (yaw rate)
$w$	Tire width
$\alpha'$	Slip angle state
$b_{Mz}$	Linear yaw rate resistance
$F_y$	Lateral force acting on axle along tire-fixed $y$ -axis
$C_\gamma$	Camber stiffness
$C_\alpha$	Lateral stiffness per slip angle
$\mu$	Friction coefficient
$F_z$	Vertical contact patch normal force along tire-fixed $z$ -axis

### Tire and Wheel Coordinate Systems

To resolve the forces and moments, the block uses the Z-Up orientation of the tire and wheel coordinate systems.

- Tire coordinate system axes ( $X_T, Y_T, Z_T$ ) are fixed in a reference frame attached to the tire. The origin is at the tire contact with the ground.
- Wheel coordinate system axes ( $X_W, Y_W, Z_W$ ) are fixed in a reference frame attached to the wheel. The origin is at the wheel center.

### Z-Up Orientation<sup>2</sup>

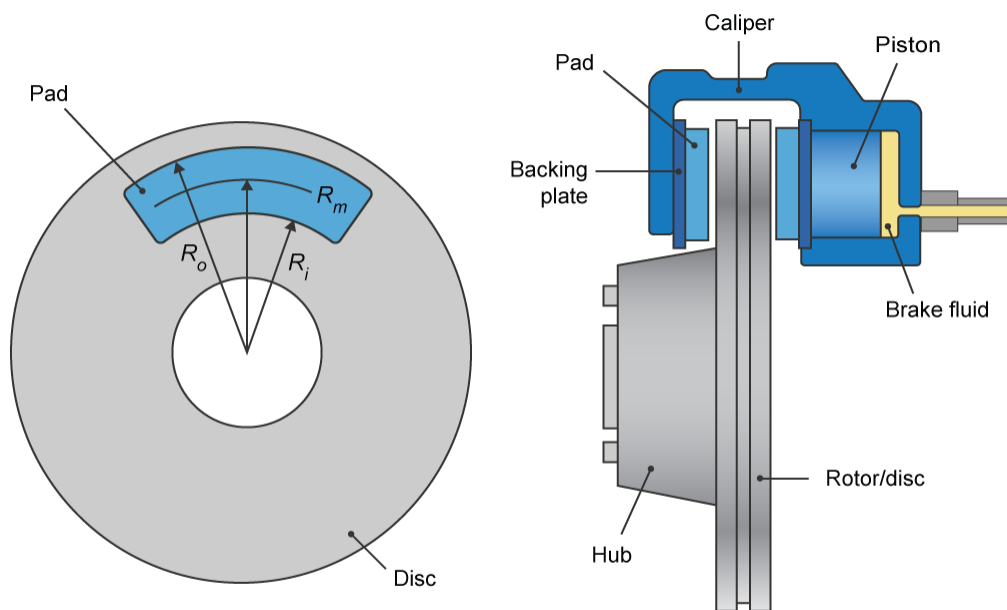


### Brakes

#### Disc

If you specify the **Brake Type** parameter Disc, the block implements a disc brake. This figure shows the side and front views of a disc brake.

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A disc brake converts brake cylinder pressure from the brake cylinder into force. The disc brake applies the force at the brake pad mean radius.

The block uses these equations to calculate brake torque for the disc brake.

$$T = \begin{cases} \frac{\mu P \pi B_a^2 R_m N_{pads}}{4} & \text{when } N \neq 0 \\ \frac{\mu_{static} P \pi B_a^2 R_m N_{pads}}{4} & \text{when } N = 0 \end{cases}$$

$$R_m = \frac{R_o + R_i}{2}$$

The equations use these variables.

$T$	Brake torque
$P$	Applied brake pressure
$N$	Wheel speed
$N_{pads}$	Number of brake pads in disc brake assembly
$\mu_{static}$	Disc pad-rotor coefficient of static friction
$\mu$	Disc pad-rotor coefficient of kinetic friction
$B_a$	Brake actuator bore diameter
$R_m$	Mean radius of brake pad force application on brake rotor
$R_o$	Outer radius of brake pad

$R_i$  Inner radius of brake pad

**Drum**

If you specify the **Brake Type** parameter Drum, the block implements a static (steady-state) simplex drum brake. A simplex drum brake consists of a single two-sided hydraulic actuator and two brake shoes. The brake shoes do not share a common hinge pin.

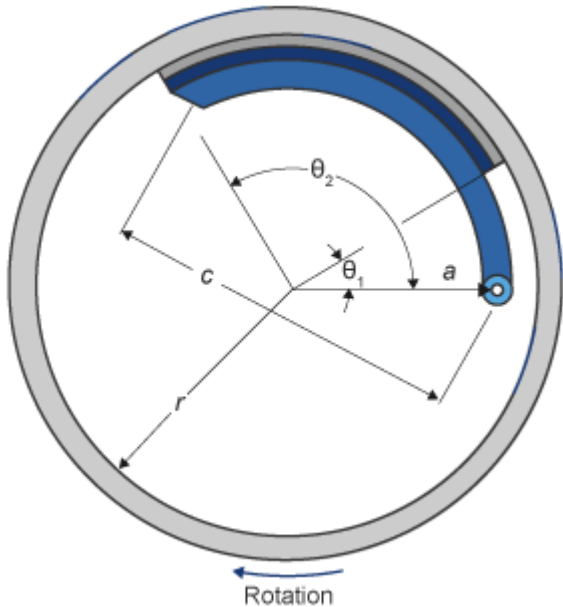
The simplex drum brake model uses the applied force and brake geometry to calculate a net torque for each brake shoe. The drum model assumes that the actuators and shoe geometry are symmetrical for both sides, allowing a single set of geometry and friction parameters to be used for both shoes.

The block implements equations that are derived from these equations in *Fundamentals of Machine Elements*.

$$T_{rshoe} = \left( \frac{\pi\mu cr(\cos\theta_2 - \cos\theta_1)B_a^2}{2\mu(2r(\cos\theta_2 - \cos\theta_1) + a(\cos^2\theta_2 - \cos^2\theta_1)) + ar(2\theta_1 - 2\theta_2 + \sin 2\theta_2 - \sin 2\theta_1)} \right) P$$

$$T_{lshoe} = \left( \frac{\pi\mu cr(\cos\theta_2 - \cos\theta_1)B_a^2}{-2\mu(2r(\cos\theta_2 - \cos\theta_1) + a(\cos^2\theta_2 - \cos^2\theta_1)) + ar(2\theta_1 - 2\theta_2 + \sin 2\theta_2 - \sin 2\theta_1)} \right) P$$

$$T = \begin{cases} T_{rshoe} + T_{lshoe} & \text{when } N \neq 0 \\ (T_{rshoe} + T_{lshoe}) \frac{\mu_{static}}{\mu} & \text{when } N = 0 \end{cases}$$



The equations use these variables.

$T$  Brake torque  
 $P$  Applied brake pressure  
 $N$  Wheel speed

$\mu_{static}$	Disc pad-rotor coefficient of static friction
$\mu$	Disc pad-rotor coefficient of kinetic friction
$T_{rshoe}$	Right shoe brake torque
$T_{lshoe}$	Left shoe brake torque
$a$	Distance from drum center to shoe hinge pin center
$c$	Distance from shoe hinge pin center to brake actuator connection on brake shoe
$r$	Drum internal radius
$B_a$	Brake actuator bore diameter
$\theta_1$	Angle from shoe hinge pin center to start of brake pad material on shoe
$\theta_2$	Angle from shoe hinge pin center to end of brake pad material on shoe

### Mapped

If you specify the **Brake Type** parameter Mapped, the block uses a lookup table to determine the brake torque.

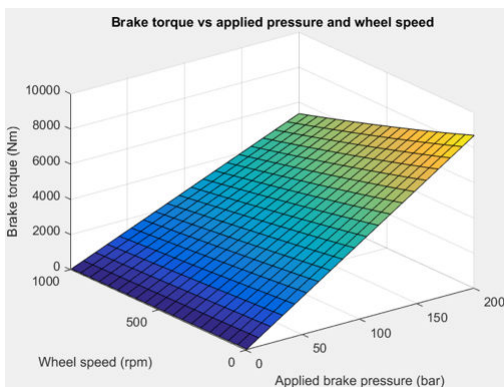
$$T = \begin{cases} f_{brake}(P, N) & \text{when } N \neq 0 \\ \left(\frac{\mu_{static}}{\mu}\right)f_{brake}(P, N) & \text{when } N = 0 \end{cases}$$

The equations use these variables.

$T$	Brake torque
$f_{brake}(P, N)$	Brake torque lookup table
$P$	Applied brake pressure
$N$	Wheel speed
$\mu_{static}$	Friction coefficient of drum pad-face interface under static conditions
$\mu$	Friction coefficient of disc pad-rotor interface

The lookup table for the brake torque,  $f_{brake}(P, N)$ , is a function of applied brake pressure and wheel speed, where:

- $T$  is brake torque, in N·m.
- $P$  is applied brake pressure, in bar.
- $N$  is wheel speed, in rpm.



## Ports

### Input

#### **BrkPrs — Brake pressure**

scalar | N-by-1 vector

Brake pressure, in Pa.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

#### **Dependencies**

To enable this port, for the **Brake Type** parameter, specify one of these types:

- Disc
- Drum
- Mapped

#### **AxlTrq — Axle torque**

scalar | N-by-1 vector

Axle torque,  $T_a$ , about wheel spin axis, in N·m.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

#### **Vx — Longitudinal velocity**

scalar | N-by-1 vector

Axle longitudinal velocity,  $V_x$ , along tire-fixed x-axis, in m/s.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

#### **Vy — Lateral velocity**

scalar | N-by-1 vector

Axle lateral velocity,  $V_y$ , along tire-fixed y-axis, in m/s.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

#### **Camber — Camber angle**

scalar | N-by-1 vector

Camber angle,  $\gamma$ , in rad.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

#### **YawRate — Tire angular velocity**

scalar | N-by-1 vector

Tire angular velocity,  $r$ , about the tire-fixed z-axis (yaw rate), in rad/s.



Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

### Prs — Tire inflation pressure

scalar | N-by-1 vector

Tire inflation pressure,  $p_i$ , in Pa.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

### Gnd — Ground displacement

scalar | N-by-1 vector

Ground displacement along tire-fixed  $z$ -axis, in m. Positive input produces wheel lift.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

### Fext — Axle force applied to tire

scalar | N-by-1 vector

Axle force applied to tire,  $F_{ext}$ , along vehicle-fixed  $z$ -axis (positive input compresses the tire), in N·m.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

### ScaleFctrs — Scale factor

scalar | N-by-1 vector

Scale factor to account for variations in the coefficient of friction.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

## Output

### Info — Block data

bus

Block data, returned as a bus signal containing these block values.

Signal	Description	Units
Ax1Trq	Axle torque about wheel-fixed $y$ -axis	N·m
Omega	Wheel angular velocity about wheel-fixed $y$ -axis	rad/s
Fx	Longitudinal vehicle force along tire-fixed $x$ -axis	N
Fy	Lateral vehicle force along tire-fixed $y$ -axis	N
Fz	Vertical vehicle force along tire-fixed $z$ -axis	N
Mx	Overturning moment about tire-fixed $x$ -axis	N·m
My	Rolling resistance torque about tire-fixed $y$ -axis	N·m
Mz	Aligning moment about tire-fixed $z$ -axis	N·m

Signal	Description	Units
Vx	Vehicle longitudinal velocity along tire-fixed x-axis	m/s
Vy	Vehicle lateral velocity along tire-fixed y-axis	m/s
Re	Loaded effective radius	m
Kappa	Longitudinal slip ratio	NA
Alpha	Side slip angle	rad
a	Contact patch half length	m
b	Contact patch half width	m
Gamma	Camber angle	rad
psidot	Tire angular velocity about the tire-fixed z-axis (yaw rate)	rad/s
BrkTrq	Brake torque about the vehicle-fixed y-axis	N·m
BrkPrs	Brake pressure	Pa
z	Axle vertical displacement along tire-fixed z-axis	m
zdot	Axle vertical velocity along tire-fixed z-axis	m/s
Gnd	Ground displacement along tire-fixed z-axis (positive input produces wheel lift)	m
GndFz	Vertical sidewall force on ground along tire-fixed z-axis	N
Prs	Tire inflation pressure	Pa

**Omega — Wheel angular velocity**

scalar | N-by-1 vector

Wheel angular velocity,  $\omega$ , about wheel-fixed y-axis, in rad/s.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

**Fx — Longitudinal axle force**

scalar | N-by-1 vector

Longitudinal force acting on axle,  $F_x$ , along tire-fixed x-axis, in N. Positive force acts to move the vehicle forward.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

**Fy — Lateral axle force**

scalar | N-by-1 vector

Lateral force acting on axle,  $F_y$ , along tire-fixed y-axis, in N.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

**Fz — Vertical axle force**

scalar | N-by-1 vector

Vertical force acting on axle,  $F_z$ , along tire-fixed z-axis, in N.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

### **Mx – Overturning moment**

scalar | N-by-1 vector

Longitudinal moment acting on axle,  $M_x$ , about tire-fixed x-axis, in N·m.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

### **My – Rolling resistive moment**

scalar | N-by-1 vector

Lateral moment acting on axle,  $M_y$ , about tire-fixed y-axis, in N·m.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

### **Mz – Aligning moment**

scalar | N-by-1 vector

Vertical moment acting on axle,  $M_z$ , about tire-fixed z-axis, in N·m.

Vector is the number of wheels,  $N$ , by 1. If you provide a scalar value, the block assumes that number of wheels is one.

## **Parameters**

### **Block Options**

#### **Brake Type – Select type**

None | Disc | Drum | Mapped

Use the **Brake Type** parameter to select the brake.

<b>Brake Type Setting</b>	<b>Brake Implementation</b>
None	None
Disc	Brake that converts the brake cylinder pressure into a braking force
Drum	Simplex drum brake that converts the applied force and brake geometry into a net braking torque
Mapped	Lookup table that is a function of the wheel speed and applied brake pressure

#### **Rolling Resistance – Select type**

None (default) | Pressure and velocity | ISO 28580 | Magic Formula | Mapped torque

To calculate the rolling resistance torque, specify one of these **Rolling Resistance** parameters.

Setting	Block Implementation
None	None
Pressure and velocity	Method in <i>Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance</i> . The rolling resistance is a function of tire pressure, normal force, and velocity.
ISO 28580	Method specified in ISO 28580:2018, <i>Passenger car, truck and bus tyre rolling resistance measurement method – Single point test and correlation of measurement results</i> .
Magic Formula	Magic formula equations from 4.E70 in <i>Tire and Vehicle Dynamics</i> . The magic formula is an empirical equation based on fitting coefficients.
Mapped torque	Lookup table that is a function of the normal force and spin axis longitudinal velocity.

**Dependencies**

Selecting	Parameters
Pressure and velocity	<p><b>Velocity independent force coefficient, <math>a_{My}</math></b></p> <p><b>Linear velocity force component, <math>b_{My}</math></b></p> <p><b>Quadratic velocity force component, <math>c_{My}</math></b></p> <p><b>Tire pressure exponent, <math>\alpha_{My}</math></b></p> <p><b>Normal force exponent, <math>\beta_{My}</math></b></p>
ISO 28580	<p><b>Parasitic losses force, <math>F_{pl}</math></b></p> <p><b>Rolling resistance constant, <math>C_r</math></b></p> <p><b>Thermal correction factor, <math>K_t</math></b></p> <p><b>Measured temperature, <math>T_{meas}</math></b></p> <p><b>Parasitic losses force, <math>F_{pl}</math></b></p> <p><b>Ambient temperature, <math>T_{amb}</math></b></p>

Selecting	Parameters
Magic Formula	<b>Rolling resistance torque coefficient, QSY</b> <b>Longitudinal force rolling resistance coefficient, QSY2</b> <b>Linear rotational speed rolling resistance coefficient, QSY3</b> <b>Quartic rotational speed rolling resistance coefficient, QSY4</b> <b>Camber squared rolling resistance torque, QSY5</b> <b>Load based camber squared rolling resistance torque, QSY6</b> <b>Normal load rolling resistance coefficient, QSY7</b> <b>Pressure load rolling resistance coefficient, QSY8</b> <b>Rolling resistance scaling factor, lam_My</b>
Mapped torque	<b>Spin axis velocity breakpoints, VxMy</b> <b>Normal force breakpoints, FzMy</b> <b>Rolling resistance torque map, MyMap</b>

### Vertical Motion – Select type

None (default) | Mapped stiffness and damping

To calculate vertical motion, specify one of these **Vertical Motion** parameters.

Setting	Block Implementation
None	Block passes the applied chassis forces directly through to the rolling resistance and longitudinal force calculations.
Mapped stiffness and damping	Vertical motion depends on wheel stiffness and damping. Stiffness is a function of tire sidewall displacement and pressure. Damping is a function of tire sidewall velocity and pressure.

Selecting	Enables These Parameters
Mapped stiffness and damping	<b>Wheel mass, MASS</b> <b>Initial tire deflection, zo</b> <b>Initial velocity, zdoto</b> <b>Initial wheel vertical velocity (wheel fixed frame), zdoto</b> <b>Vertical deflection breakpoints, zFz</b> <b>Pressure breakpoints, pFz</b> <b>Force due to deflection, Fzz</b> <b>Vertical velocity breakpoints, zdotFz</b> <b>Force due to velocity, Fzzdot</b>

### Longitudinal and Lateral

#### Longitudinal stiffness, Ckappa – Longitudinal stiffness

1e7 (default) | scalar

Longitudinal stiffness,  $C_k$ , in N.

#### Lateral stiffness per slip angle, Calpha – Lateral stiffness

4.5e4 (default) | scalar

Lateral stiffness per slip angle,  $C_\alpha$ , in N/rad.

#### Camber stiffness, Cgamma – Camber stiffness

1e3 (default) | scalar

Camber stiffness,  $C_y$ , in N/rad.

#### Kinematic friction, muMin – Friction

.8 (default) | scalar

Kinematic friction,  $\mu_k$ , dimensionless.

#### Static friction, muMax – Friction

1 (default) | scalar

Static friction,  $\mu_s$ , dimensionless.

#### Longitudinal relaxation length, Lrelx – Length

.05 (default) | scalar

Longitudinal relaxation length,  $L_{relx}$ , in m.

#### Lateral relaxation length, Lrely – Length

.15 (default) | scalar

Lateral relaxation length,  $L_{rely}$ , in m/rad.

## Rolling

### Rotational damping, $br$ – Damping

1e-3 (default) | scalar

Rotational damping,  $br$ , in N·m·s/rad.

### Rotational inertia (rolling axis), $IYY$ – Inertia

0.74 (default) | scalar

Rotational inertia (rolling axis),  $IYY$ , in kg·m<sup>2</sup>.

### Initial rotational velocity, $\omega_0$ – Velocity

0 (default) | scalar

Initial rotational velocity, in rad/s.

### Unloaded radius, UNLOADED\_RADIUS – Radius

0.309384029954441 (default) | scalar

Unloaded radius, in m.

## Pressure and Velocity

### Velocity independent force coefficient, $aMy$ – Force coefficient

8e-4 (default) | scalar

Velocity-independent force coefficient,  $a$ , in s/m.

### Dependencies

To create this parameter, select the **Rolling Resistance** parameter Pressure and velocity.

### Linear velocity force component, $bMy$ – Force component

.001 (default) | scalar

Linear velocity force component,  $b$ , in s/m.

### Dependencies

To create this parameter, select the **Rolling Resistance** parameter Pressure and velocity.

### Quadratic velocity force component, $cMy$ – Force component

1.6e-4 (default) | scalar

Quadratic velocity force component,  $c$ , in s<sup>2</sup>/m<sup>2</sup>.

### Dependencies

To create this parameter, select the **Rolling Resistance** parameter Pressure and velocity.

### Tire pressure exponent, $\alpha My$ – Pressure exponent

-0.003 (default) | scalar

Tire pressure exponent,  $\alpha$ , dimensionless.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Pressure and velocity.

**Normal force exponent, betaMy – Force exponent**

0.97 (default) | scalar

Normal force exponent,  $\beta$ , dimensionless.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Pressure and velocity.

**ISO 28580****Parasitic losses force, Fpl – Force loss**

10 (default) | scalar

Parasitic force loss,  $F_{pl}$ , in N.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

**Rolling resistance constant, Cr – Constant**

1e-3 (default) | scalar

Rolling resistance constant,  $C_r$ , in N/kN. ISO 28580 specifies the rolling resistance unit as one newton of tractive resistance for every kilonewtons of normal load.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

**Thermal correction factor, Kt – Correction factor**

.008 (default) | scalar

Thermal correction factor,  $K_t$ , in 1/degC.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

**Measured temperature, Tmeas – Temperature**

298.15 (default) | scalar

Measured temperature,  $T_{meas}$ , in K.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

**Ambient temperature, Tamb – Temperature**

298.15 (default) | scalar

Measured temperature,  $T_{amb}$ , in K.



**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

**Input ambient temperature – Selection**

off (default) | on

Select to create input port Tamb.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

**Magic Formula****Rolling resistance torque coefficient, QSY1 – Torque coefficient**

0.007 (default) | scalar

Rolling resistance torque coefficient, dimensionless.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

**Longitudinal force rolling resistance coefficient, QSY2 – Force resistance coefficient**

0 (default) | scalar

Longitudinal force rolling resistance coefficient, dimensionless.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

**Linear rotational speed rolling resistance coefficient, QSY3 – Linear speed coefficient**

0.0015 (default) | scalar

Linear rotational speed rolling resistance coefficient, dimensionless.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

**Quartic rotational speed rolling resistance coefficient, QSY4 – Quartic speed coefficient**

8.5e-05 (default) | scalar

Quartic rotational speed rolling resistance coefficient, dimensionless.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

**Camber squared rolling resistance torque, QSY5 – Camber resistance torque**

0 (default) | scalar

Camber squared rolling resistance torque, in 1/rad<sup>2</sup>.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

**Load based camber squared rolling resistance torque, QSY6 – Load resistance torque**

0 (default) | scalar

Load based camber squared rolling resistance torque, in  $1/\text{rad}^2$ .

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

**Normal load rolling resistance coefficient, QSY7 – Normal resistance coefficient**

0.9 (default) | scalar

Normal load rolling resistance coefficient, dimensionless.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

**Pressure load rolling resistance coefficient, QSY8 – Pressure resistance coefficient**

-0.4 (default) | scalar

Pressure load rolling resistance coefficient, dimensionless.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

**Rolling resistance scaling factor, lam\_My – Scale**

1 (default) | scalar

Rolling resistance scaling factor, dimensionless.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

**Mapped****Spin axis velocity breakpoints, VxMy – Breakpoints**

-20:1:20 (default) | vector

Spin axis velocity breakpoints, in m/s.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Mapped torque.

**Normal force breakpoints, FzMy – Breakpoints**

0:200:1e4 (default) | vector

Normal force breakpoints, in N.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Mapped torque.

**Rolling resistance torque map, MyMap – Lookup table**

array

Rolling resistance torque versus axle speed and normal force, in N·m.

**Dependencies**

To create this parameter, select the **Rolling Resistance** parameter Mapped torque.

**Aligning****Wheel width, WIDTH – Width**

0.209 (default) | scalar

Wheel width, *WIDTH*, in m.

**Linear yaw rate resistance, bMz – Resistance**

0 | scalar

Linear yaw rate resistance,  $b_{Mz}$ , in N·m·s/rad.

**Brake****Static friction coefficient, mu\_static – Static friction**

.3 (default) | scalar

Static friction coefficient, dimensionless.

**Dependencies**

To enable this parameter, for the **Brake Type** parameter, specify one of these types:

- Disc
- Drum
- Mapped

**Kinetic friction coefficient, mu\_kinetic – Kinetic friction**

.2 (default) | scalar

Kinematic friction coefficient, dimensionless.

**Dependencies**

To enable this parameter, for the **Brake Type** parameter, specify one of these types:

- Disc
- Drum
- Mapped

**Disc****Disc brake actuator bore, disc\_abore – Bore distance**

.05 (default) | scalar

Disc brake actuator bore, in m.

**Dependencies**

To enable the disc brake parameters, select Disc for the **Brake Type** parameter.

**Brake pad mean radius, Rm — Radius**

.177 (default) | scalar

Brake pad mean radius, in m.

**Dependencies**

To enable the disc brake parameters, select Disc for the **Brake Type** parameter.

**Number of brake pads, num\_pads — Count**

2 (default) | scalar

Number of brake pads.

**Dependencies**

To enable the disc brake parameters, select Disc for the **Brake Type** parameter.

**Drum****Drum brake actuator bore, disc\_abore — Bore distance**

0.0508 (default) | scalar

Drum brake actuator bore, in m.

**Dependencies**

To enable the drum brake parameters, select Drum for the **Brake Type** parameter.

**Shoe pin to drum center distance, drum\_a — Distance**

0.123 (default) | scalar

Shoe pin to drum center distance, in m.

**Dependencies**

To enable the drum brake parameters, select Drum for the **Brake Type** parameter.

**Shoe pin center to force application point distance, drum\_c — Distance**

0.212 (default) | scalar

Shoe pin center to force application point distance, in m.

**Dependencies**

To enable the drum brake parameters, select Drum for the **Brake Type** parameter.

**Drum internal radius, drum\_r — Radius**

0.15 (default) | scalar

Drum internal radius, in m.

**Dependencies**

To enable the drum brake parameters, select Drum for the **Brake Type** parameter.

**Shoe pin to pad start angle, drum\_theta1 – Angle**

0 (default) | scalar

Shoe pin to pad start angle, in deg.

**Dependencies**

To enable the drum brake parameters, select Drum for the **Brake Type** parameter.

**Shoe pin to pad end angle, drum\_theta2 – Angle**

126 (default) | scalar

Shoe pin to pad end angle, in deg.

**Dependencies**

To enable the drum brake parameters, select Drum for the **Brake Type** parameter.

**Mapped****Brake actuator pressure breakpoints, brake\_p\_bpt – Breakpoints**

vector

Brake actuator pressure breakpoints, in bar.

**Dependencies**

To enable the mapped brake parameters, select Mapped for the **Brake Type** parameter.

**Wheel speed breakpoints, brake\_n\_bpt – Breakpoints**

vector

Wheel speed breakpoints, in rpm.

**Dependencies**

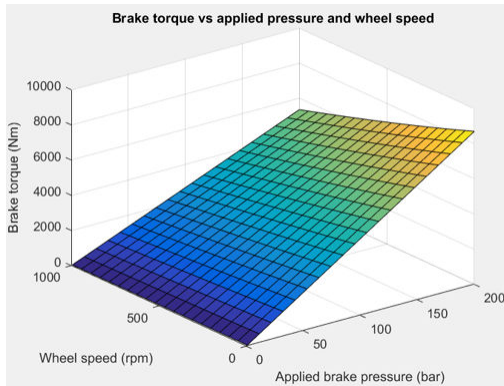
To enable the mapped brake parameters, select Mapped for the **Brake Type** parameter.

**Brake torque map, f\_brake\_t – Lookup table**

array

The lookup table for the brake torque,  $f_{brake}(P, N)$ , is a function of applied brake pressure and wheel speed, where:

- $T$  is brake torque, in N·m.
- $P$  is applied brake pressure, in bar.
- $N$  is wheel speed, in rpm.



#### Dependencies

To enable the mapped brake parameters, select **Mapped** for the **Brake Type** parameter.

#### Vertical

##### Wheel mass, $m$ – Mass

9.46491996974568 (default) | scalar

Wheel mass, in kg. Used in the vertical motion calculations.

#### Dependencies

To enable this parameter, set **Vertical Motion** to **Mapped stiffness and damping**.

##### Initial tire deflection, $z_0$ – Deflection

0 (default) | scalar

Initial axle displacement along wheel-fixed z-axis, in m.

#### Dependencies

To enable this parameter, set **Vertical Motion** to **Mapped stiffness and damping**.

##### Initial wheel vertical velocity (wheel fixed frame), $z_{dot_0}$ – Velocity

0 (default) | scalar

Initial axle velocity along wheel-fixed z-axis, in m.

#### Dependencies

To enable this parameter, set **Vertical Motion** to **Mapped stiffness and damping**.

##### Gravitational acceleration, GRAVITY – Gravity

-9.81 (default) | scalar

Gravitational acceleration, in  $m/s^2$ .

#### Dependencies

To enable this parameter, set **Vertical Motion** to **Mapped stiffness and damping**.

**Mapped Stiffness and Damping****Vertical deflection breakpoints, zFz — Breakpoints**

[0 .01 .1] (default) | vector

Vector of sidewall deflection breakpoints corresponding to the force table, in m.

**Dependencies**

To enable this parameter, set **Vertical Motion** to Mapped stiffness and damping.

**Pressure breakpoints, pFz — Breakpoints**

[10000 1000000] (default) | vector

Vector of pressure data points corresponding to the force table, in Pa.

**Dependencies**

To enable this parameter, set **Vertical Motion** to Mapped stiffness and damping.

**Force due to deflection, Fzz — Force**

[0 1e3 1e4; 0 1e4 1e5] (default) | vector

Force due to sidewall deflection and pressure along wheel-fixed z-axis, in N.

**Dependencies**

To enable this parameter, set **Vertical Motion** to Mapped stiffness and damping.

**Vertical velocity breakpoints, zdotFz — Breakpoints**

[-20 0 20] (default) | scalar

Vector of sidewall velocity breakpoints corresponding to the force due to velocity table, in m.

**Dependencies**

To enable this parameter, set **Vertical Motion** to Mapped stiffness and damping.

**Force due to velocity, Fzzdot — Force**

[500 0 -500; 250 0 -250] (default) | array

Force due to sidewall velocity and pressure along wheel-fixed z-axis, in N.

**Dependencies**

To enable this parameter, set **Vertical Motion** to Mapped stiffness and damping.

**Simulation****Maximum normal force, FZMAX — Force**

10000 (default) | scalar

Maximum normal force, in N. Used with all vertical force calculations.

**Minimum normal force, FZMIN — Force**

0 (default) | scalar

Minimum normal force, in N. Used with all vertical force calculations.

**Maximum pressure, PRESMAX — Pressure**

1003118 (default) | scalar

Maximum pressure, *PRESMAX*, in Pa.**Minimum pressure, PRESMIN — Pressure**

9982 (default) | scalar

Minimum pressure, *PRESMIN*, in Pa.**Max allowable slip ratio (absolute), KPUMAX — Ratio**

1.5 (default) | scalar

Max allowable slip ratio (absolute), *KPUMAX*, dimensionless.**Minimum allowable slip ratio (absolute), KPUMIN — Ratio**

-1.5 (default) | scalar

Minimum allowable slip ratio (absolute), *KPUMIN*, dimensionless.**Max allowable slip angle (absolute), ALPMAX — Angle**

1.5708 (default) | scalar

Max allowable slip angle (absolute), *ALPMAX*, in rad.**Minimum allowable slip angle (absolute), ALPMIN — Angle**

-1.5708 (default) | scalar

Minimum allowable slip angle (absolute), *ALPMIN*, in rad.**Maximum allowable camber angle, CAMMAX — Angle**

0.173 (default) | scalar

Maximum allowable camber angle *CAMMAX*, in rad.**Minimum allowable camber angle, CAMMIN — Angle**

-0.173 (default) | scalar

Minimum allowable camber angle, *CAMMIN*, in rad.**Minimum ambient temperature, TMIN — Tmin**

0 (default) | scalar

Minimum ambient temperature,  $T_{MIN}$ , in K.**Dependencies**To create this parameter, select the **Rolling Resistance** parameter ISO 28580.**Maximum ambient temperature, TMAX — Tmax**

400 (default) | scalar

Maximum ambient temperature,  $T_{MAX}$ , in K.**Dependencies**To create this parameter, select the **Rolling Resistance** parameter ISO 28580.



## References

- [1] Fiala, E. "Seitenkräfte am Rollenden Luftreifen." *VDI Zeitschrift, V.D.I.*. Vol 96, 1954.
- [2] Highway Tire Committee. *Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance*. Standard J2452\_199906. Warrendale, PA: SAE International, June 1999.
- [3] ISO 28580:2018. *Passenger car, truck and bus tyre rolling resistance measurement method — Single point test and correlation of measurement results*. ISO (International Organization for Standardization), 2018.
- [4] Pacejka, H. B. *Tire and Vehicle Dynamics*. 3rd ed. Oxford, UK: SAE and Butterworth-Heinemann, 2012.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

### See Also

Longitudinal Wheel

### Topics

"Coordinate Systems in Vehicle Dynamics Blockset"

### Introduced in R2019a



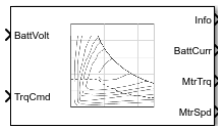
# Propulsion Blocks

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## Mapped Motor

Mapped motor and drive electronics operating in torque-control mode

**Library:** Powertrain Blockset / Propulsion / Electric Motors and Inverters  
Vehicle Dynamics Blockset / Powertrain / Propulsion



### Description

The Mapped Motor block implements a mapped motor and drive electronics operating in torque-control mode. The output torque tracks the torque reference demand and includes a motor-response and drive-response time constant. Use the block for fast system-level simulations when you do not know detailed motor parameters, for example, for motor power and torque tradeoff studies. The block assumes that the speed fluctuations due to mechanical load do not affect the motor torque tracking.

You can specify:

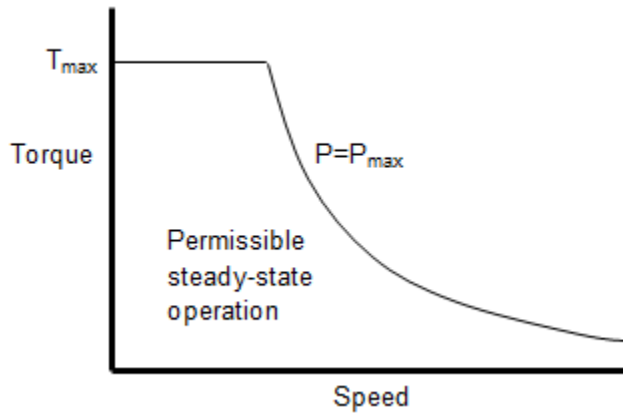
- Port configuration — Input torque or speed.
- Electrical torque range — Torque speed envelope or maximum motor power and torque.
- Electrical loss — Single operating point, measured efficiency, or measured loss. If you have Model-Based Calibration Toolbox™, you can virtually calibrate the measured loss tables.

### Electrical Torque

To specify the range of torque and speed that the block allows, on the **Electrical Torque** tab, for **Parametrized by**, select one of these options.

Setting	Block Implementation
Tabulated torque-speed envelope	Range specified as a set of speed data points and corresponding maximum torque values.
Maximum torque and power	Range specified with maximum torque and maximum power.

For either method, the block implements an envelope similar to this.



### Electrical Losses

To specify the electrical losses, on the **Electrical Losses** tab, for **Parameterize losses by**, select one of these options.

Setting	Block Implementation
Single efficiency measurement	<p>Sum of these terms, measured at a single measurement point:</p> <ul style="list-style-type: none"> <li>• Fixed losses independent of torque and speed, <math>P_0</math>. Use <math>P_0</math> to account for fixed converter losses.</li> <li>• A torque-dependent electrical loss <math>k\tau^2</math>, where <math>k</math> is a constant and <math>\tau</math> is the torque. Represents ohmic losses in the copper windings.</li> <li>• A speed-dependent electrical loss <math>k_w\omega^2</math>, where <math>k_w</math> is a constant and <math>\omega</math> is the speed. Represents iron losses due to eddy currents.</li> </ul>
Tabulated loss data	<p>Loss lookup table that is a function of motor speeds and load torques.</p> <p>If you have Model-Based Calibration Toolbox, click <b>Calibrate Maps</b> to virtually calibrate the 2D lookup tables using measured data.</p>
Tabulated loss data with temperature	<p>Loss lookup table that is a function of motor speeds, load torques, and operating temperature.</p> <p>If you have Model-Based Calibration Toolbox, click <b>Calibrate Maps</b> to virtually calibrate the 3D lookup tables using measured data.</p>

Setting	Block Implementation
Tabulated efficiency data	2D efficiency lookup table that is a function of motor speeds and load torques: <ul style="list-style-type: none"> <li>• Converts the efficiency values you provide into losses and uses the tabulated losses for simulation.</li> <li>• Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero.</li> <li>• Uses linear interpolation to determine losses. Provide tabulated data for low speeds and low torques, as required, to get the desired level of accuracy for lower power conditions.</li> <li>• Does not extrapolate loss values for speed and torque magnitudes that exceed the range of the table.</li> </ul>
Tabulated efficiency data with temperature	3D efficiency lookup table that is a function of motor speeds, load torques, and operating temperature: <ul style="list-style-type: none"> <li>• Converts the efficiency values you provide into losses and uses the tabulated losses for simulation.</li> <li>• Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero.</li> <li>• Uses linear interpolation to determine losses. Provide tabulated data for low speeds and low torques, as required, to get the desired level of accuracy for lower power conditions.</li> <li>• Does not extrapolate loss values for speed, torque, or temperature magnitudes that exceed the range of the table.</li> </ul>

For best practice, use Tabulated loss data instead of Tabulated efficiency data:

- Efficiency becomes ill defined for zero speed or zero torque.
- You can account for fixed losses that are still present for zero speed or torque.

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**Note** Due to system losses, the motor can draw a current when the motor torque is zero.

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### Virtual Calibration

If you have Model-Based Calibration Toolbox, you can virtually calibrate the measured loss lookup tables.

- 1 On the **Electrical Losses** tab, set **Parameterize losses by** to either:
  - Tabulated loss data
  - Tabulated loss data with temperature
- 2 Click **Calibrate Maps**.

The dialog box steps through these tasks.

Task	Description						
Import Loss Data	<p>Import this loss data from a file. For example, open <code>&lt;matlabroot&gt;/toolbox/autoblocks/autoblocksshared/mbctemplates/MappedMotorDataset.xlsx</code>.</p> <p>For more information, see “Using Data” (Model-Based Calibration Toolbox).</p> <table border="1"> <thead> <tr> <th>Parameterize losses by</th> <th>Required Data</th> </tr> </thead> <tbody> <tr> <td>Tabulated loss data</td> <td> <ul style="list-style-type: none"> <li>• Motor speed, rad/s</li> <li>• Motor torque, N·m</li> <li>• Power loss, W</li> </ul> </td> </tr> <tr> <td>Tabulated loss data with temperature</td> <td> <ul style="list-style-type: none"> <li>• Motor speed, rad/s</li> <li>• Motor torque, N·m</li> <li>• Motor temperature, K</li> <li>• Power loss, W</li> </ul> </td> </tr> </tbody> </table> <p>Collect motor data at steady-state operating conditions. Data should cover the motor speed, torque, and temperature operating range.</p> <p>To filter or edit the data, select <b>Edit in Application</b>. The Model-Based Calibration Toolbox Data Editor opens.</p>	Parameterize losses by	Required Data	Tabulated loss data	<ul style="list-style-type: none"> <li>• Motor speed, rad/s</li> <li>• Motor torque, N·m</li> <li>• Power loss, W</li> </ul>	Tabulated loss data with temperature	<ul style="list-style-type: none"> <li>• Motor speed, rad/s</li> <li>• Motor torque, N·m</li> <li>• Motor temperature, K</li> <li>• Power loss, W</li> </ul>
Parameterize losses by	Required Data						
Tabulated loss data	<ul style="list-style-type: none"> <li>• Motor speed, rad/s</li> <li>• Motor torque, N·m</li> <li>• Power loss, W</li> </ul>						
Tabulated loss data with temperature	<ul style="list-style-type: none"> <li>• Motor speed, rad/s</li> <li>• Motor torque, N·m</li> <li>• Motor temperature, K</li> <li>• Power loss, W</li> </ul>						
Generate Response Models	<p>Model-Based Calibration Toolbox uses test plans to fit data to Gaussian process models (GPMs).</p> <p>To assess or adjust the response model fit, select <b>Edit in Application</b>. The Model-Based Calibration Toolbox Model Browser opens. For more information, see “Model Assessment” (Model-Based Calibration Toolbox).</p>						
Generate Calibration	<p>Model-Based Calibration Toolbox calibrates the response models and generates calibrated tables.</p> <p>To assess or adjust the calibration, select <b>Edit in Application</b>. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration Lookup Tables” (Model-Based Calibration Toolbox).</p>						

Task	Description	
Update block parameters	Update these parameters with the calibration.	
	Parameterize losses by	Parameters
	Tabulated loss data	<ul style="list-style-type: none"> <li>• Vector of speeds(<b>w</b>) for tabulated losses, <b>w_eff_bp</b></li> <li>• Vector of torques (<b>T</b>) for tabulated losses, <b>T_eff_bp</b></li> <li>• Corresponding losses, <b>losses_table</b></li> </ul>
Tabulated loss data with temperature	<ul style="list-style-type: none"> <li>• Vector of speeds(<b>w</b>) for tabulated losses, <b>w_eff_bp</b></li> <li>• Vector of torques (<b>T</b>) for tabulated losses, <b>T_eff_bp</b></li> <li>• Vector of temperatures for tabulated losses, <b>Temp_eff_bp</b></li> <li>• Corresponding losses, <b>losses_table_3d</b></li> </ul>	

### Battery Current

The block calculates the battery current using the mechanical power, power loss, and battery voltage. Positive current indicates battery discharge. Negative current indicates battery charge.

$$BattAmp = \frac{MechPwr + PwrLoss}{BattVolt}$$

The equation uses these variables.

- BattVolt* Battery voltage
- MechPwr* Mechanical power
- PwrLoss* Power loss
- BattCurr* Battery current

### Power Accounting

For the power accounting, the block implements these equations.

Bus Signal		Description	Variable	Equations	
PwrIn fo	PwrTrnsfrd	PwrMtr	Mechanical power	$P_{mot}$	$P_{mot} = \omega_m T_e$
	<ul style="list-style-type: none"> <li>• Positive signals indicate power flow into the block.</li> <li>• Negative signals indicate power flow out of the block.</li> </ul>	PwrBus	Electrical power	$P_{bus}$	$P_{bus} = P_{mot} + P_{loss}$
	PwrNotTrnsfrd	PwrLoss	Motor power loss	$P_{loss}$	$P_{stored} = \omega_m \dot{\omega}_m J$
	<ul style="list-style-type: none"> <li>• Negative signals indicate power loss.</li> </ul>				



Bus Signal		Description	Variable	Equations	
	PwrStored <ul style="list-style-type: none"> <li>Positive signals indicate power gain.</li> </ul>	PwrStoredShft	Motor power stored	$P_{str}$	$P_{loss} = - (P_{mot} + P_{loss} - P_{stored})$

The equations use these variables.

$T_e$	Motor output shaft torque
$\omega$	Motor shaft speed
$J$	Motor inertia

## Ports

### Input

#### BattVolt – Battery voltage

scalar

Battery voltage,  $BattVolt$ , in V.

#### TrqCmd – Commanded motor torque

scalar

Commanded motor torque,  $Trq_{cmd}$ , in N·m.

#### Dependencies

To create this input port, for the **Port configuration**, select Torque.

#### MtrSpd – Motor output shaft speed

scalar

Motor shaft speed,  $Mtr_{spd}$ , in rad/s.

#### Dependencies

To create this input port, for the **Port configuration**, select Speed.

### Output

#### Info – Bus signal

bus

The bus signal contains these block calculations.

Signal		Description	Units	
MechPwr		Mechanical power	rad	
PwrLoss		Internal inverter and motor power loss	N·m	
PwrInfo	PwrTrnsfrd	PwrMtr	Mechanical power	W
		PwrBus	Electrical power	W

Signal		Description	Units
	PwrNotTrnsfrd	PwrLoss	Motor power loss
	PwrStored	PwrStored Shft	Motor power stored
			W
			W

**BattCurr – Battery current**

scalar

Battery current draw or demand,  $I_{batt}$ , in A.

**MtrTrq – Motor torque**

scalar

Motor output shaft torque,  $Mtr_{trq}$ , in N·m.

**MtrSpd – Motor shaft speed**

scalar

Motor shaft speed,  $Mtr_{spd}$ , in rad/s.

**Dependencies**

To create this output port, for the **Port configuration**, select Torque.

**Parameters**

**Block Options**

**Port configuration – Select port configuration**

Torque (default) | Speed

This table summarizes the port configurations.

Port Configuration	Creates Ports
Torque	Output MtrSpd
Speed	Input MtrSpd

**Calibrate Maps – Calibrate tables with measured data**

selection

If you have Model-Based Calibration Toolbox, you can virtually calibrate the measured loss lookup tables.

- 1 On the **Electrical Losses** tab, set **Parameterize losses by** to either:
  - Tabulated loss data
  - Tabulated loss data with temperature
- 2 Click **Calibrate Maps**.

The dialog box steps through these tasks.

Task	Description						
Import Loss Data	<p>Import this loss data from a file. For example, open <code>&lt;matlabroot&gt;/toolbox/autoblocks/autoblocksshared/mbctemplates/MappedMotorDataset.xlsx</code>.</p> <p>For more information, see “Using Data” (Model-Based Calibration Toolbox).</p> <table border="1"> <thead> <tr> <th>Parameterize losses by</th> <th>Required Data</th> </tr> </thead> <tbody> <tr> <td>Tabulated loss data</td> <td> <ul style="list-style-type: none"> <li>• Motor speed, rad/s</li> <li>• Motor torque, N·m</li> <li>• Power loss, W</li> </ul> </td> </tr> <tr> <td>Tabulated loss data with temperature</td> <td> <ul style="list-style-type: none"> <li>• Motor speed, rad/s</li> <li>• Motor torque, N·m</li> <li>• Motor temperature, K</li> <li>• Power loss, W</li> </ul> </td> </tr> </tbody> </table> <p>Collect motor data at steady-state operating conditions. Data should cover the motor speed, torque, and temperature operating range.</p> <p>To filter or edit the data, select <b>Edit in Application</b>. The Model-Based Calibration Toolbox Data Editor opens.</p>	Parameterize losses by	Required Data	Tabulated loss data	<ul style="list-style-type: none"> <li>• Motor speed, rad/s</li> <li>• Motor torque, N·m</li> <li>• Power loss, W</li> </ul>	Tabulated loss data with temperature	<ul style="list-style-type: none"> <li>• Motor speed, rad/s</li> <li>• Motor torque, N·m</li> <li>• Motor temperature, K</li> <li>• Power loss, W</li> </ul>
Parameterize losses by	Required Data						
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Tabulated loss data with temperature	<ul style="list-style-type: none"> <li>• Motor speed, rad/s</li> <li>• Motor torque, N·m</li> <li>• Motor temperature, K</li> <li>• Power loss, W</li> </ul>						
Generate Response Models	<p>Model-Based Calibration Toolbox uses test plans to fit data to Gaussian process models (GPMs).</p> <p>To assess or adjust the response model fit, select <b>Edit in Application</b>. The Model-Based Calibration Toolbox Model Browser opens. For more information, see “Model Assessment” (Model-Based Calibration Toolbox).</p>						
Generate Calibration	<p>Model-Based Calibration Toolbox calibrates the response models and generates calibrated tables.</p> <p>To assess or adjust the calibration, select <b>Edit in Application</b>. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration Lookup Tables” (Model-Based Calibration Toolbox).</p>						

Task	Description	
Update block parameters	Update these parameters with the calibration.	
	Parameterize losses by	Parameters
	Tabulated loss data	<ul style="list-style-type: none"> <li>• Vector of speeds(<math>w</math>) for tabulated losses, <math>w\_eff\_bp</math></li> <li>• Vector of torques (<math>T</math>) for tabulated losses, <math>T\_eff\_bp</math></li> <li>• Corresponding losses, <math>losses\_table</math></li> </ul>
Tabulated loss data with temperature	<ul style="list-style-type: none"> <li>• Vector of speeds(<math>w</math>) for tabulated losses, <math>w\_eff\_bp</math></li> <li>• Vector of torques (<math>T</math>) for tabulated losses, <math>T\_eff\_bp</math></li> <li>• Vector of temperatures for tabulated losses, <math>Temp\_eff\_bp</math></li> <li>• Corresponding losses, <math>losses\_table\_3d</math></li> </ul>	

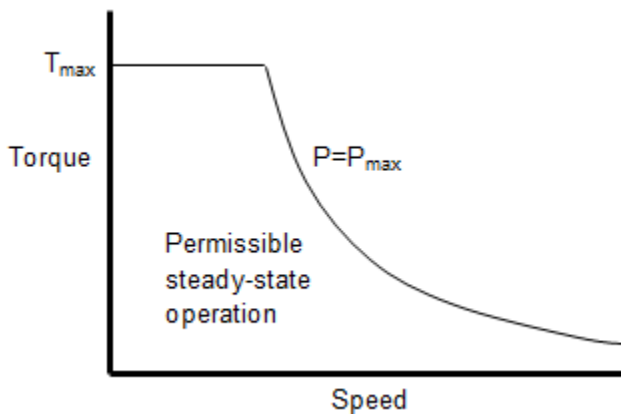
**Electrical Torque**

**Parameterized by – Select type**

Tabulated torque-speed envelope (default) | Maximum torque and power

Setting	Block Implementation
Tabulated torque-speed envelope	Range specified as a set of speed data points and corresponding maximum torque values.
Maximum torque and power	Range specified with maximum torque and maximum power.

For either method, the block implements an envelope similar to this.



**Vector of rotational speeds,  $w\_t$  – Rotational speeds**

[0 375 750 800] (default) | vector

Rotational speeds for permissible steady-state operation, in rad/s. To avoid poor performance due to an infinite slope in the torque-speed curve, specify a vector of rotational speeds that does not contain duplicate consecutive values.

**Dependencies**

To create this parameter, for the **Parameterized by** parameter, select Tabulated torque-speed envelope.

**Vector of maximum torque values,  $T_t$  – Torque**

[0.09 0.08 0.07 0] (default) | vector

Maximum torque values for permissible steady state, in N·m.

**Dependencies**

To create this parameter, for the **Parameterized by** parameter, select Tabulated torque-speed envelope.

**Maximum torque,  $\text{torque\_max}$  – Torque**

.1 (default) | scalar

The maximum permissible motor torque, in N·m.

**Dependencies**

To create this parameter, for the **Parameterized by** parameter, select Maximum torque and power.

**Maximum power,  $\text{power\_max}$  – Power**

30 (default) | scalar

The maximum permissible motor power, in W.

**Dependencies**

To create this parameter, for the **Parameterized by** parameter, select Maximum torque and power.

**Torque control time constant,  $T_c$  – Time constant**

0.02 (default) | scalar

Time constant with which the motor driver tracks a torque demand, in s.

**Electrical Losses****Parameterize losses by – Select type**

Single efficiency measurement (default) | Tabulated loss data | Tabulated efficiency data

Setting	Block Implementation
Single efficiency measurement	<p>Sum of these terms, measured at a single measurement point:</p> <ul style="list-style-type: none"> <li>• Fixed losses independent of torque and speed, <math>P_0</math>. Use <math>P_0</math> to account for fixed converter losses.</li> <li>• A torque-dependent electrical loss <math>k\tau^2</math>, where <math>k</math> is a constant and <math>\tau</math> is the torque. Represents ohmic losses in the copper windings.</li> <li>• A speed-dependent electrical loss <math>k_w\omega^2</math>, where <math>k_w</math> is a constant and <math>\omega</math> is the speed. Represents iron losses due to eddy currents.</li> </ul>
Tabulated loss data	<p>Loss lookup table that is a function of motor speeds and load torques.</p> <p>If you have Model-Based Calibration Toolbox, click <b>Calibrate Maps</b> to virtually calibrate the 2D lookup tables using measured data.</p>
Tabulated loss data with temperature	<p>Loss lookup table that is a function of motor speeds, load torques, and operating temperature.</p> <p>If you have Model-Based Calibration Toolbox, click <b>Calibrate Maps</b> to virtually calibrate the 3D lookup tables using measured data.</p>
Tabulated efficiency data	<p>2D efficiency lookup table that is a function of motor speeds and load torques:</p> <ul style="list-style-type: none"> <li>• Converts the efficiency values you provide into losses and uses the tabulated losses for simulation.</li> <li>• Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero.</li> <li>• Uses linear interpolation to determine losses. Provide tabulated data for low speeds and low torques, as required, to get the desired level of accuracy for lower power conditions.</li> <li>• Does not extrapolate loss values for speed and torque magnitudes that exceed the range of the table.</li> </ul>

Setting	Block Implementation
Tabulated efficiency data with temperature	<p>3D efficiency lookup table that is a function of motor speeds, load torques, and operating temperature:</p> <ul style="list-style-type: none"> <li>• Converts the efficiency values you provide into losses and uses the tabulated losses for simulation.</li> <li>• Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero.</li> <li>• Uses linear interpolation to determine losses. Provide tabulated data for low speeds and low torques, as required, to get the desired level of accuracy for lower power conditions.</li> <li>• Does not extrapolate loss values for speed, torque, or temperature magnitudes that exceed the range of the table.</li> </ul>

For best practice, use **Tabulated loss data** instead of **Tabulated efficiency data**:

- Efficiency becomes ill defined for zero speed or zero torque.
- You can account for fixed losses that are still present for zero speed or torque.

---

**Note** Due to system losses, the motor can draw a current when the motor torque is zero.

---

### Motor and drive overall efficiency, **eff** – Efficiency

100 (default) | scalar

The block defines overall efficiency as:

$$\eta = 100 \frac{\tau_0 \omega_0}{\tau_0 \omega_0 + P_0 + k\tau_0^2 + k_w \omega_0^2}$$

The equation uses these variables.

$\tau_0$	Torque at which efficiency is measured
$\omega_0$	Speed at which efficiency is measured
$P_0$	Fixed losses independent of torque or speed
$k\tau_0^2$	Torque-dependent electrical losses
$k_w \omega_0^2$	Speed-dependent iron losses

At initialization, the block solves the efficiency equation for  $k$ . The block neglects losses associated with the rotor damping.

#### Dependencies

To create this parameter, for the **Parameterize losses by** parameter, select **Single efficiency measurement**.

### Speed at which efficiency is measured, **w\_eff** – Speed

375 (default) | scalar

Speed at which efficiency is measured, in rad/s.

**Dependencies**

To create this parameter, for the **Parameterize losses by** parameter, select **Single efficiency measurement**.

**Torque at which efficiency is measured,  $T_{\text{eff}}$  – Torque**

0.08 (default) | scalar

Torque at which efficiency is measured, in N·m.

**Dependencies**

To create this parameter, for the **Parameterize losses by** parameter, select **Single efficiency measurement**.

**Iron losses,  $P_{\text{iron}}$  – Power**

0 (default) | scalar

Iron losses at the speed and torque at which efficiency is defined, in W.

**Dependencies**

To create this parameter, for the **Parameterize losses by** parameter, select **Single efficiency measurement**.

**Fixed losses independent of torque and speed,  $P_{\text{base}}$  – Power**

0 (default) | scalar

Fixed electrical loss associated with the driver when the motor current and torque are zero, in W.

**Dependencies**

To create this parameter, for the **Parameterize losses by** parameter, select **Single efficiency measurement**.

**Vector of speeds ( $w$ ) for tabulated losses,  $w_{\text{eff\_bp}}$  – Breakpoints**

[-8000 -4000 0 4000 8000] (default) | 1-by-M vector

Speed breakpoints for lookup table when calculating losses, in rad/s. Array dimensions are 1 by the number of speed breakpoints, M.

**Dependencies**

To create this parameter, for the **Parameterize losses by** parameter, select one of these:

- Tabulated loss data
- Tabulated loss data with temperature
- Tabulated efficiency data
- Tabulated efficiency data with temperature

**Vector of torques ( $T$ ) for tabulated losses,  $T_{\text{eff\_bp}}$  – Breakpoints**

[0 0.03 0.06 0.09] (default) | 1-by-N vector

Torque breakpoints for lookup table when calculating losses, in N·m. Array dimensions are 1 by the number of torque breakpoints, N.



**Dependencies**

To create this parameter, for the **Parameterize losses by** parameter, select one of these:

- Tabulated loss data
- Tabulated loss data with temperature
- Tabulated efficiency data
- Tabulated efficiency data with temperature

**Vector of temperatures for tabulated losses, Temp\_eff\_bp – Breakpoints**

[233.15 293.15 373.15] (default) | 1-by-L vector

Temperature breakpoints for lookup table when calculating losses, in K. Array dimensions are 1 by the number of temperature breakpoints, L.

**Dependencies**

To create this parameter, for the **Parameterize losses by** parameter, select one of these:

- Tabulated loss data with temperature
- Tabulated efficiency data with temperature

**Corresponding losses, losses\_table – 2D lookup table**

M-by-N matrix

Array of values for electrical losses as a function of speed and torque, in W. Each value specifies the losses for a specific combination of speed and torque. The array dimensions must match the speed, M, and torque, N, breakpoint vector dimensions.

**Dependencies**

To create this parameter, for the **Parameterize losses by** parameter, select Tabulated loss data.

**Corresponding losses, losses\_table\_3d – 3D lookup table**

M-by-N-by-L array

Array of values for electrical losses as a function of speed, torque, and temperature, in W. Each value specifies the losses for a specific combination of speed, torque, and temperature. The array dimensions must match the speed, M, torque, N, and temperature, L, breakpoint vector dimensions.

**Dependencies**

To create this parameter, for the **Parameterize losses by** parameter, select Tabulated loss data with temperature.

**Corresponding efficiency, efficiency\_table – 2D lookup table**

M-by-N matrix

Array of efficiency as a function of speed and torque, in %. Each value specifies the losses for a specific combination of speed and torque. The array dimensions must match the speed, M, and torque, N, breakpoint vector dimensions.

The block ignores efficiency values for zero speed or zero torque. Losses are zero when either torque or speed is zero. The block uses linear interpolation.

To get the desired level of accuracy for lower power conditions, you can provide tabulated data for low speeds and low torques.

**Dependencies**

To create this parameter, for the **Parameterize losses by** parameter, select Tabulated efficiency data.

**Corresponding efficiency, efficiency\_table\_3d – 3D lookup table**

M-by-N-by-L array

Array of efficiency as a function of speed and torque, in %. Each value specifies the losses for a specific combination of speed and torque. The array dimensions must match the speed, M, torque, N, and temperature, L, breakpoint vector dimensions.

The block ignores efficiency values for zero speed or zero torque. Losses are zero when either torque or speed is zero. The block uses linear interpolation.

To get the desired level of accuracy for lower power conditions, you can provide tabulated data for low speeds and low torques.

**Dependencies**

To create this parameter, for the **Parameterize losses by** parameter, select Tabulated efficiency data.

**Mechanical****Rotor inertia, J – Inertia**

5e-6 (default) | scalar

Rotor resistance to change in motor motion, in kg\*m<sup>2</sup>. The value can be zero.

**Dependencies**

To create this parameter, for the **Port configuration** parameter, select Torque.

**Rotor damping, b – Damping**

1e-5 (default) | scalar

Rotor damping, in N·m/(rad/s). The value can be zero.

**Dependencies**

To create this parameter, for the **Port configuration** parameter, select Torque.

**Initial rotor speed, omega\_o – Speed**

0 (default) | scalar

Rotor speed at the start of the simulation, in rad/s.

**Dependencies**

To create this parameter, for the **Port configuration** parameter, select Torque.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

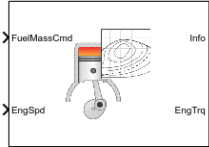
Open Differential

### **Introduced in R2017a**

## Mapped CI Engine

Compression-ignition engine model using lookup tables

**Library:** Powertrain Blockset / Propulsion / Combustion Engines  
Vehicle Dynamics Blockset / Powertrain / Propulsion



### Description

The Mapped CI Engine block implements a mapped compression-ignition (CI) engine model using power, air mass flow, fuel flow, exhaust temperature, efficiency, and emission performance lookup tables. You can use the block for:

- Hardware-in-the-loop (HIL) engine control design
- Vehicle-level fuel economy and performance simulations

The lookup tables, developed with the Model-Based Calibration Toolbox, are functions of injected fuel mass,  $F$ , engine torque,  $T$ , engine speed,  $N$ , and engine temperature,  $Temp_{Eng}$ .

Input Command Setting	Input Engine Temperature Parameter Setting	Lookup Tables
Fuel mass	off	$f(F,N)$
	on	$f(F,N,Temp_{Eng})$
Torque	off	$f(T,N)$
	on	$f(T,N,Temp_{Eng})$

The block enables you to specify lookup tables for these engine characteristics:

- Power
- Air
- Fuel
- Temperature
- Efficiency
- Hydrocarbon (HC) emissions
- Carbon monoxide (CO) emissions
- Nitric oxide and nitrogen dioxide (NOx) emissions
- Carbon dioxide (CO<sub>2</sub>) emissions
- Particulate matter (PM) emissions

To bound the Mapped CI Engine block output, the block does not extrapolate the lookup table data.

## Virtual Calibration

If you have Model-Based Calibration Toolbox, click **Calibrate Maps** to virtually calibrate the 2D lookup tables using measured data. The dialog box steps through these tasks.

Task	Description									
Import firing data	<p>Import this loss data from a file. For example, open <code>&lt;matlabroot&gt;/toolbox/autoblks/autodemos/projectsrc/CIDynamometer/CalMappedEng/CiEngineData.xlsx</code>.</p> <p>For more information, see “Using Data” (Model-Based Calibration Toolbox).</p> <table border="1"> <thead> <tr> <th>Input command</th> <th>Required Data</th> <th>Optional Data</th> </tr> </thead> <tbody> <tr> <td>Fuel mass</td> <td> <ul style="list-style-type: none"> <li>Engine speed, rpm</li> <li>Commanded fuel mass per injection, mg</li> <li>Engine torque, N·m</li> </ul> </td> <td> <ul style="list-style-type: none"> <li>Air mass flow rate, kg/s</li> <li>Brake specific fuel consumption, g/(kW·h)</li> <li>CO<sub>2</sub> mass flow rate, kg/s</li> </ul> </td> </tr> <tr> <td>Torque</td> <td> <ul style="list-style-type: none"> <li>Engine speed, rpm</li> <li>Engine torque, N·m</li> </ul> </td> <td> <ul style="list-style-type: none"> <li>CO mass flow rate, kg/s</li> <li>Exhaust temperature, K</li> <li>Fuel mass flow rate, kg/s</li> <li>HC mass flow rate, kg/s</li> <li>NO<sub>x</sub> mass flow rate, kg/s</li> <li>Particulate matter mass flow rate, kg/s</li> </ul> </td> </tr> </tbody> </table> <p>Collect firing data at steady-state operating conditions when injectors deliver the fuel. Data should cover the engine speed and torque operating range. Model-Based Calibration Toolbox uses the firing data boundary as the maximum torque.</p> <p>To filter or edit the data, select <b>Edit in Application</b>. The Model-Based Calibration Toolbox Data Editor opens.</p>	Input command	Required Data	Optional Data	Fuel mass	<ul style="list-style-type: none"> <li>Engine speed, rpm</li> <li>Commanded fuel mass per injection, mg</li> <li>Engine torque, N·m</li> </ul>	<ul style="list-style-type: none"> <li>Air mass flow rate, kg/s</li> <li>Brake specific fuel consumption, g/(kW·h)</li> <li>CO<sub>2</sub> mass flow rate, kg/s</li> </ul>	Torque	<ul style="list-style-type: none"> <li>Engine speed, rpm</li> <li>Engine torque, N·m</li> </ul>	<ul style="list-style-type: none"> <li>CO mass flow rate, kg/s</li> <li>Exhaust temperature, K</li> <li>Fuel mass flow rate, kg/s</li> <li>HC mass flow rate, kg/s</li> <li>NO<sub>x</sub> mass flow rate, kg/s</li> <li>Particulate matter mass flow rate, kg/s</li> </ul>
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Import non-firing data	<p>Import this non-firing data from a file. For example, open <code>&lt;matlabroot&gt;/toolbox/autoblks/autodemos/projectsrc/CIDynamometer/CalMappedEng/CiEngineData.xlsx</code>.</p> <ul style="list-style-type: none"> <li>Engine speed, rpm</li> <li>Engine torque, N·m</li> </ul> <p>Collect non-firing (motoring) data at steady-state operating conditions when fuel is cut off. All non-firing torque points must be less than zero. Non-firing data is a function of engine speed only.</p>									

Task	Description
Generate response models	For both firing and non-firing data, the Model-Based Calibration Toolbox uses test plans to fit data to Gaussian process models (GPMs).  To assess or adjust the response model fit, select <b>Edit in Application</b> . The Model-Based Calibration Toolbox Model Browser opens. For more information, see “Model Assessment” (Model-Based Calibration Toolbox).
Generate calibration	Model-Based Calibration Toolbox calibrates the firing and non-firing response models and generates calibrated tables.  To assess or adjust the calibration, select <b>Edit in Application</b> . The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration Lookup Tables” (Model-Based Calibration Toolbox).
Update block parameters	Update the block lookup table and breakpoint parameters with the calibration.

### Cylinder Air Mass

The block calculates the normalized cylinder air mass using these equations.

$$M_{Nom} = \frac{P_{std}V_d}{N_{cyl}R_{air}T_{std}}$$

$$L = \frac{\left(\frac{60s}{min}\right)Cps \cdot \dot{m}_{air}}{\left(\frac{1000g}{Kg}\right)N_{cyl} \cdot N \cdot M_{Nom}}$$

The equations use these variables.

$L$	Normalized cylinder air mass
$M_{Nom}$	Nominal engine cylinder air mass at standard temperature and pressure, piston at bottom dead center (BDC) maximum volume, in kg
$Cps$	Crankshaft revolutions per power stroke, rev/stroke
$P_{std}$	Standard pressure
$T_{std}$	Standard temperature
$R_{air}$	Ideal gas constant for air and burned gas mixture
$V_d$	Displaced volume
$N_{cyl}$	Number of engine cylinders
$N$	Engine speed
$\dot{m}_{intk}$	Engine air mass flow, in g/s

### Turbocharger Lag

To model turbocharger lag, select **Include turbocharger lag effect**. Turbocharger lag limits the maximum fuel mass per injection. To model the maximum fuel mass per injection, the block uses a first-order system with a time constant. At low torque, the engine does not require boost to provide sufficient air flow. When the requested fuel mass requires boost, the block uses a time constant to determine the maximum fuel mass per injection. The block uses these equations for the specified **Input command** setting.

Calculation	Input command Parameter Setting	
	Fuel mass	Torque
Dynamic torque	$\frac{dF_{max}}{dt} = \frac{1}{\tau_{eng}}(F_{cmd} - F_{max})$	$\frac{dT_{max}}{dt} = \frac{1}{\tau_{eng}}(T_{cmd} - T_{max})$
Fuel mass per injection or torque - with turbocharger lag	$F = \begin{cases} F_{cmd} & \text{when } F_{cmd} < F_{max} \\ F_{max} & \text{when } F_{cmd} \geq F_{max} \end{cases}$	$T_{target} = \begin{cases} T_{cmd} & \text{when } T_{cmd} < T_{max} \\ T_{max} & \text{when } T_{cmd} \geq T_{max} \end{cases}$
Fuel mass per injection or torque- without turbocharger lag	$F = F_{cmd} = F_{max}$	$T_{target} = T_{cmd} = T_{max}$
Boost time constant	$\tau_{bst} = \begin{cases} \tau_{bst, rising} & \text{when } F_{cmd} > F_{max} \\ \tau_{bst, falling} & \text{when } F_{cmd} \leq F_{max} \end{cases}$	$\tau_{bst} = \begin{cases} \tau_{bst, rising} & \text{when } T_{cmd} > T_{max} \\ \tau_{bst, falling} & \text{when } T_{cmd} \leq T_{max} \end{cases}$
Final time constant	$\tau_{eng} = \begin{cases} \tau_{nat} & \text{when } T_{brake} < f_{bst}(N) \\ \tau_{bst} & \text{when } T_{brake} \geq f_{bst}(N) \end{cases}$	

The equations use these variables.

$T_{brake}$	Brake torque
$F$	Fuel mass per injection
$F_{cmd}, F_{max}$	Commanded and maximum fuel mass per injection, respectively
$T_{target}, T_{cmd}, T_{max}$	Target, commanded, and maximum torque, respectively
$\tau_{bst}$	Boost time constant
$\tau_{bst, rising}, \tau_{bst, falling}$	Boost rising and falling time constant, respectively
$\tau_{eng}$	Final time constant
$\tau_{nat}$	Time constant below the boost torque speed line
$f_{bst}(N)$	Boost torque/speed line
$N$	Engine speed

### Fuel Flow

To calculate the fuel economy for high-fidelity models, the block uses the volumetric fuel flow.

$$Q_{fuel} = \frac{\dot{m}_{fuel}}{\left(\frac{1000kg}{m^3}\right)Sg_{fuel}}$$

The equation uses these variables.

$\dot{m}_{fuel}$	Fuel mass flow
$Sg_{fuel}$	Specific gravity of fuel

$Q_{fuel}$  Volumetric fuel flow

### Power Accounting

For the power accounting, the block implements these equations.

Bus Signal		Description	Equations
PwrInflow	PwrTrnsfrd — Power transferred between blocks <ul style="list-style-type: none"> <li>Positive signals indicate flow into block</li> <li>Negative signals indicate flow out of block</li> </ul>	PwrCrkshft	Crankshaft power $-\tau_{eng}\omega$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred <ul style="list-style-type: none"> <li>Positive signals indicate an input</li> <li>Negative signals indicate a loss</li> </ul>	PwrFuel	Fuel input power $\dot{m}_{fuel}LHV$
		PwrLoss	Power loss $\tau_{eng}\omega - \dot{m}_{fuel}LHV$
PwrStored — Stored energy rate of change <ul style="list-style-type: none"> <li>Positive signals indicate an increase</li> <li>Negative signals indicate a decrease</li> </ul>		<i>Not used</i>	

The equations use these variables.

$LHV$  Fuel lower heating value  
 $\omega$  Engine speed, rad/s  
 $\dot{m}_{fuel}$  Fuel mass flow  
 $\tau_{eng}$  Fuel mass per injection time constant

### Ports

#### Input

##### FuelMassCmd — Injected fuel mass command

scalar

Injected fuel mass command,  $F$ , in mg/inj.

##### Dependencies

To enable this port, for **Input command**, select Fuel mass.

##### TrqCmd — Torque command

scalar

Torque command,  $T$ , in N·m.

##### Dependencies

To enable this port, for **Input command**, select Torque.



**EngSpd – Engine speed**

scalar

Engine speed,  $N$ , in rpm.**EngTemp – Engine temperature**

scalar

Engine temperature,  $Temp_{Eng}$ , in K.**Dependencies**To enable this port, select **Input engine temperature**.**Output****Info – Bus signal**

bus

Bus signal containing these block calculations.

Signal	Description	Units
IntkGasMassFlw	Engine air mass flow output	kg/s
NrmlzdAirChrg	Normalized engine cylinder air mass	N/A
Afr	Air-fuel ratio (AFR)	N/A
FuelMassFlw	Engine fuel flow output	kg/s
FuelVolFlw	Volumetric fuel flow	m <sup>3</sup> /s
ExhManGasTemp	Engine exhaust gas temperature	K
EngTrq	Engine torque output	N·m
EngSpd	Engine speed	rpm
CrkAng	Engine crankshaft absolute angle $\int_0^{(360)Cps} EngSpd \frac{180}{30} d\theta$ where $Cps$ is crankshaft revolutions per power stroke.	degrees crank angle
Bsfc	Engine brake-specific fuel consumption (BSFC)	g/kWh
EoHC	Engine out hydrocarbon emission mass flow	kg/s
EoCO	Engine out carbon monoxide emission mass flow rate	kg/s
EoNOx	Engine out nitric oxide and nitrogen dioxide emissions mass flow	kg/s
EoCO2	Engine out carbon dioxide emission mass flow	kg/s

Signal			Description	Units
EoPM			Engine out particulate matter emission mass flow	kg/s
PwrInfo	PwrTrnsfrd	PwrCrkshft	Crankshaft power	W
	PwrNotTrnsfrd	PwrFuel	Fuel input power	W
		PwrLoss	Power loss	W
	PwrStored		<i>Not used</i>	

**EngTrq – Power**

scalar

Engine power,  $T_{brake}$ , in N·m.

**Parameters**

**Block Options**

**Input command – Table functions**

Fuel mass (default) | Torque

The lookup tables, developed with the Model-Based Calibration Toolbox, are functions of injected fuel mass,  $F$ , engine torque,  $T$ , engine speed,  $N$ , and engine temperature,  $Temp_{Eng}$ .

Input Command Setting	Input Engine Temperature Parameter Setting	Lookup Tables
Fuel mass	off	$f(F,N)$
	on	$f(F,N,Temp_{Eng})$
Torque	off	$f(T,N)$
	on	$f(T,N,Temp_{Eng})$

**Dependencies**

- Selecting Fuel mass enables **Breakpoints for commanded fuel mass input, f\_tbrake\_f\_bpt.**
- Selecting Torque enables **Breakpoints for commanded torque input, f\_tbrake\_t\_bpt.**
- Selecting **Input engine temperature** enables **Breakpoints for temperature input, f\_tbrake\_engtmp\_bpt.**

**Include turbocharger lag effect – Increase time constant**

off (default)

To model turbocharger lag, select **Include turbocharger lag effect**. Turbocharger lag limits the maximum fuel mass per injection. To model the maximum fuel mass per injection, the block uses a first-order system with a time constant. At low torque, the engine does not require boost to provide sufficient air flow. When the requested fuel mass requires boost, the block uses a time constant to determine the maximum fuel mass per injection. The block uses these equations for the specified **Input command** setting.

Calculation	Input command Parameter Setting	
	Fuel mass	Torque
Dynamic torque	$\frac{dF_{max}}{dt} = \frac{1}{\tau_{eng}}(F_{cmd} - F_{max})$	$\frac{dT_{max}}{dt} = \frac{1}{\tau_{eng}}(T_{cmd} - T_{max})$
Fuel mass per injection or torque - with turbocharger lag	$F = \begin{cases} F_{cmd} & \text{when } F_{cmd} < F_{max} \\ F_{max} & \text{when } F_{cmd} \geq F_{max} \end{cases}$	$T_{target} = \begin{cases} T_{cmd} & \text{when } T_{cmd} < T_{max} \\ T_{max} & \text{when } T_{cmd} \geq T_{max} \end{cases}$
Fuel mass per injection or torque- without turbocharger lag	$F = F_{cmd} = F_{max}$	$T_{target} = T_{cmd} = T_{max}$
Boost time constant	$\tau_{bst} = \begin{cases} \tau_{bst, rising} & \text{when } F_{cmd} > F_{max} \\ \tau_{bst, falling} & \text{when } F_{cmd} \leq F_{max} \end{cases}$	$\tau_{bst} = \begin{cases} \tau_{bst, rising} & \text{when } T_{cmd} > T_{max} \\ \tau_{bst, falling} & \text{when } T_{cmd} \leq T_{max} \end{cases}$
Final time constant	$\tau_{eng} = \begin{cases} \tau_{nat} & \text{when } T_{brake} < f_{bst}(N) \\ \tau_{bst} & \text{when } T_{brake} \geq f_{bst}(N) \end{cases}$	

The equations use these variables.

$T_{brake}$	Brake torque
$F$	Fuel mass per injection
$F_{cmd}, F_{max}$	Commanded and maximum fuel mass per injection, respectively
$T_{target}, T_{cmd}, T_{max}$	Target, commanded, and maximum torque, respectively
$\tau_{bst}$	Boost time constant
$\tau_{bst, rising}, \tau_{bst, falling}$	Boost rising and falling time constant, respectively
$\tau_{eng}$	Final time constant
$\tau_{nat}$	Time constant below the boost torque speed line
$f_{bst}(N)$	Boost torque/speed line
$N$	Engine speed

### Dependencies

Selecting **Include turbocharger lag effect** enables these parameters:

- **Boost torque line, f\_tbrake\_bst**
- **Time constant below boost line, tau\_nat**
- **Rising maximum fuel mass boost time constant, tau\_bst\_rising**
- **Falling maximum fuel mass boost time constant, tau\_bst\_falling**

### Input engine temperature – Create input port

off (default) | on

Select this to create the EngTemp input port.

The lookup tables, developed with the Model-Based Calibration Toolbox, are functions of injected fuel mass,  $F$ , engine torque,  $T$ , engine speed,  $N$ , and engine temperature,  $Temp_{Eng}$ .

Input Command Setting	Input Engine Temperature Parameter Setting	Lookup Tables
Fuel mass	off	$f(F,N)$
	on	$f(F,N,Temp_{Eng})$
Torque	off	$f(T,N)$
	on	$f(T,N,Temp_{Eng})$

**Configuration**

**Calibrate Maps – Calibrate tables with measured data selection**

If you have Model-Based Calibration Toolbox, click **Calibrate Maps** to virtually calibrate the 2D lookup tables using measured data. The dialog box steps through these tasks.

Task	Description									
Import firing data	<p>Import this loss data from a file. For example, open <code>&lt;matlabroot&gt;/toolbox/autoblks/autodemos/projectsrc/CIDynamometer/CalMappedEng/CiEngineData.xlsx</code>.</p> <p>For more information, see “Using Data” (Model-Based Calibration Toolbox).</p>									
	<table border="1"> <thead> <tr> <th>Input command</th> <th>Required Data</th> <th>Optional Data</th> </tr> </thead> <tbody> <tr> <td>Fuel mass</td> <td> <ul style="list-style-type: none"> <li>Engine speed, rpm</li> <li>Commanded fuel mass per injection, mg</li> <li>Engine torque, N·m</li> </ul> </td> <td> <ul style="list-style-type: none"> <li>Air mass flow rate, kg/s</li> <li>Brake specific fuel consumption, g/(kW·h)</li> <li>CO2 mass flow rate, kg/s</li> </ul> </td> </tr> <tr> <td>Torque</td> <td> <ul style="list-style-type: none"> <li>Engine speed, rpm</li> <li>Engine torque, N·m</li> </ul> </td> <td> <ul style="list-style-type: none"> <li>CO mass flow rate, kg/s</li> <li>Exhaust temperature, K</li> <li>Fuel mass flow rate, kg/s</li> <li>HC mass flow rate, kg/s</li> <li>NOx mass flow rate, kg/s</li> <li>Particulate matter mass flow rate, kg/s</li> </ul> </td> </tr> </tbody> </table>	Input command	Required Data	Optional Data	Fuel mass	<ul style="list-style-type: none"> <li>Engine speed, rpm</li> <li>Commanded fuel mass per injection, mg</li> <li>Engine torque, N·m</li> </ul>	<ul style="list-style-type: none"> <li>Air mass flow rate, kg/s</li> <li>Brake specific fuel consumption, g/(kW·h)</li> <li>CO2 mass flow rate, kg/s</li> </ul>	Torque	<ul style="list-style-type: none"> <li>Engine speed, rpm</li> <li>Engine torque, N·m</li> </ul>	<ul style="list-style-type: none"> <li>CO mass flow rate, kg/s</li> <li>Exhaust temperature, K</li> <li>Fuel mass flow rate, kg/s</li> <li>HC mass flow rate, kg/s</li> <li>NOx mass flow rate, kg/s</li> <li>Particulate matter mass flow rate, kg/s</li> </ul>
	Input command	Required Data	Optional Data							
Fuel mass	<ul style="list-style-type: none"> <li>Engine speed, rpm</li> <li>Commanded fuel mass per injection, mg</li> <li>Engine torque, N·m</li> </ul>	<ul style="list-style-type: none"> <li>Air mass flow rate, kg/s</li> <li>Brake specific fuel consumption, g/(kW·h)</li> <li>CO2 mass flow rate, kg/s</li> </ul>								
Torque	<ul style="list-style-type: none"> <li>Engine speed, rpm</li> <li>Engine torque, N·m</li> </ul>	<ul style="list-style-type: none"> <li>CO mass flow rate, kg/s</li> <li>Exhaust temperature, K</li> <li>Fuel mass flow rate, kg/s</li> <li>HC mass flow rate, kg/s</li> <li>NOx mass flow rate, kg/s</li> <li>Particulate matter mass flow rate, kg/s</li> </ul>								
<p>Collect firing data at steady-state operating conditions when injectors deliver the fuel. Data should cover the engine speed and torque operating range. Model-Based Calibration Toolbox uses the firing data boundary as the maximum torque.</p> <p>To filter or edit the data, select <b>Edit in Application</b>. The Model-Based Calibration Toolbox Data Editor opens.</p>										

Task	Description
Import non-firing data	<p>Import this non-firing data from a file. For example, open <code>&lt;matlabroot&gt;/toolbox/autoblks/autodemos/projectsrc/CIDynamometer/CalMappedEng/CiEngineData.xlsx</code>.</p> <ul style="list-style-type: none"> <li>• Engine speed, rpm</li> <li>• Engine torque, N·m</li> </ul> <p>Collect non-firing (motoring) data at steady-state operating conditions when fuel is cut off. All non-firing torque points must be less than zero. Non-firing data is a function of engine speed only.</p>
Generate response models	<p>For both firing and non-firing data, the Model-Based Calibration Toolbox uses test plans to fit data to Gaussian process models (GPMs).</p> <p>To assess or adjust the response model fit, select <b>Edit in Application</b>. The Model-Based Calibration Toolbox Model Browser opens. For more information, see “Model Assessment” (Model-Based Calibration Toolbox).</p>
Generate calibration	<p>Model-Based Calibration Toolbox calibrates the firing and non-firing response models and generates calibrated tables.</p> <p>To assess or adjust the calibration, select <b>Edit in Application</b>. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration Lookup Tables” (Model-Based Calibration Toolbox).</p>
Update block parameters	Update the block lookup table and breakpoint parameters with the calibration.

### Dependencies

To enable this parameter, clear **Input engine temperature**.

### Breakpoints for commanded fuel mass input, `f_tbrake_f_bpt` — Breakpoints

1-by-M vector

Breakpoints, in mg/inj.

### Dependencies

Setting **Input command** to Fuel mass enables this parameter.

### Breakpoints for commanded torque input, `f_tbrake_t_bpt` — Breakpoints

1-by-M vector

Breakpoints, in N·m.

### Dependencies

Setting **Input command** to Torque enables this parameter.

### Breakpoints for engine speed input, `f_tbrake_n_bpt` — Breakpoints

1-by-N vector

Breakpoints, in rpm.

**Breakpoints for temperature input, f\_tbrake\_engtmp\_bpt – Breakpoints**  
[233.15 273.15 373.15] (default) | 1-by-L vector

Breakpoints, in K.

**Dependencies**

To enable this parameter, select **Input engine temperature**.

**Number of cylinders, NCyl – Number**  
4 (default) | scalar

Number of cylinders.

**Crank revolutions per power stroke, Cps – Crank revolutions**  
2 (default) | scalar

Crank revolutions per power stroke.

**Total displaced volume, Vd – Volume**  
0.0015 (default) | scalar

Volume displaced by engine, in  $m^3$ .

**Fuel lower heating value, Lhv – Heating value**  
45e6 (default) | scalar

Fuel lower heating value,  $LHV$ , in J/kg.

**Fuel specific gravity, Sg – Specific gravity**  
0.832 (default) | scalar

Specific gravity of fuel,  $Sg_{fuel}$ , dimensionless.

**Ideal gas constant air, Rair – Constant**  
287 (default) | scalar

Ideal gas constant of air and residual gas entering the engine intake port, in J/(kg·K).

**Air standard pressure, Pstd – Pressure**  
101325 (default) | scalar

Standard air pressure, in Pa.

**Air standard temperature, Tstd – Temperature**  
293.15 (default) | scalar

Standard air temperature, in K.

**Boost torque line, f\_tbrake\_bst – Boost lag**  
[90, 95, 95, 95, 96, 100, 104, 104, 104, 100, 95, 85, 75, 67, 60, 55] (default) | 1-by-M vector

Boost torque line,  $f_{bst}(N)$ , in N·m.

**Dependencies**

To enable this parameter, select **Include turbocharger lag effect**.

**Time constant below boost line – Time constant below**

0.1 (default) | scalar

Time constant below boost line,  $\tau_{nat}$ , in s.**Dependencies**To enable this parameter, select **Include turbocharger lag effect**.**Rising maximum fuel mass boost time constant, tau\_bst\_rising – Rising time constant**

1.0 (default) | scalar

Rising maximum fuel mass boost time constant,  $\tau_{bst,rising}$ , in s.**Dependencies**To enable this parameter, select **Include turbocharger lag effect**.**Falling maximum fuel mass boost time constant, tau\_bst\_falling – Falling time constant**

0.7 (default) | scalar

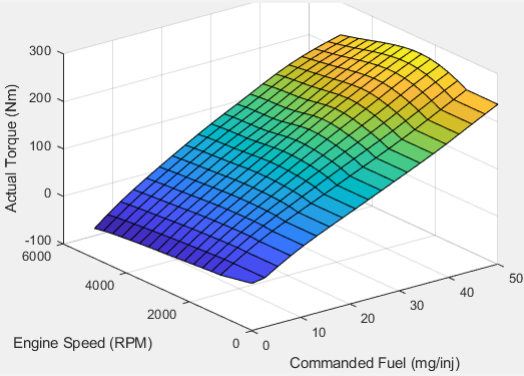
Falling maximum fuel mass boost time constant,  $\tau_{bst,falling}$ , in s.**Dependencies**To enable this parameter, select **Include turbocharger lag effect**.**Turbocharger time constant blend fuel mass fraction, f\_blend\_frac – Time constant**

0.01 (default) | scalar

Turbocharger time constant blend fuel mass fraction, in s.

**Dependencies**To enable this parameter, select **Include turbocharger lag effect**.**Power****Brake torque map, f\_tbrake – 2D lookup table**

M-by-N matrix

Input Command Setting	Description
Fuel mass	<p>The engine brake torque lookup table is a function of commanded fuel mass and engine speed, <math>T_{brake} = f(F, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>T_{brake}</math> is engine torque, in N·m.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul> 
Torque	<p>The engine brake torque lookup table is a function of target torque and engine speed, <math>T_{brake} = f(T_{target}, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>T_{brake}</math> is engine torque, in N·m.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul>

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**Plot brake torque map – Plot table button**

Click to plot table.

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**Brake torque map, f\_tbrake\_3d – 3D lookup table**  
M-by-N-by-L array

Input Command Setting	Description
Fuel mass	<p>The engine brake torque lookup table is a function of commanded fuel mass and engine speed, <math>T_{brake} = f(F, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>T_{brake}</math> is engine torque, in N·m.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>



Input Command Setting	Description
Torque	<p>The engine brake torque lookup table is a function of target torque and engine speed, <math>T_{brake} = f(T_{target}, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>T_{brake}</math> is engine torque, in N·m.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>

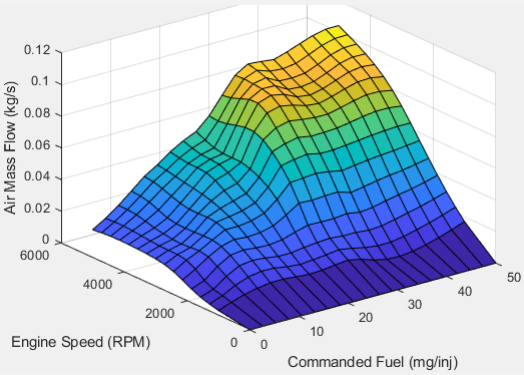
#### Dependencies

To enable this parameter, select **Input engine temperature**.

#### Air

#### Air mass flow map, $f_{air}$ – 2D lookup table

M-by-N matrix

Input Command Setting	Description
Fuel mass	<p>The air mass flow lookup table is a function of commanded fuel mass and engine speed, <math>\dot{m}_{intk} = f(F_{max}, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>\dot{m}_{intk}</math> is engine air mass flow, in kg/s.</li> <li>• <math>F_{max}</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul> 
Torque	<p>The air mass flow lookup table is a function of maximum torque and engine speed, <math>\dot{m}_{intk} = f(T_{max}, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>\dot{m}_{intk}</math> is engine air mass flow, in kg/s.</li> <li>• <math>T_{max}</math> is maximum torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul>

#### Dependencies

To enable this parameter, clear **Input engine temperature**.

#### Plot air mass map – Plot table

button

Click to plot table.

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**Air mass flow map, f\_air\_3d – 3D lookup table**

M-by-N-by-L array

Input Command Setting	Description
Fuel mass	<p>The air mass flow lookup table is a function of commanded fuel mass and engine speed, <math>\dot{m}_{intk} = f(F_{max}, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>\dot{m}_{intk}</math> is engine air mass flow, in kg/s.</li> <li>• <math>F_{max}</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>
Torque	<p>The air mass flow lookup table is a function of maximum torque and engine speed, <math>\dot{m}_{intk} = f(T_{max}, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>\dot{m}_{intk}</math> is engine air mass flow, in kg/s.</li> <li>• <math>T_{max}</math> is maximum torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>

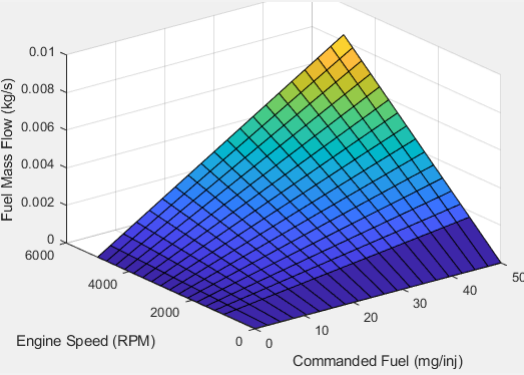
**Dependencies**

To enable this parameter, select **Input engine temperature**.

**Fuel**

**Fuel flow map, f\_fuel – 2D lookup table**

M-by-N matrix

Input Command Setting	Description
Fuel mass	<p>The engine fuel flow lookup table is a function of commanded fuel mass and engine speed, <math>MassFlow = f(F, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>MassFlow</math> is engine fuel mass flow, in kg/s.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul> 
Torque	<p>The engine fuel flow lookup table is a function of target torque and engine speed, <math>MassFlow = f(T_{target}, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>MassFlow</math> is engine fuel mass flow, in kg/s.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul>

### Dependencies

To enable this parameter, clear **Input engine temperature**.

### Plot fuel flow map – Plot table

button

Click to plot table.

### Dependencies

To enable this parameter, clear **Input engine temperature**.

### Fuel flow map, f\_fuel\_3d – 3D lookup table

M-by-N-by-L array

Input Command Setting	Description
Fuel mass	<p>The engine fuel flow lookup table is a function of commanded fuel mass, engine speed, and engine temperature, <math>MassFlow = f(F, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>MassFlow</math> is engine fuel mass flow, in kg/s.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>
Torque	<p>The engine fuel flow lookup table is a function of target torque and engine speed, and engine temperature, <math>MassFlow = f(T_{target}, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>MassFlow</math> is engine fuel mass flow, in kg/s.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>

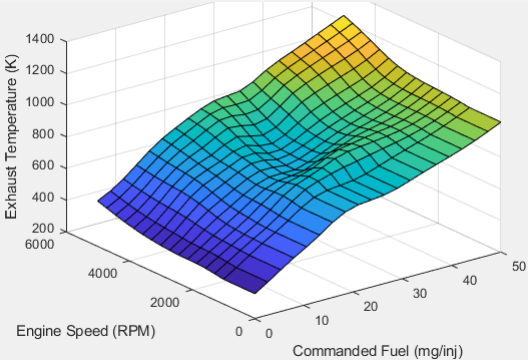
**Dependencies**

To enable this parameter, select **Input engine temperature**.

**Temperature**

**Exhaust temperature map,  $f_{texh}$  – 2D lookup table**

M-by-N matrix

Input Command Setting	Description
Fuel mass	<p>The engine exhaust temperature table is a function of commanded fuel mass and engine speed, <math>T_{exh} = f(F, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>T_{exh}</math> is exhaust temperature, in K.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul> 

Input Command Setting	Description
Torque	<p>The engine exhaust temperature table is a function of target torque and engine speed, <math>T_{exh} = f(T_{target}, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>T_{exh}</math> is exhaust temperature, in K.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul>

#### Dependencies

To enable this parameter, clear **Input engine temperature**.

#### Plot exhaust temperature map – Plot table

button

Click to plot table.

#### Dependencies

To enable this parameter, clear **Input engine temperature**.

#### Exhaust temperature map, f\_texh\_3d – 3D lookup table

M-by-N-by-L array

Input Command Setting	Description
Fuel mass	<p>The engine exhaust temperature table is a function of commanded fuel mass and engine speed, <math>T_{exh} = f(F, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>T_{exh}</math> is exhaust temperature, in K.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>
Torque	<p>The engine exhaust temperature table is a function of target torque and engine speed, <math>T_{exh} = f(T_{target}, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>T_{exh}</math> is exhaust temperature, in K.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>

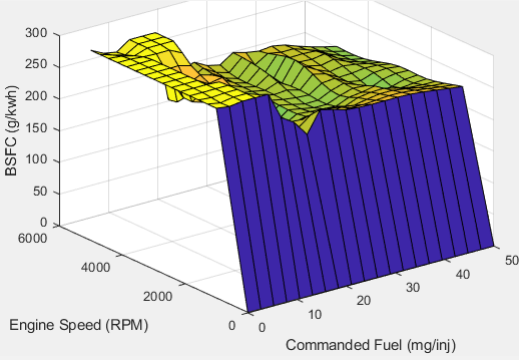
#### Dependencies

To enable this parameter, select **Input engine temperature**.

#### Efficiency

#### BSFC map, f\_eff – 2D lookup table

M-by-N matrix

Input Command Setting	Description
Fuel mass	<p>The brake-specific fuel consumption (BSFC) efficiency is a function of commanded fuel mass and engine speed, <math>BSFC = f(F, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>BSFC</math> is BSFC, in g/kWh.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul> 
Torque	<p>The brake-specific fuel consumption (BSFC) efficiency is a function of target torque and engine speed, <math>BSFC = f(T_{target}, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>BSFC</math> is BSFC, in g/kWh.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul>

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**Plot BSFC map – Plot table**  
button

Click to plot table.

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**BSFC map, f\_eff\_3d – 3D lookup table**

M-by-N-by-L array

Input Command Setting	Description
Fuel mass	<p>The brake-specific fuel consumption (BSFC) efficiency is a function of commanded fuel mass and engine speed, <math>BSFC = f(F, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>BSFC</math> is BSFC, in g/kWh.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>

Input Command Setting	Description
Torque	<p>The brake-specific fuel consumption (BSFC) efficiency is a function of target torque and engine speed, <math>BSFC = f(T_{target}, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>BSFC</math> is BSFC, in g/kWh.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>

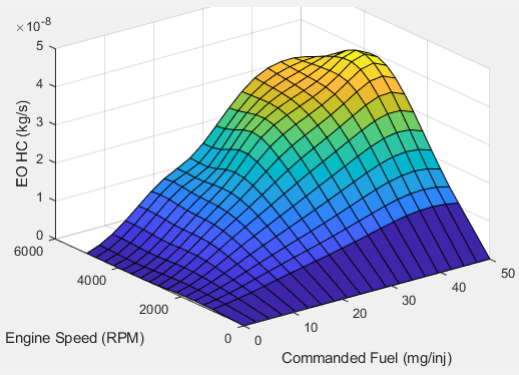
### Dependencies

To enable this parameter, select **Input engine temperature**.

### HC

#### E0 HC map, $f_{hc}$ – 2D lookup table

M-by-N matrix

Input Command Setting	Description
Fuel mass	<p>The engine-out hydrocarbon emissions are a function of commanded fuel mass and engine speed, <math>EO HC = f(F, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO HC</math> is engine-out hydrocarbon emissions, in kg/s.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul> 
Torque	<p>The engine-out hydrocarbon emissions are a function of target torque and engine speed, <math>EO HC = f(T_{target}, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO HC</math> is engine-out hydrocarbon emissions, in kg/s.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul>

### Dependencies

To enable this parameter, clear **Input engine temperature**.

#### Plot E0 HC map – Plot table

button

Click to plot table.

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**E0 HC map, f\_hc\_3d – 3D lookup table**

M-by-N-by-L array

Input Command Setting	Description
Fuel mass	<p>The engine-out hydrocarbon emissions are a function of commanded fuel mass and engine speed, <math>EO\ HC = f(F, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ HC</math> is engine-out hydrocarbon emissions, in kg/s.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>
Torque	<p>The engine-out hydrocarbon emissions are a function of target torque and engine speed, <math>EO\ HC = f(T_{target}, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ HC</math> is engine-out hydrocarbon emissions, in kg/s.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>

**Dependencies**

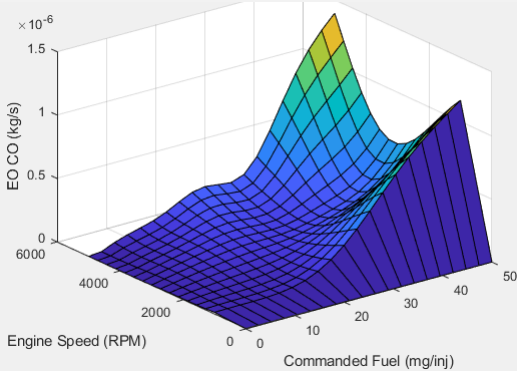
To enable this parameter, select **Input engine temperature**.

**CO**

**E0 CO map, f\_co – 2D lookup table**

M-by-N matrix



Input Command Setting	Description
Fuel mass	<p>The engine-out carbon monoxide emissions are a function of commanded fuel mass and engine speed, <math>EO\ CO = f(F, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ CO</math> is engine-out carbon monoxide emissions, in kg/s.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul> 
Torque	<p>The engine-out carbon monoxide emissions are a function of target torque and engine speed, <math>EO\ CO = f(T_{target}, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ CO</math> is engine-out carbon monoxide emissions, in kg/s.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul>

### Dependencies

To enable this parameter, clear **Input engine temperature**.

### Plot EO CO map – Plot table

button

Click to plot table.

### Dependencies

To enable this parameter, clear **Input engine temperature**.

### EO CO map, f\_co\_3d – 3D lookup table

M-by-N-by-L array

Input Command Setting	Description
Fuel mass	<p>The engine-out carbon monoxide emissions are a function of commanded fuel mass and engine speed, <math>EO\ CO = f(F, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ CO</math> is engine-out carbon monoxide emissions, in kg/s.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>
Torque	<p>The engine-out carbon monoxide emissions are a function of target torque and engine speed, <math>EO\ CO = f(T_{target}, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ CO</math> is engine-out carbon monoxide emissions, in kg/s.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>

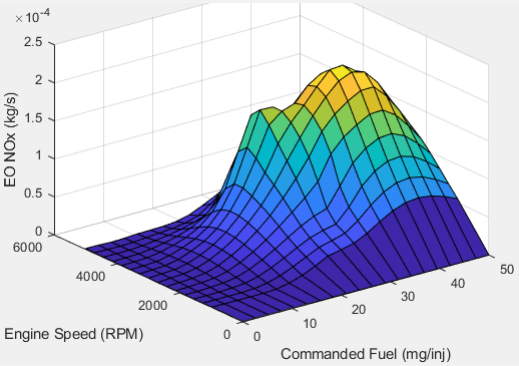
**Dependencies**

To enable this parameter, select **Input engine temperature**.

**NOx**

**EO NOx map, f\_nox – 2D lookup table**

M-by-N matrix

Input Command Setting	Description
Fuel mass	<p>The engine-out nitric oxide and nitrogen dioxide emissions are a function of commanded fuel mass and engine speed, <math>EO\ NOx = f(F, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ NOx</math> is engine-out nitric oxide and nitrogen dioxide emissions, in kg/s.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul> 

Input Command Setting	Description
Torque	<p>The engine-out nitric oxide and nitrogen dioxide emissions are a function of target torque and engine speed, <math>EO\ NO_x = f(T_{target}, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ NO_x</math> is engine-out nitric oxide and nitrogen dioxide emissions, in kg/s.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul>

#### Dependencies

To enable this parameter, clear **Input engine temperature**.

#### Plot EO NOx map – Plot table

button

Click to plot table.

#### Dependencies

To enable this parameter, clear **Input engine temperature**.

#### EO NOx map, f\_nox\_3d – 3D lookup table

M-by-N-by-L array

Input Command Setting	Description
Fuel mass	<p>The engine-out nitric oxide and nitrogen dioxide emissions are a function of commanded fuel mass, engine speed, and engine temperature, <math>EO\ NO_x = f(F, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ NO_x</math> is engine-out nitric oxide and nitrogen dioxide emissions, in kg/s.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>
Torque	<p>The engine-out nitric oxide and nitrogen dioxide emissions are a function of target torque, engine speed, and engine temperature, <math>EO\ NO_x = f(T_{target}, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ NO_x</math> is engine-out nitric oxide and nitrogen dioxide emissions, in kg/s.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>

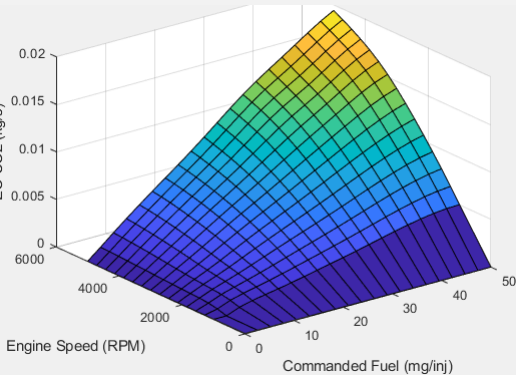
#### Dependencies

To enable this parameter, select **Input engine temperature**.

**CO2**

**E0 CO2 map, f\_co2 – 2D lookup table**

M-by-N matrix

Input Command Setting	Description
Fuel mass	<p>The engine-out carbon dioxide emissions are a function of commanded fuel mass and engine speed, <math>EO\ CO2 = f(F, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ CO2</math> is engine-out carbon dioxide emissions, in kg/s.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul> 
Torque	<p>The engine-out carbon dioxide emissions are a function of target torque and engine speed, <math>EO\ CO2 = f(T_{target}, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ CO2</math> is engine-out carbon dioxide emissions, in kg/s.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul>

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**Plot CO2 map – Plot table**

button

Click to plot table.

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**E0 CO2 map, f\_co2\_3d – 3D lookup table**

M-by-N-by-L array

Input Command Setting	Description
Fuel mass	<p>The engine-out carbon dioxide emissions are a function of commanded fuel mass, engine speed, and engine temperature, <math>EO\ CO_2 = f(F, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ CO_2</math> is engine-out carbon dioxide emissions, in kg/s.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>
Torque	<p>The engine-out carbon dioxide emissions are a function of target torque, engine speed, and engine temperature, <math>EO\ CO_2 = f(T_{target}, N, Temp_{Eng})</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ CO_2</math> is engine-out carbon dioxide emissions, in kg/s.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>

#### Dependencies

To enable this parameter, select **Input engine temperature**.

#### PM

#### E0 PM map, f\_pm – 2D lookup table

M-by-N matrix

Input Command Setting	Description
Fuel mass	<p>The engine-out PM emissions are a function of commanded fuel mass and engine speed, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ PM</math> is engine-out PM emissions, in kg/s.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul>
Torque	<p>The engine-out PM emissions are a function of target torque and engine speed, <math>EO\ PM = f(T_{target}, N)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ PM</math> is engine-out PM emissions, in kg/s.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> </ul>

#### Dependencies

To enable this parameter, clear **Input engine temperature**.

#### Plot E0 PM map – Plot table

button

Click to plot table.

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**E0 PM map, f\_pm\_3d — 3D lookup table**

M-by-N-by-L array

Input Command Setting	Description
Fuel mass	<p>The engine-out PM emissions are a function of commanded fuel mass, engine speed, and engine temperature, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ PM</math> is engine-out PM emissions, in kg/s.</li> <li>• <math>F</math> is commanded fuel mass, in mg per injection.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>
Torque	<p>The engine-out PM emissions are a function of target torque, engine speed, and engine temperature, <math>EO\ PM = f(T_{target}, N, T)</math>, where:</p> <ul style="list-style-type: none"> <li>• <math>EO\ PM</math> is engine-out PM emissions, in kg/s.</li> <li>• <math>T_{target}</math> is target torque, in N·m.</li> <li>• <math>N</math> is engine speed, in rpm.</li> <li>• <math>Temp_{Eng}</math> is engine temperature, in K.</li> </ul>

**Dependencies**

To enable this parameter, select **Input engine temperature**.

**Extended Capabilities**

**C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Mapped Motor | Mapped SI Engine

**Topics**

“Engine Calibration Maps”

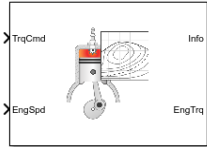
“Model-Based Calibration Toolbox”

**Introduced in R2017a**

# Mapped SI Engine

Spark-ignition engine model using lookup tables

**Library:** Powertrain Blockset / Propulsion / Combustion Engines  
Vehicle Dynamics Blockset / Powertrain / Propulsion



## Description

The Mapped SI Engine block implements a mapped spark-ignition (SI) engine model using power, air mass flow, fuel flow, exhaust temperature, efficiency, and emission performance lookup tables. You can use the block for:

- Hardware-in-the-loop (HIL) engine control design
- Vehicle-level fuel economy and performance simulations

The block enables you to specify lookup tables for these engine characteristics. The lookup tables, developed with the Model-Based Calibration Toolbox, are functions of commanded torque,  $T_{cmd}$ , brake torque,  $T_{brake}$ , and engine speed,  $N$ . If you select **Input engine temperature**, the tables are also a function of engine temperature,  $Temp_{Eng}$ .

Table	Input Engine Temperature Parameter Setting	
	off	on
Power	$f(T_{cmd}, N)$	$f(T_{cmd}, N, Temp_{Eng})$
Air	$f(T_{brake}, N)$	$f(T_{brake}, N, Temp_{Eng})$
Fuel		
Temperature		
Efficiency		
HC		
CO		
NOx		
CO2		
PM		

To bound the Mapped SI Engine block output, the block does not extrapolate the lookup table data.

## Virtual Calibration

If you have Model-Based Calibration Toolbox, click **Calibrate Maps** to virtually calibrate the 2D lookup tables using measured data. The dialog box steps through these tasks.

Task	Description				
Import firing data	<p>Import this loss data from a file. For example, open <code>&lt;matlabroot&gt;/toolbox/autobks/autodemos/projectsrc/SIDynamometer/CalMappedEng/SiEngineData.xlsx</code>.</p> <p>For more information, see “Using Data” (Model-Based Calibration Toolbox).</p> <table border="1"> <thead> <tr> <th>Required Data</th> <th>Optional Data</th> </tr> </thead> <tbody> <tr> <td> <ul style="list-style-type: none"> <li>• Engine speed, rpm</li> <li>• Engine torque, N·m</li> </ul> </td> <td> <ul style="list-style-type: none"> <li>• Air mass flow rate, kg/s</li> <li>• Brake specific fuel consumption, g/(kW·h)</li> <li>• CO<sub>2</sub> mass flow rate, kg/s</li> <li>• CO mass flow rate, kg/s</li> <li>• Exhaust temperature, K</li> <li>• Fuel mass flow rate, kg/s</li> <li>• HC mass flow rate, kg/s</li> <li>• NO<sub>x</sub> mass flow rate, kg/s</li> <li>• Particulate matter mass flow rate, kg/s</li> </ul> </td> </tr> </tbody> </table> <p>Collect firing data at steady-state operating conditions when injectors deliver the fuel. Data should cover the engine speed and torque operating range. Model-Based Calibration Toolbox uses the firing data boundary as the maximum torque.</p> <p>To filter or edit the data, select <b>Edit in Application</b>. The Model-Based Calibration Toolbox Data Editor opens.</p>	Required Data	Optional Data	<ul style="list-style-type: none"> <li>• Engine speed, rpm</li> <li>• Engine torque, N·m</li> </ul>	<ul style="list-style-type: none"> <li>• Air mass flow rate, kg/s</li> <li>• Brake specific fuel consumption, g/(kW·h)</li> <li>• CO<sub>2</sub> mass flow rate, kg/s</li> <li>• CO mass flow rate, kg/s</li> <li>• Exhaust temperature, K</li> <li>• Fuel mass flow rate, kg/s</li> <li>• HC mass flow rate, kg/s</li> <li>• NO<sub>x</sub> mass flow rate, kg/s</li> <li>• Particulate matter mass flow rate, kg/s</li> </ul>
Required Data	Optional Data				
<ul style="list-style-type: none"> <li>• Engine speed, rpm</li> <li>• Engine torque, N·m</li> </ul>	<ul style="list-style-type: none"> <li>• Air mass flow rate, kg/s</li> <li>• Brake specific fuel consumption, g/(kW·h)</li> <li>• CO<sub>2</sub> mass flow rate, kg/s</li> <li>• CO mass flow rate, kg/s</li> <li>• Exhaust temperature, K</li> <li>• Fuel mass flow rate, kg/s</li> <li>• HC mass flow rate, kg/s</li> <li>• NO<sub>x</sub> mass flow rate, kg/s</li> <li>• Particulate matter mass flow rate, kg/s</li> </ul>				
Import non-firing data	<p>Import this non-firing data from a file. For example, open <code>&lt;matlabroot&gt;/toolbox/autobks/autodemos/projectsrc/SIDynamometer/CalMappedEng/SiEngineData.xlsx</code>.</p> <ul style="list-style-type: none"> <li>• Engine speed, rpm</li> <li>• Engine torque, N·m</li> </ul> <p>Collect non-firing (motoring) data at steady-state operating conditions when fuel is cut off. All non-firing torque points must be less than zero. Non-firing data is a function of engine speed only.</p>				
Generate response models	<p>For both firing and non-firing data, the Model-Based Calibration Toolbox uses test plans to fit data to Gaussian process models (GPMs).</p> <p>To assess or adjust the response model fit, select <b>Edit in Application</b>. The Model-Based Calibration Toolbox Model Browser opens. For more information, see “Model Assessment” (Model-Based Calibration Toolbox).</p>				
Generate calibration	<p>Model-Based Calibration Toolbox calibrates the firing and non-firing response models and generates calibrated tables.</p> <p>To assess or adjust the calibration, select <b>Edit in Application</b>. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration Lookup Tables” (Model-Based Calibration Toolbox).</p>				



Task	Description
Update block parameters	Update the block lookup table and breakpoint parameters with the calibration.

### Cylinder Air Mass

The block calculates the normalized cylinder air mass using these equations.

$$M_{Nom} = \frac{P_{std} V_d}{N_{cyl} R_{air} T_{std}}$$

$$L = \frac{\left(\frac{60s}{min}\right) Cps \cdot \dot{m}_{air}}{\left(\frac{1000g}{Kg}\right) N_{cyl} \cdot N \cdot M_{Nom}}$$

The equations use these variables.

$L$	Normalized cylinder air mass
$M_{Nom}$	Nominal engine cylinder air mass at standard temperature and pressure, piston at bottom dead center (BDC) maximum volume, in kg
$Cps$	Crankshaft revolutions per power stroke, rev/stroke
$P_{std}$	Standard pressure
$T_{std}$	Standard temperature
$R_{air}$	Ideal gas constant for air and burned gas mixture
$V_d$	Displaced volume
$N_{cyl}$	Number of engine cylinders
$N$	Engine speed
$\dot{m}_{intk}$	Engine air mass flow, in g/s

### Turbocharger Lag

To model turbocharger lag, select **Include turbocharger lag effect**. During throttle control, the time constant models the manifold filling and emptying dynamics. When the torque request requires a turbocharger boost, the block uses a larger time constant to represent the turbocharger lag. The block uses these equations.

Dynamic torque	$\frac{dT_{brake}}{dt} = \frac{1}{\tau_{eng}} (T_{stdy} - T_{brake})$
Boost time constant	$\tau_{bst} = \begin{cases} \tau_{bst, rising} & \text{when } T_{stdy} > T_{brake} \\ \tau_{bst, falling} & \text{when } T_{stdy} \leq T_{brake} \end{cases}$
Final time constant	$\tau_{eng} = \begin{cases} \tau_{thr} & \text{when } T_{brake} < f_{bst}(N) \\ \tau_{bst} & \text{when } T_{brake} \geq f_{bst}(N) \end{cases}$

The equations use these variables.

$T_{brake}$	Brake torque
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$T_{stdy}$	Steady-state target torque
$\tau_{bst}$	Boost time constant
$\tau_{bst,rising}$	Boost rising and falling time constant, respectively
$\tau_{bst,falling}$	
$\tau_{eng}$	Final time constant
$\tau_{thr}$	Time constant during throttle control
$f_{bst}(N)$	Boost torque speed line
$N$	Engine speed

### Fuel Flow

To calculate the fuel economy for high-fidelity models, the block uses the volumetric fuel flow.

$$Q_{fuel} = \frac{\dot{m}_{fuel}}{\left(\frac{1000kg}{m^3}\right)Sg_{fuel}}$$

The equation uses these variables.

$\dot{m}_{fuel}$	Fuel mass flow
$Sg_{fuel}$	Specific gravity of fuel
$Q_{fuel}$	Volumetric fuel flow

### Power Accounting

For the power accounting, the block implements these equations.

Bus Signal	Description	Equations
PwrInflow	PwrTrnsfrd — Power transferred between blocks <ul style="list-style-type: none"> <li>Positive signals indicate flow into block</li> <li>Negative signals indicate flow out of block</li> </ul>	PwrCrkshft Crankshaft power  $-\tau_{eng}\omega$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred <ul style="list-style-type: none"> <li>Positive signals indicate an input</li> <li>Negative signals indicate a loss</li> </ul>	PwrFuel Fuel input power $\dot{m}_{fuel}LHV$
		PwrLoss Power loss $\tau_{eng}\omega - \dot{m}_{fuel}LHV$
PwrStored — Stored energy rate of change <ul style="list-style-type: none"> <li>Positive signals indicate an increase</li> <li>Negative signals indicate a decrease</li> </ul>	Not used	

The equations use these variables.

$LHV$	Fuel lower heating value
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$\omega$	Engine speed, rad/s
$\dot{m}_{fuel}$	Fuel mass flow
$\tau_{eng}$	Fuel mass per injection time constant

## Ports

### Input

#### TrqCmd – Commanded torque

scalar

Torque,  $T_{cmd}$ , in N·m.

#### EngSpd – Engine speed

scalar

Engine speed,  $N$ , in rpm.

#### EngTemp – Engine temperature

scalar

Engine temperature,  $Temp_{Eng}$ , in K.

### Dependencies

To enable this port, select **Input engine temperature**.

### Output

#### Info – Bus signal

bus

Bus signal containing these block calculations.

Signal	Description	Units
IntkGassMassFlw	Engine air mass flow output	kg/s
NrmlzdAirChrg	Normalized engine cylinder air mass	N/A
Afr	Air-fuel ratio (AFR)	N/A
FuelMassFlw	Engine fuel flow output	kg/s
FuelVolFlw	Volumetric fuel flow	m <sup>3</sup> /s
ExhManGasTemp	Engine exhaust gas temperature	K
EngTrq	Engine torque output	N·m
EngSpd	Engine speed	rpm

Signal			Description	Units
CrkAng			Engine crankshaft absolute angle $\int_0^{(360)Cps} EngSpd \frac{180}{30} d\theta$ where <i>Cps</i> is crankshaft revolutions per power stroke.	degrees crank angle
Bsfc			Engine brake-specific fuel consumption (BSFC)	g/kWh
EoHC			Engine out hydrocarbon emission mass flow	kg/s
EoCO			Engine out carbon monoxide emission mass flow rate	kg/s
EoNOx			Engine out nitric oxide and nitrogen dioxide emissions mass flow	kg/s
EoCO2			Engine out carbon dioxide emission mass flow	kg/s
EoPM			Engine out particulate matter emission mass flow	kg/s
PwrInfo	PwrTrnsfrd	PwrCrkshft	Crankshaft power	W
	PwrNotTrnsfrd	PwrFuel	Fuel input power	W
		PwrLoss	Power loss	W
	PwrStored		<i>Not used</i>	

**EngTrq – Engine brake torque**

scalar

Engine brake torque,  $T_{brake}$ , in N·m.

**Parameters**

**Block Options**

**Include turbocharger lag effect – Increase time constant**

off (default)

To model turbocharger lag, select **Include turbocharger lag effect**. During throttle control, the time constant models the manifold filling and emptying dynamics. When the torque request requires a turbocharger boost, the block uses a larger time constant to represent the turbocharger lag. The block uses these equations.

Dynamic torque	$\frac{dT_{brake}}{dt} = \frac{1}{\tau_{eng}}(T_{stdy} - T_{brake})$
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Boost time constant	$\tau_{bst} = \begin{cases} \tau_{bst, rising} & \text{when } T_{stdy} > T_{brake} \\ \tau_{bst, falling} & \text{when } T_{stdy} \leq T_{brake} \end{cases}$
Final time constant	$\tau_{eng} = \begin{cases} \tau_{thr} & \text{when } T_{brake} < f_{bst}(N) \\ \tau_{bst} & \text{when } T_{brake} \geq f_{bst}(N) \end{cases}$

The equations use these variables.

$T_{brake}$	Brake torque
$T_{stdy}$	Steady-state target torque
$\tau_{bst}$	Boost time constant
$\tau_{bst, rising}$ , $\tau_{bst, falling}$	Boost rising and falling time constant, respectively
$\tau_{eng}$	Final time constant
$\tau_{thr}$	Time constant during throttle control
$f_{bst}(N)$	Boost torque speed line
$N$	Engine speed

#### Dependencies

Selecting **Include turbocharger lag effect** enables these parameters:

- **Boost torque line, f\_tbrake\_bst**
- **Time constant below boost line, tau\_thr**
- **Rising torque boost time constant, tau\_bst\_rising**
- **Falling torque boost time constant, tau\_bst\_falling**

#### Input engine temperature – Create input port

off (default) | on

Select this to create the EngTemp input port.

The block enables you to specify lookup tables for these engine characteristics. The lookup tables, developed with the Model-Based Calibration Toolbox, are functions of commanded torque,  $T_{cmd}$ , brake torque,  $T_{brake}$ , and engine speed,  $N$ . If you select **Input engine temperature**, the tables are also a function of engine temperature,  $Temp_{Eng}$ .

Table	Input Engine Temperature Parameter Setting	
	off	on
Power	$f(T_{cmd}, N)$	$f(T_{cmd}, N, Temp_{Eng})$
Air	$f(T_{brake}, N)$	$f(T_{brake}, N, Temp_{Eng})$
Fuel		
Temperature		
Efficiency		
HC		
CO		

Table	Input Engine Temperature Parameter Setting	
	off	on
NOx		
CO2		
PM		

**Configuration**

**Calibrate Maps – Calibrate tables with measured data selection**

If you have Model-Based Calibration Toolbox, click **Calibrate Maps** to virtually calibrate the 2D lookup tables using measured data. The dialog box steps through these tasks.

Task	Description				
Import firing data	<p>Import this loss data from a file. For example, open <code>&lt;matlabroot&gt;/toolbox/autoblks/autodemos/projectsrc/SIDynamometer/CalMappedEng/SiEngineData.xlsx</code>.</p> <p>For more information, see “Using Data” (Model-Based Calibration Toolbox).</p> <table border="1"> <thead> <tr> <th>Required Data</th> <th>Optional Data</th> </tr> </thead> <tbody> <tr> <td> <ul style="list-style-type: none"> <li>• Engine speed, rpm</li> <li>• Engine torque, N·m</li> </ul> </td> <td> <ul style="list-style-type: none"> <li>• Air mass flow rate, kg/s</li> <li>• Brake specific fuel consumption, g/(kW·h)</li> <li>• CO2 mass flow rate, kg/s</li> <li>• CO mass flow rate, kg/s</li> <li>• Exhaust temperature, K</li> <li>• Fuel mass flow rate, kg/s</li> <li>• HC mass flow rate, kg/s</li> <li>• NOx mass flow rate, kg/s</li> <li>• Particulate matter mass flow rate, kg/s</li> </ul> </td> </tr> </tbody> </table> <p>Collect firing data at steady-state operating conditions when injectors deliver the fuel. Data should cover the engine speed and torque operating range. Model-Based Calibration Toolbox uses the firing data boundary as the maximum torque.</p> <p>To filter or edit the data, select <b>Edit in Application</b>. The Model-Based Calibration Toolbox Data Editor opens.</p>	Required Data	Optional Data	<ul style="list-style-type: none"> <li>• Engine speed, rpm</li> <li>• Engine torque, N·m</li> </ul>	<ul style="list-style-type: none"> <li>• Air mass flow rate, kg/s</li> <li>• Brake specific fuel consumption, g/(kW·h)</li> <li>• CO2 mass flow rate, kg/s</li> <li>• CO mass flow rate, kg/s</li> <li>• Exhaust temperature, K</li> <li>• Fuel mass flow rate, kg/s</li> <li>• HC mass flow rate, kg/s</li> <li>• NOx mass flow rate, kg/s</li> <li>• Particulate matter mass flow rate, kg/s</li> </ul>
Required Data	Optional Data				
<ul style="list-style-type: none"> <li>• Engine speed, rpm</li> <li>• Engine torque, N·m</li> </ul>	<ul style="list-style-type: none"> <li>• Air mass flow rate, kg/s</li> <li>• Brake specific fuel consumption, g/(kW·h)</li> <li>• CO2 mass flow rate, kg/s</li> <li>• CO mass flow rate, kg/s</li> <li>• Exhaust temperature, K</li> <li>• Fuel mass flow rate, kg/s</li> <li>• HC mass flow rate, kg/s</li> <li>• NOx mass flow rate, kg/s</li> <li>• Particulate matter mass flow rate, kg/s</li> </ul>				

Task	Description
Import non-firing data	<p>Import this non-firing data from a file. For example, open <code>&lt;matlabroot&gt;/toolbox/autoblks/autodemos/projectsrc/SIDynamometer/CalMappedEng/SiEngineData.xlsx</code>.</p> <ul style="list-style-type: none"> <li>Engine speed, rpm</li> <li>Engine torque, N·m</li> </ul> <p>Collect non-firing (motoring) data at steady-state operating conditions when fuel is cut off. All non-firing torque points must be less than zero. Non-firing data is a function of engine speed only.</p>
Generate response models	<p>For both firing and non-firing data, the Model-Based Calibration Toolbox uses test plans to fit data to Gaussian process models (GPMs).</p> <p>To assess or adjust the response model fit, select <b>Edit in Application</b>. The Model-Based Calibration Toolbox Model Browser opens. For more information, see “Model Assessment” (Model-Based Calibration Toolbox).</p>
Generate calibration	<p>Model-Based Calibration Toolbox calibrates the firing and non-firing response models and generates calibrated tables.</p> <p>To assess or adjust the calibration, select <b>Edit in Application</b>. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration Lookup Tables” (Model-Based Calibration Toolbox).</p>
Update block parameters	Update the block lookup table and breakpoint parameters with the calibration.

### Dependencies

To enable this parameter, clear **Input engine temperature**.

### Breakpoints for commanded torque, `f_tbrake_t_bpt` – Breakpoints

1-by-M vector

Breakpoints, in N·m.

### Breakpoints for engine speed input, `f_tbrake_n_bpt` – Breakpoints

1-by-N vector

Breakpoints, in rpm.

### Breakpoints for temperature input, `f_tbrake_engtmp_bpt` – Breakpoints

[233.15 273.15 373.15] (default) | 1-by-L vector

Breakpoints, in K.

### Dependencies

To enable this parameter, select **Input engine temperature**.

### Number of cylinders, `NCyl` – Number

4 (default) | scalar

Number of cylinders.

**Crank revolutions per power stroke, Cps – Crank revolutions**

2 (default) | scalar

Crank revolutions per power stroke.

**Total displaced volume, Vd – Volume**

0.0015 (default) | scalar

Volume displaced by engine, in  $m^3$ .**Fuel lower heating value, Lhv – Heating value**

45e6 (default) | scalar

Fuel lower heating value,  $LHV$ , in J/kg.**Fuel specific gravity, Sg – Specific gravity**

0.745 (default) | scalar

Specific gravity of fuel,  $Sg_{fuel}$ , dimensionless.**Ideal gas constant air, Rair – Constant**

287 (default) | scalar

Ideal gas constant of air and residual gas entering the engine intake port, in J/(kg\*K).

**Air standard pressure, Pstd – Pressure**

101325 (default) | scalar

Standard air pressure, in Pa.

**Air standard temperature, Tstd – Temperature**

293.15 (default) | scalar

Standard air temperature, in K.

**Boost torque line, f\_tbrake\_bst – Boost lag**

1-by-M vector

Boost torque line,  $f_{bst}(N)$ , in N·m.**Dependencies**To enable this parameter, select **Include turbocharger lag effect**.**Time constant below boost line – Time constant below**

0.2 (default) | scalar

Time constant below boost line,  $\tau_{thr}$ , in s.**Dependencies**To enable this parameter, select **Include turbocharger lag effect**.**Rising torque boost time constant, tau\_bst\_rising – Rising time constant**

1.5 (default) | scalar

Rising torque boost time constant,  $\tau_{bst,rising}$ , in s.



### Dependencies

To enable this parameter, select **Include turbocharger lag effect**.

### Falling torque boost time constant, $\tau_{bst\_falling}$ — Falling time constant

1 (default) | scalar

Falling torque boost time constant,  $\tau_{bst,falling}$ , in s.

### Dependencies

To enable this parameter, select **Include turbocharger lag effect**.

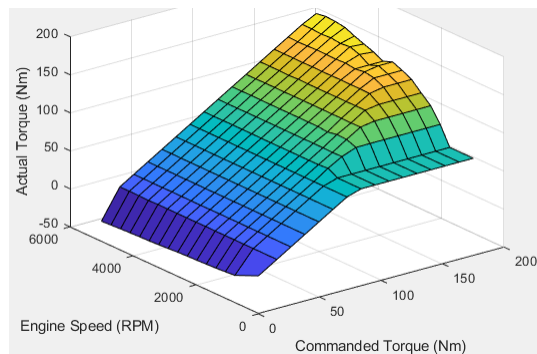
### Power

### Brake torque map, $f\_tbrake$ — 2D lookup table

M-by-N matrix

The engine torque lookup table is a function of commanded engine torque and engine speed,  $T = f(T_{cmd}, N)$ , where:

- $T$  is engine torque, in N·m.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.



### Plot brake torque map — Plot table

button

Click to plot table.

### Dependencies

To enable this parameter, clear **Input engine temperature**.

### Brake torque map, $f\_tbrake\_3d$ — 3D lookup table

M-by-N-by-L array

The engine torque lookup table is a function of commanded engine torque, engine speed, and engine temperature,  $T = f(T_{cmd}, N, Temp_{Eng})$ , where:

- $T$  is engine torque, in N·m.
- $T_{cmd}$  is commanded engine torque, in N·m.

- $N$  is engine speed, in rpm.
- $Temp_{Eng}$  is engine temperature, in K.

**Dependencies**

To enable this parameter, select **Input engine temperature**.

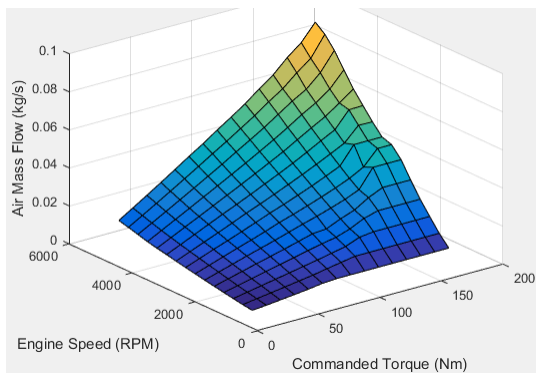
**Air**

**Air mass flow map,  $f_{air}$  – 2D lookup table**

M-by-N matrix

The engine air mass flow lookup table is a function of commanded engine torque and engine speed,  $\dot{m}_{intk} = f(T_{cmd}, N)$ , where:

- $\dot{m}_{intk}$  is engine air mass flow, in kg/s.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.



**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**Plot air mass map – Plot table**

button

Click to plot table.

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**Air mass flow map,  $f_{air\_3d}$  – 3D lookup table**

M-by-N-by-L array

The engine air mass flow lookup table is a function of commanded engine torque, engine speed, and engine temperature,  $\dot{m}_{intk} = f(T_{cmd}, N, Temp_{Eng})$ , where:

- $\dot{m}_{intk}$  is engine air mass flow, in kg/s.
- $T_{cmd}$  is commanded engine torque, in N·m.

- $N$  is engine speed, in rpm.
- $Temp_{Eng}$  is engine temperature, in K.

### Dependencies

To enable this parameter, select **Input engine temperature**.

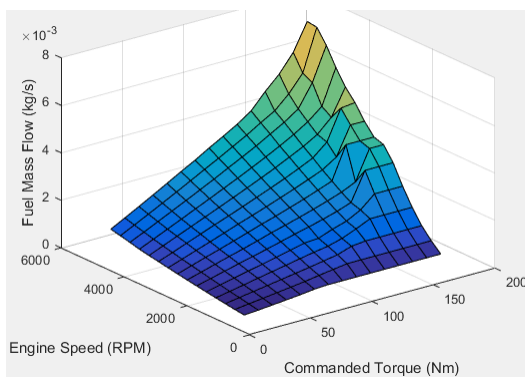
### Fuel

#### Fuel flow map, $f\_fuel$ – 2D lookup table

M-by-N matrix

The engine fuel mass flow lookup table is a function of commanded engine torque and engine speed,  $MassFlow = f(T_{cmd}, N)$ , where:

- $MassFlow$  is engine fuel mass flow, in kg/s.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.



### Dependencies

To enable this parameter, clear **Input engine temperature**.

#### Plot fuel flow map – Plot table

button

Click to plot table.

### Dependencies

To enable this parameter, clear **Input engine temperature**.

#### Fuel flow map, $f\_fuel\_3d$ – 3D lookup table

M-by-N-by-L array

The engine fuel mass flow lookup table is a function of commanded engine torque, engine speed, and engine temperature,  $MassFlow = f(T_{cmd}, N, Temp_{Eng})$ , where:

- $MassFlow$  is engine fuel mass flow, in kg/s.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.

- $Temp_{Eng}$  is engine temperature, in K.

**Dependencies**

To enable this parameter, select **Input engine temperature**.

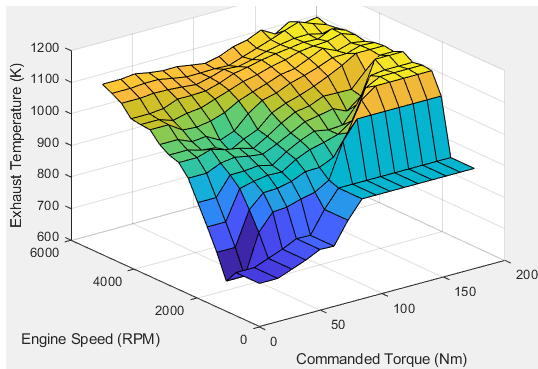
**Temperature**

**Exhaust temperature map, f\_texh – 2D lookup table**

M-by-N matrix

The engine exhaust temperature lookup table is a function of commanded engine torque and engine speed,  $T_{exh} = f(T_{cmd}, N)$ , where:

- $T_{exh}$  is exhaust temperature, in K.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.



**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**Plot exhaust temperature map – Plot table**

button

Click to plot table.

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**Exhaust temperature map, f\_texh\_3d – 3D lookup table**

array

The engine exhaust temperature lookup table is a function of commanded engine torque, engine speed, and engine temperature,  $T_{exh} = f(T_{cmd}, N, Temp_{Eng})$ , where:

- $T_{exh}$  is exhaust temperature, in K.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.
- $Temp_{Eng}$  is engine temperature, in K.

**Dependencies**

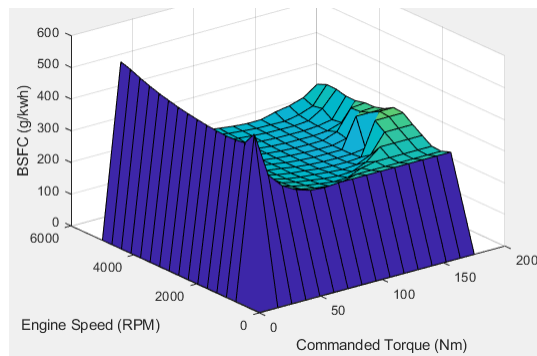
To enable this parameter, select **Input engine temperature**.

**Efficiency****BSFC map,  $f_{eff}$  – 2D lookup table**

M-by-N-by-L array

The brake-specific fuel consumption (BSFC) efficiency is a function of commanded engine torque and engine speed,  $BSFC = f(T_{cmd}, N)$ , where:

- $BSFC$  is BSFC, in g/kWh.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**Plot BSFC map – Plot table**

button

Click to plot table.

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**BSFC map,  $f_{eff\_3d}$  – 3D lookup table**

M-by-N-by-L array

The brake-specific fuel consumption (BSFC) efficiency is a function of commanded engine torque, engine speed, and engine temperature,  $BSFC = f(T_{cmd}, N, Temp_{Eng})$ , where:

- $BSFC$  is BSFC, in g/kWh.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.
- $Temp_{Eng}$  is engine temperature, in K.

**Dependencies**

To enable this parameter, select **Input engine temperature**.

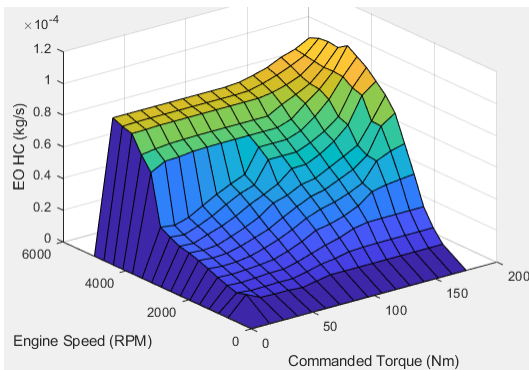
**HC**

**E0 HC map, f\_hc – 2D lookup table**

M-by-N matrix

The engine-out hydrocarbon emissions are a function of commanded engine torque and engine speed,  $EO\ HC = f(T_{cmd}, N)$ , where:

- $EO\ HC$  is engine-out hydrocarbon emissions, in kg/s.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.



**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**Plot E0 HC map – Plot table**

button

Click to plot table.

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**E0 HC map, f\_hc\_3d – 3D lookup table**

M-by-N-by-L array

The engine-out hydrocarbon emissions are a function of commanded engine torque, engine speed, and engine temperature,  $EO\ HC = f(T_{cmd}, N, Temp_{Eng})$ , where:

- $EO\ HC$  is engine-out hydrocarbon emissions, in kg/s.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.
- $Temp_{Eng}$  is engine temperature, in K.

**Dependencies**

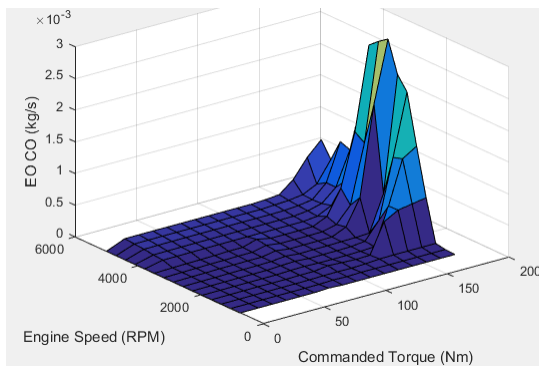
To enable this parameter, select **Input engine temperature**.

**CO****E0 CO map, f\_co – 2D lookup table**

M-by-N matrix

The engine-out carbon monoxide emissions are a function of commanded engine torque and engine speed,  $EO\ CO = f(T_{cmd}, N)$ , where:

- $EO\ CO$  is engine-out carbon monoxide emissions, in kg/s.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**Plot E0 CO map – Plot table**

button

Click to plot table.

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**E0 HC map, f\_hc\_3d – 3D lookup table**

M-by-N-by-L array

The engine-out hydrocarbon emissions are a function of commanded engine torque, engine speed, and engine temperature,  $EO\ HC = f(T_{cmd}, N, Temp_{Eng})$ , where:

- $EO\ HC$  is engine-out hydrocarbon emissions, in kg/s.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.
- $Temp_{Eng}$  is engine temperature, in K.

**Dependencies**

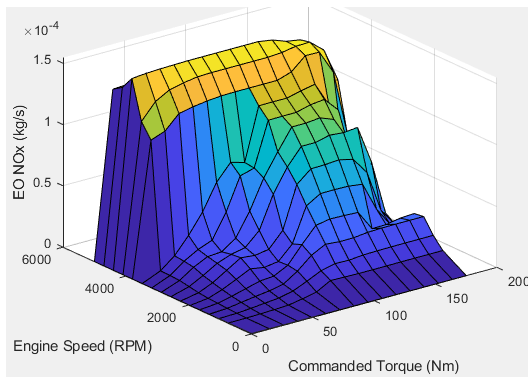
To enable this parameter, select **Input engine temperature**.

**NOx****E0 NOx map, f\_nox – 2D lookup table**

M-by-N matrix

The engine-out nitric oxide and nitrogen dioxide emissions are a function of commanded engine torque and engine speed,  $EO\ NOx = f(T_{cmd}, N)$ , where:

- $EO\ NOx$  is engine-out nitric oxide and nitrogen dioxide emissions, in kg/s.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**Plot E0 NOx map – Plot table**

button

Click to plot table.

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**E0 NOx map, f\_nox\_3d – 3D lookup table**

M-by-N-by-L array

The engine-out nitric oxide and nitrogen dioxide emissions are a function of commanded engine torque, engine speed, and engine temperature,  $EO\ NOx = f(T_{cmd}, N, Temp_{Eng})$ , where:

- $EO\ NOx$  is engine-out nitric oxide and nitrogen dioxide emissions, in kg/s.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.
- $Temp_{Eng}$  is engine temperature, in K.

**Dependencies**

To enable this parameter, select **Input engine temperature**.

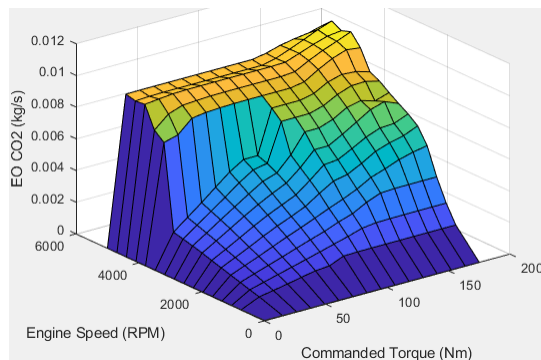


**CO2****E0 CO2 map, f\_co2 – 2D lookup table**

M-by-N matrix

The engine-out carbon dioxide emissions are a function of commanded engine torque and engine speed,  $EO\ CO2 = f(T_{cmd}, N)$ , where:

- $EO\ CO2$  is engine-out carbon dioxide emissions, in kg/s.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**Plot CO2 map – Plot table**

button

Click to plot table.

**Dependencies**

To enable this parameter, clear **Input engine temperature**.

**E0 CO2 map, f\_co2\_3d – 3D lookup table**

M-by-N-by-L array

The engine-out carbon dioxide emissions are a function of commanded engine torque, engine speed, and engine temperature,  $EO\ CO2 = f(T_{cmd}, N, Temp_{Eng})$ , where:

- $EO\ CO2$  is engine-out carbon dioxide emissions, in kg/s.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.
- $Temp_{Eng}$  is engine temperature, in K.

**Dependencies**

To enable this parameter, select **Input engine temperature**.

### PM

#### E0 PM map, $f_{pm}$ – 2D lookup table

M-by-N matrix

The engine-out particulate matter emissions are a function of commanded engine torque and engine speed, where:

- $EO\ PM$  is engine-out PM emissions, in kg/s.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.

#### Dependencies

To enable this parameter, clear **Input engine temperature**.

#### Plot E0 PM map – Plot table

button

Click to plot table.

#### Dependencies

To enable this parameter, clear **Input engine temperature**.

#### E0 PM map, $f_{pm\_3d}$ – 3D lookup table

M-by-N-by-L array

The engine-out particulate matter emissions are a function of commanded engine torque, engine speed, and engine temperature, where:

- $EO\ PM$  is engine-out PM emissions, in kg/s.
- $T_{cmd}$  is commanded engine torque, in N·m.
- $N$  is engine speed, in rpm.
- $Temp_{Eng}$  is engine temperature, in K.

#### Dependencies

To enable this parameter, select **Input engine temperature**.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

### See Also

Mapped CI Engine | Mapped Motor

### Topics

“Engine Calibration Maps”

“Model-Based Calibration Toolbox”

**Introduced in R2017a**



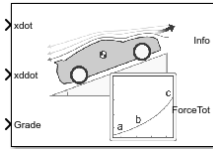
# Vehicle Dynamics Blocks

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## Vehicle Body Total Road Load

Vehicle motion using coast-down testing coefficients

**Library:** Powertrain Blockset / Vehicle Dynamics  
Vehicle Dynamics Blockset / Vehicle Body



### Description

The Vehicle Body Total Road Load block implements a one degree-of-freedom (1DOF) rigid vehicle model using coast-down testing coefficients. You can use this block in a vehicle model to represent the load that the driveline and chassis applies to a transmission or engine. It is suitable for system-level performance, component sizing, fuel economy, or drive cycle tracking studies. The block calculates the dynamic powertrain load with minimal parameterization or computational cost.

You can configure the block for kinematic, force, or total power input.

- Kinematic — Block uses the vehicle longitudinal velocity and acceleration to calculate the tractive force and power.
- Force — Block uses the tractive force to calculate the vehicle longitudinal displacement and velocity.
- Power — Block uses the engine or transmission power to calculate the vehicle longitudinal displacement and velocity.

### Dynamics

To calculate the total road load acting on the vehicle, the block implements this equation.

$$F_{road} = a + b\dot{x} + c\dot{x}^2 + mg\sin(\theta)$$

To determine the coefficients  $a$ ,  $b$ , and  $c$ , you can use a test procedure similar to the one described in *Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques*. You can also use Simulink® Design Optimization™ to fit the coefficients to measured data.

To calculate the vehicle motion, the block uses Newton's law for rigid bodies.

$$F_{total} = m\ddot{x} + F_{road}$$

Total power input is a product of the total force and longitudinal velocity. Power due to road and gravitational forces is a product of the road force and longitudinal velocity.

$$P_{total} = F_{total}\dot{x}$$

$$P_{road} = F_{road}\dot{x}$$

### Power Accounting

For the power accounting, the block implements these equations.

Bus Signal		Description	Variable	Equations	
PwrInfo	PwrTrnsfrd — Power transferred between blocks <ul style="list-style-type: none"> <li>Positive signals indicate flow into block</li> <li>Negative signals indicate flow out of block</li> </ul>	PwrFxExt	Externally applied force power	$P_{FxExt}$	$P_{FxExt} = F_{total}\dot{x}$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred <ul style="list-style-type: none"> <li>Positive signals indicate an input</li> <li>Negative signals indicate a loss</li> </ul>	PwrFxDrag	Drag force power	$P_D$	$P_D = -(a + b\dot{x} + c\dot{x}^2)\dot{x}$
	PwrStored — Stored energy rate of change <ul style="list-style-type: none"> <li>Positive signals indicate an increase</li> <li>Negative signals indicate a decrease</li> </ul>	wrStoredGrvty	Rate change in gravitational potential energy	$P_g$	$P_g = -mg\dot{z}$
		PwrStoredxdot	Rate in change of longitudinal kinetic energy	$P_{xdot}$	$P_{\dot{x}} = m\ddot{x}\dot{x}$

The equations use these variables.

$a$	Steady-state rolling resistance coefficient
$b$	Viscous driveline and rolling resistance coefficient
$c$	Aerodynamic drag coefficient
$g$	Gravitational acceleration
$x$	Vehicle longitudinal displacement with respect to ground, in the vehicle-fixed frame
$\dot{x}$	Vehicle longitudinal velocity with respect to ground, in the vehicle-fixed frame
$\ddot{x}$	Vehicle longitudinal acceleration with respect to ground, vehicle-fixed frame
$m$	Vehicle body mass
$\Theta$	Road grade angle
$F_{total}$	Total force acting on vehicle
$F_{road}$	Resistive road load due to losses and gravitational load
$P_{total}$	Total tractive input power
$P_{road}$	Total power due to losses and gravitational load
$\dot{z}$	Vehicle vertical velocity along the vehicle-fixed z-axis

## Ports

### Input

#### **xdot — Vehicle longitudinal velocity**

scalar

Vehicle total longitudinal velocity,  $\dot{x}$ , in m/s.

#### **Dependencies**

To enable this port, for the **Input Mode** parameter, select Kinematic.

#### **xddot — Vehicle longitudinal acceleration**

scalar

Vehicle total longitudinal acceleration,  $\ddot{x}$ , in m/s<sup>2</sup>.

#### **Dependencies**

To enable this port, for the **Input Mode** parameter, select Kinematic.

#### **PwrTot — Tractive input power**

scalar

Tractive input power,  $P_{total}$ , in W.

#### **Dependencies**

To enable this port, for the **Input Mode** parameter, select Power.

#### **ForceTot — Tractive input force**

scalar

Tractive input force,  $F_{total}$ , in N.

#### **Dependencies**

To enable this port, for the **Input Mode** parameter, select Force.

#### **Grade — Road grade angle**

scalar

Road grade angle,  $\theta$ , in deg.

### Output

#### **Info — Bus signal**

bus

Bus signal containing these block calculations.

Signal				Description	Value	Units
In	Cg	Disp	X	Vehicle CG displacement along earth-fixed X-axis	Computed	m



Signal			Description	Value	Units	
tF rm		Y	Vehicle CG displacement along earth-fixed Y-axis	0	m	
			Z	Vehicle CG displacement along earth-fixed Z-axis	Computed	m
		Vel	Xdot	Vehicle CG velocity along earth-fixed X-axis	Computed	m/s
			Ydot	Vehicle CG velocity along earth-fixed Y-axis	0	m/s
			Zdot	Vehicle CG velocity along earth-fixed Z-axis	Computed	m/s
		Ang	phi	Rotation of vehicle-fixed frame about the earth-fixed X-axis (roll)	0	rad
			theta	Rotation of vehicle-fixed frame about the earth-fixed Y-axis (pitch)	Computed	rad
			psi	Rotation of vehicle-fixed frame about the earth-fixed Z-axis (yaw)	0	rad
		Bd yF rm	Cg	Disp	x	Vehicle CG displacement along the vehicle-fixed x-axis
y	Vehicle CG displacement along the vehicle-fixed y-axis				0	m
z	Vehicle CG displacement along the vehicle-fixed z-axis				0	m
Vel	xdot			Vehicle CG velocity along the vehicle-fixed x-axis	Computed	m/s
	ydot			Vehicle CG velocity along the vehicle-fixed y-axis	0	m/s
	zdot			Vehicle CG velocity along the vehicle-fixed z-axis	0	m/s
Acc	ax			Vehicle CG acceleration along the vehicle-fixed x-axis	Computed	gn
	ay			Vehicle CG acceleration along the vehicle-fixed y-axis	0	gn
	az			Vehicle CG acceleration along the vehicle-fixed z-axis	0	gn
Forc es	Body		Fx	Net force on vehicle CG along the vehicle-fixed x-axis	Computed	N
			Fy	Net force on vehicle CG along the vehicle-fixed y-axis	0	N
			Fz	Net force on vehicle CG along the vehicle-fixed z-axis	0	N
	Ext		Fx	External force on vehicle CG along the vehicle-fixed x-axis	Computed	N

Signal			Description	Value	Units	
		Fy	External force on vehicle CG along the vehicle-fixed y-axis	0	N	
		Fz	External force on vehicle CG along the vehicle-fixed z-axis	0	N	
		Drag	Fx	Drag force on vehicle CG along the vehicle-fixed x-axis	Computed	N
			Fy	Drag force on vehicle CG along the vehicle-fixed y-axis	0	N
			Fz	Drag force on vehicle CG along the vehicle-fixed z-axis	0	N
		Grvty	Fx	Gravity force on vehicle CG along the vehicle-fixed x-axis	Computed	N
			Fy	Gravity force on vehicle CG along the vehicle-fixed y-axis	0	N
			Fz	Gravity force on vehicle CG along the vehicle-fixed z-axis	Computed	N
		Pwr	PwrExt		Applied external power	Computed
	Drag		Power loss due to drag	Computed	W	
PwrInfno	PwrTrnsfrd	PwrFxExt	Externally applied force power	$P_{FxExt}$	W	
	PwrTotTrnsfrd	PwrFxDrag	Drag force power	$P_D$	W	
	PwrStored	wrStoredGrvty	Rate change in gravitational potential energy	$P_g$	W	
		PwrStoredxdot	Rate in change of longitudinal kinetic energy	$P_{xdot}$	W	

**xdot – Vehicle longitudinal velocity**

scalar

Vehicle total longitudinal velocity,  $\dot{x}$ , in m/s.

**Dependencies**

To enable this port, for the **Input Mode** parameter, select Power or Force.

**ForceTot – Tractive input force**

scalar

Tractive input force,  $F_{total}$ , in N.

**Dependencies**

To enable this port, for the **Input Mode** parameter, select Kinematic.

## Parameters

### Input Mode — Specify input mode

Kinematic (default) | Force | Power

Specify the input type.

- **Kinematic** — Block uses the vehicle longitudinal velocity and acceleration to calculate the tractive force and power. Use this configuration for powertrain, driveline, and braking system design, or component sizing.
- **Force** — Block uses the tractive force to calculate the vehicle longitudinal displacement and velocity. Use this configuration for system-level performance, fuel economy, or drive cycle tracking studies.
- **Power** — Block uses the engine or transmission power to calculate the vehicle longitudinal displacement and velocity. Use this configuration for system-level performance, fuel economy, or drive cycle tracking studies.

### Dependencies

This table summarizes the port and input mode configurations.

Input Mode	Creates Ports
Kinematic	xdot xddot
Force	Force
Power	Power

### Mass — Vehicle body mass

1200 (default) | scalar

Vehicle body mass,  $m$ , in kg.

### Rolling resistance coefficient, $a$ — Rolling

196 (default) | scalar

Steady-state rolling resistance coefficient,  $a$ , in N.

### Rolling and driveline resistance coefficient, $b$ — Rolling and driveline

2.232 (default) | scalar

Viscous driveline and rolling resistance coefficient,  $b$ , in N\*s/m.

### Aerodynamic drag coefficient, $c$ — Drag

0.389 (default) | scalar

Aerodynamic drag coefficient,  $c$ , in N\*s<sup>2</sup>/m.

### Gravitational acceleration, $g$ — Gravity

9.81 (default) | scalar

Gravitational acceleration,  $g$ , in m/s<sup>2</sup>.

### **Initial position, $x_o$ – Position**

0 (default) | scalar

Vehicle longitudinal initial position, in m.

### **Initial velocity, $\dot{x}_o$ – Velocity**

0 (default) | scalar

Vehicle longitudinal initial velocity with respect to ground, in m/s.

## **References**

- [1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers (SAE), 1992.
- [2] Light Duty Vehicle Performance And Economy Measure Committee. *Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques*. Standard J1263\_201003. SAE International, March 2010.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Drive Cycle Source | Vehicle Body 1DOF Longitudinal | Vehicle Body 3DOF Longitudinal

### **Topics**

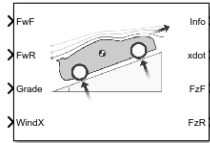
“Coordinate Systems in Vehicle Dynamics Blockset”

### **Introduced in R2017a**

# Vehicle Body 1DOF Longitudinal

Two-axle vehicle in forward and reverse motion

**Library:** Powertrain Blockset / Vehicle Dynamics  
Vehicle Dynamics Blockset / Vehicle Body



## Description

The Vehicle Body 1DOF Longitudinal block implements a one degree-of-freedom (1DOF) rigid vehicle body with constant mass undergoing longitudinal (that is, forward and reverse) motion. Use the block:

- In powertrain and fuel economy studies to represent the vehicle inertial and drag loads when weight transfer from vertical and pitch motions are negligible.
- To determine the engine torque and power required for the vehicle to follow a specified drive cycle.

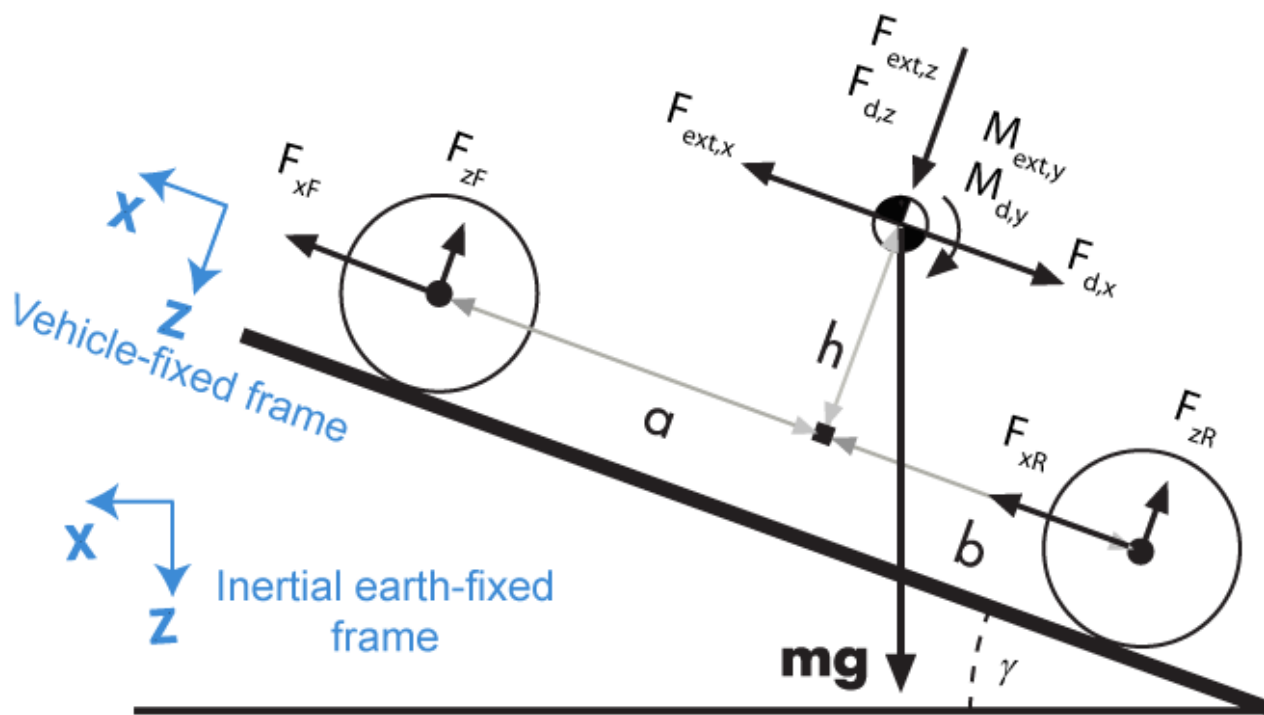
You can select block options to create input ports for external forces, moments, air temperature, and wind speed.

Block Option Setting	External Input Ports	Description
<b>External forces</b>	FExt	External force applied to vehicle CG in the vehicle-fixed frame.
<b>External moments</b>	MExt	External moment about vehicle CG in the vehicle-fixed frame.
<b>Air temperature</b>	AirTemp	Ambient air temperature. Consider this option if you want to vary the temperature during run-time.
<b>Wind X,Y,Z</b>	WindXYZ	Wind speed along earth-fixed X-, Y-, and Z-axes.  If you do not select this option, the block implements input port WindX — Longitudinal wind speed along the earth-fixed X-axis.

## Vehicle Body Model

The vehicle axles are parallel and form a plane. The longitudinal direction lies in this plane and is perpendicular to the axles. If the vehicle is traveling on an inclined slope, the normal direction is not parallel to gravity but is always perpendicular to the axle-longitudinal plane.

The block uses the net effect of all the forces and torques acting on it to determine the vehicle motion. The longitudinal tire forces push the vehicle forward or backward. The weight of the vehicle acts through its center of gravity (CG). The grade angle changes the direction of the resolved gravitational force acting on the vehicle CG. Similarly, the block resolves the resistive aerodynamic drag force on the vehicle CM.



The Vehicle Body 1DOF Longitudinal block implements these equations.

$$F_b = m\ddot{x}$$

$$F_b = F_{xF} + F_{xR} - F_{d,x} + F_{ext,x} - mgsin\gamma$$

Zero normal acceleration and zero pitch torque determine the normal force on each front and rear axles.

$$F_{zF} = \frac{-M_{ext,y} - M_{d,y} + b(F_{d,z} + F_{ext,z} + mg\cos\gamma) - h(-F_{ext,x} + F_{d,x} + mgsin\gamma + m\ddot{x})}{N_F(a + b)}$$

$$F_{zR} = \frac{M_{ext,y} + M_{d,y} + a(F_{d,z} + F_{ext,z} + mg\cos\gamma) + h(-F_{ext,x} + F_{d,x} + mgsin\gamma + m\ddot{x})}{N_R(a + b)}$$

The wheel normal forces satisfy this equation.

$$N_FF_{zF} + N_RF_{zR} - F_{ext,z} = mg\cos\gamma$$

### Wind and Drag Forces

The block subtracts the wind speeds from the vehicle velocity components to obtain a net relative airspeed. To calculate the drag force and moments acting on the vehicle, the block uses the net relative airspeed.

$$F_{d,x} = \frac{1}{2TR} C_d A_f P_{abs} \dot{x}$$

$$F_{d,z} = \frac{1}{2TR} C_l A_f P_{abs} \dot{x}$$

$$M_{d,y} = \frac{1}{2TR} C_{pm} A_f P_{abs} \dot{x} (a + b)$$

By default, to calculate the wind speed along the vehicle-fixed  $x$ -axis, the block uses the longitudinal wind speed along the earth-fixed  $X$ -axis. If you select **WindX,Y,Z**, the block uses the wind speed along the earth-fixed  $X$ -,  $Y$ -,  $Z$ -axes.

### Power Accounting

For the power accounting, the block implements these equations.

Bus Signal		Description	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks <ul style="list-style-type: none"> <li>Positive signals indicate flow into block</li> <li>Negative signals indicate flow out of block</li> </ul>	PwrFxExt	Externally applied force power $P_{FxExt} = F_{xExt} \dot{x}$
		PwrFwFx	Longitudinal force power applied at the front axle $P_{FwFx} = F_{wFx} \dot{x}$
		PwrFwRx	Longitudinal force power applied at the rear axle $P_{FwRx} = F_{wRx} \dot{x}$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred <ul style="list-style-type: none"> <li>Positive signals indicate an input</li> <li>Negative signals indicate a loss</li> </ul>	PwrFxDrag	Drag force power $P_d = - \frac{0.5 C_d A_f P_{abs} (\dot{x}^2 - w_x)^2}{287.058T} \dot{x}$
	PwrStored — Stored energy rate of change <ul style="list-style-type: none"> <li>Positive signals indicate an increase</li> <li>Negative signals indicate a decrease</li> </ul>	wrStoredGrvty	Rate change in gravitational potential energy $P_g = - mg \dot{Z}$
PwrStoredxdot		Rate in change of longitudinal kinetic energy $P_{\dot{x}} = m \ddot{x} \dot{x}$	

The equations use these variables.

$F_{xf}$ ,  $F_{xr}$  Longitudinal forces on each wheel at the front and rear ground contact points, respectively

$F_{zf}, F_{zr}$	Normal load forces on each wheel at the front and rear ground contact points, respectively
$F_{wF}, F_{wR}$	Longitudinal force on front and rear axles along vehicle-fixed x-axis
$F_{xExt}, F_{wR}$	External force along the vehicle-fixed x-axis
$F_{d,x}, F_{d,z}$	Longitudinal and normal drag force on vehicle CG
$M_{d,y}$	Torque due to drag on vehicle about the vehicle-fixed y-axis
$F_d$	Aerodynamic drag force
$V_x$	Velocity of the vehicle. When $V_x > 0$ , the vehicle moves forward. When $V_x < 0$ , the vehicle moves backward.
$N_f, N_r$	Number of wheels on front and rear axle, respectively
$\gamma$	Angle of road grade
$m$	Vehicle body mass
$a, b$	Distance of front and rear axles, respectively, from the normal projection point of vehicle CG onto the common axle plane
$h$	Height of vehicle CG above the axle plane
$C_d$	Frontal air drag coefficient
$A_f$	Frontal area
$P_{abs}$	Absolute pressure
$\rho$	Mass density of air
$x, \dot{x}, \ddot{x}$	Vehicle longitudinal position, velocity, and acceleration along the vehicle-fixed x-axis
$w_x$	Wind speed along the vehicle-fixed x-axis
$\dot{z}$	Vehicle vertical velocity along the vehicle-fixed z-axis

## Limitations

The Vehicle Body 1DOF Longitudinal block lets you model only longitudinal dynamics, parallel to the ground and oriented along the direction of motion. The vehicle is assumed to be in pitch and normal equilibrium. The block does not model pitch or vertical movement. To model a vehicle with three degrees-of-freedom (DOF), use the Vehicle Body 3DOF Longitudinal.

## Ports

### Input

#### FExt — External force on vehicle CG

array

External forces applied to vehicle CG,  $F_{xext}, F_{yext}, F_{zext}$ , in vehicle-fixed frame, in N. Signal vector dimensions are [1x3] or [3x1].

### Dependencies

To enable this port, select **External forces**.



**MExt — External moment about vehicle CG**

array

External moment about vehicle CG,  $M_x$ ,  $M_y$ ,  $M_z$ , in the vehicle-fixed frame, in N·m. Signal vector dimensions are [1x3] or [3x1].

**Dependencies**

To enable this port, select **External moments**.

**FwF — Total longitudinal force on front axle**

scalar

Longitudinal force on the front axle,  $F_{wf}$ , along vehicle-fixed x-axis, in N.

**FwR — Total longitudinal force on rear axle**

scalar

Longitudinal force on the rear axle,  $F_{wr}$ , along vehicle-fixed x-axis, in N.

**Grade — Road grade angle**

scalar

Road grade angle,  $\gamma$ , in deg.

**WindX — Longitudinal wind speed**

scalar

Longitudinal wind speed,  $W_w$ , along earth-fixed X-axis, in m/s.

**Dependencies**

To enable this port, clear **Wind X,Y,Z components**.

**WindXYZ — Wind speed**

array

Wind speed,  $W_w$ ,  $W_{wy}$ ,  $W_{wz}$  along inertial X-, Y-, and Z-axes, in m/s. Signal vector dimensions are [1x3] or [3x1].

**Dependencies**

To enable this port, select **Wind X,Y,Z components**.

**AirTemp — Ambient air temperature**

scalar

Ambient air temperature,  $T_{air}$ , in K. Considering this option if you want to vary the temperature during run-time.

**Dependencies**

To enable this port, select **Air temperature**.

**Output****Info — Bus signal**

bus

Bus signal containing these block values.

Signal				Description	Value	Units
InertFrm	Cg	Disp	X	Vehicle CG displacement along earth-fixed X-axis	Computed	m
			Y	Vehicle CG displacement along earth-fixed Y-axis	0	m
			Z	Vehicle CG displacement along earth-fixed Z-axis	Computed	m
		Vel	Xdot	Vehicle CG velocity along earth-fixed X-axis	Computed	m/s
			Ydot	Vehicle CG velocity along earth-fixed Y-axis	0	m/s
			Zdot	Vehicle CG velocity along earth-fixed Z-axis	Computed	m/s
		Ang	phi	Rotation of vehicle-fixed frame about the earth-fixed X-axis (roll)	0	rad
			theta	Rotation of vehicle-fixed frame about the earth-fixed Y-axis (pitch)	Computed (input - grade angle)	rad
			psi	Rotation of vehicle-fixed frame about the earth-fixed Z-axis (yaw)	0	rad
	FrntAxl	Disp	X	Front axle displacement along the earth-fixed X-axis	Computed	m
			Y	Front axle displacement along the earth-fixed Y-axis	0	m
			Z	Front axle displacement along the earth-fixed Z-axis	Computed	m
		Vel	Xdot	Front axle velocity along the earth-fixed X-axis	Computed	m/s
			Ydot	Front axle velocity along the earth-fixed Y-axis	0	m/s
			Zdot	Front axle velocity along the earth-fixed Z-axis	Computed	m/s
	RearAxl	Disp	X	Rear axle displacement along the earth-fixed X-axis	Computed	m
			Y	Rear axle displacement along the earth-fixed Y-axis	0	m
			Z	Rear axle displacement along the earth-fixed Z-axis	Computed	m

Signal			Description	Value	Units			
		Vel	Xdot	Rear axle velocity along the earth-fixed X-axis	Computed	m/s		
			Ydot	Rear axle velocity along the earth-fixed Y-axis	0	m/s		
			Zdot	Rear axle velocity along the earth-fixed Z-axis	Computed	m/s		
BdyFrm	Cg	Disp	x	Vehicle CG displacement along the vehicle-fixed x-axis	Computed	m		
			y	Vehicle CG displacement along the vehicle-fixed y-axis	0	m		
			z	Vehicle CG displacement along the vehicle-fixed z-axis	0	m		
		Vel	xdot	Vehicle CG velocity along the vehicle-fixed x-axis	Computed	m/s		
			ydot	Vehicle CG velocity along the vehicle-fixed y-axis	0	m/s		
			zdot	Vehicle CG velocity along the vehicle-fixed z-axis	0	m/s		
		AngVel	p	Vehicle angular velocity about the vehicle-fixed x-axis (roll rate)	0	rad/s		
			q	Vehicle angular velocity about the vehicle-fixed y-axis (pitch rate)	0	rad/s		
			r	Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate)	0	rad/s		
		Accel	ax	Vehicle CG acceleration along the vehicle-fixed x-axis	Computed	gn		
			ay	Vehicle CG acceleration along the vehicle-fixed y-axis	0	gn		
			az	Vehicle CG acceleration along the vehicle-fixed z-axis	0	gn		
			Forces	Body	Fx	Net force on vehicle CG along the vehicle-fixed x-axis	0	N

Signal		Description	Value	Units			
		Fy	Net force on vehicle CG along the vehicle-fixed y-axis	0	N		
			Fz	Net force on vehicle CG along the vehicle-fixed z-axis	0	N	
		Ext	Fx	External force on vehicle CG along the vehicle-fixed x-axis	Computed	N	
			Fy	External force on vehicle CG along the vehicle-fixed y-axis	Computed	N	
			Fz	External force on vehicle CG along the vehicle-fixed z-axis	Computed	N	
		FrntAxl	Fx	Longitudinal force on front axle, along the vehicle-fixed x-axis	0	N	
			Fy	Lateral force on front axle, along the vehicle-fixed y-axis	0	N	
			Fz	Normal force on front axle, along the vehicle-fixed z-axis	Computed	N	
		RearAxl	Fx	Longitudinal force on rear axle, along the vehicle-fixed x-axis	0	N	
			Fy	Lateral force on rear axle, along the vehicle-fixed y-axis	0	N	
			Fz	Normal force on rear axle, along the vehicle-fixed z-axis	Computed	N	
		Tires	FrntTire	Fx	Front tire force, along the vehicle-fixed x-axis	0	N
				Fy	Front tire force, along the vehicle-fixed y-axis	0	N
				Fz	Front tire force, along the vehicle-fixed z-axis	Computed	N
			RearTire	Fx	Rear tire force, along the vehicle-fixed x-axis	0	N
Fy	Rear tire force, along the vehicle-fixed y-axis			0	N		

Signal				Description	Value	Units		
			F <sub>z</sub>	Rear tire force, along the vehicle-fixed z-axis	Computed	N		
		Drag	F <sub>x</sub>	Drag force on vehicle CG along the vehicle-fixed x-axis	Computed	N		
			F <sub>y</sub>	Drag force on vehicle CG along the vehicle-fixed y-axis	Computed	N		
			F <sub>z</sub>	Drag force on vehicle CG along the vehicle-fixed z-axis	Computed	N		
		Grvty	F <sub>x</sub>	Gravity force on vehicle CG along the vehicle-fixed x-axis	Computed	N		
			F <sub>y</sub>	Gravity force on vehicle CG along the vehicle-fixed y-axis	0	N		
			F <sub>z</sub>	Gravity force on vehicle CG along the vehicle-fixed z-axis	Computed	N		
	Moments	Body	M <sub>x</sub>	Net moment on vehicle CG about the vehicle-fixed x-axis	0	N·m		
				M <sub>y</sub>	Net moment on vehicle CG about the vehicle-fixed y-axis	0	N·m	
				M <sub>z</sub>	Net moment on vehicle CG about the vehicle-fixed z-axis	0	N·m	
			Drag	M <sub>x</sub>	Drag moment on vehicle CG about the vehicle-fixed x-axis	Computed	N·m	
					M <sub>y</sub>	Drag moment on vehicle CG about the vehicle-fixed y-axis	Computed	N·m
					M <sub>z</sub>	Drag moment on vehicle CG about the vehicle-fixed z-axis	Computed	N·m
			Ext	F <sub>x</sub>	External moment on vehicle CG about the vehicle-fixed x-axis	Computed	N·m	
					F <sub>y</sub>	External moment on vehicle CG about the vehicle-fixed y-axis	Computed	N·m

Signal			Description	Value	Units	
		Fz	External moment on vehicle CG about the vehicle-fixed z-axis	Computed	N·m	
FrntAxl	Disp	x	Front axle displacement along the vehicle-fixed x-axis	Computed	m	
		y	Front axle displacement along the vehicle-fixed y-axis	0	m	
		z	Front axle displacement along the vehicle-fixed z-axis	Computed	m	
	Vel	xdot	Front axle velocity along the vehicle-fixed x-axis	Computed	m/s	
		ydot	Front axle velocity along the vehicle-fixed y-axis	0	m/s	
		zdot	Front axle velocity along the vehicle-fixed z-axis	Computed	m/s	
	Steer	WhlAngFL	Front left wheel steering angle	Computed	rad	
		WhlAngFR	Front right wheel steering angle	Computed	rad	
	RearAxl	Disp	x	Rear axle displacement along the vehicle-fixed x-axis	Computed	m
			y	Rear axle displacement along the vehicle-fixed y-axis	0	m
			z	Rear axle displacement along the vehicle-fixed z-axis	Computed	m
		Vel	xdot	Rear axle velocity along the vehicle-fixed x-axis	Computed	m/s
ydot			Rear axle velocity along the vehicle-fixed y-axis	0	m/s	
zdot			Rear axle velocity along the vehicle-fixed z-axis	Computed	m/s	
Steer		WhlAngRL	Rear left wheel steering angle	Computed	rad	
		WhlAngRR	Rear right wheel steering angle	Computed	rad	
Pwr		PwrExt		Applied external power	Computed	W
		Drag		Power loss due to drag	Computed	W

Signal			Description	Value	Units
PwrInfo	PwrTrnsfrd	PwrFxExt	Externally applied force power	Computed	W
		PwrFwFx	Longitudinal force power applied at the front axle	Computed	W
		PwrFwRx	Longitudinal force power applied at the rear axle	Computed	W
	PwrNotTrnsfrd	PwrFxDrag	Drag force power	Computed	W
	PwrStored	wrStoredGrvty	Rate change in gravitational potential energy	Computed	W
		PwrStoredxdot	Rate in change of longitudinal kinetic energy	Computed	W

**xdot – Vehicle body longitudinal velocity**

scalar

Vehicle body longitudinal velocity along the earth-fixed reference frame X-axis, in m/s.

**FzF – Front axle normal force**

scalar

Normal load force on the front axle,  $F_{zf}$ , along vehicle-fixed z-axis, in N.

**FzR – Rear axle normal force**

scalar

Normal force on rear axle,  $F_{zr}$ , along the vehicle-fixed z-axis, in N.

**Parameters****Options****External forces – FExt input port**

off (default) | on

Specify to create input port FExt.

**External moments – MExt input port**

off (default) | on

Specify to create input port MExt.

**Air temperature – AirTemp input port**

off (default) | on

Specify to create input port AirTemp.

**Wind X,Y,Z components – WindXYZ input port**

off (default) | on

Specify to create input port WindXYZ.

**Longitudinal****Number of wheels on front axle, NF – Front wheel count**

2 (default) | scalar

Number of wheels on front axle,  $N_F$ . The value is dimensionless.

**Number of wheels on rear axle, NR – Rear wheel count**

2 (default) | scalar

Number of wheels on rear axle,  $N_R$ . The value is dimensionless.

**Mass, m – Vehicle mass**

1500 (default) | scalar

Vehicle mass,  $M$ , in kg.

**Horizontal distance from CG to front axle, a – Front axle distance**

1.4 (default) | scalar

Horizontal distance  $a$  from the vehicle CG to the front wheel axle, in m.

**Horizontal distance from CG to rear axle, b – Rear axle distance**

1.8 (default) | scalar

Horizontal distance  $b$  from the vehicle CG to the rear wheel axle, in m.

**CG height above axles, h – Height**

.35 (default) | scalar

Height of vehicle CG above the ground,  $h$ , in m.

**Drag coefficient, Cd – Drag**

.3 (default) | scalar

Air drag coefficient,  $C_d$ . The value is dimensionless.

**Lift coefficient, Cl – Lift**

0 (default) | scalar

Air lift coefficient,  $C_l$ . The value is dimensionless.

**Pitch drag moment coefficient, Cpm – Pitch drag**

0 (default) | scalar

Pitch drag moment coefficient,  $C_{pm}$ . The value is dimensionless.

**Frontal area, Af – Area**

4 (default) | scalar

Effective vehicle cross-sectional area,  $A$ , to calculate the aerodynamic drag force on the vehicle, in  $m^2$ .

**Initial position, x\_o – Position**

0 (default) | scalar



Vehicle body longitudinal initial position along the vehicle-fixed x-axis,  $x_0$ , in m.

**Initial velocity,  $\dot{x}_0$  – Velocity**

0 (default) | scalar

Vehicle body longitudinal initial velocity along the vehicle-fixed x-axis,  $\dot{x}_0$ , in m/s.

**Environment****Absolute air pressure,  $P_{abs}$  – Pressure**

101325 (default) | scalar

Environmental air absolute pressure,  $P_{abs}$ , in Pa.

**Air temperature,  $T$  – Ambient air temperature**

273 (default) | scalar

Ambient air temperature,  $T_{air}$ , in K.

**Dependencies**

To enable this parameter, clear **Air temperature**.

**Gravitational acceleration,  $g$  – Gravity**

9.81 (default) | scalar

Gravitational acceleration,  $g$ , in  $\text{m/s}^2$ .

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Vehicle Body 3DOF Longitudinal | Vehicle Body Total Road Load

**Topics**

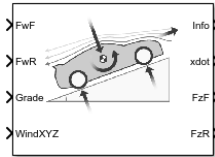
“Coordinate Systems in Vehicle Dynamics Blockset”

**Introduced in R2017a**

## Vehicle Body 3DOF Longitudinal

3DOF rigid vehicle body to calculate longitudinal, vertical, and pitch motion

**Library:** Powertrain Blockset / Vehicle Dynamics  
Vehicle Dynamics Blockset / Vehicle Body



### Description

The Vehicle Body 3DOF Longitudinal block implements a three degrees-of-freedom (3DOF) rigid vehicle body model with configurable axle stiffness to calculate longitudinal, vertical, and pitch motion. The block accounts for body mass, aerodynamic drag, road incline, and weight distribution between the axles due to acceleration and the road profile.

You can specify the type of axle attachment to the vehicle:

- Grade angle — Vertical axle displacement from road surface to axles remains constant. The block uses tabular stiffness and damping parameters to model the suspension forces acting between the vehicle body and axles.
- Axle displacement — Axles have input-provided vertical displacement and velocity with respect to the road grade. The block uses tabular stiffness and damping parameters to model the suspension forces acting between the vehicle body and axle.
- External suspension — Axles have externally applied forces for coupling the vehicle body to custom suspension models.

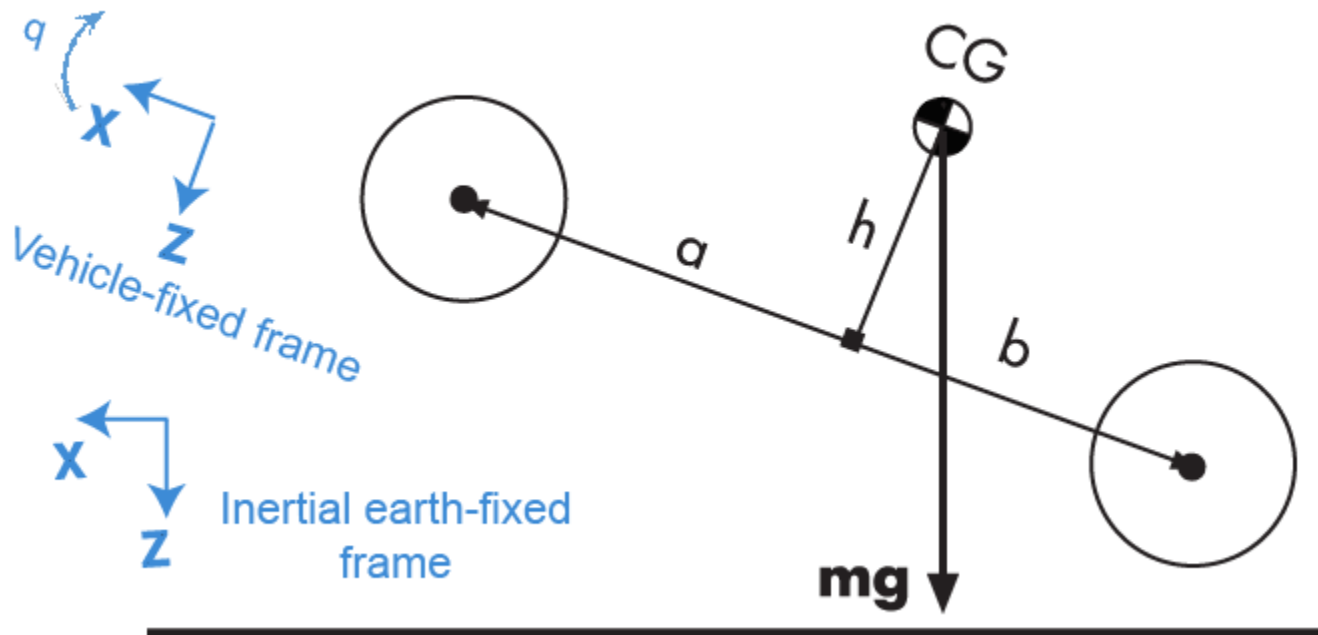
If the weight transfer from vertical and pitch motions are not negligible, consider using this block to represent vehicle motion in powertrain and fuel economy studies. For example, in studies with heavy braking or acceleration or road profiles that contain larger vertical changes.

The block uses rigid-body vehicle motion, suspension system forces, and wind and drag forces to calculate the normal forces on the front and rear axles. The block resolves the force components and moments on the rigid vehicle body frame:

$$F_x = F_{wF} + F_{wR} - F_{d,x} - F_{sx,F} - F_{sx,R} + F_{g,x}$$

$$F_z = F_{d,z} - F_{sz,F} - F_{sz,R} + F_{g,z}$$

$$M_y = aF_{sz,F} - bF_{sz,R} + h(F_{wF} + F_{wR} + F_{sx,F} + F_{sx,R}) - M_{d,y}$$



### Rigid-Body Vehicle Motion

The vehicle axles are parallel and form a plane. The longitudinal direction lies in this plane and is perpendicular to the axles. If the vehicle is traveling on an inclined slope, the normal direction is not parallel to gravity but is always perpendicular to the axle-longitudinal plane.

The block uses the net effect of all the forces and torques acting on it to determine the vehicle motion. The longitudinal tire forces push the vehicle forward or backward. The weight of the vehicle acts through its center of gravity (CG). Depending on the inclined angle, the weight pulls the vehicle to the ground and either forward or backward. Whether the vehicle travels forward or backward, aerodynamic drag slows it down. For simplicity, the drag is assumed to act through the CG.

The Vehicle Body 3DOF Longitudinal implements these equations.

$$\ddot{x} = \frac{F_x}{m} - qz$$

$$\ddot{z} = \frac{F_z}{m} - qx$$

$$\dot{q} = \frac{M_y}{I_{yy}}$$

$$\dot{\theta} = q$$

### Suspension System Forces

If you configure the block with the **Ground interaction type** parameter `Grade angle` or `Axle displacement, velocity`, the block uses nonlinear stiffness and damping parameters to model the suspension system.

The front and rear axle suspension forces are given by:

$$F_{S_F} = N_F[Fk_F + Fb_F]$$

$$F_{S_R} = N_R[Fk_R + Fb_R]$$

The block uses lookup tables to implement the front and rear suspension stiffness. To account for kinematic and material nonlinearities, including collisions with end-stops, the tables are functions of the stroke.

$$Fk_F = f(dZ_F)$$

$$Fk_R = f(dZ_R)$$

The block uses lookup tables to implement the front and rear suspension damping. To account for nonlinearities, compression, and rebound, the tables are functions of the stroke rate.

$$Fb_F = f(d\dot{Z}_F)$$

$$Fb_R = f(d\dot{Z}_R)$$

The stroke is the difference in the vehicle vertical and axle positions. The stroke rate is the difference in the vertical and axle velocities.

$$dZ_F = Z_F - \bar{Z}_F$$

$$dZ_R = Z_R - \bar{Z}_R$$

$$d\dot{Z}_F = \dot{Z}_F - \dot{\bar{Z}}_F$$

$$d\dot{Z}_R = \dot{Z}_R - \dot{\bar{Z}}_R$$

When the **Ground interaction type** parameter is `Grade angle`, the axle vertical positions ( $\bar{Z}_F, \bar{Z}_R$ ) and velocities ( $\dot{\bar{Z}}_F, \dot{\bar{Z}}_R$ ) are set to  $\theta$ .

### Wind and Drag Forces

The block subtracts the wind speeds from the vehicle velocity components to obtain a net relative airspeed. To calculate the drag force and moments acting on the vehicle, the block uses the net relative airspeed:

$$F_{d,x} = \frac{1}{2TR} C_d A_f P_{abs}(\dot{x})$$

$$F_{d,z} = \frac{1}{2TR} C_l A_f P_{abs}(\dot{x})$$

$$M_{d,y} = \frac{1}{2TR} C_{pm} A_f P_{abs}(\dot{x})(a + b)$$

### Power Accounting

For the power accounting, the block implements these equations.

Bus Signal		Description	Equations	
PwrInfo	PwrTrnsfrd — Power transferred between blocks	PwrFxExt	Externally applied longitudinal force power	$P_{FxExt} = F_{xExt}\dot{x}$
		PwrFzExt	Externally applied longitudinal force power	$P_{FzExt} = F_{zExt}\dot{z}$
		PwrMyExt	Externally applied pitch moment power	$P_{MzExt} = M_{zExt}\dot{\theta}$
		PwrFwFx	Longitudinal force applied at the front axle	$P_{FwFx} = F_{wFx}\dot{x}$
		PwrFwRx	Longitudinal force applied at the rear axle	$P_{FwRx} = F_{wRx}\dot{x}$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred	PwrFsF	Internal power transferred between suspension and vehicle body at the front axle	$P_{Fs,F} = -P_{FwFx} + P_{FsbF} + P_{Fsk,F} + F_{xF}\dot{x}_F + F_{zF}\dot{z}_F$
		PwrFsR	Internal power transferred between suspension and vehicle body at the rear axle	$P_{Fs,R} = -P_{FwRx} + P_{Fsb,R} + P_{Fsk,R} + F_{xR}\dot{x}_R + F_{zR}\dot{z}_R$
		PwrFxDrag	Longitudinal drag force power	$P_{d,x} = F_{d,x}\dot{x}$
		PwrFzDrag	Vertical drag force power	$P_{d,z} = F_{d,z}\dot{z}$
		PwrMyDrag	Drag pitch moment power	$P_{d,My} = M_{d,y}\dot{\theta}$
		PwrFsb	Total suspension damping power	$P_{Fsb} = \sum_{i=F,R} F_{sb,i}\dot{z}_i$
		PwrStored — Stored energy rate of change	PwrStoredGrvty	Rate change in gravitational potential energy
	PwrStoredxdot		Rate of change of longitudinal kinetic energy	$P_{\dot{x}} = m\dot{x}\dot{x}$
	PwrStoredzdot		Rate of change of longitudinal kinetic energy	$P_{\dot{z}} = m\dot{z}\dot{z}$
		<ul style="list-style-type: none"> <li>Positive signals indicate flow into block</li> <li>Negative signals indicate flow out of block</li> </ul>		
	<ul style="list-style-type: none"> <li>Positive signals indicate an input</li> <li>Negative signals indicate a loss</li> </ul>			
	<ul style="list-style-type: none"> <li>Positive signals indicate an increase</li> <li>Negative signals indicate a decrease</li> </ul>			

Bus Signal		Description	Equations
	PwrStoredq	Rate of change of rotational pitch kinetic energy	$P_{\dot{\theta}} = I_{yy}\ddot{\theta}\dot{\theta}$
	PwrStoredFsFzSprng	Stored spring energy from front suspension	$P_{FskF} = F_{sk,F}\dot{z}_F$
	PwrStoredFsRzSprng	Stored spring energy from rear suspension	$P_{FskR} = F_{sk,R}\dot{z}_R$

The equations use these variables.

$F_x$	Longitudinal force on vehicle
$F_z$	Normal force on vehicle
$M_y$	Torque on vehicle about the vehicle-fixed y-axis
$F_{wF}, F_{wR}$	Longitudinal force on front and rear axles along vehicle-fixed x-axis
$F_{d,x}, F_{d,z}$	Longitudinal and normal drag force on vehicle CG
$F_{sx,F}, F_{sx,R}$	Longitudinal suspension force on front and rear axles
$F_{sz,F}, F_{sz,R}$	Normal suspension force on front and rear axles
$F_{g,x}, F_{g,z}$	Longitudinal and normal gravitational force on vehicle along the vehicle-fixed frame
$M_{d,y}$	Torque due to drag on vehicle about the vehicle-fixed y-axis
$a, b$	Distance of front and rear axles, respectively, from the normal projection point of vehicle CG onto the common axle plane
$h$	Height of vehicle CG above the axle plane along vehicle-fixed z-axis
$F_{sF}, F_{sR}$	Front and rear axle suspension force along vehicle-fixed z-axis
$Z_{wF}, Z_{wR}$	Front and rear vehicle normal position along earth-fixed z-axis
$\Theta$	Vehicle pitch angle about the vehicle-fixed y-axis
$m$	Vehicle body mass
$N_F, N_R$	Number of front and rear wheels
$I_{yy}$	Vehicle body moment of inertia about the vehicle-fixed y-axis
$x, \dot{x}, \ddot{x}$	Vehicle longitudinal position, velocity, and acceleration along the vehicle-fixed x-axis
$z, \dot{z}, \ddot{z}$	Vehicle normal position, velocity, and acceleration along the vehicle-fixed z-axis
$Fk_F, Fk_R$	Front and rear wheel suspension stiffness force along vehicle-fixed z-axis
$Fb_F, Fb_R$	Front and rear wheel suspension damping force along vehicle-fixed z-axis
$Z_F, Z_R$	Front and rear vehicle vertical position along earth-fixed Z-axis
$\dot{Z}_F, \dot{Z}_R$	Front and rear vehicle vertical velocity along vehicle-fixed z-axis
$\bar{Z}_F, \bar{Z}_R$	Front and rear wheel axle vertical position along vehicle-fixed z-axis
$\dot{\bar{Z}}_F, \dot{\bar{Z}}_R$	Front and rear wheel axle vertical velocity along earth-fixed z-axis

$dZ_F, dZ_R$	Front and rear axle suspension deflection along vehicle-fixed $z$ -axis
$d\dot{Z}_F, d\dot{Z}_R$	Front and rear axle suspension deflection rate along vehicle-fixed $z$ -axis
$C_d$	Frontal air drag coefficient acting along the vehicle-fixed $x$ -axis
$C_l$	Lateral air drag coefficient acting along the vehicle-fixed $z$ -axis
$C_{pm}$	Air drag pitch moment acting about the vehicle-fixed $y$ -axis
$A_f$	Frontal area
$P_{abs}$	Environmental absolute pressure
$R$	Atmospheric specific gas constant
$T$	Environmental air temperature
$w_x$	Wind speed along the vehicle-fixed $x$ -axis

## Ports

### Input

#### **FExt — External force on vehicle CG**

array

External forces applied to vehicle CG,  $F_{x_{ext}}, F_{y_{ext}}, F_{z_{ext}}$ , in vehicle-fixed frame, in N. Signal vector dimensions are [1x3] or [3x1].

#### **Dependencies**

To enable this port, select **External forces**.

#### **MExt — External moment about vehicle CG**

array

External moment about vehicle CG,  $M_x, M_y, M_z$ , in the vehicle-fixed frame, in N·m. Signal vector dimensions are [1x3] or [3x1].

#### **Dependencies**

To enable this port, select **External moments**.

#### **FwF — Total longitudinal force on the front axle**

scalar

Longitudinal force on the front axle,  $F_{wF}$ , along vehicle-fixed  $x$ -axis, in N.

#### **FwR — Total longitudinal force on the rear axle**

scalar

Longitudinal force on the rear axle,  $F_{wR}$ , along vehicle-fixed  $x$ -axis, in N.

#### **Grade — Road grade angle**

scalar

Road grade angle,  $\gamma$ , in deg.

#### **FsF — Suspension force on front axle per wheel**

vector

Suspension force on front axle,  $F_{s_F}$ , along the vehicle-fixed  $z$ -axis, in N.

**Dependencies**

To enable this port, for the **Ground interaction type** parameter, select External suspension.

**FsR — Suspension force on rear axle per wheel**

vector

Suspension force on rear axle,  $F_{s_R}$ , along the vehicle-fixed  $z$ -axis, in N.

**Dependencies**

To enable this port, for the **Ground interaction type** parameter, select External suspension.

**WindXYZ — Wind speed**

array

Wind speed,  $W_x$ ,  $W_y$ ,  $W_z$  along earth-fixed  $X$ -,  $Y$ -, and  $Z$ -axes, in m/s. Signal vector dimensions are  $[1 \times 3]$  or  $[3 \times 1]$ .

**AirTemp — Ambient air temperature**

scalar

Ambient air temperature,  $T_{air}$ , in K. Considering this option if you want to vary the temperature during run-time.

**Dependencies**

To enable this port, select **Air temperature**.

**zF,R — Forward and rear axle positions**

vector

Forward and rear axle positions along the vehicle-fixed  $z$ -axis,  $\bar{z}_F$ ,  $\bar{z}_R$ , in m.

**Dependencies**

To enable this port, for the **Ground interaction type** parameter, select Axle displacement, velocity.

**zdotF,R — Forward and rear axle velocities**

vector

Forward and rear axle velocities along the vehicle-fixed  $z$ -axis,  $\dot{\bar{z}}_F$ ,  $\dot{\bar{z}}_R$ , in m/s.

**Dependencies**

To enable this port, for the **Ground interaction type** parameter, select Axle displacement, velocity.

**Output****Info — Bus signal**

bus

Bus signal containing these block values.



Signal				Description	Value	Units
InertFrm	Cg	Disp	X	Vehicle CG displacement along earth-fixed X-axis	Computed	m
			Y	Vehicle CG displacement along earth-fixed Y-axis	0	m
			Z	Vehicle CG displacement along earth-fixed Z-axis	Computed	m
		Vel	Xdot	Vehicle CG velocity along earth-fixed X-axis	Computed	m/s
			Ydot	Vehicle CG velocity along earth-fixed Y-axis	0	m/s
			Zdot	Vehicle CG velocity along earth-fixed Z-axis	Computed	m/s
		Ang	phi	Rotation of vehicle-fixed frame about the earth-fixed X-axis (roll)	0	rad
			theta	Rotation of vehicle-fixed frame about the earth-fixed Y-axis (pitch)	Computed	rad
			psi	Rotation of vehicle-fixed frame about the earth-fixed Z-axis (yaw)	0	rad
	FrntAxl	Disp	X	Front axle displacement along the earth-fixed X-axis	Computed	m
			Y	Front axle displacement along the earth-fixed Y-axis	0	m
			Z	Front axle displacement along the earth-fixed Z-axis	Computed	m
		Vel	Xdot	Front axle velocity along the earth-fixed X-axis	Computed	m/s
			Ydot	Front axle velocity along the earth-fixed Y-axis	0	m/s
			Zdot	Front axle velocity along the earth-fixed Z-axis	Computed	m/s
	RearAxl	Disp	X	Rear axle displacement along the earth-fixed X-axis	Computed	m
			Y	Rear axle displacement along the earth-fixed Y-axis	0	m
			Z	Rear axle displacement along the earth-fixed Z-axis	Computed	m
		Vel	Xdot	Rear axle velocity along the earth-fixed X-axis	Computed	m/s
			Ydot	Rear axle velocity along the earth-fixed Y-axis	0	m/s

Signal				Description	Value	Units	
			Zdot	Rear axle velocity along the earth-fixed Z-axis	Computed	m/s	
BdyFrm	Cg	Disp	x	Vehicle CG displacement along the vehicle-fixed x-axis	Computed	m	
			y	Vehicle CG displacement along the vehicle-fixed y-axis	0	m	
			z	Vehicle CG displacement along the vehicle-fixed z-axis	Computed	m	
		Vel	xdot	Vehicle CG velocity along the vehicle-fixed x-axis	Computed	m/s	
			ydot	Vehicle CG velocity along the vehicle-fixed y-axis	0	m/s	
			zdot	Vehicle CG velocity along the vehicle-fixed z-axis	Computed	m/s	
		AngVel	p	Vehicle angular velocity about the vehicle-fixed x-axis (roll rate)	0	rad/s	
			q	Vehicle angular velocity about the vehicle-fixed y-axis (pitch rate)	Computed	rad/s	
			r	Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate)	0	rad/s	
		Accel	ax	Vehicle CG acceleration along the vehicle-fixed x-axis	Computed	gn	
			ay	Vehicle CG acceleration along the vehicle-fixed y-axis	0	gn	
			az	Vehicle CG acceleration along the vehicle-fixed z-axis	Computed	gn	
		Forces	Body	Fx	Net force on vehicle CG along the vehicle-fixed x-axis	Computed	N
				Fy	Net force on vehicle CG along the vehicle-fixed y-axis	0	N
				Fz	Net force on vehicle CG along the vehicle-fixed z-axis	Computed	N

Signal		Description		Value	Units		
	Ext	Fx	External force on vehicle CG along the vehicle-fixed x-axis	Computed	N		
			Fy	External force on vehicle CG along the vehicle-fixed y-axis	Computed	N	
			Fz	External force on vehicle CG along the vehicle-fixed z-axis	Computed	N	
		FrntAxl	Fx	Longitudinal force on front axle, along the vehicle-fixed x-axis	Computed	N	
				Fy	Lateral force on front axle, along the vehicle-fixed y-axis	0	N
				Fz	Normal force on front axle, along the vehicle-fixed z-axis	Computed	N
		RearAxl	Fx	Longitudinal force on rear axle, along the vehicle-fixed x-axis	Computed	N	
				Fy	Lateral force on rear axle, along the vehicle-fixed y-axis	0	N
				Fz	Normal force on rear axle, along the vehicle-fixed z-axis	Computed	N
	Tires	FrntTire	Fx	Front tire force, along the vehicle-fixed x-axis	0	N	
			Fy	Front tire force, along the vehicle-fixed y-axis	0	N	
			Fz	Front tire force, along the vehicle-fixed z-axis	Computed	N	
		RearTire	Fx	Rear tire force, along the vehicle-fixed x-axis	0	N	
			Fy	Rear tire force, along the vehicle-fixed y-axis	0	N	
			Fz	Rear tire force, along the vehicle-fixed z-axis	Computed	N	
	Drag	Fx	Drag force on vehicle CG along the vehicle-fixed x-axis	Computed	N		

Signal			Description	Value	Units	
		Grvty	Fy	Drag force on vehicle CG along the vehicle-fixed y-axis	Computed	N
			Fz	Drag force on vehicle CG along the vehicle-fixed z-axis	Computed	N
			Fx	Gravity force on vehicle CG along the vehicle-fixed x-axis	Computed	N
			Fy	Gravity force on vehicle CG along the vehicle-fixed y-axis	0	N
			Fz	Gravity force on vehicle CG along the vehicle-fixed z-axis	Computed	N
	Moments	Body	Mx	Body moment on vehicle CG about the vehicle-fixed x-axis	0	N·m
			My	Body moment on vehicle CG about the vehicle-fixed y-axis	Computed	N·m
			Mz	Body moment on vehicle CG about the vehicle-fixed z-axis	0	N·m
		Drag	Mx	Drag moment on vehicle CG about the vehicle-fixed x-axis	0	N·m
			My	Drag moment on vehicle CG about the vehicle-fixed y-axis	Computed	N·m
			Mz	Drag moment on vehicle CG about the vehicle-fixed z-axis	0	N·m
		Ext	Fx	External moment on vehicle CG about the vehicle-fixed x-axis	Computed	N·m
			Fy	External moment on vehicle CG about the vehicle-fixed y-axis	Computed	N·m
			Fz	External moment on vehicle CG about the vehicle-fixed z-axis	Computed	N·m
	FrntAxl	Disp	x	Front axle displacement along the vehicle-fixed x-axis	Computed	m

Signal				Description	Value	Units	
			y	Front axle displacement along the vehicle-fixed y-axis	0	m	
			z	Front axle displacement along the vehicle-fixed z-axis	Computed	m	
			Vel	x <sub>dot</sub>	Front axle velocity along the vehicle-fixed x-axis	Computed	m/s
				y <sub>dot</sub>	Front axle velocity along the vehicle-fixed y-axis	0	m/s
				z <sub>dot</sub>	Front axle velocity along the vehicle-fixed z-axis	Computed	m/s
			Steer	WhlAngFL	Front left wheel steering angle	Computed	rad
		WhlAngFR		Front right wheel steering angle	Computed	rad	
		RearAxl	Disp	x	Rear axle displacement along the vehicle-fixed x-axis	Computed	m
				y	Rear axle displacement along the vehicle-fixed y-axis	0	m
				z	Rear axle displacement along the vehicle-fixed z-axis	Computed	m
			Vel	x <sub>dot</sub>	Rear axle velocity along the vehicle-fixed x-axis	Computed	m/s
				y <sub>dot</sub>	Rear axle velocity along the vehicle-fixed y-axis	0	m/s
	z <sub>dot</sub>			Rear axle velocity along the vehicle-fixed z-axis	Computed	m/s	
	Steer		WhlAngRL	Rear left wheel steering angle	Computed	rad	
			WhlAngRR	Rear right wheel steering angle	Computed	rad	
	Pwr		PwrExt	Applied external power	Computed	W	
		Drag	Power loss due to drag	Computed	W		
	PwrInfo	PwrTrns frd	PwrFxExt	Externally applied longitudinal force power	Computed	W	
			PwrFzExt	Externally applied longitudinal force power	Computed	W	
			PwrMyExt	Externally applied pitch moment power	Computed	W	

Signal		Description	Value	Units	
		PwrFwFx	Longitudinal force applied at the front axle	Computed	W
		PwrFwRx	Longitudinal force applied at the rear axle	Computed	W
	PwrNotTrnsfrd	PwrFsF	Internal power transferred between suspension and vehicle body at the front axle	Computed	W
		PwrFsR	Internal power transferred between suspension and vehicle body at the rear axle	Computed	W
		PwrFxDrag	Longitudinal drag force power	Computed	W
		PwrFzDrag	Vertical drag force power	Computed	W
		PwrMyDrag	Drag pitch moment power	Computed	W
		PwrFsb	Total suspension damping power	Computed	W
		PwrStored	PwrStoredGrvty	Rate change in gravitational potential energy	Computed
	PwrStoredxdot		Rate of change of longitudinal kinetic energy	Computed	W
	PwrStoredzdot		Rate of change of longitudinal kinetic energy	Computed	W
	PwrStoredq		Rate of change of rotational pitch kinetic energy	Computed	W
	PwrStoredFsFzSprng		Stored spring energy from front suspension	Computed	W
	PwrStoredFsRzSprng		Stored spring energy from rear suspension	Computed	W

**xdot – Vehicle longitudinal velocity**

scalar

Vehicle CG velocity along the vehicle-fixed  $x$ -axis, in m/s.

**FzF – Front axle normal force**

scalar

Normal force on front axle,  $Fz_F$ , along the vehicle-fixed  $z$ -axis, in N.

**FzR – Rear axle normal force**

scalar

Normal force on rear axle,  $Fz_R$ , along the vehicle-fixed  $z$ -axis, in N.

## Parameters

### Options

#### External forces — FExt input port

off (default) | on

Specify to create input port FExt.

#### External moments — MExt input port

off (default) | on

Specify to create input port MExt.

#### Air temperature — AirTemp input port

off (default) | on

Specify to create input port AirTemp.

### Longitudinal

#### Number of wheels on front axle, NF — Front wheel count

2 (default) | scalar

Number of wheels on front axle,  $N_F$ . The value is dimensionless.

#### Number of wheels on rear axle, NR — Rear wheel count

2 (default) | scalar

Number of wheels on rear axle,  $N_R$ . The value is dimensionless.

#### Mass, m — Vehicle mass

1200 (default) | scalar

Vehicle mass,  $m$ , in kg.

#### Horizontal distance from CG to front axle, a — Front axle distance

1.4 (default) | scalar

Horizontal distance  $a$  from the vehicle CG to the front wheel axle, in m.

#### Horizontal distance from CG to rear axle, b — Rear axle distance

1.8 (default) | scalar

Horizontal distance  $b$  from the vehicle CG to the rear wheel axle, in m.

#### CG height above axles, h — Height

0.35 (default) | scalar

Height of vehicle CG above the axles,  $h$ , in m.

#### Drag coefficient, Cd — Drag

.3 (default) | scalar

Air drag coefficient,  $C_d$ . The value is dimensionless.

**Frontal area, Af – Area**

2 (default) | scalar

Effective vehicle cross-sectional area,  $A_f$  to calculate the aerodynamic drag force on the vehicle, in  $m^2$ .

**Initial position, x\_o – Position**

0 (default) | scalar

Vehicle body longitudinal initial position along earth-fixed x-axis,  $x_o$ , in m.

**Initial velocity, xdot\_o – Velocity**

0 (default) | scalar

Vehicle body longitudinal initial velocity along earth-fixed x-axis,  $\dot{x}_o$ , in m/s.

**Vertical****Lift coefficient, Cl – Lift**

.1 (default) | scalar

Lift coefficient,  $C_l$ . The value is dimensionless.

**Initial vertical position, z\_o – Position**

-.35 (default) | scalar

Initial vertical CG position,  $z_o$ , along the vehicle-fixed z-axis, in m.

**Initial vertical velocity, zdot\_o – Velocity**

0 (default) | scalar

Initial vertical CG velocity,  $\dot{z}_o$ , along the vehicle-fixed z-axis, in m.

**Pitch****Inertia, Iyy – About body y-axis**

3500 (default) | scalar

Vehicle body moment of inertia about body z-axis.

**Pitch drag moment coefficient, Cpm – Drag coefficient**

.1 (default) | scalar

Pitch drag moment coefficient. The value is dimensionless.

**Initial pitch angle, theta\_o – Pitch**

0 (default) | scalar

Initial pitch angle about body z-axis, in rad.

**Initial angular velocity, q\_o – Pitch velocity**

0 (default) | scalar

Initial vehicle body angular velocity about body z-axis, in rad/s.



## Suspension

### Front axle stiffness force data, FskF — Force

`[-50, -1, 0, 2, 3, 52].*1.5e4` (default) | vector

Front axle stiffness force data,  $Fk_F$ , in N.

#### Dependencies

To enable this parameter, for the **Ground interaction type** parameter, select `Grade angle` or `Axle displacement, velocity`.

### Front axle displacement data, dzsF — Displacement

`[-5e-3, -1e-4, 0, .2, .2001, .2051]` (default) | vector

Front axle displacement data, in m.

#### Dependencies

To enable this parameter, for the **Ground interaction type** parameter, select `Grade angle` or `Axle displacement, velocity`.

### Front axle damping force data, FsbF — Damping force

`[-10000 -100 -10 0 10 100 10000]` (default) | vector

Front axle damping force, in N.

#### Dependencies

To enable this parameter, for the **Ground interaction type** parameter, select `Grade angle` or `Axle displacement, velocity`.

### Front axle velocity data, dzdotsF — Velocity

`[-10 -1 -.1 0 .1 1 10]` (default) | vector

Front axle velocity data, in m/s.

#### Dependencies

To enable this parameter, for the **Ground interaction type** parameter, select `Grade angle` or `Axle displacement, velocity`.

### Rear axle stiffness force data, FskR — Force

`[-50, -1, 0, 2, 3, 52].*1e4` (default) | vector

Rear axle stiffness force data, in N.

#### Dependencies

To enable this parameter, for the **Ground interaction type** parameter, select `Grade angle` or `Axle displacement, velocity`.

### Rear axle displacement data, dzsR — Displacement

`[-5e-3, -1e-4, 0, .2, .2001, .2051]` (default) | vector

Rear axle displacement data, in m.

**Dependencies**

To enable this parameter, for the **Ground interaction type** parameter, select `Grade angle` or `Axle displacement, velocity`.

**Rear axle damping force data, FsbR — Damping force**

`[-10000 -100 -10 0 10 100 10000]` (default) | `vector`

Rear axle damping force, in N.

**Dependencies**

To enable this parameter, for the **Ground interaction type** parameter, select `Grade angle` or `Axle displacement, velocity`.

**Rear axle velocity data, dzdotsR — Velocity**

`[-10 -1 -.1 0 .1 1 10]` (default) | `vector`

Rear axle velocity data, in m/s.

**Dependencies**

To enable this parameter, for the **Ground interaction type** parameter, select `Grade angle` or `Axle displacement, velocity`.

**Environment****Absolute air pressure, Pabs — Pressure**

`101325` (default) | `scalar`

Environmental air absolute pressure,  $P_{abs}$ , in Pa.

**Air temperature, Tair — Ambient air temperature**

`273` (default) | `scalar`

Ambient air temperature,  $T_{air}$ , in K.

**Dependencies**

To enable this parameter, clear **Air temperature**.

**Gravitational acceleration, g — Gravity**

`9.81` (default)

Gravitational acceleration,  $g$ , in  $m/s^2$ .

**References**

- [1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers, 1992.
- [2] Vehicle Dynamics Standards Committee. *Vehicle Dynamics Terminology*. SAE J670. Warrendale, PA: Society of Automotive Engineers, 2008.
- [3] Technical Committee. *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*. ISO 8855:2011. Geneva, Switzerland: International Organization for Standardization, 2011.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Vehicle Body 1DOF Longitudinal | Vehicle Body Total Road Load

### **Topics**

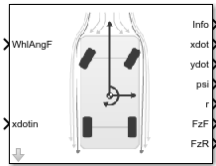
“Coordinate Systems in Vehicle Dynamics Blockset”

### **Introduced in R2017a**

## Vehicle Body 3DOF

3DOF rigid vehicle body to calculate longitudinal, lateral, and yaw motion

**Library:** Vehicle Dynamics Blockset / Vehicle Body



### Description

The Vehicle Body 3DOF block implements a rigid two-axle vehicle body model to calculate longitudinal, lateral, and yaw motion. The block accounts for body mass and aerodynamic drag between the axles due to acceleration and steering.

Use this block in vehicle dynamics and automated driving studies to model nonholonomic vehicle motion when vehicle pitch, roll, and vertical motion are not significant.

In the Vehicle Dynamics Blockset™ library, there are two types of Vehicle Body 3DOF blocks that model longitudinal, lateral, and yaw motion.

Block	Vehicle Track Setting	Implementation
Vehicle Body 3DOF Single Track 	Single (bicycle)	<ul style="list-style-type: none"> <li>Forces act along the center line at the front and rear axles.</li> <li>No lateral load transfer.</li> </ul>
Vehicle Body 3DOF Dual Track 	Dual	Forces act at the four vehicle corners or <i>hard points</i> .

Use the **Axle forces** parameter to specify the type of force.

Axle Forces Setting	Implementation
External longitudinal velocity	<ul style="list-style-type: none"> <li>The block assumes that the external longitudinal velocity is in a quasi-steady state, so the longitudinal acceleration is approximately zero.</li> <li>Because the motion is quasi-steady, the block calculates lateral forces using the tire slip angles and linear cornering stiffness.</li> <li>Consider this setting when you want to: <ul style="list-style-type: none"> <li>Generate virtual sensor signal data.</li> <li>Conduct high-level software studies that are not impacted by driveline or nonlinear tire responses.</li> </ul> </li> </ul>
External longitudinal forces	<ul style="list-style-type: none"> <li>The block uses the external longitudinal force to accelerate or brake the vehicle.</li> <li>The block calculates lateral forces using the tire slip angles and linear cornering stiffness.</li> <li>Consider this setting when you want to: <ul style="list-style-type: none"> <li>Account for changes in the longitudinal velocity on the lateral and yaw motion.</li> <li>Specify the external longitudinal motion through a force instead of an external longitudinal velocity.</li> <li>Connect the block to tractive actuators, wheels, brakes, and hitches.</li> </ul> </li> </ul>
External forces	<ul style="list-style-type: none"> <li>The block uses the external lateral and longitudinal forces to steer, accelerate, or brake the vehicle.</li> <li>The block does not use the steering input to calculate vehicle motion.</li> <li>Consider this setting when you need tire models with more accurate nonlinear combined lateral and longitudinal slip.</li> </ul>

You can use these block parameters to create additional input ports. This table summarizes the settings.

Input Signals Pane Parameter	Input Port	Description
Front wheel steering	WhlAngF	Front wheel angle, $\delta_F$
External wind	WindXYZ	Wind speed, $W_x$ , $W_y$ , $W_z$ , in the inertial reference frame
External forces	FExt	External force on vehicle center of gravity (CG), $F_x$ , $F_y$ , $F_z$ , in the vehicle-fixed frame
Rear wheel steering	WhlAngR	Rear wheel angle, $\delta_R$
External friction	Mu	Friction coefficient
External moments	MExt	External moment about vehicle CG, $M_x$ , $M_y$ , $M_z$ , in vehicle-fixed frame

Input Signals Pane Parameter	Input Port	Description
<b>Hitch forces</b>	Fh	Hitch force applied to the body at the hitch location, $Fh_x$ , $Fh_y$ , and $Fh_z$ , in the vehicle-fixed frame
<b>Hitch moments</b>	Mh	Hitch moment at the hitch location, $Mh_x$ , $Mh_y$ , and $Mh_z$ , about the vehicle-fixed frame
<b>Initial longitudinal position</b>	X_o	Initial vehicle CG displacement along the earth-fixed X-axis, in m
<b>Initial lateral position</b>	Y_o	Initial vehicle CG displacement along the earth-fixed Y-axis, in m
<b>Initial longitudinal velocity</b>	xdot_o	Initial vehicle CG velocity along the vehicle-fixed x-axis, in m/s
<b>Initial lateral velocity</b>	ydot_o	Initial vehicle CG velocity along the vehicle-fixed y-axis, in m/s
<b>Initial yaw angle</b>	psi_o	Initial rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw), in rad
<b>Initial yaw rate</b>	r_o	Initial vehicle angular velocity about the vehicle-fixed z-axis (yaw rate), in rad/s
<b>Air temperature</b>	AirTemp	Ambient air temperature. Considering this option if you want to vary the temperature during run-time.

### Theory

The Vehicle Body 3DOF block implements a rigid two-axle vehicle body model to calculate longitudinal, lateral, and yaw motion. The block accounts for body mass, aerodynamic drag, and weight distribution between the axles due to acceleration and steering. To determine the vehicle motion, the block implements these equations for the single track, dual track, and drag calculations.

### Single Track

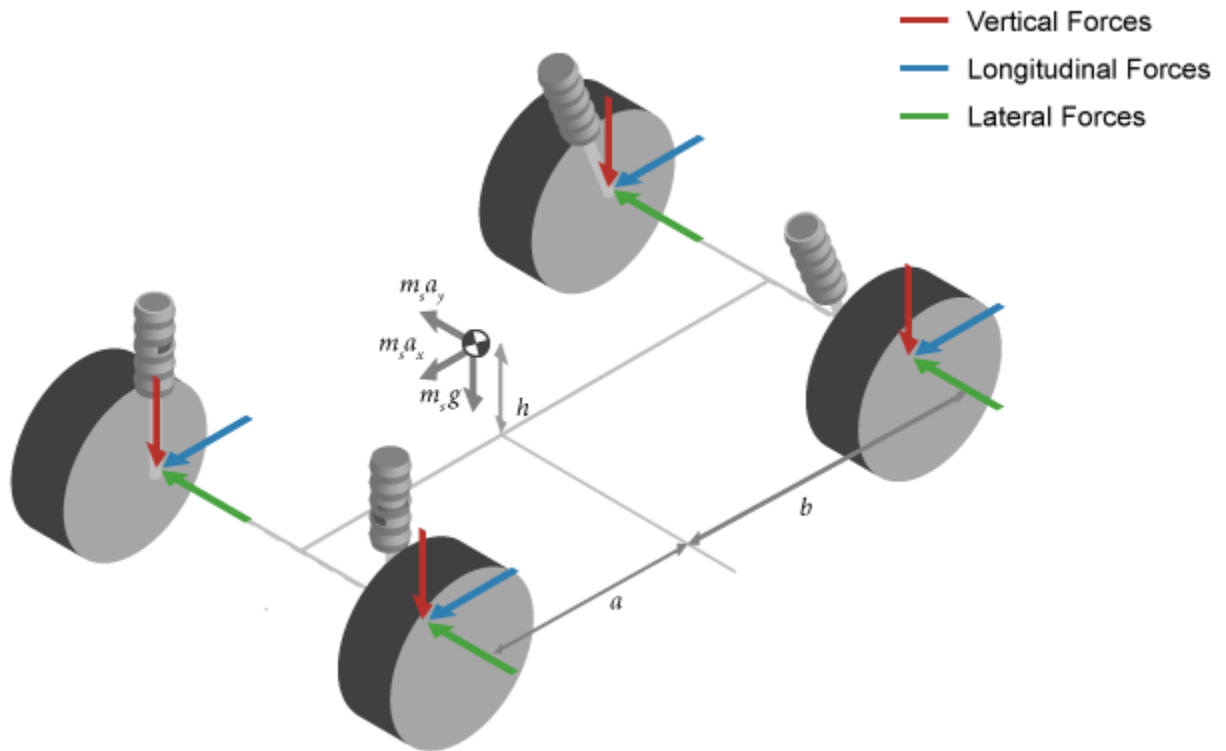
Calculation	Description
<i>Dynamics</i>	<p>The block uses these equations to calculate the rigid body planar dynamics.</p> $\ddot{y} = -\dot{x}r + \frac{F_{yf} + F_{yr} + F_{yext}}{m}$ $\dot{r} = \frac{aF_{yf} - bF_{yr} + M_{zext}}{I_{zz}}$ $r = \dot{\psi}$ <p>If you set <b>Axle forces</b> to either External longitudinal forces or External forces, the block uses this equation for the longitudinal acceleration.</p> $\ddot{x} = \dot{y}r + \frac{F_{xf} + F_{xr} + F_{xext}}{m}$ <p>If you set <b>Axle forces</b> to External longitudinal velocity, the block assumes a quasi-steady state for the longitudinal acceleration.</p> $\ddot{x} = 0$

Calculation	Description
<p><i>External forces</i></p>	<p>External forces include both drag and external force inputs. The forces act on the vehicle CG.</p> $F_{x,y,z \text{ ext}} = F_{d \ x,y,z} + F_{x,y,z \text{ input}}$ $M_{x,y,z \text{ ext}} = M_{d \ x,y,z} + M_{x,y,z \text{ input}}$ <p>If you set <b>Axle forces</b> to External longitudinal forces, the block uses these equations.</p> $F_{xft} = F_{xfinput}$ $F_{yft} = -C_{yf}\alpha_f\mu_f\frac{F_{zf}}{F_{znom}}$ $F_{xrt} = F_{xrinput}$ $F_{yrt} = -C_{yr}\alpha_r\mu_r\frac{F_{zr}}{F_{znom}}$ <p>If you set <b>Axle forces</b> to External longitudinal velocity, the block uses these equations.</p> $F_{xft} = 0$ $F_{yft} = -C_{yf}\alpha_f\mu_f\frac{F_{zf}}{F_{znom}}$ $F_{xrt} = 0$ $F_{yrt} = -C_{yr}\alpha_r\mu_r\frac{F_{zr}}{F_{znom}}$ <p>The block divides the normal forces by the nominal normal load to vary the effective friction parameters during weight and load transfer. The block uses these equations to maintain pitch and roll equilibrium.</p> $F_{zf} = \frac{bmg - (\ddot{x} - \dot{y}r)mh + hF_{xext} + bF_{zext} - M_{yext}}{a + b}$ $F_{zr} = \frac{amg + (\ddot{x} - \dot{y}r)mh - hF_{xext} + aF_{zext} + M_{yext}}{a + b}$



Calculation	Description
Tire forces	<p>The block uses the ratio of the local and longitudinal and lateral velocities to determine the slip angles.</p> $\alpha_f = \operatorname{atan}\left(\frac{\dot{y} + ar}{\dot{x}}\right) - \delta_f$ $\alpha_r = \operatorname{atan}\left(\frac{\dot{y} - br}{\dot{x}}\right) - \delta_r$ <p>To determine the tire forces, the block uses the slip angles.</p> $F_{xf} = F_{xft}\cos(\delta_f) - F_{yft}\sin(\delta_f)$ $F_{yf} = -F_{xft}\sin(\delta_f) + F_{yft}\cos(\delta_f)$ $F_{xr} = F_{xrt}\cos(\delta_r) - F_{yrt}\sin(\delta_r)$ $F_{yr} = -F_{xrt}\sin(\delta_r) + F_{yrt}\cos(\delta_r)$ <p>If you set <b>Axle forces</b> to External forces, the block sets the tire forces equal to the external input force.</p> $F_{xf} = F_{xft} = F_{xfinput}$ $F_{yf} = F_{yft} = F_{yfinput}$ $F_{xr} = F_{xrt} = F_{xrinput}$ $F_{yr} = F_{yrt} = F_{yrinput}$

### Dual Track



Calculation	Description
<i>Dynamics</i>	<p>The block uses these equations to calculate the rigid body planar dynamics.</p> $\ddot{x} = \dot{y}r + \frac{F_{xfl} + F_{xfr} + F_{xrl} + F_{xrr} + F_{xext}}{m}$ $\ddot{y} = -\dot{x}r + \frac{F_{yfl} + F_{yfr} + F_{yrl} + F_{yrr} + F_{yext}}{m}$ $\dot{r} = \frac{a(F_{yfl} + F_{yfr}) - b(F_{yrl} + F_{yrr}) + \frac{w_f(F_{xfl} - F_{xfr})}{2} + \frac{w_r(F_{xrl} - F_{xrr})}{2} + M_{zext}}{I_{zz}}$ $r = \dot{\psi}$ <p>If you set <b>Axle forces</b> to External longitudinal velocity, the block assumes a quasi-steady state for the longitudinal acceleration.</p> $\ddot{x} = 0$

Calculation	Description
<i>External forces</i>	<p>External forces include both drag and external force inputs. The forces act on the vehicle CG.</p> $F_{x,y,z \text{ ext}} = F_{d \ x,y,z} + F_{x,y,z \text{ input}}$ $M_{x,y,z \text{ ext}} = M_{d \ x,y,z} + M_{x,y,z \text{ input}}$ <p>If you set <b>Axle forces</b> to External longitudinal forces, the block uses these equations.</p> $F_{xflt} = F_{xflinput}$ $F_{yflt} = -C_{yfl}\alpha_{fl}\mu_{fl}\frac{F_{zfl}}{2F_{znom}}$ $F_{xfrt} = F_{xflinput}$ $F_{yfrt} = -C_{yfr}\alpha_{fr}\mu_{fr}\frac{F_{zfr}}{2F_{znom}}$ $F_{xrlt} = F_{xrlinput}$ $F_{yrlt} = -C_{yrl}\alpha_{rl}\mu_{rl}\frac{F_{zrl}}{2F_{znom}}$ $F_{xrrt} = F_{xrrinput}$ $F_{yrrt} = -C_{yrr}\alpha_{rr}\mu_{rr}\frac{F_{zrr}}{2F_{znom}}$ <p>If you set <b>Axle forces</b> to External longitudinal velocity, the block uses these equations.</p> $F_{xflt} = 0$ $F_{yflt} = -C_{yfl}\alpha_{fl}\mu_{fl}\frac{F_{zfl}}{2F_{znom}}$ $F_{xfrt} = 0$ $F_{yfrt} = -C_{yfr}\alpha_{fr}\mu_{fr}\frac{F_{zfr}}{2F_{znom}}$ $F_{xrlt} = 0$ $F_{yrlt} = -C_{yrl}\alpha_{rl}\mu_{rl}\frac{F_{zrl}}{2F_{znom}}$ $F_{xrrt} = 0$ $F_{yrrt} = -C_{yrr}\alpha_{rr}\mu_{rr}\frac{F_{zrr}}{2F_{znom}}$ <p>The block divides the normal forces by the nominal normal load to vary the effective friction parameters during weight and load transfer. The block uses these equations to maintain pitch and roll equilibrium.</p>

Calculation	Description
	$F_{zf} = \frac{bmg - (\ddot{x} - \dot{y}r)mh + hF_{xext} + bF_{zext} - M_{yext}}{a + b}$ $F_{zr} = \frac{amg + (\ddot{x} - \dot{y}r)mh - hF_{xext} + aF_{zext} + M_{yext}}{(a + b)}$ $F_{zfl} = F_{zf} + (mh(\ddot{y} + \dot{x}r) - hF_{yext} - M_{xext})\frac{2}{w_f}$ $F_{zfr} = F_{zf} + (-mh(\ddot{y} + \dot{x}r) + hF_{yext} + M_{xext})\frac{2}{w_f}$ $F_{zrl} = F_{zr} + (mh(\ddot{y} + \dot{x}r) - hF_{yext} - M_{xext})\frac{2}{w_r}$ $F_{zrr} = F_{zr} + (-mh(\ddot{y} + \dot{x}r) + hF_{yext} + M_{xext})\frac{2}{w_r}$
Tire forces	<p>The block uses the ratio of the local and longitudinal and lateral velocities to determine the slip angles.</p> $\alpha_{fl} = \operatorname{atan}\left(\frac{\dot{y} + ar}{\dot{x} + r\frac{w_f}{2}}\right) - \delta_{fl}$ $\alpha_{fr} = \operatorname{atan}\left(\frac{\dot{y} + ar}{\dot{x} - r\frac{w_f}{2}}\right) - \delta_{fr}$ $\alpha_{rl} = \operatorname{atan}\left(\frac{\dot{y} - ar}{\dot{x} + r\frac{w_r}{2}}\right) - \delta_{rl}$ $\alpha_{rr} = \operatorname{atan}\left(\frac{\dot{y} - ar}{\dot{x} - r\frac{w_r}{2}}\right) - \delta_{rr}$ <p>The block uses the steering angles to transform the tire forces to the vehicle-fixed frame.</p> $F_{xf} = F_{xft}\cos(\delta_f) - F_{yft}\sin(\delta_f)$ $F_{yf} = -F_{xft}\sin(\delta_f) + F_{yft}\cos(\delta_f)$ $F_{xr} = F_{xrt}\cos(\delta_r) - F_{yrt}\sin(\delta_r)$ $F_{yr} = -F_{xrt}\sin(\delta_r) + F_{yrt}\cos(\delta_r)$ <p>If you set <b>Axle forces</b> to External forces, the block uses these equations. The blocks assumes that the externally provided forces are in the vehicle-fixed frame at the axle-wheel location.</p> $F_{xf} = F_{xft} = F_{xfinput}$ $F_{yf} = F_{yft} = F_{yfinput}$ $F_{xr} = F_{xrt} = F_{xrinput}$ $F_{yr} = F_{yrt} = F_{yrinput}$

Drag

Calculation	Description
<i>Coordinate transformation</i>	<p>The block transforms the wind speeds from the inertial frame to the vehicle-fixed frame.</p> $w_x = W_x \cos(\psi) + W_y \sin(\psi)$ $w_y = W_y \cos(\psi) - W_x \sin(\psi)$ $w_z = W_z$
<i>Drag forces</i>	<p>To determine a relative airspeed, the block subtracts the wind speed from the CG vehicle velocity. Using the relative airspeed, the block determines the drag forces.</p> $\bar{w} = \sqrt{(\dot{x}_b - w_x)^2 + (\dot{y}_b - w_y)^2 + (w_z)^2}$ $F_{dx} = -\frac{1}{2TR} C_d A_f P_{abs}(\bar{w})$ $F_{dy} = -\frac{1}{2TR} C_s A_f P_{abs}(\bar{w})$ $F_{dz} = -\frac{1}{2TR} C_l A_f P_{abs}(\bar{w})$
<i>Drag moments</i>	<p>Using the relative airspeed, the block determines the drag moments.</p> $M_{dr} = -\frac{1}{2TR} C_{rm} A_f P_{abs}(\bar{w})(a + b)$ $M_{dp} = -\frac{1}{2TR} C_{pm} A_f P_{abs}(\bar{w})(a + b)$ $M_{dy} = -\frac{1}{2TR} C_{ym} A_f P_{abs}(\bar{w})(a + b)$

### Lateral Corner Stiffness and Relaxation Dynamics

Description	Implementation
<i>Constant values.</i>	The block uses constant stiffness values for $Cy_f$ and $Cy_r$ .
<i>Lookup tables as a function of corner stiffness data and slip angles.</i>	<p>The block uses lookup tables that are functions of the corner stiffness data and slip angles.</p> $Cy_f = f(\alpha_f, Cy_{fdata})$ $Cy_r = f(\alpha_r, Cy_{rdata})$

Description	Implementation
<p><i>Lookup tables as a function of corner stiffness data and slip angles.</i></p> <p><i>Slip angles include the relaxation length dynamic settings.</i></p>	<p>The block uses lookup tables that are functions of the corner stiffness data and slip angles. The slip angles include the relaxation length dynamic settings. The relaxation length approximates an effective corner stiffness force that is a function of wheel travel.</p> $C_{yf} = f(\alpha_{f\sigma}, C_{yfdata})$ $C_{yr} = f(\alpha_{r\sigma}, C_{yrdata})$ $\alpha_{f\sigma} = \frac{1}{s} \left[ \frac{(\alpha_f - \alpha_{f\sigma})v_{wf}}{\alpha_f} \right]$ $\alpha_{r\sigma} = \frac{1}{s} \left[ \frac{(\alpha_r - \alpha_{r\sigma})v_{wr}}{\alpha_r} \right]$

The equations use these variables.

$x, \dot{x}, \ddot{x}$	Vehicle CG displacement, velocity, and acceleration, along the vehicle-fixed x-axis
$y, \dot{y}, \ddot{y}$	Vehicle CG displacement, velocity, and acceleration, along the vehicle-fixed y-axis
$\psi$	Rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw)
$r, \dot{\psi}$	Vehicle angular velocity, about the vehicle-fixed z-axis (yaw rate)
$F_{xf}, F_{xr}$	Longitudinal forces applied to front and rear wheels, along the vehicle-fixed x-axis
$F_{yf}, F_{yr}$	Lateral forces applied to front and rear wheels, along vehicle-fixed y-axis
$F_{xext}, F_{yext}, F_{zext}$	External forces applied to vehicle CG, along the vehicle-fixed x-, y-, and z-axes
$F_{dx}, F_{dy}, F_{dz}$	Drag forces applied to vehicle CG, along the vehicle-fixed x-, y-, and z-axes
$F_{xinput}, F_{yinput}, F_{zinput}$	Input forces applied to vehicle CG, along the vehicle-fixed x-, y-, and z-axes
$M_{xext}, M_{yext}, M_{zext}$	External moment about vehicle CG, about the vehicle-fixed x-, y-, and z-axes
$M_{dx}, M_{dy}, M_{dz}$	Drag moment about vehicle CG, about the vehicle-fixed x-, y-, and z-axes
$M_{xinput}, M_{yinput}, M_{zinput}$	Input moment about vehicle CG, about the vehicle-fixed x-, y-, and z-axes
$I_{zz}$	Vehicle body moment of inertia about the vehicle-fixed z-axis
$F_{xft}, F_{xrt}$	Longitudinal tire force applied to front and rear wheels, along the vehicle-fixed x-axis
$F_{yft}, F_{yrt}$	Lateral tire force applied to front and rear wheels, along vehicle-fixed y-axis
$F_{xfl}, F_{xfr}$	Longitudinal force applied to front left and front right wheels, along the vehicle-fixed x-axis
$F_{yfl}, F_{yfr}$	Lateral force applied to front left and front right wheels, along the vehicle-fixed y-axis
$F_{xrl}, F_{xrr}$	Longitudinal force applied to rear left and rear right wheels, along the vehicle-fixed x-axis

$F_{yrl}, F_{yrr}$	Lateral force applied to rear left and rear right wheels, along the vehicle-fixed y-axis
$F_{xflt}, F_{xfrt}$	Longitudinal tire force applied to front left and front right wheels, along the vehicle-fixed x-axis
$F_{yflt}, F_{yfrt}$	Lateral force tire applied to front left and front right wheels, along the vehicle-fixed y-axis
$F_{xrlt}, F_{xrtr}$	Longitudinal tire force applied to rear left and rear right wheels, along the vehicle-fixed x-axis
$F_{yrlt}, F_{yrrt}$	Lateral force applied to rear left and rear right wheels, along the vehicle-fixed y-axis
$F_{zf}, F_{zr}$	Normal force applied to front and rear wheels, along vehicle-fixed z-axis
$F_{znom}$	Nominal normal force applied to axles, along the vehicle-fixed z-axis
$F_{zfl}, F_{zfr}$	Normal force applied to front left and right wheels, along vehicle-fixed z-axis
$F_{zrl}, F_{zrr}$	Normal force applied to rear left and right wheels, along vehicle-fixed z-axis
$m$	Vehicle body mass
$a, b$	Distance of front and rear wheels, respectively, from the normal projection point of vehicle CG onto the common axle plane
$h$	Height of vehicle CG above the axle plane
$d$	Lateral distance from the geometric centerline to the center of mass along the vehicle-fixed y-axis
$hh$	Height of the hitch above the axle plane along the vehicle-fixed z-axis
$dh$	Longitudinal distance of the hitch from the normal projection point of tractor CG onto the common axle plane
$hl$	Lateral distance from center of mass to hitch along the vehicle-fixed y-axis.
$\alpha_f, \alpha_r$	Front and rear wheel slip angles
$\alpha_{fl}, \alpha_{fr}$	Front left and right wheel slip angles
$\alpha_{rl}, \alpha_{rr}$	Rear left and right wheel slip angles
$\delta_f, \delta_r$	Front and rear wheel steering angles
$\delta_{rl}, \delta_{rr}$	Rear left and right wheel steering angles
$\delta_{fl}, \delta_{fr}$	Front left and right wheel steering angles
$w_f, w_r$	Front and rear track widths
$Cy_f, Cy_r$	Front and rear wheel cornering stiffness
$Cy_{fdata}, Cy_{rdata}$	Front and rear wheel cornering stiffness data
$\sigma_f, \sigma_r$	Front and rear wheel relaxation length
$\alpha_{f\sigma}, \alpha_{r\sigma}$	Front and rear wheel slip angles that include relaxation length
$v_{wf}, v_{wr}$	Magnitude of front and rear wheel hardpoint velocity
$\mu_f, \mu_r$	Front and rear wheel friction coefficient
$\mu_{fl}, \mu_{fr}$	Front left and right wheel friction coefficient
$\mu_{rl}, \mu_{rr}$	Rear left and right wheel friction coefficient

$C_d$	Air drag coefficient acting along vehicle-fixed x-axis
$C_s$	Air drag coefficient acting along vehicle-fixed y-axis
$C_l$	Air drag coefficient acting along vehicle-fixed z-axis
$C_{rm}$	Air drag roll moment acting about the vehicle-fixed x-axis
$C_{pm}$	Air drag pitch moment acting about the vehicle-fixed y-axis
$C_{ym}$	Air drag yaw moment acting about the vehicle-fixed z-axis
$A_f$	Frontal area
$R$	Atmospheric specific gas constant
$T$	Environmental air temperature
$P_{abs}$	Environmental absolute pressure
$w_x, w_y, w_z$	Wind speed, along the vehicle-fixed x-, y-, and z-axes
$W_x, W_y, W_z$	Wind speed, along inertial X-, Y-, and Z-axes

## Ports

### Input

#### WhlAngF — Front wheel steering angles

scalar | array

Front wheel steering angles,  $\delta_F$ , in rad.

Vehicle Track Setting	Variable	Signal Dimension
Single (bicycle)	$\delta_F$	Scalar - 1
Dual	$\delta_F = [\delta_{fl} \ \delta_{fr}]$ or $\begin{bmatrix} \delta_{fl} \\ \delta_{fr} \end{bmatrix}$	Array - [1x2] or [2x1]

#### Dependencies

To enable this port, on the **Input signals** pane, select **Front wheel steering**.

#### WhlAngR — Rear wheel steering angles

scalar | array

Rear wheel steering angles,  $\delta_R$ , in rad.

Vehicle Track Setting	Variable	Signal Dimension
Single (bicycle)	$\delta_R$	Scalar - 1
Dual	$\delta_R = [\delta_{rl} \ \delta_{rr}]$ or $\begin{bmatrix} \delta_{rl} \\ \delta_{rr} \end{bmatrix}$	Array - [1x2] or [2x1]

#### Dependencies

To enable this port, on the **Input signals** pane, select **Rear wheel steering**.

#### xdotin — Longitudinal velocity

scalar



Vehicle CG velocity along the vehicle-fixed x-axis, in m/s.

### Dependencies

To enable this port, set **Axle forces** to External longitudinal velocity.

### FwF — Total force on the front wheels

scalar | array

Force on the front wheels,  $F_{wF}$ , along the vehicle-fixed axis, in N.

Vehicle Track Setting	Axle Forces Setting	Description	Variable	Signal Dimension
Single (bicycle)	External longitudinal forces	Longitudinal force on the front wheel	$F_{wF} = F_{x_f}$	Scalar - 1
	External forces	Longitudinal and lateral forces on the front wheel	$F_{wF} = [F_{x_f} \ F_{y_f}]$ or $\begin{bmatrix} F_{x_f} \\ F_{y_f} \end{bmatrix}$	Array - [1x2] or [2x1]
Dual	External longitudinal forces	Longitudinal force on the front wheels	$F_{wF} = [F_{x_{fl}} \ F_{x_{fr}}]$ or $\begin{bmatrix} F_{x_{fl}} \\ F_{x_{fr}} \end{bmatrix}$	Array - [1x2] or [2x1]
	External forces	Longitudinal and lateral forces on the front wheels	$F_{wF} = \begin{bmatrix} F_{x_{fl}} & F_{x_{fr}} \\ F_{y_{fl}} & F_{y_{fr}} \end{bmatrix}$	Array - [2x2]

### Dependencies

To enable this port, set **Axle forces** to one of these options:

- External longitudinal forces
- External forces

### FwR — Total force on the rear wheels

scalar | array

Force on the rear wheels,  $F_{wR}$ , along the vehicle-fixed axis, in N.

Vehicle Track Setting	Axle Forces Setting	Description	Variable	Signal Dimension
Single (bicycle)	External longitudinal forces	Longitudinal force on the rear wheel	$F_{wR} = F_{x_r}$	Scalar - 1
	External forces	Longitudinal and lateral forces on the rear wheel	$F_{wR} = [F_{x_r} \ F_{y_r}]$ or $\begin{bmatrix} F_{x_r} \\ F_{y_r} \end{bmatrix}$	Array - [1x2] or [2x1]

Vehicle Track Setting	Axle Forces Setting	Description	Variable	Signal Dimension
Dual	External longitudinal forces	Longitudinal force on the rear wheels	$FwR = [F_{xrl} \ F_{xrr}] \text{ or } \begin{bmatrix} F_{xrl} \\ F_{xrr} \end{bmatrix}$	Array - [1x2] or [2x1]
	External forces	Longitudinal and lateral forces on the rear wheels	$FwR = \begin{bmatrix} F_{xrl} & F_{xrr} \\ F_{yrl} & F_{yrr} \end{bmatrix}$	Array - [2x2]

**Dependencies**

To enable this port, set **Axle forces** to one of these options:

- External longitudinal forces
- External forces

**FExt — External force on vehicle CG**

array

External forces applied to vehicle CG,  $F_{xext}, F_{yext}, F_{zext}$ , in vehicle-fixed frame, in N. Signal vector dimensions are [1x3] or [3x1].

**Dependencies**

To enable this port, on the **Input signals** pane, select **External forces**.

**MExt — External moment about vehicle CG**

array

External moment about vehicle CG,  $M_x, M_y, M_z$ , in the vehicle-fixed frame, in N·m. Signal vector dimensions are [1x3] or [3x1].

**Dependencies**

To enable this port, on the **Input signals** pane, select **External moments**.

**Fh — Hitch force on the body**

array

Hitch force applied to the body at the hitch location,  $Fh_x, Fh_y, Fh_z$ , in the vehicle-fixed frame, in N, specified as a 1-by-3 or 3-by-1 array.

**Dependencies**

To enable this port, under **Input signals**, select **Hitch forces**.

**Mh — Hitch moment about body**

array

Hitch moment at the hitch location,  $Mh_x, Mh_y, Mh_z$ , about the vehicle-fixed frame, in N·m, specified as a 1-by-3 or 3-by-1 array.

**Dependencies**

To enable this port, under **Input signals**, select **Hitch moments**.

**WindXYZ – Wind speed**

array

Wind speed,  $W_x$ ,  $W_y$ ,  $W_z$  along inertial X-, Y-, and Z-axes, in m/s. Signal vector dimensions are [1x3] or [3x1].

**Dependencies**

To enable this port, on the **Input signals** pane, select **External wind**.

**Mu – Tire friction coefficient**

scalar

Tire friction coefficient,  $\mu$ . The value is dimensionless.

Vehicle Track Setting	Description	Variable	Signal Dimension
Single (bicycle)	Longitudinal force on the front wheel	$Mu = [\mu_f \ \mu_r]$ or $\begin{bmatrix} \mu_f \\ \mu_r \end{bmatrix}$	Array - [1x2] or [2x1]
Dual	Longitudinal force on the front wheels	$Mu = \begin{bmatrix} \mu_{fl} & \mu_{fr} \\ \mu_{rl} & \mu_{rr} \end{bmatrix}$	Array - [2x2]

**Dependencies**

To enable this port, on the **Input signals** pane, select **External friction**.

**AirTemp – Ambient air temperature**

scalar

Ambient air temperature, in K.

**Dependencies**

To enable this port, on the **Input signals** pane, select **Air temperature**.

**X\_o – Initial longitudinal position**

scalar

Initial vehicle CG displacement along the earth-fixed X-axis, in m.

**Dependencies**

To enable this port, on the **Input signals** pane, select **Initial longitudinal position**.

**Y\_o – Initial lateral position**

scalar

Initial vehicle CG displacement along the earth-fixed Y-axis, in m.

**Dependencies**

To enable this port, on the **Input signals** pane, select **Initial lateral position**.

**xdot\_o – Initial longitudinal position**

scalar

Initial vehicle CG velocity along the vehicle-fixed x-axis, in m/s.

**Dependencies**

To enable this port:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal forces
  - External forces
- 2 On the **Input signals** pane, select **Initial longitudinal velocity**

**ydot\_o – Initial lateral position**

scalar

Initial vehicle CG velocity along the vehicle-fixed y-axis, in m/s.

**Dependencies**

To enable this port, on the **Input signals** pane, select **Initial lateral velocity**.

**psi\_o – Initial yaw angle**

scalar

Rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw), in rad.

**Dependencies**

To enable this port, on the **Input signals** pane, select **Initial yaw angle**.

**r\_o – Initial yaw rate**

scalar

Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate), in rad/s.

**Dependencies**

To enable this port, on the **Input signals** pane, select **Initial yaw rate**.

**Output**

**Info – Bus signal**

bus

Bus signal containing these block values.

Signal				Description	Value	Units
InertFrm	Cg	Disp	X	Vehicle CG displacement along the earth-fixed X-axis	Computed	m

Signal				Description	Value	Units	
			Y	Vehicle CG displacement along the earth-fixed Y-axis	Computed	m	
			Z	Vehicle CG displacement along the earth-fixed Z-axis	0	m	
			Vel	Xdot	Vehicle CG velocity along the earth-fixed X-axis	Computed	m/s
			Ydot	Vehicle CG velocity along the earth-fixed Y-axis	Computed	m/s	
			Zdot	Vehicle CG velocity along the earth-fixed Z-axis	0	m/s	
		Ang	phi	Rotation of the vehicle-fixed frame about the earth-fixed X-axis (roll)	0	rad	
			theta	Rotation of the vehicle-fixed frame about the earth-fixed Y-axis (pitch)	0	rad	
			psi	Rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw)	Computed	rad	
		FrntAxl	Lft	Disp	X	Front left wheel displacement along the earth-fixed X-axis	Computed
	Y				Front left wheel displacement along the earth-fixed Y-axis	Computed	m
	Z				Front left wheel displacement along the earth-fixed Z-axis	0	m
	Vel			Xdot	Front left wheel velocity along the earth-fixed X-axis	Computed	m/s
				Ydot	Front left wheel velocity along the earth-fixed Y-axis	Computed	m/s
Zdot				Front left wheel velocity along the earth-fixed Z-axis	0	m/s	
Right	Disp	X	Front right wheel displacement along the earth-fixed X-axis	Computed	m		

Signal				Description	Value	Units			
				Y	Front right wheel displacement along the earth-fixed Y-axis	Computed	m		
				Z	Front right wheel displacement along the earth-fixed Z-axis	0	m		
				Vel	Xdot	Front right wheel velocity along the earth-fixed X-axis	Computed	m/s	
				Ydot	Front right wheel velocity along the earth-fixed Y-axis	Computed	m/s		
				Zdot	Front right wheel velocity along the earth-fixed Z-axis	0	m/s		
			RearAx1	Lft	Disp	X	Rear left wheel displacement along the earth-fixed X-axis	Computed	m
						Y	Rear left wheel displacement along the earth-fixed Y-axis	Computed	m
						Z	Rear left wheel displacement along the earth-fixed Z-axis	0	m
					Vel	Xdot	Rear left wheel velocity along the earth-fixed X-axis	Computed	m/s
	Ydot	Rear left wheel velocity along the earth-fixed Y-axis				Computed	m/s		
	Zdot	Rear left wheel velocity along the earth-fixed Z-axis				0	m/s		
	RearAx1	Rght	Disp	X	Rear right wheel displacement along the earth-fixed X-axis	Computed	m		
				Y	Rear right wheel displacement along the earth-fixed Y-axis	Computed	m		
				Z	Rear right wheel displacement along the earth-fixed Z-axis	0	m		
			Vel	Xdot	Rear right wheel velocity along the earth-fixed X-axis	Computed	m/s		

Signal				Description	Value	Units	
				Ydot	Rear right wheel velocity along the earth-fixed Y-axis	Computed	m/s
				Zdot	Rear right wheel velocity along the earth-fixed Z-axis	0	m/s
	Hitch	Disp	X	Hitch offset from axle plane along the earth-fixed X-axis	Computed	m	
			Y	Hitch offset from center plane along the earth-fixed Y-axis	Computed	m	
			Z	Hitch offset from axle plane along the earth-fixed Z-axis	Computed	m	
		Vel	Xdot	Hitch offset velocity from axle plane along the earth-fixed X-axis	Computed	m	
			Ydot	Hitch offset velocity from center plane along the earth-fixed Y-axis	Computed	m	
			Zdot	Hitch offset velocity from axle plane along the earth-fixed Z-axis	Computed	m	
	Geom	Disp	X	Vehicle chassis offset from axle plane along the earth-fixed X-axis	Computed	m	
			Y	Vehicle chassis offset from center plane along the earth-fixed Y-axis	Computed	m	
			Z	Vehicle chassis offset from axle plane along the earth-fixed Z-axis	Computed	m	
		Vel	Xdot	Vehicle chassis offset velocity along the earth-fixed X-axis	Computed	m/s	
			Ydot	Vehicle chassis offset velocity along the earth-fixed Y-axis	Computed	m/s	
			Zdot	Vehicle chassis offset velocity along the earth-fixed Z-axis	Computed	m/s	
	BdyFrm	Cg	Vel	xdot	Vehicle CG velocity along the vehicle-fixed x-axis	Computed	m/s

Signal		Description	Value	Units	
		ydot	Vehicle CG velocity along the vehicle-fixed y-axis	Computed	m/s
		zdot	Vehicle CG velocity along the vehicle-fixed z-axis	0	m/s
	Ang	Beta	Body slip angle, $\beta$ $\beta = \frac{V_y}{V_x}$	Computed	rad
	AngVel	p	Vehicle angular velocity about the vehicle-fixed x-axis (roll rate)	0	rad/s
		q	Vehicle angular velocity about the vehicle-fixed y-axis (pitch rate)	0	rad/s
		r	Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate)	Computed	rad/s
	Acc	ax	Vehicle CG acceleration along the vehicle-fixed x-axis	Computed	gn
		ay	Vehicle CG acceleration along the vehicle-fixed y-axis	Computed	gn
		az	Vehicle CG acceleration along the vehicle-fixed z-axis	0	gn
		xddot	Vehicle CG acceleration along the vehicle-fixed x-axis	Computed	m/s <sup>2</sup>
		yddot	Vehicle CG acceleration along the vehicle-fixed y-axis	Computed	m/s <sup>2</sup>
		zddot	Vehicle CG acceleration along the vehicle-fixed z-axis	0	m/s <sup>2</sup>
	AngAcc	pdot	Vehicle angular acceleration about the vehicle-fixed x-axis	0	rad/s
		qdot	Vehicle angular acceleration about the vehicle-fixed y-axis	0	rad/s
		rdot	Vehicle angular acceleration about the vehicle-fixed z-axis	Computed	rad/s



Signal			Description		Value	Units
		DCM	Direction cosine matrix		Computed	rad
	Forces	Body	Fx	Net force on vehicle CG along the vehicle-fixed x-axis	Computed	N
			Fy	Net force on vehicle CG along the vehicle-fixed y-axis	Computed	N
			Fz	Net force on vehicle CG along the vehicle-fixed z-axis	0	N
		Ext	Fx	External force on vehicle CG along the vehicle-fixed x-axis	Computed	N
			Fy	External force on vehicle CG along the vehicle-fixed y-axis	Computed	N
			Fz	External force on vehicle CG along the vehicle-fixed z-axis	0	N
		Hitch	Fx	Hitch force applied to body at the hitch location along the vehicle-fixed x-axis	Input	N
			Fy	Hitch force applied to body at the hitch location along the vehicle-fixed y-axis	Input	N
			Fz	Hitch force applied to body at the hitch location along the vehicle-fixed z-axis	Input	N
	FrntAxl	Lft	Fx	Longitudinal force on left front wheel, along the vehicle-fixed x-axis	Computed	N
			Fy	Lateral force on left front wheel along the vehicle-fixed y-axis	Computed	N
			Fz	Normal force on left front wheel, along the vehicle-fixed z-axis	Computed	N
		Rght	Fx	Longitudinal force on right front wheel, along the vehicle-fixed x-axis	Computed	N

Signal				Description	Value	Units		
		RearAxl	Lft	Fy	Lateral force on right front wheel along the vehicle-fixed y-axis	Computed	N	
				Fz	Normal force on right front wheel, along the vehicle-fixed z-axis	Computed	N	
			Rght	Fx	Longitudinal force on left rear wheel, along the vehicle-fixed x-axis	Computed	N	
				Fy	Lateral force on left rear wheel along the vehicle-fixed y-axis	Computed	N	
				Fz	Normal force on left rear wheel, along the vehicle-fixed z-axis	Computed	N	
			Rght	Fx	Longitudinal force on right rear wheel, along the vehicle-fixed x-axis	Computed	N	
		Fy		Lateral force on right rear wheel along the vehicle-fixed y-axis	Computed	N		
		Fz		Normal force on right rear wheel, along the vehicle-fixed z-axis	Computed	N		
		Tires	FrntTires	Lft	Fx	Front left tire force, along the vehicle-fixed x-axis	Computed	N
					Fy	Front left tire force, along the vehicle-fixed y-axis	Computed	N
					Fz	Front left tire force, along the vehicle-fixed z-axis	Computed	N
			Rght	Fx	Front right tire force, along the vehicle-fixed x-axis	Computed	N	
				Fy	Front right tire force, along the vehicle-fixed y-axis	Computed	N	
				Fz	Front right tire force, along the vehicle-fixed z-axis	Computed	N	
		RearTires	Lft	Fx	Rear left tire force, along the vehicle-fixed x-axis	Computed	N	
Fy	Rear left tire force, along the vehicle-fixed y-axis			Computed	N			

Signal					Description	Value	Units	
				Fz	Rear left tire force, along the vehicle-fixed z-axis	Computed	N	
				Rx	Rear right tire force, along the vehicle-fixed x-axis	Computed	N	
				Ry	Rear right tire force, along the vehicle-fixed y-axis	Computed	N	
				Rz	Rear right tire force, along the vehicle-fixed z-axis	Computed		
		Drag	Fx	Drag force on vehicle CG along the vehicle-fixed x-axis		Computed	N	
				Fy	Drag force on vehicle CG along the vehicle-fixed y-axis	Computed	N	
				Fz	Drag force on vehicle CG along the vehicle-fixed z-axis	Computed	N	
		Grvty	Fx	Gravity force on vehicle CG along the vehicle-fixed x-axis		Computed	N	
				Fy	Gravity force on vehicle CG along the vehicle-fixed y-axis	Computed	N	
				Fz	Gravity force on vehicle CG along the vehicle-fixed z-axis	Computed	N	
		Moments	Body	Mx	Body moment on vehicle CG about the vehicle-fixed x-axis	0	N·m	
				My	Body moment on vehicle CG about the vehicle-fixed y-axis	Computed	N·m	
				Mz	Body moment on vehicle CG about the vehicle-fixed z-axis	0	N·m	
			Drag	Mx	Drag moment on vehicle CG about the vehicle-fixed x-axis		0	N·m
					My	Drag moment on vehicle CG about the vehicle-fixed y-axis	Computed	N·m

Signal				Description	Value	Units		
		Ext	Mz	Drag moment on vehicle CG about the vehicle-fixed z-axis	0	N·m		
			Mx	External moment on vehicle CG about the vehicle-fixed x-axis	0	N·m		
			My	External moment on vehicle CG about the vehicle-fixed y-axis	Computed	N·m		
		Hitch	Mz	External moment on vehicle CG about the vehicle-fixed z-axis	0	N·m		
			Mx	Hitch moment at the hitch location about vehicle-fixed x-axis	0	N·m		
			My	Hitch moment at the hitch location about vehicle-fixed y-axis	Computed	N·m		
		FrntAxl	Lft	Disp	x	Front left wheel displacement along the vehicle-fixed x-axis	Computed	m
					y	Front left wheel displacement along the vehicle-fixed y-axis	Computed	m
					z	Front left wheel displacement along the vehicle-fixed z-axis	Computed	m
	Vel		xdot	Front left wheel velocity along the vehicle-fixed x-axis	Computed	m/s		
			ydott	Front left wheel velocity along the vehicle-fixed y-axis	Computed	m/s		
			zdot	Front left wheel velocity along the vehicle-fixed z-axis	0	m/s		
	Rght	Disp	x	Front right wheel displacement along the vehicle-fixed x-axis	Computed	m		
			y	Front right wheel displacement along the vehicle-fixed y-axis	Computed	m		

Signal				Description	Value	Units	
			Vel	z	Front right wheel displacement along the vehicle-fixed z-axis	Computed	m
				xdo t	Front right wheel velocity along the vehicle-fixed x-axis	Computed	m/s
				ydo t	Front right wheel velocity along the vehicle-fixed y-axis	Computed	m/s
		zdo t	Front right wheel velocity along the vehicle-fixed z-axis	0	m/s		
		Steer	WhlAngFL		Front left wheel steering angle	Computed	rad
			WhlAngFR		Front right wheel steering angle	Computed	rad
	RearAxl	Lft	Disp	x	Rear left wheel displacement along the vehicle-fixed x-axis	Computed	m
				y	Rear left wheel displacement along the vehicle-fixed y-axis	Computed	m
				z	Rear left wheel displacement along the vehicle-fixed z-axis	Computed	m
			Vel	xdo t	Rear left wheel velocity along the vehicle-fixed x-axis	Computed	m/s
				ydo t	Rear left wheel velocity along the vehicle-fixed y-axis	Computed	m/s
				zdo t	Rear left wheel velocity along the vehicle-fixed z-axis	0	m/s
Rght		Disp	x	Rear right wheel displacement along the vehicle-fixed x-axis	Computed	m	
			y	Rear right wheel displacement along the vehicle-fixed y-axis	Computed	m	
			z	Rear right wheel displacement along the vehicle-fixed z-axis	Computed	m	

Signal				Description	Value	Units	
		Vel	xdo t	Rear right wheel velocity along the vehicle-fixed x-axis	Computed	m/s	
			ydo t	Rear right wheel velocity along the vehicle-fixed y-axis	Computed	m/s	
			zdo t	Rear right wheel velocity along the vehicle-fixed z-axis	0	m/s	
		Steer	WhlAngRL		Rear left wheel steering angle	Computed	rad
			WhlAngRR		Rear right wheel steering angle	Computed	rad
		Hitch	Disp		x	Hitch offset from axle plane along the vehicle-fixed x-axis	Input
y	Hitch offset from center plane along the vehicle-fixed y-axis				Input	m	
z	Hitch offset from axle plane along the earth-fixed z-axis				Input	m	
Vel			xdo t	Hitch offset velocity along the vehicle-fixed x-axis	Computed	m/s	
			ydo t	Hitch offset velocity along the vehicle-fixed y-axis	Computed	m/s	
			zdo t	Hitch offset velocity along the vehicle-fixed z-axis	Computed	m/s	
Pwr	Ext		Applied external power	Computed	W		
	Hitch		Power loss due to hitch	Computed	W		
	Drag		Power loss due to drag	Computed	W		
Geom	Disp		x	Vehicle chassis offset from axle plane along the vehicle-fixed x-axis	Input	m	
			y	Vehicle chassis offset from center plane along the vehicle-fixed y-axis	Input	m	
			z	Vehicle chassis offset from axle plane along the earth-fixed z-axis	Input	m	
	Vel		xdo t	Vehicle chassis offset velocity along the vehicle-fixed x-axis	Computed	m/s	

Signal			Description	Value	Units	
			ydot	Vehicle chassis offset velocity along the vehicle-fixed y-axis	Computed	m/s
			zdot	Vehicle chassis offset velocity along the vehicle-fixed z-axis	0	m/s
		Beta	Beta $\beta = \frac{V_y}{V_x}$	Computed	rad	

Signal			Description	Value	Units
PwrInfo	PwrTrnsfrd	PwrFxExt	Externally applied longitudinal force power	Computed	W
		PwrFyExt	Externally applied lateral force power	Computed	W
		PwrMzExt	Externally applied roll moment power	Computed	W
		PwrFwFLx	Longitudinal force applied at the front left axle power	Computed	W
		PwrFwFLy	Lateral force applied at the front left axle power	Computed	W
		PwrFwFRx	Longitudinal force applied at the front right axle power	Computed	W
		PwrFwFRy	Lateral force applied at the front right axle power	Computed	W
		PwrFwRLx	Longitudinal force applied at the rear left axle power	Computed	W
		PwrFwRLy	Lateral force applied at the rear left axle power	Computed	W
		PwrFwRRx	Longitudinal force applied at the rear right axle power	Computed	W
	PwrFwRRy	Lateral force applied at the rear right axle power	Computed	W	
	PwrNotTrnsfrd	PwrFxDrag	Longitudinal drag force power	Computed	W
		PwrFyDrag	Lateral drag force power	Computed	W
PwrMzDrag		Drag pitch moment power	Computed	W	
PwrStored	PwrStoredGrvty	Rate change in gravitational potential energy	Computed	W	

Signal		Description	Value	Units
	PwrStoredxdot	Rate of change of longitudinal kinetic energy	Computed	W
	PwrStoredydot	Rate of change of lateral kinetic energy	Computed	W
	PwrStoredr	Rate of change of rotational yaw kinetic energy	Computed	W

**xdot – Vehicle longitudinal velocity**

scalar

Vehicle CG velocity along the vehicle-fixed x-axis, in m/s.

**ydot – Vehicle lateral velocity**

scalar

Vehicle CG velocity along the vehicle-fixed y-axis, in m/s.

**psi – Yaw**

scalar

Rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw), in rad.

**r – Yaw rate**

scalar

Vehicle angular velocity,  $r$ , about the vehicle-fixed z-axis (yaw rate), in rad/s.

**FzF – Normal force on front wheels**

scalar | array

Normal force on front wheels,  $F_{zF}$ , along the vehicle-fixed z-axis, in N.

Vehicle Track Setting	Description	Variable	Signal Dimension
Single (bicycle)	Normal force on front axle	$F_{zF} = F_{z_f}$	Scalar - 1
Dual	Normal force on the front wheels	$F_{zF} = [F_{z_{fl}} \ F_{z_{fr}}]$	Array - [1x2]

**FzR – Normal force on rear wheels**

scalar | array

Normal force on rear wheels,  $F_{zR}$ , along the vehicle-fixed z-axis, in N.

Vehicle Track Setting	Description	Variable	Signal Dimension
Single (bicycle)	Normal force on rear wheel	$F_{zR} = F_{z_r}$	Scalar - 1



Vehicle Track Setting	Description	Variable	Signal Dimension
Dual	Normal force on the rear wheels	$FzR = [Fz_{rl} \ Fz_{rr}]$	Array - [1x2]

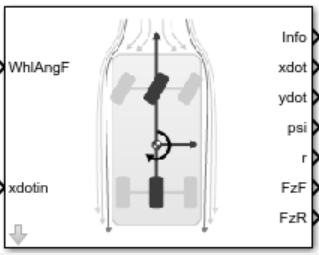
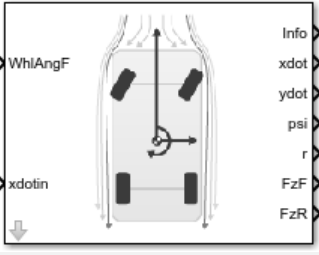
## Parameters

### Options

#### Vehicle track – Number of tracks

Single (bicycle) | Dual

In the Vehicle Dynamics Blockset library, there are two types of Vehicle Body 3DOF blocks that model longitudinal, lateral, and yaw motion.

Block	Vehicle Track Setting	Implementation
	Single (bicycle)	<ul style="list-style-type: none"> <li>Forces act along the center line at the front and rear axles.</li> <li>No lateral load transfer.</li> </ul>
	Dual	Forces act at the four vehicle corners or <i>hard points</i> .

#### Axle forces – Type of axle force

External longitudinal velocity | External longitudinal forces | External forces

Use the **Axle forces** parameter to specify the type of force.

Axle Forces Setting	Implementation
External longitudinal velocity	<ul style="list-style-type: none"> <li>• The block assumes that the external longitudinal velocity is in a quasi-steady state, so the longitudinal acceleration is approximately zero.</li> <li>• Because the motion is quasi-steady, the block calculates lateral forces using the tire slip angles and linear cornering stiffness.</li> <li>• Consider this setting when you want to:               <ul style="list-style-type: none"> <li>• Generate virtual sensor signal data.</li> <li>• Conduct high-level software studies that are not impacted by driveline or nonlinear tire responses.</li> </ul> </li> </ul>
External longitudinal forces	<ul style="list-style-type: none"> <li>• The block uses the external longitudinal force to accelerate or brake the vehicle.</li> <li>• The block calculates lateral forces using the tire slip angles and linear cornering stiffness.</li> <li>• Consider this setting when you want to:               <ul style="list-style-type: none"> <li>• Account for changes in the longitudinal velocity on the lateral and yaw motion.</li> <li>• Specify the external longitudinal motion through a force instead of an external longitudinal velocity.</li> <li>• Connect the block to tractive actuators, wheels, brakes, and hitches.</li> </ul> </li> </ul>
External forces	<ul style="list-style-type: none"> <li>• The block uses the external lateral and longitudinal forces to steer, accelerate, or brake the vehicle.</li> <li>• The block does not use the steering input to calculate vehicle motion.</li> <li>• Consider this setting when you need tire models with more accurate nonlinear combined lateral and longitudinal slip.</li> </ul>

**Input Signals**

**Front wheel steering — WhlAngF input port**

on (default) | off

Specify to create input port WhlAngF.

**External wind — WindXYZ input port**

off (default) | on

Specify to create input port WindXYZ.

**External forces — FExt input port**

off (default) | on

Specify to create input port FExt.

**External moments — MExt input port**

off (default) | on

Specify to create input port MExt.

**Rear wheel steering — WhlAngR input port**

off (default) | on

Specify to create input port WhlAngR.

**External friction — Mu input port**

off (default) | on

Specify to create input port Mu.

**Hitch forces — Fh input port**

on (default) | off

Select to create input port Fh.

**Hitch moments — Mh input port**

on (default) | off

Specify to create input port Mh.

**Initial longitudinal position — X\_o input port**

off (default) | on

Specify to create input port X\_o.

**Initial lateral position — Y\_o input port**

off (default) | on

Specify to create input port Y\_o.

**Initial longitudinal velocity — xdot\_o input port**

off (default) | on

Specify to create input port xdot\_o.

**Initial lateral velocity — ydot\_o input port**

off (default) | on

Specify to create input port ydot\_o.

**Initial yaw angle — psi\_o input port**

off (default) | on

Specify to create input port psi\_o.

**Initial yaw rate — r\_o input port**

off (default) | on

Specify to create input port r\_o.

**Air temperature — AirTemp input port**

off (default) | on

Specify to create input port AirTemp.

**Longitudinal****Number of wheels on front axle,  $N_F$  — Front wheel count**

2 (default) | scalar

Number of wheels on front axle,  $N_F$ . The value is dimensionless.**Number of wheels on rear axle,  $N_R$  — Rear wheel count**

2 (default) | scalar

Number of wheels on rear axle,  $N_R$ . The value is dimensionless.**Vehicle mass,  $m$  — Vehicle mass**

2000 (default) | scalar

Vehicle mass,  $m$ , in kg.**Longitudinal distance from center of mass to front axle,  $a$  — Front axle distance**

1.4 (default) | scalar

Horizontal distance  $a$  from the vehicle CG to the front wheel axle, in m.**Longitudinal distance from center of mass to rear axle,  $b$  — Rear axle distance**

1.6 (default) | scalar

Horizontal distance  $b$  from the vehicle CG to the rear wheel axle, in m.**Vertical distance from center of mass to axle plane,  $h$  — Height**

0.35 (default) | scalar

Height of vehicle CG above the axles,  $h$ , in m.**Longitudinal distance from center of mass to hitch,  $dh$  — Distance from CM to hitch**

1 (default) | scalar

Longitudinal distance from center of mass to hitch,  $dh$ , in m.**Dependencies**To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.**Vertical distance from hitch to axle plane,  $hh$  — Distance from hitch to axle plane**

0.2 (default) | scalar

Vertical distance from hitch to axle plane,  $hh$ , in m.**Dependencies**To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.**Initial inertial frame longitudinal position,  $X_o$  — Position**

0 (default) | scalar

Initial vehicle CG displacement along earth-fixed  $X$ -axis, in m.

**Initial longitudinal velocity,  $\dot{x}_o$  – Velocity** $0$  (default) | scalar

Initial vehicle CG velocity along vehicle-fixed x-axis, in m/s.

**Dependencies**For the Vehicle Body 3DOF Single Track or Vehicle Body 3DOF Dual Track blocks, to enable this parameter, set **Axle forces** to one of these options:

- External longitudinal forces
- External forces

**Lateral****Front tire corner stiffness,  $C_{y_f}$  – Stiffness** $12e3$  (default) | scalarFront tire corner stiffness,  $C_{y_f}$ , in N/rad.**Dependencies**

For the Vehicle Body 3DOF Single Track or Vehicle Body 3DOF Dual Track blocks, to enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Clear **Mapped corner stiffness**.

**Rear tire corner stiffness,  $C_{y_r}$  – Stiffness** $11e3$  (default) | scalarRear tire corner stiffness,  $C_{y_r}$ , in N/rad.**Dependencies**

For the Vehicle Body 3DOF Single Track or Vehicle Body 3DOF Dual Track blocks, to enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Clear **Mapped corner stiffness**.

**Initial inertial frame lateral displacement,  $Y_o$  – Position** $0$  (default) | scalar

Initial vehicle CG displacement along earth-fixed Y-axis, in m.

**Initial lateral velocity,  $\dot{y}_o$  – Velocity** $0$  (default) | scalar

Initial vehicle CG velocity along vehicle-fixed y-axis, in m/s.

**Mapped corner stiffness – Selection**

off (default) | on

Enables mapped corner stiffness calculation.

**Dependencies**

To enable this parameter, set **Axle forces** to one of these options:

- External longitudinal velocity
- External longitudinal forces

**Include relaxation length dynamics – Enable relaxation length dynamics**

on (default) | off

Enables relaxation length dynamics.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Clear **Mapped corner stiffness**.

**Lateral distance from geometric centerline to center of mass,  $d$  – Distance** $0$  (default) | scalar

Lateral distance from geometric centerline to center of mass,  $d$ , in m, along the vehicle-fixed  $y$ . Positive values indicate that the vehicle CM is to the right of the geometric centerline. Negative values indicate that the vehicle CM is to the left of the geometric centerline.

**Lateral distance from geometric centerline to hitch,  $hl$  – Distance** $0$  (default) | scalar

Lateral distance from geometric centerline to the hitch,  $hl$ , in m, along the vehicle-fixed  $y$ . Positive values indicate that the hitch is to the right of the geometric centerline. Negative values indicate that the hitch is to the left of the geometric centerline.

**Dependencies**

To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.

**Track width – Width**

[1.4, 1.4] (default) | 1-by-2 vector

Track width,  $w$ , in m.

**Dependencies**

To enable this parameter, set **Vehicle track** to Dual.

**Front tire(s) relaxation length,  $\sigma_f$  – Relaxation length**

.1 (default) | scalar

Front tire relaxation length,  $\sigma_f$ , in m.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Do either of these:
  - Select **Mapped corner stiffness**.
  - Clear **Mapped corner stiffness** and select **Include relaxation length dynamics**.

**Rear tire(s) relaxation length, sigma\_r — Relaxation length**

.1 (default) | scalar

Rear tire relaxation length,  $\sigma_r$ , in m.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Do either of these:
  - Select **Mapped corner stiffness**.
  - Clear **Mapped corner stiffness** and select **Include relaxation length dynamics**.

**Front axle slip angle breakpoints, alpha\_f\_brk — Breakpoints**

[-.1 .1] (default) | vector

Front axle slip angle breakpoints,  $\alpha_{fbrk}$ , in rad.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Select **Mapped corner stiffness**.

**Front axle corner data, Cy\_f\_data — Breakpoints**

[-9e3 9e3] (default) | vector

Front axle corner data,  $Cy_{fdata}$ , in N/rad.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Select **Mapped corner stiffness**.

**Rear axle slip angle breakpoints,  $\alpha_{r\_brk}$  — Breakpoints**

[-.1 .1] (default) | vector

Rear axle slip angle breakpoints,  $\alpha_{rbrk}$ , in rad.**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Select **Mapped corner stiffness**.

**Rear axle corner data,  $Cy_{r\_data}$  — Data**

[-9e3 9e3] (default) | vector

Rear axle corner data,  $Cy_{rdata}$ , in N/rad.**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Select **Mapped corner stiffness**.

**Yaw****Yaw polar inertia,  $I_{zz}$  — Inertia**

4000 (default) | scalar

Yaw polar inertia, in  $\text{kg}\cdot\text{m}^2$ .**Initial yaw angle,  $\psi_o$  — Psi rotation**

0 (default) | scalar

Rotation of the vehicle-fixed frame about earth-fixed Z-axis (yaw), in rad.

**Initial yaw rate,  $r_o$  — Yaw rate**

0 (default) | scalar

Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate), in rad/s.



**Aerodynamic****Longitudinal drag area, Af — Effective vehicle cross-sectional area**

2 (default) | scalar

Effective vehicle cross-sectional area,  $A_f$ , to calculate the aerodynamic drag force on the vehicle, in  $m^2$ .

**Longitudinal drag coefficient, Cd — Air drag coefficient**

.3 (default) | scalar

Air drag coefficient,  $C_d$ . The value is dimensionless.

**Longitudinal lift coefficient, Cl — Air lift coefficient**

.1 (default) | scalar

Air lift coefficient,  $C_l$ . The value is dimensionless.

**Longitudinal drag pitch moment, Cpm — Pitch drag**

.1 (default) | scalar

Longitudinal drag pitch moment coefficient,  $C_{pm}$ . The value is dimensionless.

**Relative wind angle vector, beta\_w — Wind angle**

[0:0.01:0.3] (default) | vector

Relative wind angle vector,  $\beta_w$ , in rad.

**Side force coefficient vector, Cs — Side force coefficient**

[0:0.03:0.9] (default) | vector

Side force coefficient vector coefficient,  $C_s$ . The value is dimensionless.

**Yaw moment coefficient vector, Cym — Yaw moment drag**

[0:0.01:0.3] (default) | vector

Yaw moment coefficient vector coefficient,  $C_{ym}$ . The value is dimensionless.

**Environment****Absolute air pressure, Pabs — Pressure**

101325 (default) | scalar | scalar

Environmental absolute pressure,  $P_{abs}$ , in Pa.

**Air temperature, Tair — Temperature**

273 (default) | scalar

Environmental absolute temperature,  $T$ , in K.

**Dependencies**

To enable this parameter, clear **Air temperature**.

**Gravitational acceleration, g — Gravity**

9.81 (default) | scalar

Gravitational acceleration,  $g$ , in  $\text{m/s}^2$ .

**Nominal friction scaling factor,  $\mu$  – Friction scale factor**

1 (default) | scalar

Nominal friction scale factor,  $\mu$ . The value is dimensionless.

**Dependencies**

For the Vehicle Body 3DOF Single Track or Vehicle Body 3DOF Dual Track blocks, to enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Clear **External Friction**.

**Simulation**

**Longitudinal velocity tolerance,  $x_{\dot{t}ol}$  – Tolerance**

.01 (default) | scalar

Longitudinal velocity tolerance, in m/s.

**Nominal normal force,  $F_{znom}$  – Normal force**

5000 (default) | scalar

Nominal normal force, in N.

**Dependencies**

For the Vehicle Body 3DOF Single Track or Vehicle Body 3DOF Dual Track blocks, to enable this parameter, set **Axle forces** to one of these options:

- External longitudinal velocity
- External longitudinal forces

**Geometric longitudinal offset from axle plane,  $longOff$  – Longitudinal offset**

0 (default) | scalar

Vehicle chassis offset from axle plane along body-fixed  $x$ -axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independent of the vehicle CG.

**Geometric lateral offset from center plane,  $latOff$  – Lateral offset**

0 (default) | scalar

Vehicle chassis offset from center plane along body-fixed  $y$ -axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independent of the vehicle CG.

**Geometric vertical offset from axle plane,  $vertOff$  – Vertical offset**

0 (default) | scalar

Vehicle chassis offset from axle plane along body-fixed  $z$ -axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independent of the vehicle CG.

**Wrap Euler angles, wrapAng — Selection**

off (default) | on

Wrap the Euler angles to the interval  $[-\pi, \pi]$ . For vehicle maneuvers that might undergo vehicle yaw rotations that are outside of the interval, consider deselecting the parameter if you want to:

- Track the total vehicle yaw rotation.
- Avoid discontinuities in the vehicle state estimators.

**References**

[1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers (SAE), 1992.

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Vector Concatenate, Matrix Concatenate | Vehicle Body 6DOF | Vehicle Body 3DOF Longitudinal

**Topics**

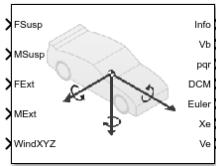
“Coordinate Systems in Vehicle Dynamics Blockset”

**Introduced in R2018a**

## Vehicle Body 6DOF

Two-axle vehicle body with translational and rotational motion

**Library:** Vehicle Dynamics Blockset / Vehicle Body



### Description

The Vehicle Body 6DOF block implements a six degrees-of-freedom (DOF) rigid two-axle vehicle body model to calculate longitudinal, lateral, vertical, pitch, roll, and yaw motion. The block accounts for body mass, inertia, aerodynamic drag, road incline, and weight distribution between the axles due to suspension and external forces and moments. Use the **Inertial Loads** parameters to analyze the vehicle dynamics under different loading conditions.

You can connect the block to virtual sensors, suspension system, or external systems like body control actuators. Use the Vehicle Body 6DOF block in ride and handling studies to model the effects of drag forces, passenger loading, and suspension hardpoint locations.

To create additional input ports, under **Input signals**, select these block parameters.

Parameter	Input Port	Description
<b>Hitch forces</b>	Fh	Hitch force applied to the body at the hitch location, $Fh_x$ , $Fh_y$ , and $Fh_z$ , in the vehicle-fixed frame
<b>Hitch moments</b>	Mh	Hitch moment at the hitch location, $Mh_x$ , $Mh_y$ , and $Mh_z$ , about the vehicle-fixed frame

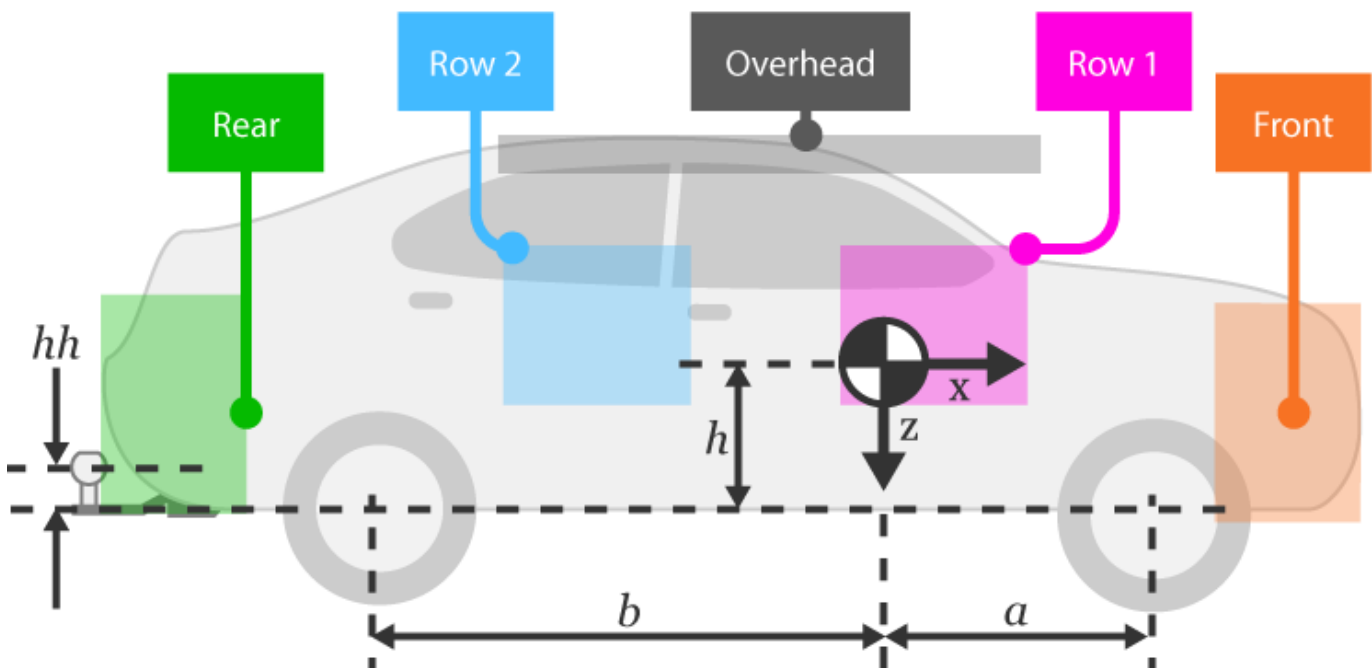
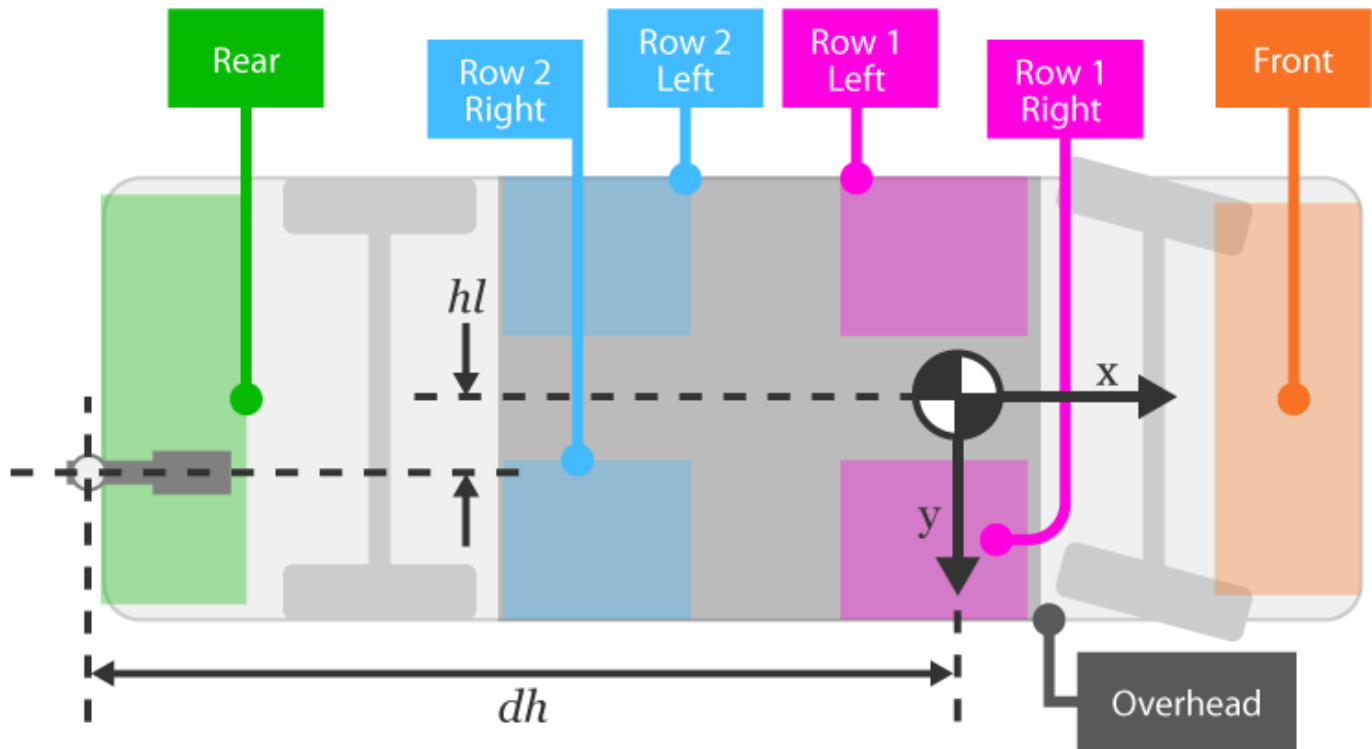
### Inertial Loads

To analyze the vehicle dynamics under different loading conditions, use the **Inertial Loads** parameters. Specifically, you can specify these loads:

- Front powertrain
- Front and rear row passengers
- Overhead cargo
- Rear cargo

For each of the loads, you can specify the mass, location, and inertia.

The illustrations provide the load locations and vehicle parameter dimensions. The table provides the corresponding location parameter sign settings.



This table summarizes the parameter settings that specify the load locations indicated by the dots. For the location, the block uses this distance vector:

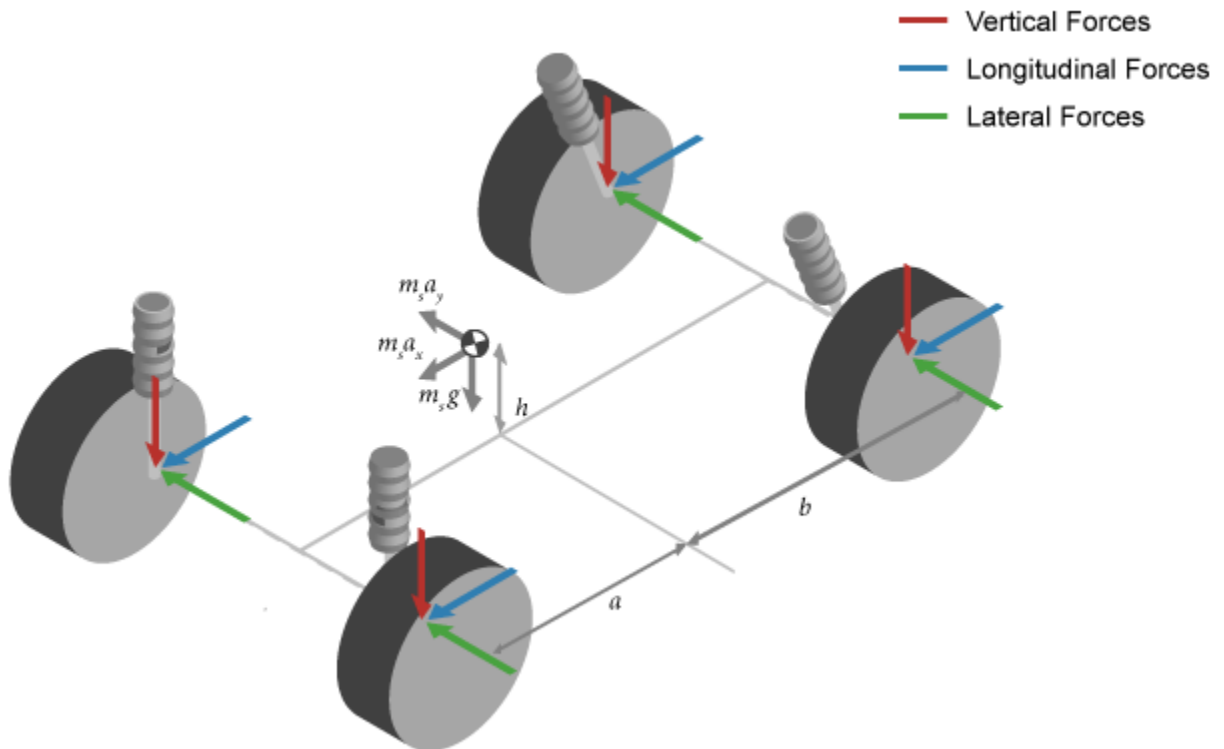
- Front suspension hardpoint to load, along the vehicle-fixed  $x$ -axis
- Vehicle centerline to load, along the vehicle-fixed  $y$ -axis
- Front suspension hardpoint to load, along the vehicle-fixed  $z$ -axis

Load	Parameter	Example Location
Front	<b>Distance vector from front axle, <math>z1R</math></b>	<ul style="list-style-type: none"> <li>• <math>z1R(1,1) &lt; 0</math> — Forward of the front axle</li> <li>• <math>z1R(1,2) &gt; 0</math> — Right of the vehicle centerline</li> <li>• <math>z1R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Overhead	<b>Distance vector from front axle, <math>z2R</math></b>	<ul style="list-style-type: none"> <li>• <math>z2R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z2R(1,2) &lt; 0</math> — Left of the vehicle centerline</li> <li>• <math>z2R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Row 1, left side	<b>Distance vector from front axle, <math>z3R</math></b>	<ul style="list-style-type: none"> <li>• <math>z3R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z3R(1,2) &lt; 0</math> — Left of the vehicle centerline</li> <li>• <math>z3R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Row 1, right side	<b>Distance vector from front axle, <math>z4R</math></b>	<ul style="list-style-type: none"> <li>• <math>z4R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z4R(1,2) &gt; 0</math> — Right of the vehicle centerline</li> <li>• <math>z4R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Row 2, left side	<b>Distance vector from front axle, <math>z5R</math></b>	<ul style="list-style-type: none"> <li>• <math>z5R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z5R(1,2) &lt; 0</math> — Left of the vehicle centerline</li> <li>• <math>z5R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Row 2, right side	<b>Distance vector from front axle, <math>z6R</math></b>	<ul style="list-style-type: none"> <li>• <math>z6R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z6R(1,2) &gt; 0</math> — Right of the vehicle centerline</li> <li>• <math>z6R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Rear	<b>Distance vector from front axle, <math>z7R</math></b>	<ul style="list-style-type: none"> <li>• <math>z7R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z7R(1,2) &gt; 0</math> — Right of the vehicle centerline</li> <li>• <math>z7R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>

### Equations of Motion

To determine the vehicle motion, the block implements calculations for the rigid body vehicle dynamics, wind drag, inertial loads, and coordinate transformations. The body-fixed and the vehicle-fixed are the same coordinate systems.

The Vehicle Body 6DOF block considers the rotation of a body-fixed coordinate frame about a flat earth-fixed inertial reference frame. The origin of the body-fixed coordinate frame is the vehicle center of gravity of the body.



The block uses this equation to calculate the translational motion of the body-fixed coordinate frame, where the applied forces  $[F_x \ F_y \ F_z]^T$  are in the body-fixed frame, and the mass of the body,  $m$ , is assumed constant.

$$\bar{F}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m(\dot{\bar{V}}_b + \bar{\omega} \times \bar{V}_b)$$

$$\bar{M}_b = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I\dot{\bar{\omega}} + \bar{\omega} \times (I\bar{\omega})$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

To determine the relationship between the body-fixed angular velocity vector,  $[p \ q \ r]^T$ , and the rate of change of the Euler angles,  $[\dot{\phi} \ \dot{\theta} \ \dot{\psi}]^T$ , the block resolves the Euler rates into the body-fixed frame.

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} \dot{\phi} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} 0 \\ \dot{\theta} \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \dot{\psi} \end{bmatrix} \equiv J^{-1} \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

Inverting  $J$  gives the required relationship to determine the Euler rate vector.

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = J \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & (\sin\phi \tan\theta) & (\cos\phi \tan\theta) \\ 0 & \cos\phi & -\sin\phi \\ 0 & \frac{\sin\phi}{\cos\theta} & \frac{\cos\phi}{\cos\theta} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

The applied forces and moments are the sum of the drag, gravitational, external, and suspension forces.

$$\bar{F}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \begin{bmatrix} F_{d_x} \\ F_{d_y} \\ F_{d_z} \end{bmatrix} + \begin{bmatrix} F_{g_x} \\ F_{g_y} \\ F_{g_z} \end{bmatrix} + \begin{bmatrix} F_{ext_x} \\ F_{ext_y} \\ F_{ext_z} \end{bmatrix} + \begin{bmatrix} F_{FL_x} \\ F_{FL_y} \\ F_{FL_z} \end{bmatrix} + \begin{bmatrix} F_{FR_x} \\ F_{FR_y} \\ F_{FR_z} \end{bmatrix} + \begin{bmatrix} F_{RL_x} \\ F_{RL_y} \\ F_{RL_z} \end{bmatrix} + \begin{bmatrix} F_{RR_x} \\ F_{RR_y} \\ F_{RR_z} \end{bmatrix}$$

$$\bar{M}_b = \begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} M_{d_x} \\ M_{d_y} \\ M_{d_z} \end{bmatrix} + \begin{bmatrix} M_{ext_x} \\ M_{ext_y} \\ M_{ext_z} \end{bmatrix} + \begin{bmatrix} M_{FL_x} \\ M_{FL_y} \\ M_{FL_z} \end{bmatrix} + \begin{bmatrix} M_{FR_x} \\ M_{FR_y} \\ M_{FR_z} \end{bmatrix} + \begin{bmatrix} M_{RL_x} \\ M_{RL_y} \\ M_{RL_z} \end{bmatrix} + \begin{bmatrix} M_{RR_x} \\ M_{RR_y} \\ M_{RR_z} \end{bmatrix} + \bar{M}_F$$

Calculation	Implementation
Load masses and inertias	Block uses parallel axis theorem to resolve the individual load masses and inertias with the vehicle mass and inertia. $J_{ij} = I_{ij} + m( R ^2\delta_{ij} - R_iR_j)$
Gravitational forces, $F_g$	Block uses direction cosine matrix (DCM) to transform the gravitational vector in the inertial-fixed frame to the body-fixed frame.
Drag forces, $F_d$ , and moments, $M_d$	To determine a relative airspeed, the block subtracts the wind speed from the vehicle center of mass (CM) velocity. Using the relative airspeed, the block determines the drag forces. $\bar{w} = \sqrt{(\dot{x}_b - w_x)^2 + (\dot{y}_b - w_y)^2 + (w_z)^2}$ $F_{dx} = -\frac{1}{2TR}C_dA_fP_{abs}(\bar{w})$ $F_{dy} = -\frac{1}{2TR}C_sA_fP_{abs}(\bar{w})$ $F_{dz} = -\frac{1}{2TR}C_lA_fP_{abs}(\bar{w})$ Using the relative airspeed, the block determines the drag moments. $M_{dr} = -\frac{1}{2TR}C_{rm}A_fP_{abs}(\bar{w})(a+b)$ $M_{dp} = -\frac{1}{2TR}C_{pm}A_fP_{abs}(\bar{w})(a+b)$ $M_{dy} = -\frac{1}{2TR}C_{ym}A_fP_{abs}(\bar{w})(a+b)$
External forces, $F_{in}$ , and moments, $M_{in}$	External forces and moments are input via ports FExt and MExt.



Calculation	Implementation
<i>Suspension forces and moments</i>	Block assumes that the suspension forces and moments act on these hardpoint locations: <ul style="list-style-type: none"> <li>• <math>F_{FL}, M_{FL}</math> — Front left</li> <li>• <math>F_{FR}, M_{FR}</math> — Front right</li> <li>• <math>F_{RL}, M_{RL}</math> — Rear left</li> <li>• <math>F_{RR}, M_{RR}</math> — Rear right</li> </ul>

The equations use these variables.

$x, \dot{x}, \ddot{x}$	Vehicle CM displacement, velocity, and acceleration along the vehicle-fixed x-axis
$y, \dot{y}, \ddot{y}$	Vehicle CM displacement, velocity, and acceleration along the vehicle-fixed y-axis
$z, \dot{z}, \ddot{z}$	Vehicle CM displacement, velocity, and acceleration along the vehicle-fixed z-axis
$\varphi$	Rotation of the vehicle-fixed frame about the earth-fixed X-axis (roll)
$\theta$	Rotation of the vehicle-fixed frame about the earth-fixed Y-axis (pitch)
$\psi$	Rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw)
$F_{FLx}, F_{FLy}, F_{FLz}$	Suspension forces applied to front left hardpoint along the vehicle-fixed x-, y-, and z-axes
$F_{FRx}, F_{FRy}, F_{FRz}$	Suspension forces applied to front right hardpoint along the vehicle-fixed x-, y-, and z-axes
$F_{RLx}, F_{RLy}, F_{RLz}$	Suspension forces applied to rear left hardpoint along the vehicle-fixed x-, y-, and z-axes
$F_{RRx}, F_{RRy}, F_{RRz}$	Suspension forces applied to rear right hardpoint along the vehicle-fixed x-, y-, and z-axes
$M_{Fx}, F_{Fy}, F_{Fz}$	Suspension moments applied to vehicle CM about the vehicle-fixed x-, y-, and z-axes
$F_{extx}, F_{exty}, F_{extz}$	External forces applied to vehicle CM along the vehicle-fixed x-, y-, and z-axes
$F_{dx}, F_{dy}, F_{dz}$	Drag forces applied to vehicle CM along the vehicle-fixed x-, y-, and z-axes
$M_{extx}, M_{exty}, M_{extz}$	External moment about vehicle CM about the vehicle-fixed x-, y-, and z-axes
$M_{dx}, M_{dy}, M_{dz}$	Drag moment about vehicle CM about the vehicle-fixed x-, y-, and z-axes
$I$	Vehicle body moments of inertia
$a, b$	Distance of front and rear wheels, respectively, from the normal projection point of vehicle CM onto the common axle plane
$d$	Lateral distance from the geometric centerline to the center of mass along the vehicle-fixed y-axis
$h$	Height of vehicle CM above the axle plane
$hh$	Height of the hitch above the axle plane along the vehicle-fixed z-axis
$dh$	Longitudinal distance of the hitch from the normal projection point of tractor CG onto the common axle plane

$hl$	Lateral distance from center of mass to hitch along the vehicle-fixed y-axis.
$w_F, w_R$	Front and rear track widths
$C_d$	Air drag coefficient acting along the vehicle-fixed x-axis
$C_s$	Air drag coefficient acting along the vehicle-fixed y-axis
$C_l$	Air drag coefficient acting along the vehicle-fixed z-axis
$C_{rm}$	Air drag roll moment acting about vehicle-fixed x-axis
$C_{pm}$	Air drag pitch moment acting about the vehicle-fixed y-axis
$C_{ym}$	Air drag yaw moment acting about vehicle-fixed z-axis
$A_f$	Frontal area
$R$	Atmospheric specific gas constant
$T$	Environmental air temperature
$P_{abs}$	Environmental absolute pressure
$w_x, w_y, w_z$	Wind speed along the vehicle-fixed x-, y-, and z-axes
$W_x, W_y, W_z$	Wind speed along inertial X-, Y-, and Z-axes

## Ports

### Input

#### FSusp — Suspension forces on vehicle

array

Suspension longitudinal, lateral, and vertical suspension forces applied to the vehicle at the hardpoint location, in N. Signal dimensions are [3x4].

$$FSusp = \begin{bmatrix} F_{FLx} & F_{FRx} & F_{RLx} & F_{RRx} \\ F_{FLy} & F_{FRy} & F_{RLy} & F_{RRy} \\ F_{FLz} & F_{FRz} & F_{RLz} & F_{RRz} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
FSusp(1,1)	Front	Left	Vehicle-fixed x-axis (longitudinal)
FSusp(1,2)	Front	Right	
FSusp(1,3)	Rear	Left	
FSusp(1,4)	Rear	Right	
FSusp(2,1)	Front	Left	Vehicle-fixed y-axis (lateral)
FSusp(2,2)	Front	Right	
FSusp(2,3)	Rear	Left	
FSusp(2,4)	Rear	Right	
FSusp(3,1)	Front	Left	Vehicle-fixed z-axis (vertical)
FSusp(3,2)	Front	Right	
FSusp(3,3)	Rear	Left	
FSusp(3,4)	Rear	Right	

**MSusp — Suspension moment on vehicle**

array

Suspension longitudinal, lateral, and vertical suspension moments applied about the vehicle at the hardpoint location, in N·m. Signal dimensions are [3x4].

$$MSusp = \begin{bmatrix} M_{FLx} & M_{FRx} & M_{RLx} & M_{RRx} \\ M_{FLy} & M_{FRy} & M_{RLy} & M_{RRy} \\ M_{FLz} & M_{FRz} & M_{RLz} & M_{RRz} \end{bmatrix}$$

Array Element	Axle	Track	Moment Axis
MSusp(1,1)	Front	Left	Vehicle-fixed x-axis (longitudinal)
MSusp(1,2)	Front	Right	
MSusp(1,3)	Rear	Left	
MSusp(1,4)	Rear	Right	
MSusp(2,1)	Front	Left	Vehicle-fixed y-axis (lateral)
MSusp(2,2)	Front	Right	
MSusp(2,3)	Rear	Left	
MSusp(2,4)	Rear	Right	
MSusp(3,1)	Front	Left	Vehicle-fixed z-axis (vertical)
MSusp(3,2)	Front	Right	
MSusp(3,3)	Rear	Left	
MSusp(3,4)	Rear	Right	

**FExt — External forces acting on vehicle**

vector

External forces on the vehicle, in N, specified as a 1-by-3 or 3-by-1 vector.

$$FExt = F_{ext} = \begin{bmatrix} F_{ext_x} & F_{ext_y} & F_{ext_z} \end{bmatrix} \text{ or } \begin{bmatrix} F_{ext_x} \\ F_{ext_y} \\ F_{ext_z} \end{bmatrix}$$

Array Element	Force Axis
FExt(1,1)	Vehicle-fixed x-axis (longitudinal)
FExt(1,2) or FExt(2,1)	Vehicle-fixed y-axis (lateral)
FExt(1,3) or FExt(3,1)	Vehicle-fixed z-axis (vertical)

**MExt — External moments acting on vehicle**

vector

External moments acting on the vehicle, in N·m, specified as a 1-by-3 or 3-by-1 vector.

$$MExt = M_{ext} = \begin{bmatrix} M_{ext_x} & M_{ext_y} & M_{ext_z} \end{bmatrix} \text{ or } \begin{bmatrix} M_{ext_x} \\ M_{ext_y} \\ M_{ext_z} \end{bmatrix}$$

Array Element	Force Axis
MExt(1,1)	Vehicle-fixed x-axis (longitudinal)
MExt(1,2) or MExt(2,1)	Vehicle-fixed y-axis (lateral)
MExt(1,3) or MExt(3,1)	Vehicle-fixed z-axis (vertical)

**Fh — Hitch force on the body**

array

Hitch force applied to the body at the hitch location,  $Fh_x, Fh_y, Fh_z$ , in the vehicle-fixed frame, in N, specified as a 1-by-3 or 3-by-1 array.

**Dependencies**

To enable this port, under **Input signals**, select **Hitch forces**.

**Mh — Hitch moment about body**

array

Hitch moment at the hitch location,  $Mh_x, Mh_y, Mh_z$ , about the vehicle-fixed frame, in N·m, specified as a 1-by-3 or 3-by-1 array.

**Dependencies**

To enable this port, under **Input signals**, select **Hitch moments**.

**WindXYZ — Wind speed**

array

Wind speed,  $W_x, W_y, W_z$  along inertial X-, Y-, and Z-axes, in m/s, specified as a 1-by-3 or 3-by-1 array.

**AirTemp — Ambient air temperature**

scalar

Ambient air temperature,  $T_{air}$ , in K, specified as a scalar.

**Dependencies**

To enable this port, under **Environment**, select **Air temperature**.

**Output**

**Info — Bus signal**

bus

Bus signal containing these block values.

Signal				Description	Value	Units	
InertFrm	Cg	Disp	X	Vehicle CM displacement along the earth-fixed X-axis	Computed	m	
			Y	Vehicle CM displacement along the earth-fixed Y-axis	Computed	m	
			Z	Vehicle CM displacement along the earth-fixed Z-axis	Computed	m	
		Vel	Xdot	Vehicle CM velocity along the earth-fixed X-axis	Computed	m/s	
			Ydot	Vehicle CM velocity along the earth-fixed Y-axis	Computed	m/s	
			Zdot	Vehicle CM velocity along the earth-fixed Z-axis	Computed	m/s	
		Ang	phi	Rotation of the vehicle-fixed frame about the earth-fixed X-axis (roll)	Computed	rad	
			theta	Rotation of the vehicle-fixed frame about the earth-fixed Y-axis (pitch)	Computed	rad	
			psi	Rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw)	Computed	rad	
	FrntAxl	Lft	Disp	X	Front left axle displacement along the earth-fixed X-axis	Computed	m
				Y	Front left axle displacement along the earth-fixed Y-axis	Computed	m
				Z	Front left axle displacement along the earth-fixed Z-axis	Computed	m
			Vel	Xdot	Front left axle velocity along the earth-fixed X-axis	Computed	m/s
				Ydot	Front left axle velocity along the earth-fixed Y-axis	Computed	m/s
				Zdot	Front left axle velocity along the earth-fixed Z-axis	Computed	m/s

Signal				Description	Value	Units	
	RearAxl	Right	Disp	X	Front right axle displacement along the earth-fixed X-axis	Computed	m
				Y	Front right axle displacement along the earth-fixed Y-axis	Computed	m
				Z	Front right axle displacement along the earth-fixed Z-axis	Computed	m
		Vel	Xdot	Front right axle velocity along the earth-fixed X-axis	Computed	m/s	
			Ydot	Front right axle velocity along the earth-fixed Y-axis	Computed	m/s	
			Zdot	Front right axle velocity along the earth-fixed Z-axis	Computed	m/s	
		Left	Disp	X	Rear left axle displacement along the earth-fixed X-axis	Computed	m
				Y	Rear left axle displacement along the earth-fixed Y-axis	Computed	m
				Z	Rear left axle displacement along the earth-fixed Z-axis	Computed	m
	Vel		Xdot	Rear left axle velocity along the earth-fixed X-axis	Computed	m/s	
			Ydot	Rear left axle velocity along the earth-fixed Y-axis	Computed	m/s	
			Zdot	Rear left axle velocity along the earth-fixed Z-axis	Computed	m/s	
	Right	Disp	X	Rear right axle displacement along the earth-fixed X-axis	Computed	m	
			Y	Rear right axle displacement along the earth-fixed Y-axis	Computed	m	
			Z	Rear right axle displacement along the earth-fixed Z-axis	Computed	m	

Signal				Description	Value	Units	
			Vel	Xdot	Rear right axle velocity along the earth-fixed X-axis	Computed	m/s
				Ydot	Rear right axle velocity along the earth-fixed Y-axis	Computed	m/s
				Zdot	Rear right axle velocity along the earth-fixed Z-axis	Computed	m/s
	Hitch	Disp	X	Hitch offset from axle plane along the earth-fixed X-axis	Computed	m	
			Y	Hitch offset from axle plane along the earth-fixed Y-axis	Computed	m	
			Z	Hitch offset from axle plane along the earth-fixed Z-axis	Computed	m	
		Vel	Xdot	Hitch velocity along the earth-fixed X-axis	Computed	m/s	
			Ydot	Hitch velocity along the earth-fixed Y-axis	Computed	m/s	
			Zdot	Hitch velocity along the earth-fixed Z-axis	Computed	m/s	
	Geom	Disp	X	Vehicle chassis offset from axle plane along the earth-fixed X-axis	Computed	m	
			Y	Vehicle chassis offset from center plane along the earth-fixed Y-axis	Computed	m	
			Z	Vehicle chassis offset from axle plane along the earth-fixed Z-axis	Computed	m	
		Vel	Xdot	Vehicle chassis offset velocity along the earth-fixed X-axis	Computed	m/s	
			Ydot	Vehicle chassis offset velocity along the earth-fixed Y-axis	Computed	m/s	
			Zdot	Vehicle chassis offset velocity along the earth-fixed Z-axis	Computed	m/s	
BdyFrm	Cg	Vel	xdot	Vehicle CM velocity along the vehicle-fixed x-axis	Computed	m/s	

Signal			Description	Value	Units	
			ydot	Vehicle CM velocity along the vehicle-fixed y-axis	Computed	m/s
			zdot	Vehicle CM velocity along the vehicle-fixed z-axis	Computed	m/s
		AngVel	p	Vehicle angular velocity about the vehicle-fixed x-axis (roll rate)	Computed	rad/s
			q	Vehicle angular velocity about the vehicle-fixed y-axis (pitch rate)	Computed	rad/s
			r	Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate)	Computed	rad/s
		Acc	ax	Vehicle CM acceleration along the vehicle-fixed x-axis	Computed	gn
			ay	Vehicle CM acceleration along the vehicle-fixed y-axis	Computed	gn
			az	Vehicle CM acceleration along the vehicle-fixed z-axis	Computed	gn
			xddot	Vehicle CM acceleration along the vehicle-fixed x-axis	Computed	m/s <sup>2</sup>
			yddot	Vehicle CM acceleration along the vehicle-fixed y-axis	Computed	m/s <sup>2</sup>
	zddot		Vehicle CM acceleration along the vehicle-fixed z-axis	Computed	m/s <sup>2</sup>	
		DCM	Direction cosine matrix		Computed	rad
	Forces	Body	Fx	Net force on vehicle CM along the vehicle-fixed x-axis	Computed	N
			Fy	Net force on vehicle CM along the vehicle-fixed y-axis	Computed	N
			Fz	Net force on vehicle CM along the vehicle-fixed z-axis	Computed	N
		Ext	Fx	External force on vehicle CM along the vehicle-fixed x-axis	Input	N



Signal			Description		Value	Units	
			Fy	External force on vehicle CM along the vehicle-fixed x-axis	Input	N	
			Fz	External force on vehicle CM along the vehicle-fixed x-axis	Input	N	
		FrntAxl	Lft	Fx	Longitudinal force on front left axle along the vehicle-fixed x-axis	Computed	N
				Fy	Lateral force on front axle left along the vehicle-fixed y-axis	Computed	N
				Fz	Normal force on front axle left along the vehicle-fixed z-axis	Computed	N
			Rght	Fx	Longitudinal force on front right axle along the vehicle-fixed x-axis	Computed	N
				Fy	Lateral force on front axle right along the vehicle-fixed y-axis	Computed	N
				Fz	Normal force on front axle right along the vehicle-fixed z-axis	Computed	N
		RearAxl	Lft	Fx	Longitudinal force on rear left axle along the vehicle-fixed x-axis	Computed	N
				Fy	Lateral force on rear left axle along the vehicle-fixed y-axis	Computed	N
				Fz	Normal force on rear left axle along the vehicle-fixed z-axis	Computed	N
			Rght	Fx	Longitudinal force on rear right axle along the vehicle-fixed x-axis	Computed	N
				Fy	Lateral force on rear right axle along the vehicle-fixed y-axis	Computed	N
				Fz	Normal force on rear right axle along the vehicle-fixed z-axis	Computed	N

Signal			Description	Value	Units		
	Hitch	Fx	Hitch force applied to body at the hitch location along the vehicle-fixed x-axis	Computed	N		
		Fy	Hitch force applied to body at the hitch location along the vehicle-fixed y-axis	Computed	N		
		Fz	Hitch force applied to body at the hitch location along the vehicle-fixed z-axis	Computed	N		
	Tires	FrntTires	L F	Front left tire force along the vehicle-fixed x-axis	Computed	N	
			t F	Front left tire force along the vehicle-fixed y-axis	Computed	N	
			y F	Front left tire force along the vehicle-fixed z-axis	Computed	N	
		R g h t	F x	Front right tire force along the vehicle-fixed x-axis	Computed	N	
			F y	Front right tire force along the vehicle-fixed y-axis	Computed	N	
			F z	Front right tire force along the vehicle-fixed z-axis	Computed	N	
		RearTires	L F	t F	Rear left tire force along the vehicle-fixed x-axis	Computed	N
				y F	Rear left tire force along the vehicle-fixed y-axis	Computed	N
				z F	Rear left tire force along the vehicle-fixed z-axis	Computed	N
	R g h t		F x	Rear right tire force along the vehicle-fixed x-axis	Computed	N	
			F y	Rear right tire force along the vehicle-fixed y-axis	Computed	N	
			F z	Rear right tire force along the vehicle-fixed z-axis	Computed	N	
Drag	Fx	Drag force on vehicle CM along the vehicle-fixed x-axis	Computed	N			

Signal			Description	Value	Units		
			Fy	Drag force on vehicle CM along the vehicle-fixed y-axis	Computed	N	
			Fz	Drag force on vehicle CM along the vehicle-fixed z-axis	Computed	N	
			Grvty	Fx	Gravity force on vehicle CM along the vehicle-fixed x-axis	Computed	N
			Fy	Gravity force on vehicle CM along the vehicle-fixed y-axis	Computed	N	
			Fz	Gravity force on vehicle CM along the vehicle-fixed z-axis	Computed	N	
		Moments	Body	Mx	Body moment on vehicle CM about the vehicle-fixed x-axis	Computed	N·m
				My	Body moment on vehicle CM about the vehicle-fixed y-axis	Computed	N·m
				Mz	Body moment on vehicle CM about the vehicle-fixed z-axis	Computed	N·m
			Drag	Mx	Drag moment on vehicle CM about the vehicle-fixed x-axis	Computed	N·m
	My			Drag moment on vehicle CM about the vehicle-fixed y-axis	Computed	N·m	
	Mz			Drag moment on vehicle CM about the vehicle-fixed z-axis	Computed	N·m	
	Ext		Mx	External moment on vehicle CG about the vehicle-fixed x-axis	Computed	N·m	
			My	External moment on vehicle CG about the vehicle-fixed y-axis	Computed	N·m	
			Mz	External moment on vehicle CG about the vehicle-fixed z-axis	Computed	N·m	
	Hitch	Mx	Hitch moment at the hitch location about vehicle-fixed x-axis	Computed	N·m		

Signal				Description	Value	Units		
			My		Hitch moment at the hitch location about vehicle-fixed y-axis	Computed	N·m	
			Mz		Hitch moment at the hitch location about vehicle-fixed z-axis	Computed	N·m	
	FrntAxl	Lft	Disp	x		Front left axle displacement along the vehicle-fixed x-axis	Computed	m
				y		Front left axle displacement along the vehicle-fixed y-axis	Computed	m
				z		Front left axle displacement along the vehicle-fixed z-axis	Computed	m
			Vel	xdo	t	Front left axle velocity along the vehicle-fixed x-axis	Computed	m/s
				ydo	t	Front left axle velocity along the vehicle-fixed y-axis	Computed	m/s
				zdo	t	Front left axle velocity along the vehicle-fixed z-axis	Computed	m/s
		Rght	Disp	x		Front right axle displacement along the vehicle-fixed x-axis	Computed	m
				y		Front right axle displacement along the vehicle-fixed y-axis	Computed	m
				z		Front right axle displacement along the vehicle-fixed z-axis	Computed	m
	Vel		xdo	t	Front right axle velocity along the vehicle-fixed x-axis	Computed	m/s	
			ydo	t	Front right axle velocity along the vehicle-fixed y-axis	Computed	m/s	
			zdo	t	Front right axle velocity along the vehicle-fixed z-axis	Computed	m/s	
	RearAxl	Lft	Disp	x	Rear left axle displacement along the vehicle-fixed x-axis	Computed	m	

Signal				Description	Value	Units			
				y	Rear left axle displacement along the vehicle-fixed y-axis	Computed	m		
				z	Rear left axle displacement along the vehicle-fixed z-axis	Computed	m		
				Vel	xdo t	Rear left axle velocity along the vehicle-fixed x-axis	Computed	m/s	
						ydo t	Rear left axle velocity along the vehicle-fixed y-axis	Computed	m/s
						zdo t	Rear left axle velocity along the vehicle-fixed z-axis	Computed	m/s
		Rght	Disp		x	Rear right axle displacement along the vehicle-fixed x-axis	Computed	m	
					y	Rear right axle displacement along the vehicle-fixed y-axis	Computed	m	
					z	Rear right axle displacement along the vehicle-fixed z-axis	Computed	m	
			Vel		xdo t	Rear right axle velocity along the vehicle-fixed x-axis	Computed	m/s	
	ydo t				Rear right axle velocity along the vehicle-fixed y-axis	Computed	m/s		
	zdo t				Rear right axle velocity along the vehicle-fixed z-axis	Computed	m/s		
	Hitch	Disp		x	Hitch offset from axle plane along the vehicle-fixed x-axis	Input	m		
				y	Hitch offset from center plane along the vehicle-fixed y-axis	Input	m		
				z	Hitch offset from axle plane along the vehicle-fixed z-axis	Input	m		
Vel			xdo t	Hitch offset velocity along the vehicle-fixed x-axis	Computed	m/s			

Signal				Description	Value	Units
			ydot	Hitch offset velocity along the vehicle-fixed y-axis	Computed	m/s
			zdot	Hitch offset velocity along the vehicle-fixed z-axis	Computed	m/s
	Pwr	PwrExt		Applied external power	Computed	W
		Drag		Power loss due to drag	Computed	W
	Geom	Disp	x	Vehicle chassis offset from axle plane along the vehicle-fixed x-axis	Input	m
			y	Vehicle chassis offset from center plane along the vehicle-fixed y-axis	Input	m
			z	Vehicle chassis offset from axle plane along the vehicle-fixed z-axis	Input	m
		Vel	xdot	Vehicle chassis offset velocity along the vehicle-fixed x-axis	Computed	m/s
			ydot	Vehicle chassis offset velocity along the vehicle-fixed y-axis	Computed	m/s
			zdot	Vehicle chassis offset velocity along the vehicle-fixed z-axis	Computed	m/s
		Ang	Beta	Body slip angle, $\beta$ $\beta = \frac{V_y}{V_x}$	Computed	rad

**Vb – Vehicle velocity along vehicle-fixed frame**

vector

Vehicle CM velocity along the vehicle-fixed x-, y-, z-axes, respectively, in m/s, returned as a vector.

**pqr – Vehicle angular velocity about vehicle-fixed frame**

vector

Vehicle CM angular velocity about the vehicle-fixed x- (roll rate), y- (pitch rate), z-axes (yaw rate), respectively, in rad/s, returned as a vector.

**DCM – Direction cosine matrix**

array

Direction cosine matrix, in rad, returned as an array.

**Euler – Euler angles**

array

Euler angles,  $\varphi$ ,  $\theta$ , and  $\psi$ , respectively, in rad, returned as an array.

**Xe – Vehicle position in inertial reference frame**

vector

Vehicle CM position along inertial-fixed X-, Y-, Z-axes, respectively, in m, returned as a vector.

**Ve – Vehicle velocity in inertial reference frame**

vector

Vehicle CM velocity along inertial-fixed X-, Y-, Z-axes, respectively, in m/s, returned as a vector.

## Parameters

### Block Options

#### Input Signals

**Hitch forces – Create input port**

off (default) | on

Select to create an input port,  $F_h$ , for the hitch forces.

**Hitch moments – Create input port**

off (default) | on

Select to create an input port,  $M_h$ , for the hitch moments.

### Chassis

**Vehicle mass,  $m$  – Mass**

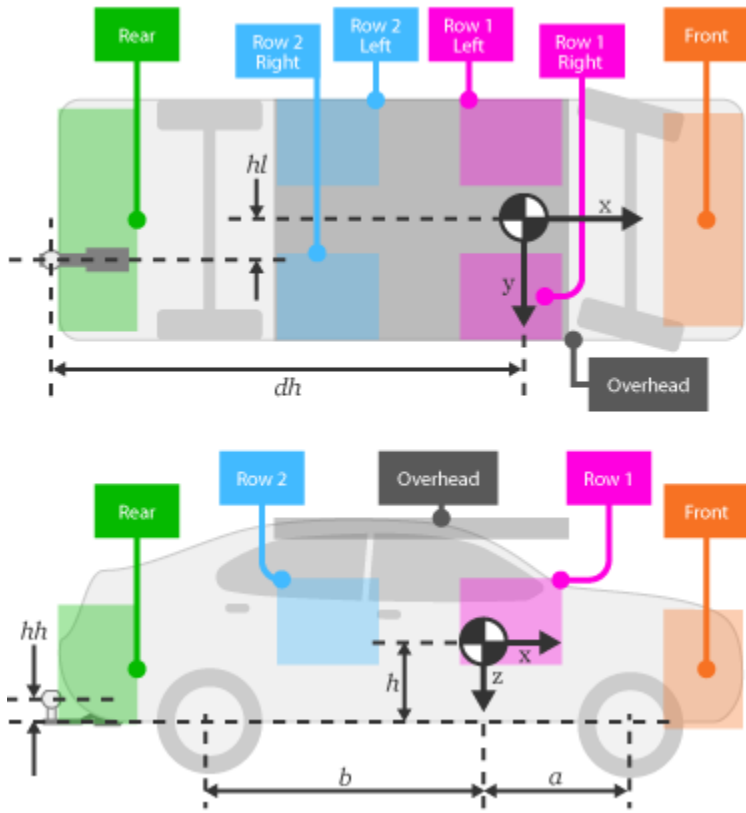
2000 (default) | scalar

Vehicle mass,  $m$ , in kg.

**Longitudinal distance from center of mass to front axle,  $a$  – Distance**

1.4 (default) | scalar

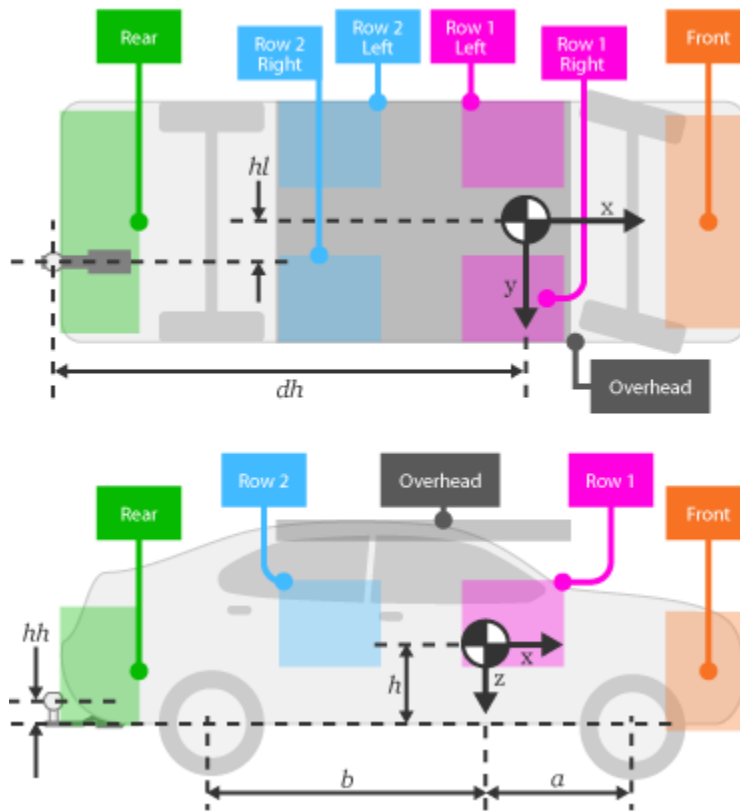
Distance from vehicle CM to front axle,  $a$ , in m.



**Longitudinal distance from center of mass to rear axle,  $b$  – Distance**  
 1.6 (default) | scalar

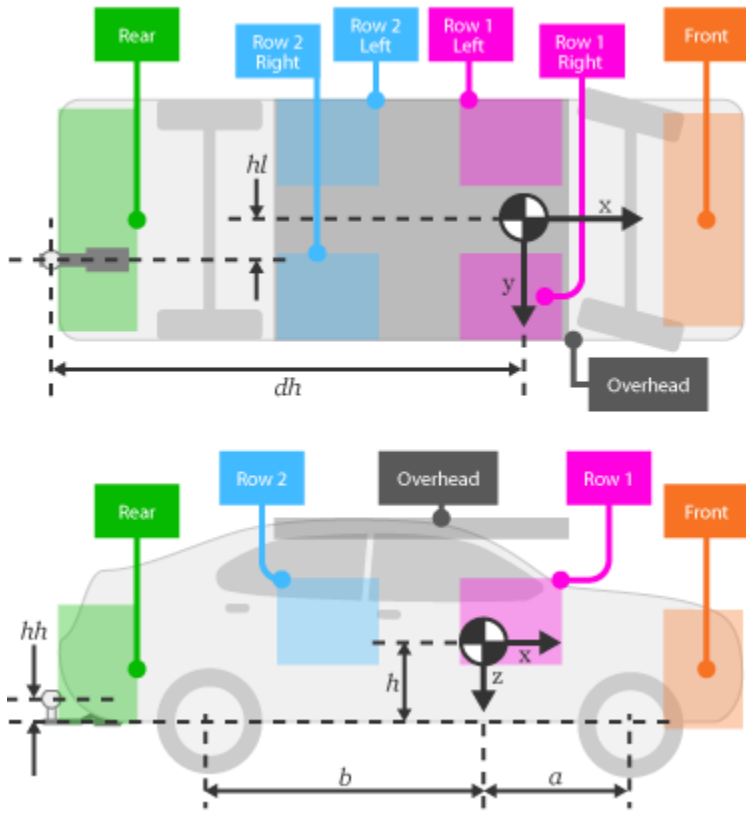
Distance from vehicle CM to front axle,  $b$ , in m.





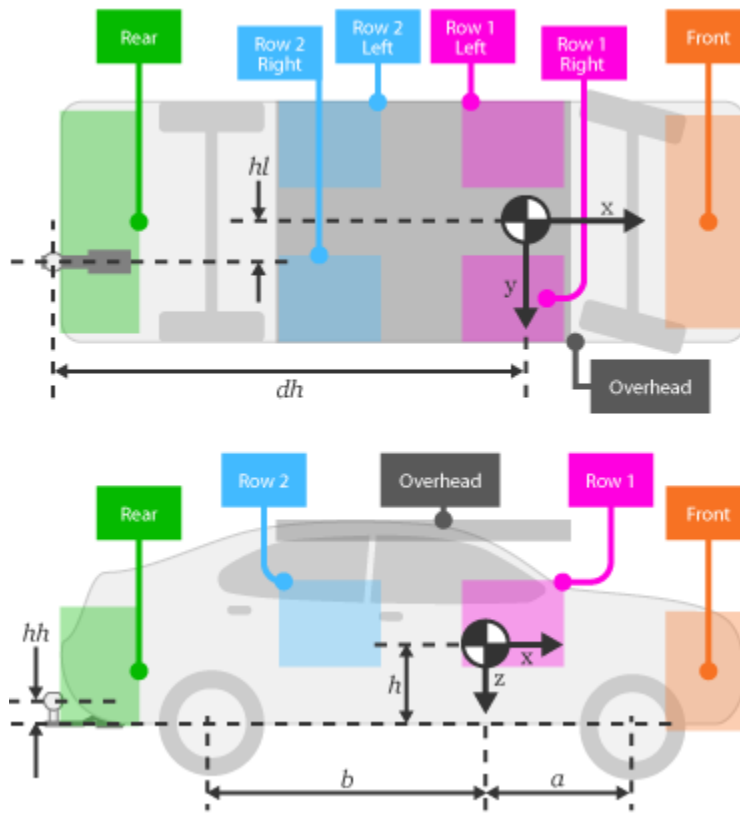
**Lateral distance from geometric centerline to center of mass,  $d$**  – Distance  
 $\theta$  (default) | scalar

Lateral distance from geometric centerline to center of mass,  $d$ , in m, along the vehicle-fixed  $y$ . Positive values indicate that the vehicle CM is to the right of the geometric centerline. Negative values indicate that the vehicle CM is to the left of the geometric centerline.



**Vertical distance from center of mass to axle plane,  $h$  – Distance**  
 .35 (default) | scalar

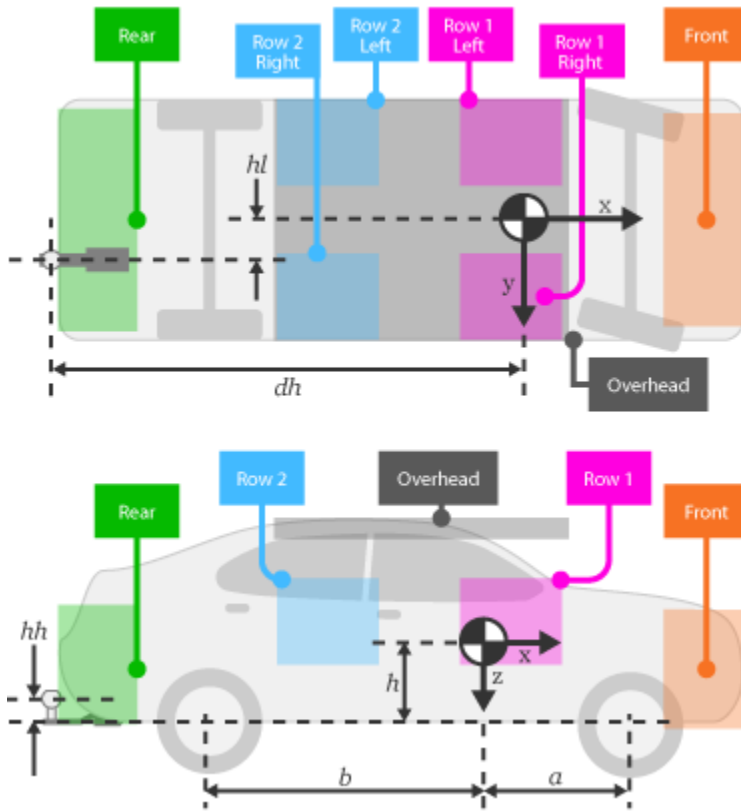
Vertical distance from vehicle CM to axle plane,  $h$ , in m.



**Longitudinal distance from center of mass to hitch,  $dh$  – Longitudinal distance from CM to hitch**

1 (default) | scalar

Longitudinal distance from center of mass to hitch,  $dh$ , in m.



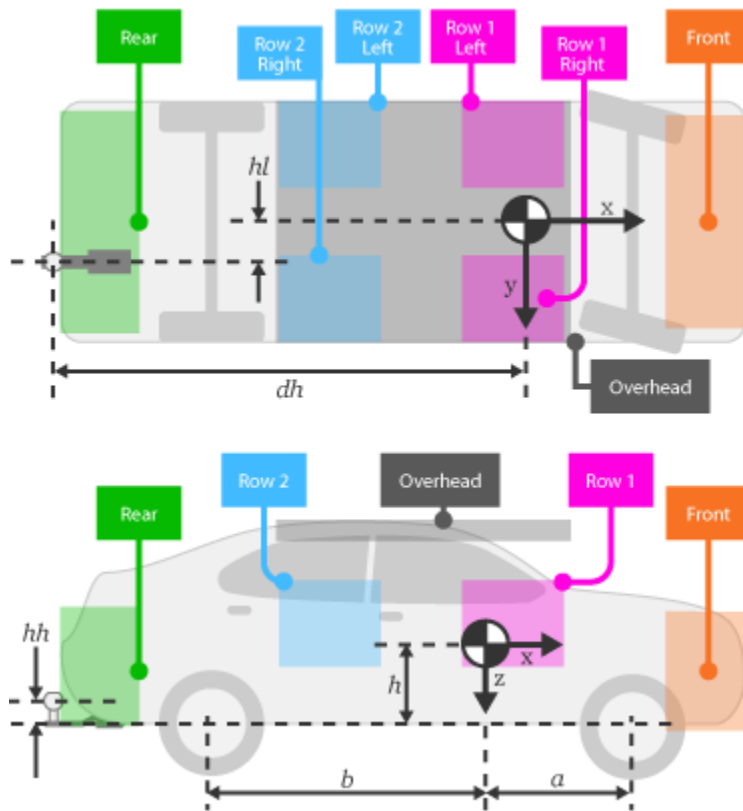
**Dependencies**

To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.

**Longitudinal distance from center of mass to hitch,  $hl$  – Lateral distance from CM to hitch**

0 (default) | scalar

Lateral distance from center of mass to hitch,  $hl$ , in m.

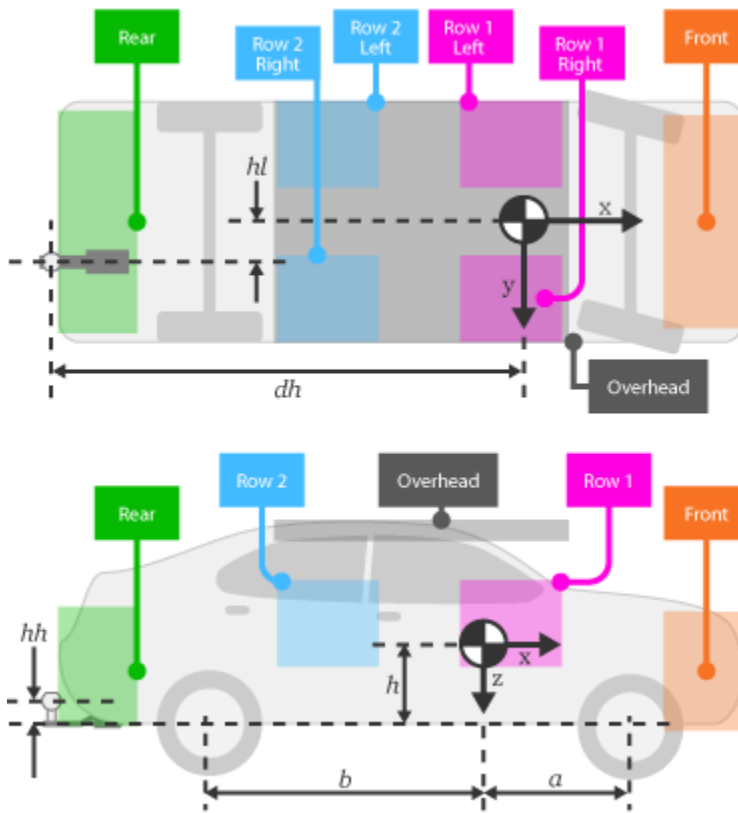


### Dependencies

To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.

**Vertical distance from hitch to axle plane, hh** — Distance from hitch to axle plane  
0.1 (default) | scalar

Vertical distance from hitch to axle plane,  $hh$ , in m.



**Dependencies**

To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.

**Initial position in the inertial frame [Xeo,Yeo,Zeo], Xe\_o – Position**  
 [0,0,0] (default) | vector

Initial position of vehicle in the inertial frame,  $Xe_o$ , in m.

**Initial velocity in body axes [xdot\_o,ydot\_o,zdot\_o], xbdot\_o – Velocity**  
 [0,0,0] (default) | vector

Initial vehicle CM velocity along the vehicle-fixed x, y-, and z- axes, respectively, in m/s.

**Initial Euler orientation [roll, pitch, yaw], eul\_o – Rotation**  
 [0,0,0] (default) | vector

Initial Euler rotation of the vehicle-fixed frame about the earth-fixed X(roll)-, Y(pitch)-, Z(yaw)- axes, respectively, in rad.

**Initial body rotation rates [p,q,r], p\_o – Rotation rate**  
 [0,0,0] (default) | vector

Initial vehicle CM angular velocity about the vehicle-fixed x(roll rate)-, y(pitch rate)-, z(yaw rate)- axes, respectively, in rad/s.

**Chassis inertia tensor,  $I_{veh}$  – Inertia**

[430 0 0; 0 1900 0; 0 0 2100] (default) | array

Vehicle inertia tensor,  $I_{veh}$ , in  $kg \cdot m^2$ . Dimensions are [3-by-3].**Track widths [front,rear],  $w$  – Widths**

[1.9,1.9] (default) | vector

Front and rear track width, in m. Dimensions are [1-by-2].

**Inertial Loads****Front****Mass,  $z1m$  – Mass**

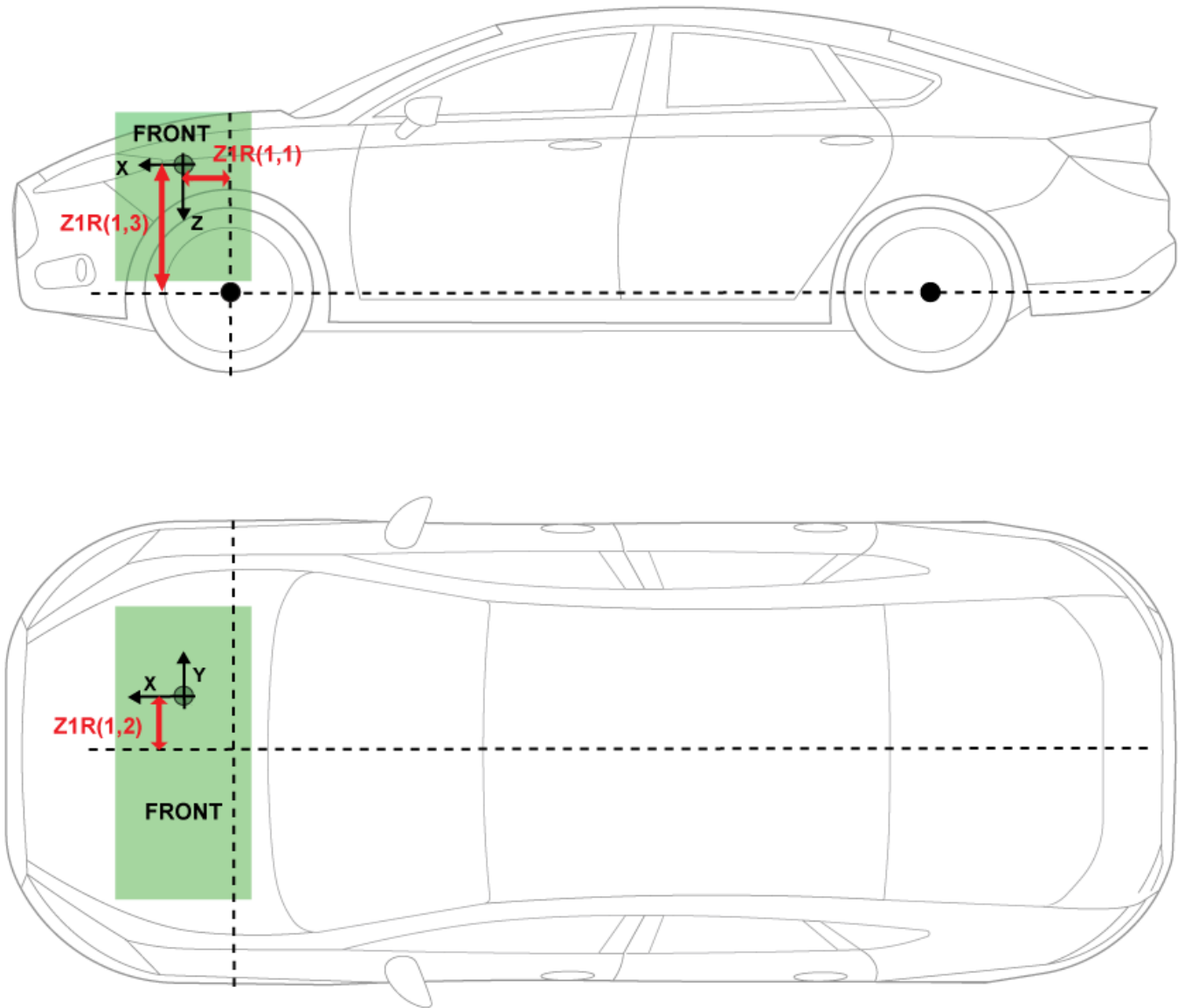
0 (default) | scalar

Mass,  $z1m$ , in kg.**Distance vector from front axle,  $z1R$  – Distance**

[-.25, .125, .15] (default) | vector

Distance vector from front axle to load,  $z1R$ , in m. Dimensions are [1-by-3].

Array Element	Description
$z1R(1,1)$	Front suspension hardpoint to load, along the vehicle-fixed x-axis
$z1R(1,2)$	Vehicle centerline to load, along the vehicle-fixed y-axis
$z1R(1,3)$	Front suspension hardpoint to load, along the vehicle-fixed z-axis



For example, this table summarizes the parameter settings that specify the load location indicated by the dots.

Example Location	Sign
• Forward of the front axle	• $z1R(1,1) < 0$
• Right of the vehicle centerline	• $z1R(1,2) > 0$
• Above the front axle suspension hardpoint	• $z1R(1,3) > 0$

**Inertia tensor, z1I – Inertia**

`[1.4, -.2, .1; -.2, 1.4, .1; .1, .1, 2.25].*0 (default) | array`

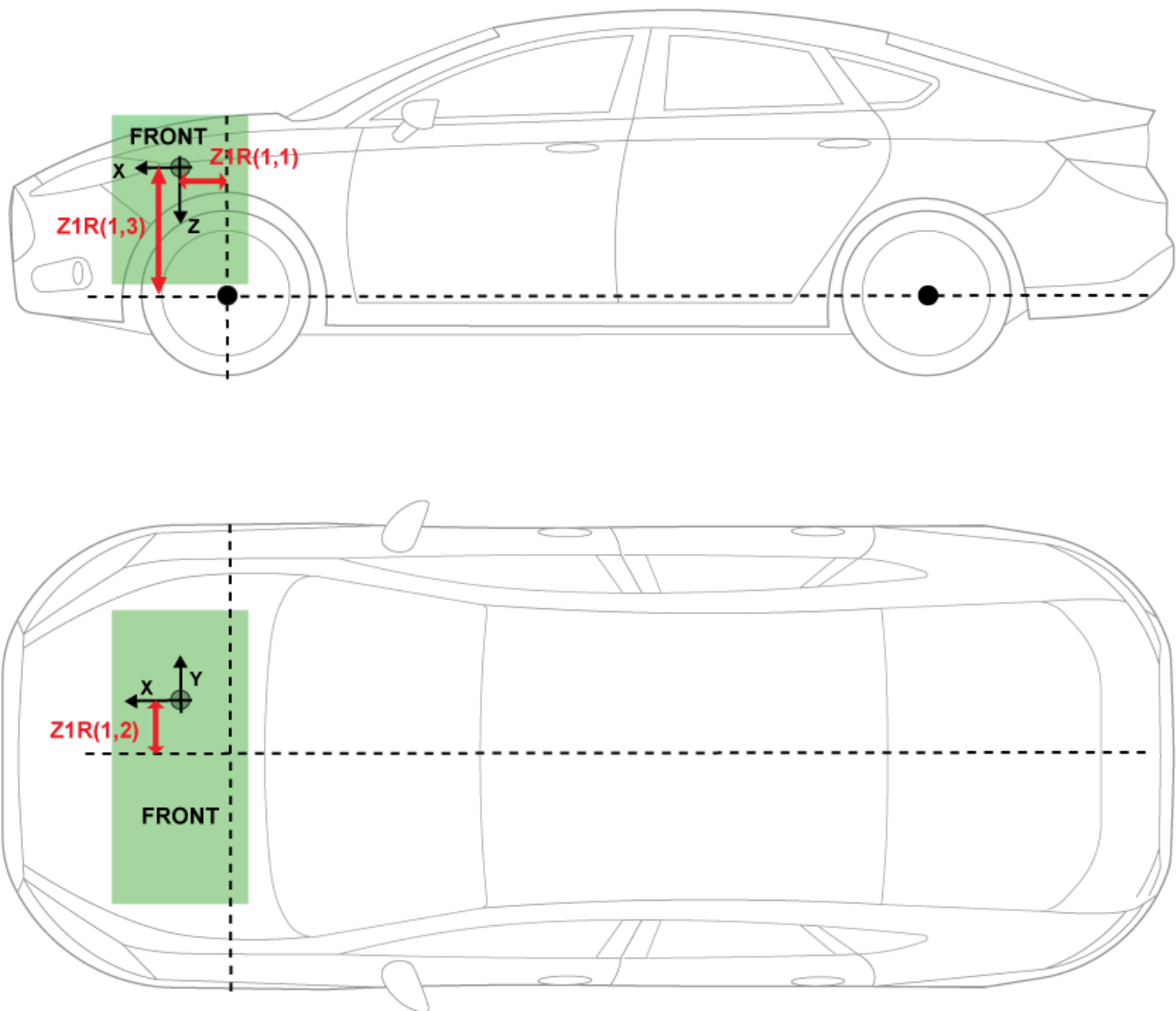
Inertia tensor,  $z1I$ , in  $\text{kg}\cdot\text{m}^2$ . Dimensions are [3-by-3].



$$z1I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis



**Overhead**

**Mass, z2m — Mass**

0 (default) | scalar

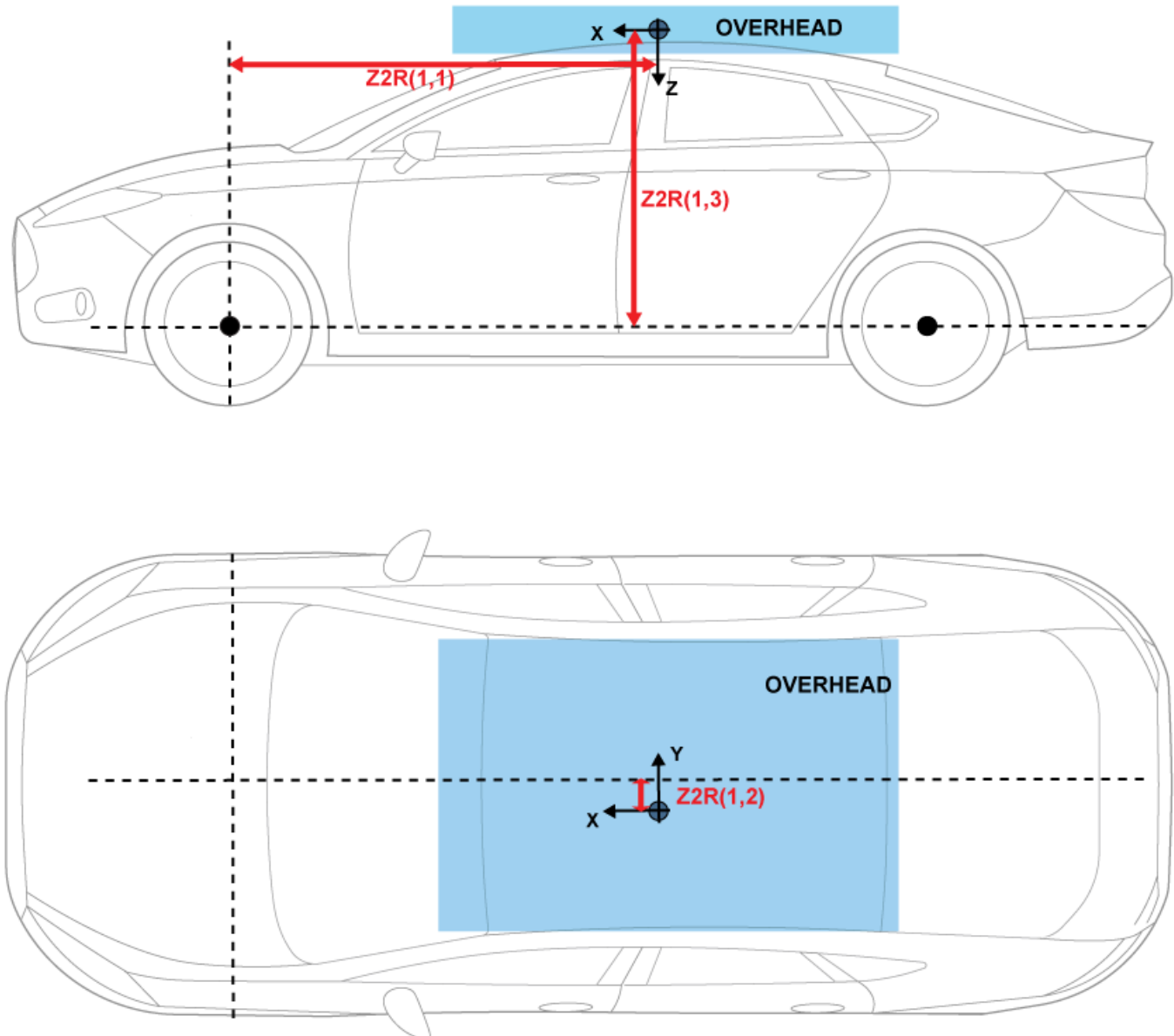
Mass,  $z2m$ , in kg.

**Distance vector from front axle, z2R — Distance**

[1.4, 0, .8] (default) | vector

Distance vector from front axle to load,  $z2R$ , in m. Dimensions are [1-by-3].

Array Element	Description
$z2R(1,1)$	Front suspension hardpoint to load, along the vehicle-fixed x-axis
$z2R(1,2)$	Vehicle centerline to load, along the vehicle-fixed y-axis
$z2R(1,3)$	Front suspension hardpoint to load, along the vehicle-fixed z-axis



For example, this table summarizes the parameter settings that specify the load location indicated by the dot.

Example Location	Sign
• Rear of the front axle	• $z2R(1,1) > 0$
• Left of the vehicle centerline	• $z2R(1,2) < 0$
• Above the front axle suspension hardpoint	• $z2R(1,3) > 0$

#### Inertia tensor, z2I – Inertia

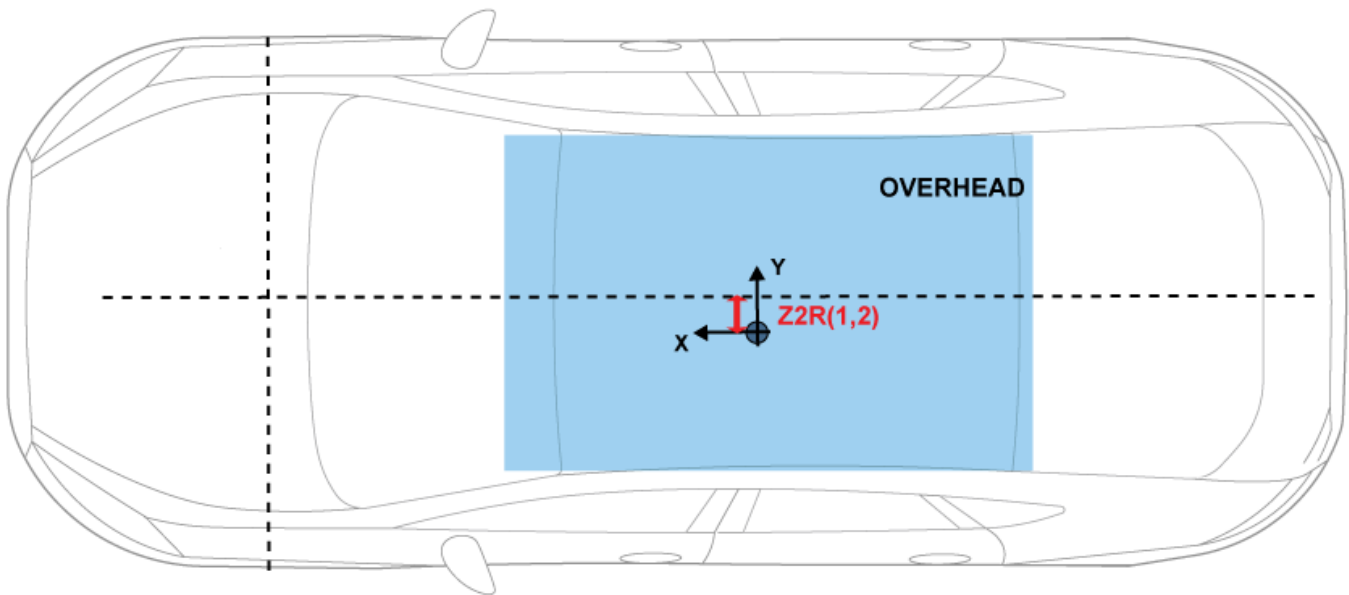
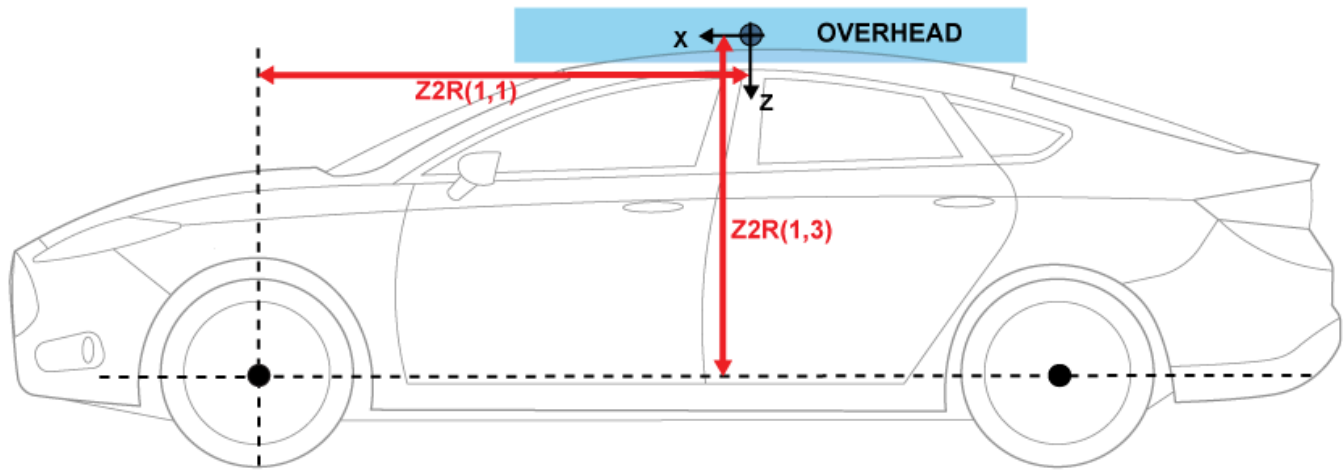
`[1.4, -.2, .1; -.2, 1.4, .1; .1, .1, 2.25].*0 (default) | array`

Inertia tensor,  $z2I$ , in  $\text{kg}\cdot\text{m}^2$ . Dimensions are [3-by-3].

$$z2I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis



**Row 1, left side****Mass, z3m — Mass**

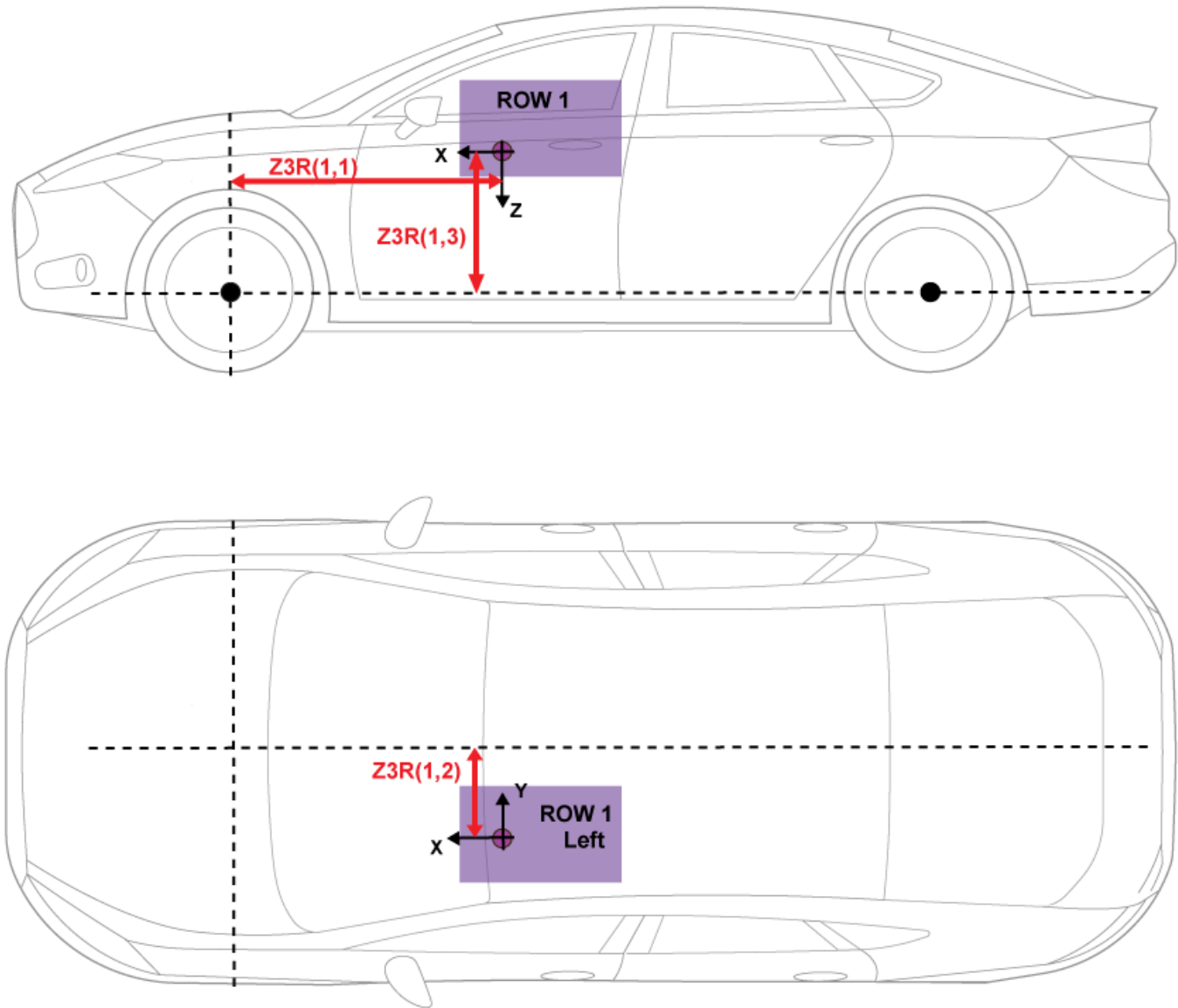
0 (default) | scalar

Mass,  $z3m$ , in kg.**Distance vector from front axle, z3R — Distance**

[.75, -.5, .4] (default) | vector

Distance vector from front axle to load,  $z3R$ , in m. Dimensions are [1-by-3].

Array Element	Description
$z3R(1,1)$	Front suspension hardpoint to load, along the vehicle-fixed x-axis
$z3R(1,2)$	Vehicle centerline to load, along the vehicle-fixed y-axis
$z3R(1,3)$	Front suspension hardpoint to load, along the vehicle-fixed z-axis



For example, this table summarizes the parameter settings that specify the load location indicated by the dot.

Example Location	Sign
• Rear of the front axle	• $z3R(1,1) > 0$
• Left of the vehicle centerline	• $z3R(1,2) < 0$
• Above the front axle suspension hardpoint	• $z3R(1,3) > 0$

**Inertia tensor, z3I – Inertia**

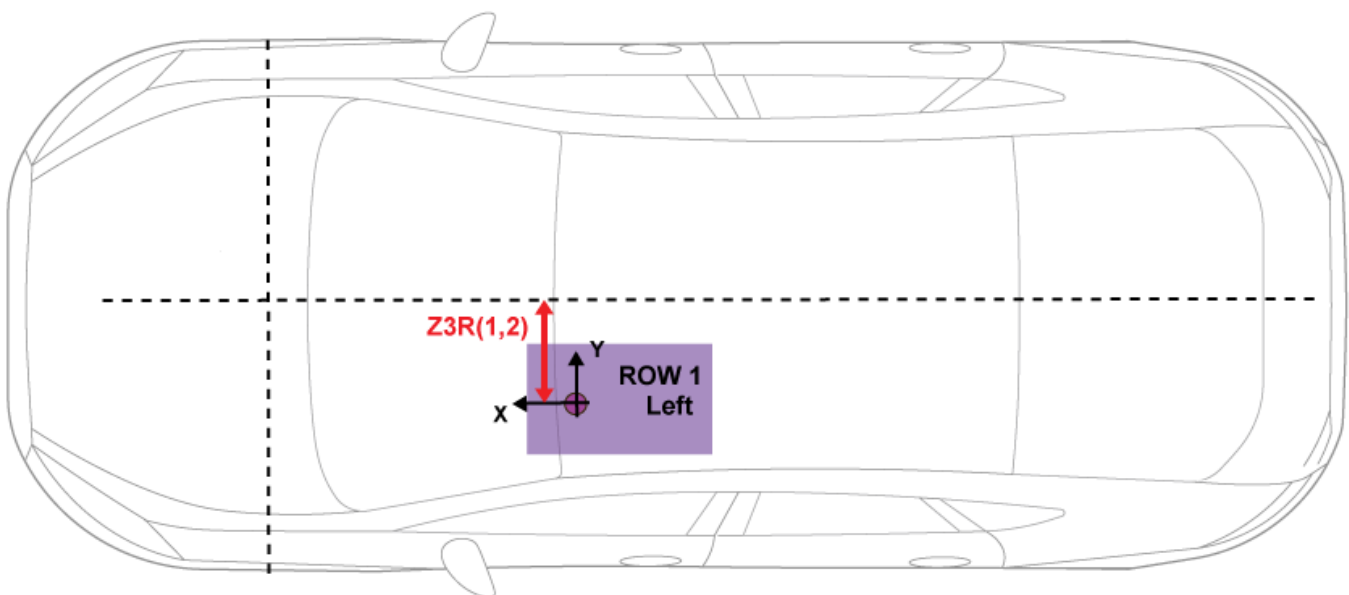
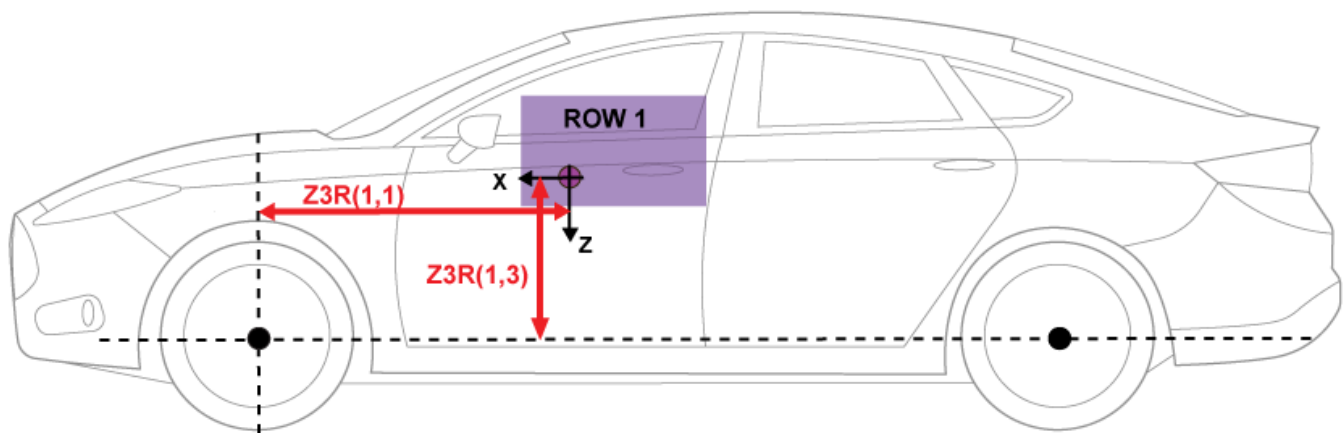
[5, -.1, -2; -2, 9, .1; -.1, .1, 6].\*0 (default) | array

Inertia tensor,  $z3I$ , in  $\text{kg}\cdot\text{m}^2$ . Dimensions are [3-by-3].

$$z3I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis



**Row 1, right side**

**Mass, z4m — Mass**

0 (default) | scalar

Mass,  $z4m$ , in kg.

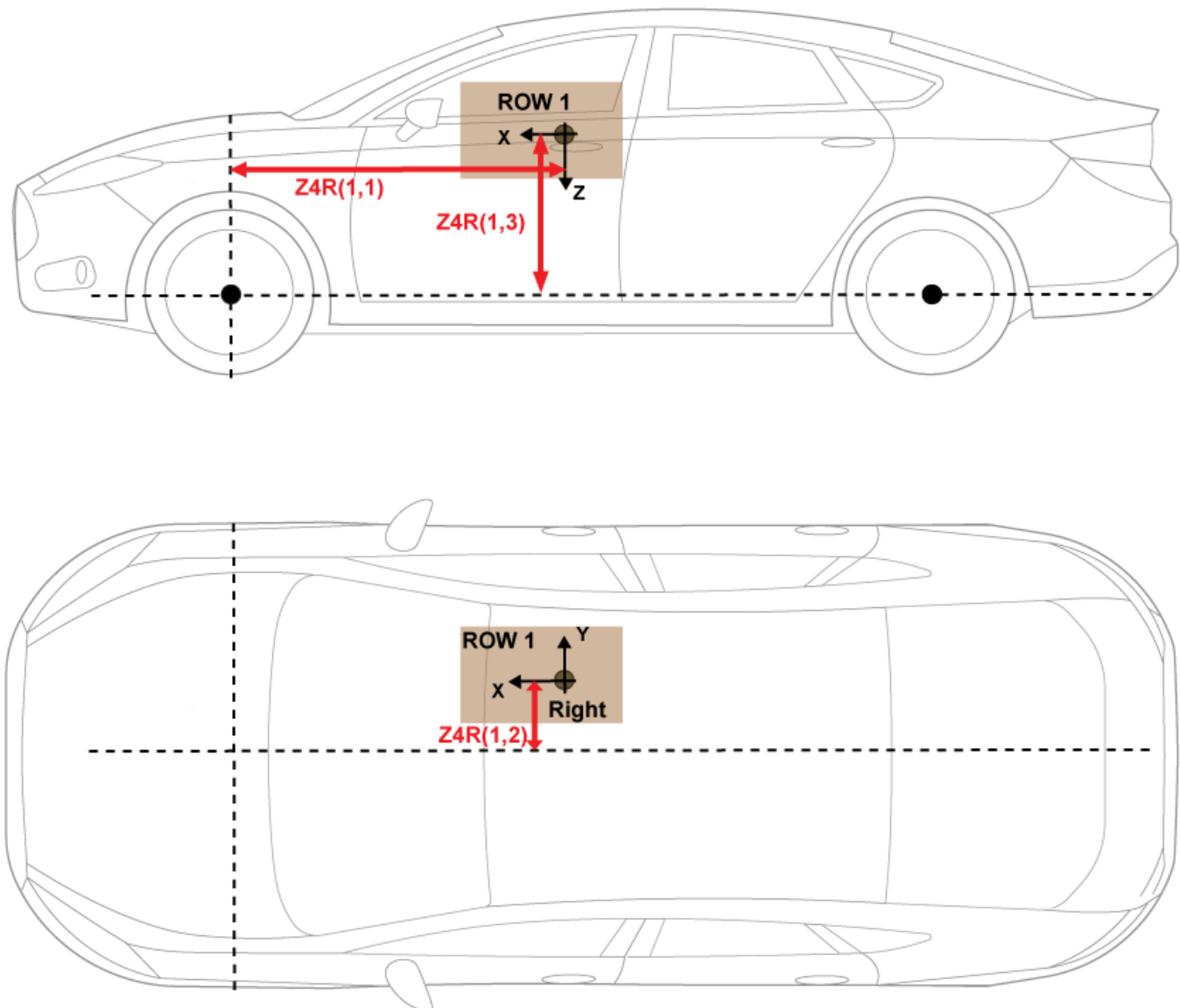
**Distance vector from front axle, z4R — Distance**

[.75, .5, .4] (default) | vector

Distance vector from front axle to load,  $z4R$ , in m. Dimensions are [1-by-3].

Array Element	Description
$z4R(1,1)$	Front suspension hardpoint to load, along the vehicle-fixed x-axis
$z4R(1,2)$	Vehicle centerline to load, along the vehicle-fixed y-axis
$z4R(1,3)$	Front suspension hardpoint to load, along the vehicle-fixed z-axis





For example, this table summarizes the parameter settings that specify the load location indicated by the dot.

Example Location	Sign
• Rear of the front axle	• $z4R(1,1) > 0$
• Right of the vehicle centerline	• $z4R(1,2) > 0$
• Above the front axle suspension hardpoint	• $z4R(1,3) > 0$

#### Inertia tensor, $z4I$ – Inertia

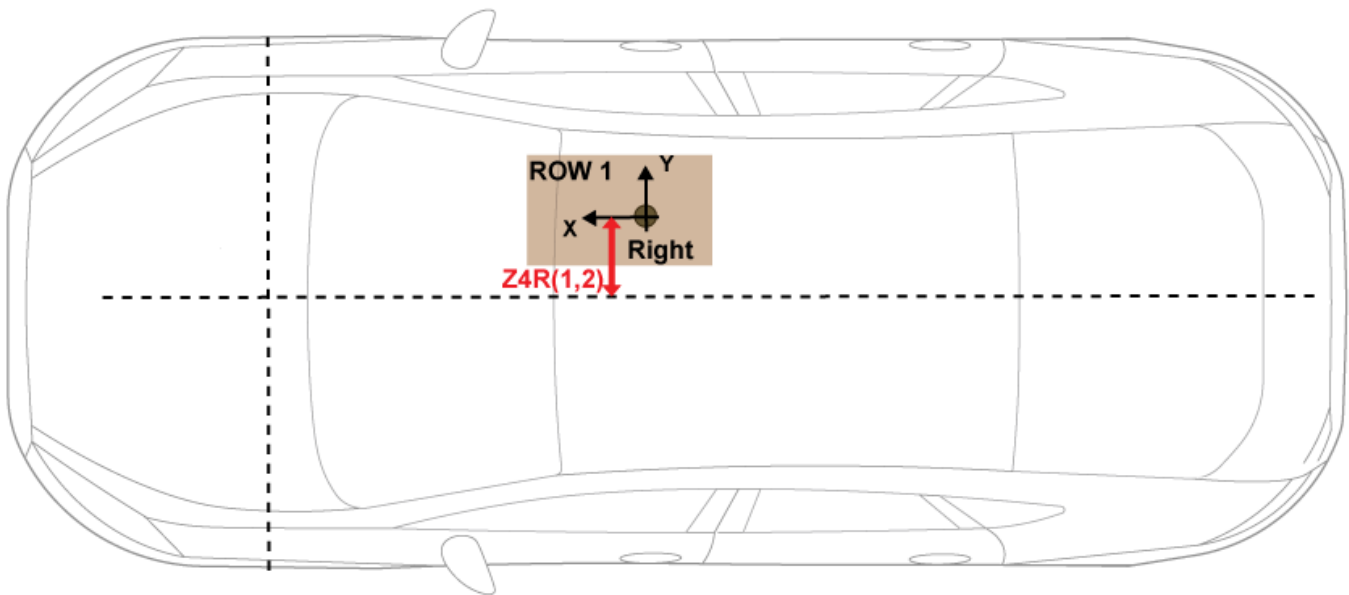
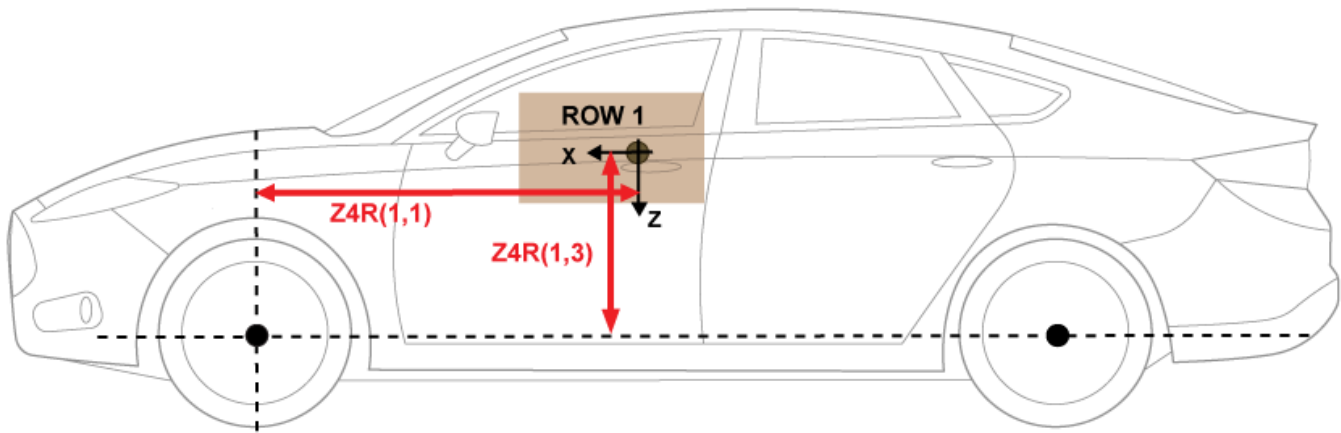
`[5, -.1, -2; -2, 9, .1; -.1, .1, 6].*0 (default) | array`

Inertia tensor,  $z4I$ , in  $\text{kg}\cdot\text{m}^2$ . Dimensions are [3-by-3].

$$z4I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis



**Row 2, left side****Mass, z5m – Mass**

0 (default) | scalar

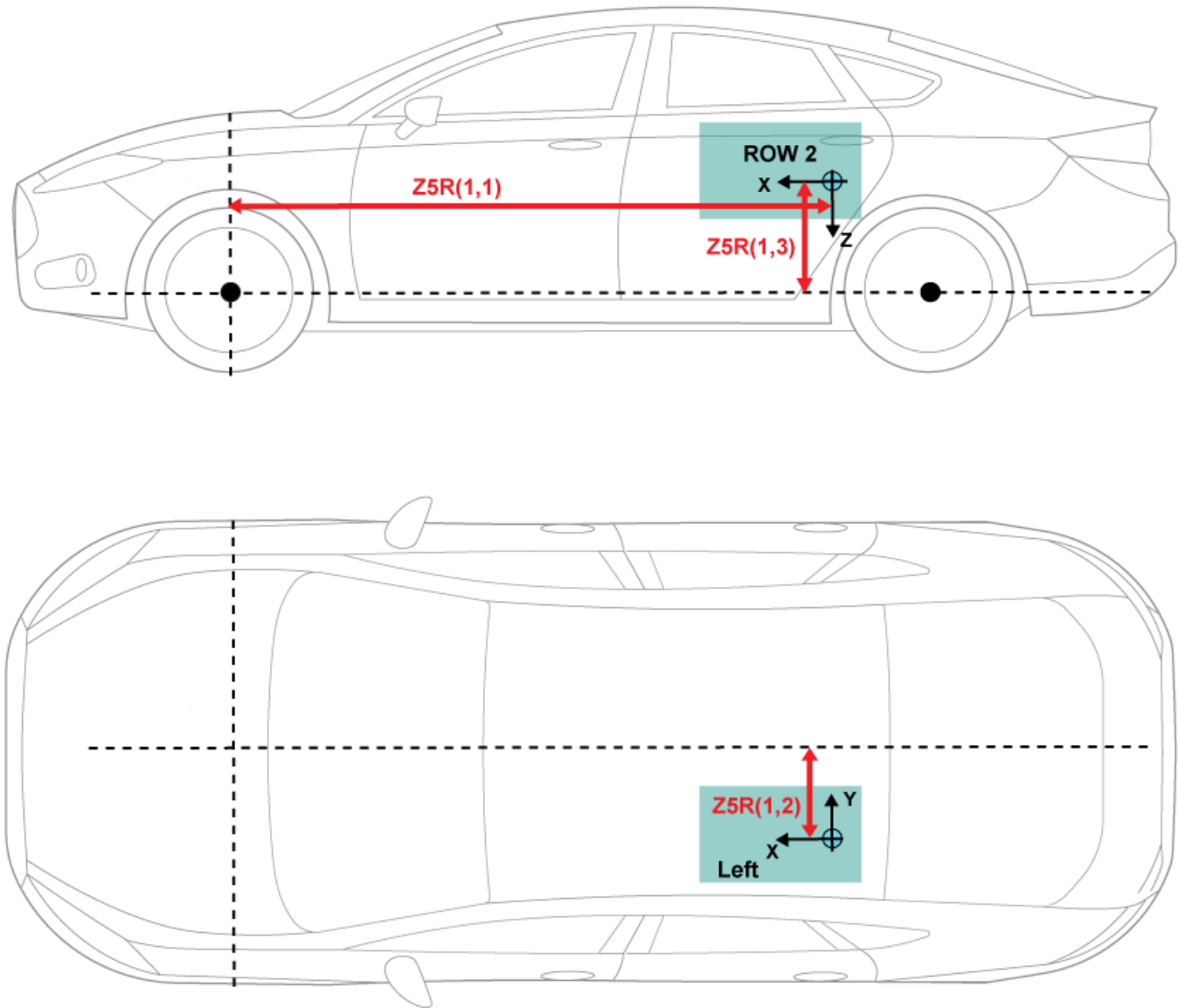
Mass, z5m, in kg.

**Distance vector from front axle, z5R – Distance**

[1.25, -.5, .4] (default) | vector

Distance vector from front axle to load, z5R, in m. Dimensions are [1-by-3].

Array Element	Description
z5R(1,1)	Front suspension hardpoint to load, along the vehicle-fixed x-axis
z5R(1,2)	Vehicle centerline to load, along the vehicle-fixed y-axis
z5R(1,3)	Front suspension hardpoint to load, along the vehicle-fixed z-axis



For example, this table summarizes the parameter settings that specify the load location indicated by the dot.

Example Location	Sign
• Rear of the front axle	• $z5R(1,1) > 0$
• Left of the vehicle centerline	• $z5R(1,2) < 0$
• Above the front axle suspension hardpoint	• $z5R(1,3) > 0$

**Inertia tensor, z5I – Inertia**

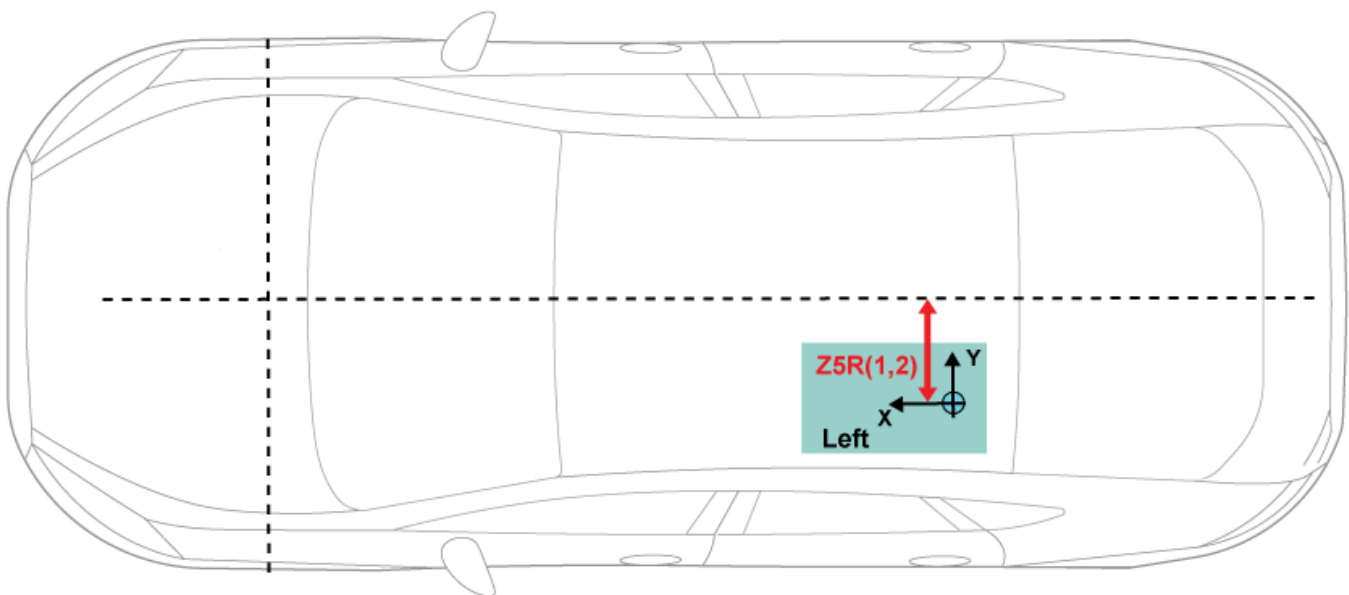
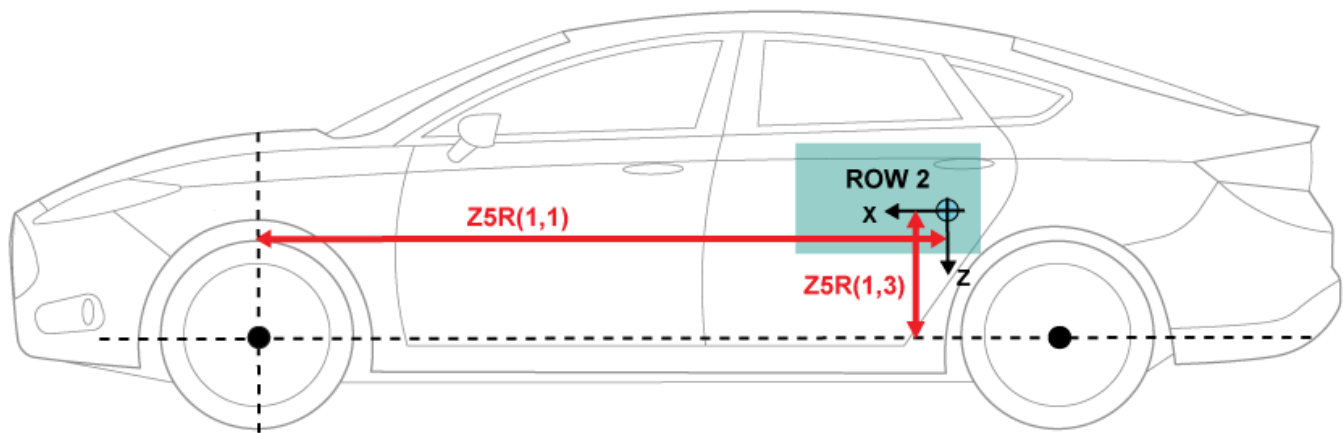
[5, -.1, -2; -2, 9, .1; -.1, .1, 6].\*0 (default) | array

Inertia tensor, z5I, in kg·m<sup>2</sup>. Dimensions are [3-by-3].

$$z5I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis



**Row 2, right side**

**Mass, z6m — Mass**

0 (default) | scalar

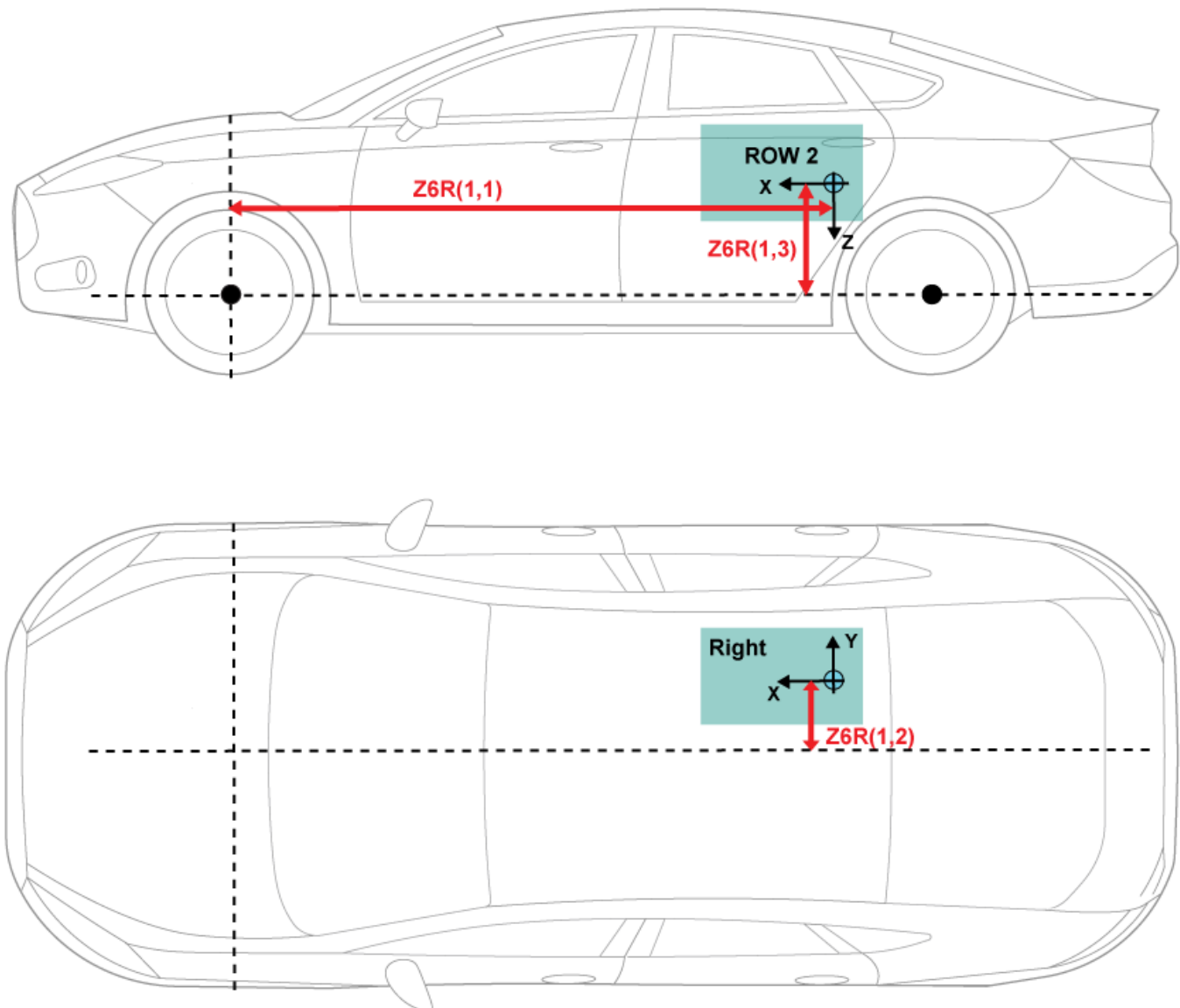
Mass,  $z6m$ , in kg.

**Distance vector from front axle, z6R — Distance**

[1.25, -.5, .4] (default) | vector

Distance vector from front axle to load,  $z6R$ , in m. Dimensions are [1-by-3].

Array Element	Description
$z6R(1,1)$	Front suspension hardpoint to load, along the vehicle-fixed x-axis
$z6R(1,2)$	Vehicle centerline to load, along the vehicle-fixed y-axis
$z6R(1,3)$	Front suspension hardpoint to load, along the vehicle-fixed z-axis



For example, this table summarizes the parameter settings that specify the load location indicated by the dot.

Example Location	Sign
• Rear of the front axle	• $z6R(1,1) > 0$
• Right of the vehicle centerline	• $z6R(1,2) > 0$
• Above the front axle suspension hardpoint	• $z6R(1,3) > 0$

#### Inertia tensor, $z6I$ – Inertia

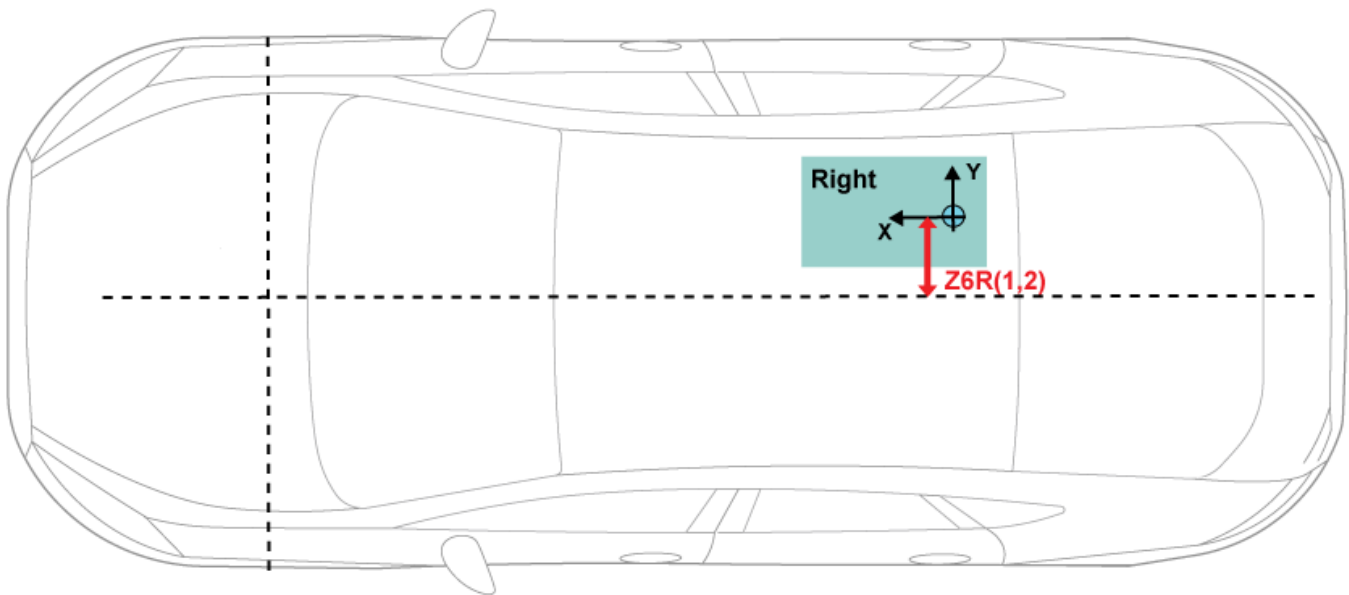
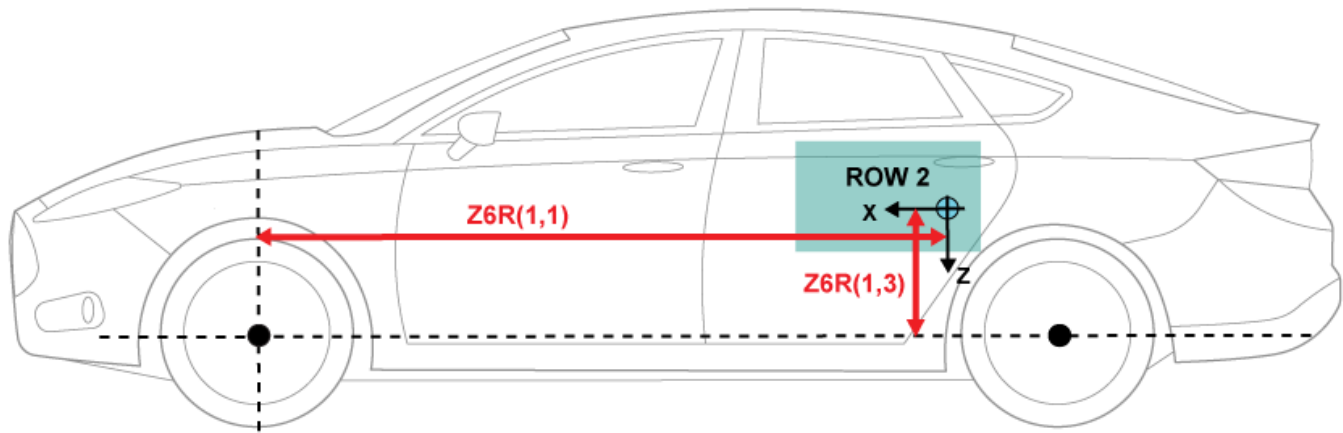
$[5, -.1, -2; -2, 9, .1; -.1, .1, 6] .* 0$  (default) | array

Inertia tensor,  $z6I$ , in  $\text{kg}\cdot\text{m}^2$ . Dimensions are [3-by-3].

$$z6I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

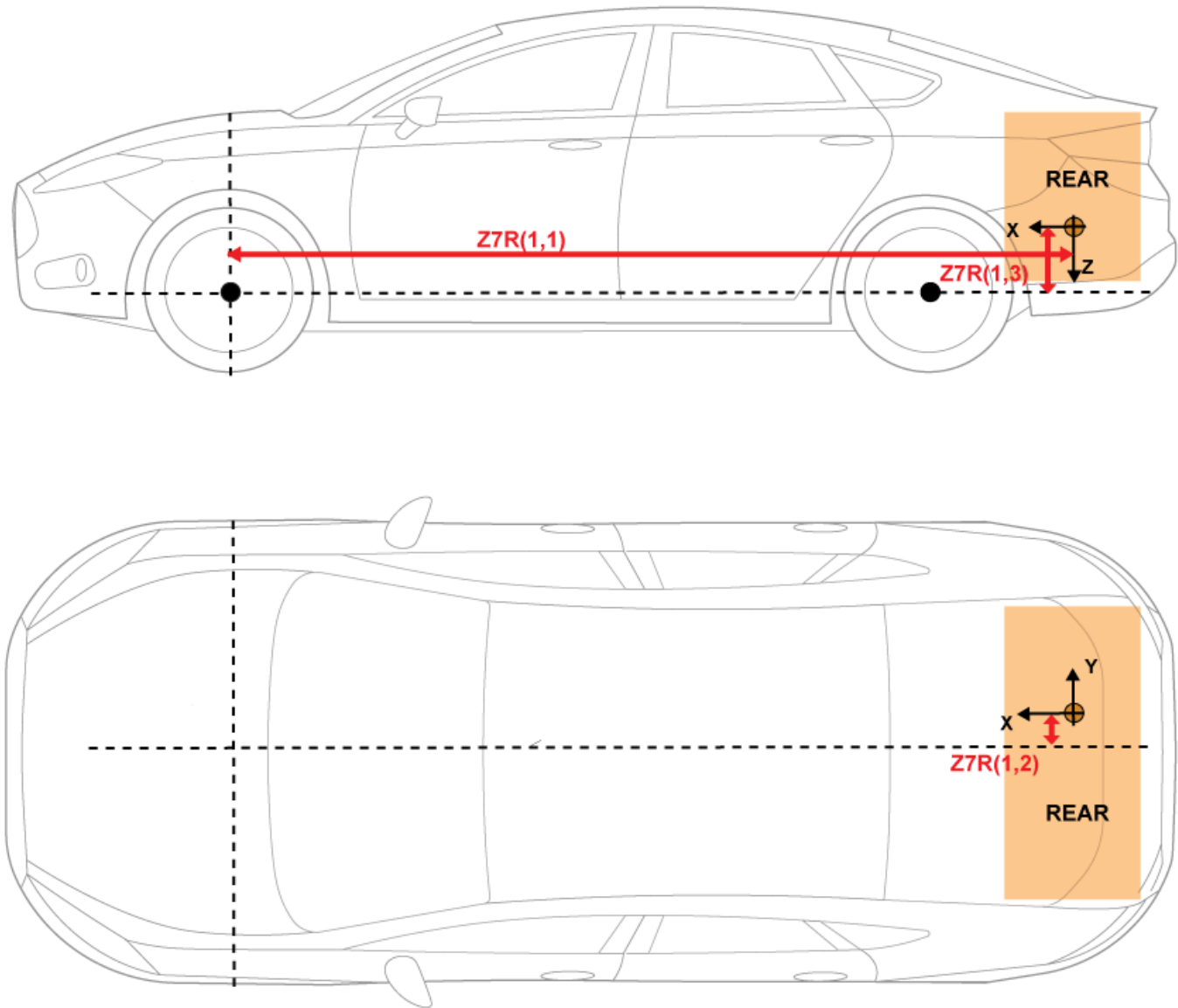
- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis





**Rear****Mass,  $z7m$  – Mass** $0$  (default) | scalarMass,  $z7m$ , in kg.**Distance vector from front axle,  $z7R$  – Distance** $[2, 0, .25]$  (default) | vectorDistance vector from front axle to load,  $z7R$ , in m. Dimensions are [1-by-3].

Array Element	Description
$z7R(1,1)$	Front suspension hardpoint to load, along the vehicle-fixed x-axis
$z7R(1,2)$	Vehicle centerline to load, along the vehicle-fixed y-axis
$z7R(1,3)$	Front suspension hardpoint to load, along the vehicle-fixed z-axis



For example, this table summarizes the parameter settings that specify the load location indicated by the dot.

Example Location	Sign
• Rear of the front axle	• $z7R(1,1) > 0$
• Right of the vehicle centerline	• $z7R(1,2) > 0$
• Above the front axle suspension hardpoint	• $z7R(1,3) > 0$

**Inertia tensor, z7I – Inertia**

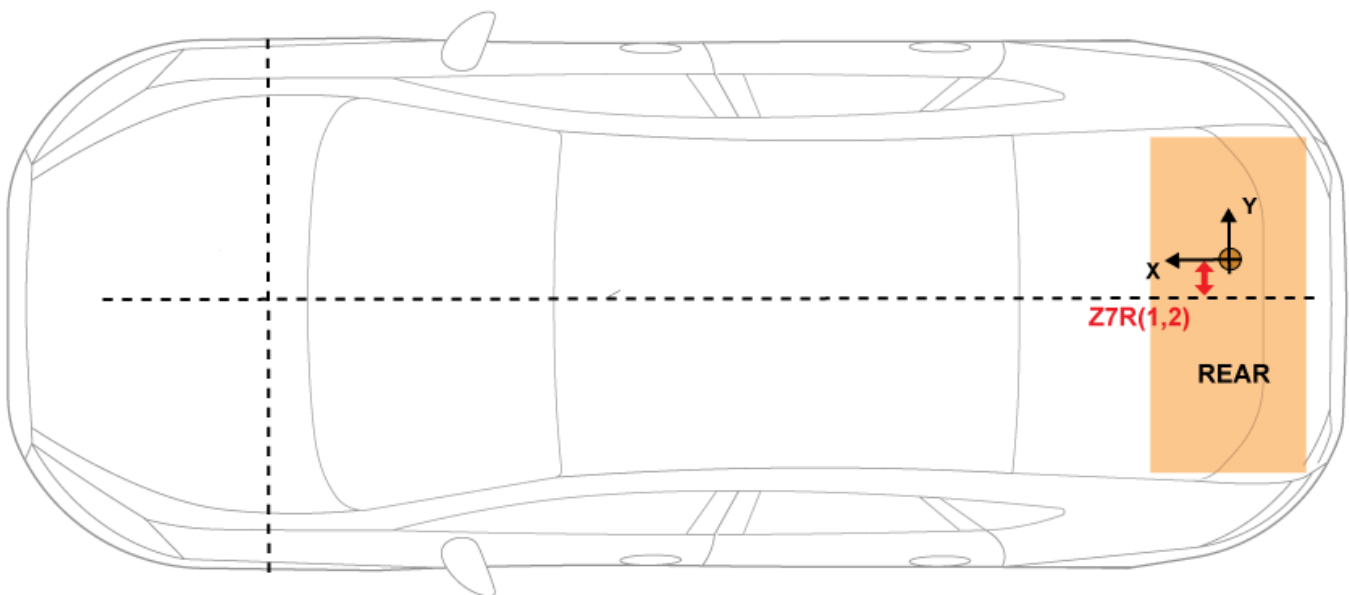
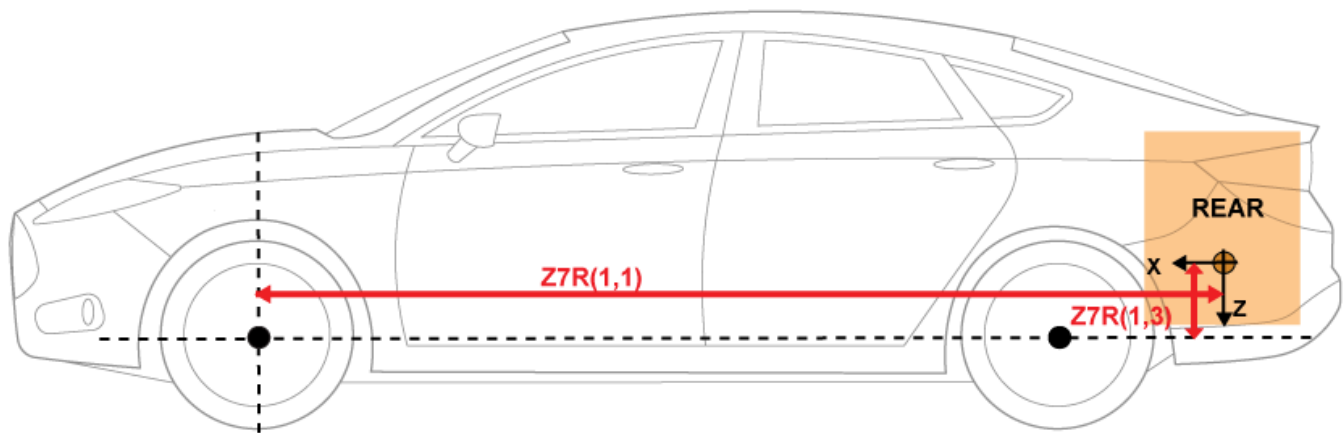
`[1.4, -.2, .1; -.2, 1.4, .1; .1, .1, 2.25].*0 (default) | array`

Inertia tensor,  $z7I$ , in  $\text{kg}\cdot\text{m}^2$ . Dimensions are [3-by-3].

$$z7I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis



**Aerodynamic****Longitudinal drag area, Af – Area**

2 (default) | scalar

Effective vehicle cross-sectional area,  $A_f$  to calculate the aerodynamic drag force on the vehicle, in  $m^2$ .

**Longitudinal drag coefficient, Cd – Drag**

.3 (default) | scalar

Air drag coefficient,  $C_d$ , dimensionless.

**Longitudinal lift coefficient, Cl – Lift**

.1 (default) | scalar

Air lift coefficient,  $C_l$ , dimensionless.

**Longitudinal drag pitch moment, Cpm – Pitch drag**

.1 (default) | scalar

Longitudinal drag pitch moment coefficient,  $C_{pm}$ , dimensionless.

**Relative wind angle vector, beta\_w – Wind angle**

[0:0.001:0.01] (default) | vector

Relative wind angle vector,  $\beta_w$ , in rad.

**Side force coefficient vector, Cs – Side force drag**

[0:0.01:0.1] (default) | vector

Side force coefficient vector coefficient,  $C_s$ , dimensionless.

**Yaw moment coefficient vector, Cym – Yaw moment drag**

[0:0.001:0.01] (default) | vector

Yaw moment coefficient vector coefficient,  $C_{ym}$ , dimensionless.

**Environment****Absolute air pressure, Pabs – Pressure**

101325 (default) | scalar

Environmental air absolute pressure,  $P_{abs}$ , in Pa.

**Air temperature, Tair – Ambient air temperature**

273 (default) | scalar

Ambient air temperature,  $T_{air}$ , in K.

**Dependencies**

To enable this parameter, clear **Air temperature**.

**Gravitational acceleration, g – Gravity**

9.81 (default) | scalar

Gravitational acceleration,  $g$ , in  $\text{m/s}^2$ .

### Simulation

#### Longitudinal velocity tolerance, `xdot_tol` — Tolerance

.1 (default) | scalar

Longitudinal velocity tolerance,  $\dot{x}_{tol}$ , in  $\text{m/s}$ .

The block uses this parameter to avoid a division by zero when it calculates the body slip angle,  $\beta$ .

#### Geometric longitudinal offset from axle plane, `longOff` — Longitudinal offset

0 (default) | scalar

Vehicle chassis offset from axle plane along body-fixed  $x$ -axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independent of the vehicle CG.

#### Geometric lateral offset from center plane, `latOff` — Lateral offset

0 (default) | scalar

Vehicle chassis offset from center plane along body-fixed  $y$ -axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independent of the vehicle CG.

#### Geometric vertical offset from axle plane, `vertOff` — Vertical offset

0 (default) | scalar

Vehicle chassis offset from axle plane along body-fixed  $z$ -axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independent of the vehicle CG.

#### Wrap Euler angles, `wrapAng` — Selection

on (default) | off

Wrap the Euler angles to the interval  $[-\pi, \pi]$ . For vehicle maneuvers that might undergo vehicle yaw rotations that are outside of the interval, consider deselecting the parameter if you want to:

- Track the total vehicle yaw rotation.
- Avoid discontinuities in the vehicle state estimators.

## References

[1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers (SAE), 1992.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

## See Also

6DOF (Euler Angles) | Vector Concatenate, Matrix Concatenate | Vehicle Body 3DOF

### Topics

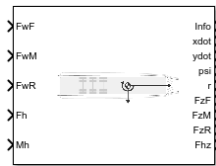
“Coordinate Systems in Vehicle Dynamics Blockset”

**Introduced in R2018a**

## Trailer Body 3DOF

Trailer body with longitudinal, lateral, and yaw motion

**Library:** Vehicle Dynamics Blockset / Vehicle Body



### Description

The Trailer Body 3DOF block implements a rigid two-axle or three-axle trailer body model to calculate longitudinal, lateral, and yaw motion. Configure the block for a single or dual track. The block accounts for axle and hitch reaction forces due to the trailer acceleration, aerodynamic drag, and steering.

Use this block in vehicle dynamics and automated driving studies to model nonholonomic vehicle motion when vehicle pitch, roll, and vertical motion are not significant.

Use the **Vehicle track** parameter to specify the number of tracks.

Vehicle Track Setting	Implementation
Single 2-axle	Trailer with a single track and two axles. <ul style="list-style-type: none"> <li>Forces act along the center line of the axles.</li> <li>No lateral load transfer.</li> </ul>
Dual 2-axle	Trailer with a dual track and two axles. Forces act at the axle hard-point locations.
Single 3-axle	Trailer with a single track and three axles. <ul style="list-style-type: none"> <li>Forces act along the center line of the axles.</li> <li>No lateral load transfer.</li> </ul>
Dual 3-axle (default)	Trailer with a dual track and three axles. Forces act at the axle hard-point locations.

Use the **Axle forces** parameter to specify the type of force.

Axle Forces Setting	Implementation
External longitudinal velocity	<ul style="list-style-type: none"> <li>The block assumes that the external longitudinal velocity is in a quasi-steady state, and the longitudinal acceleration is approximately zero.</li> <li>Because the motion is quasi-steady, the block calculates lateral forces using the tire slip angles and linear cornering stiffness.</li> <li>Consider this setting when you want to:                             <ul style="list-style-type: none"> <li>Generate virtual sensor signal data.</li> <li>Conduct high-level software studies that are not impacted by driveline or nonlinear tire responses.</li> </ul> </li> </ul>
External longitudinal forces	<ul style="list-style-type: none"> <li>The block uses the external longitudinal force to accelerate or brake the vehicle.</li> <li>The block calculates lateral forces using the tire slip angles and linear cornering stiffness.</li> <li>Consider this setting when you want to:                             <ul style="list-style-type: none"> <li>Account for changes in the longitudinal velocity on the lateral and yaw motion.</li> <li>Specify the external longitudinal motion through a force instead of an external longitudinal velocity.</li> <li>Connect the block to tractive actuators, wheels, brakes, and hitches.</li> </ul> </li> </ul>
External forces	<ul style="list-style-type: none"> <li>The block uses the external lateral and longitudinal forces to steer, accelerate, or brake the vehicle.</li> <li>The block does not use the steering input to calculate vehicle motion.</li> <li>Consider this setting when you need tire models with more accurate nonlinear combined lateral and longitudinal slip.</li> </ul>

To create additional input ports, under **Input signals**, select these block parameters.

Input Signals Pane Parameter	Input Port	Description
Front wheel steering	WhlAngF	Front wheel angle, $\delta_F$
Middle wheel steering	WhlAngM	Middle wheel angle, $\delta_M$
Rear wheel steering	WhlAngR	Rear wheel angle, $\delta_R$
External wind	WindXYZ	Wind speed, $W_x$ , $W_y$ , and $W_z$ , in an inertial reference frame
External friction	Mu	Friction coefficient
External forces	FExt	External force on the vehicle center of gravity (CG), $F_x$ , $F_y$ , and $F_z$ , in the vehicle-fixed frame
External moments	MExt	External moment about the vehicle CG, $M_x$ , $M_y$ , and $M_z$ , in the vehicle-fixed frame
Hitch forces	Fh	Hitch force applied to the body at the hitch location, $Fh_x$ , $Fh_y$ , and $Fh_z$ , in the vehicle-fixed frame



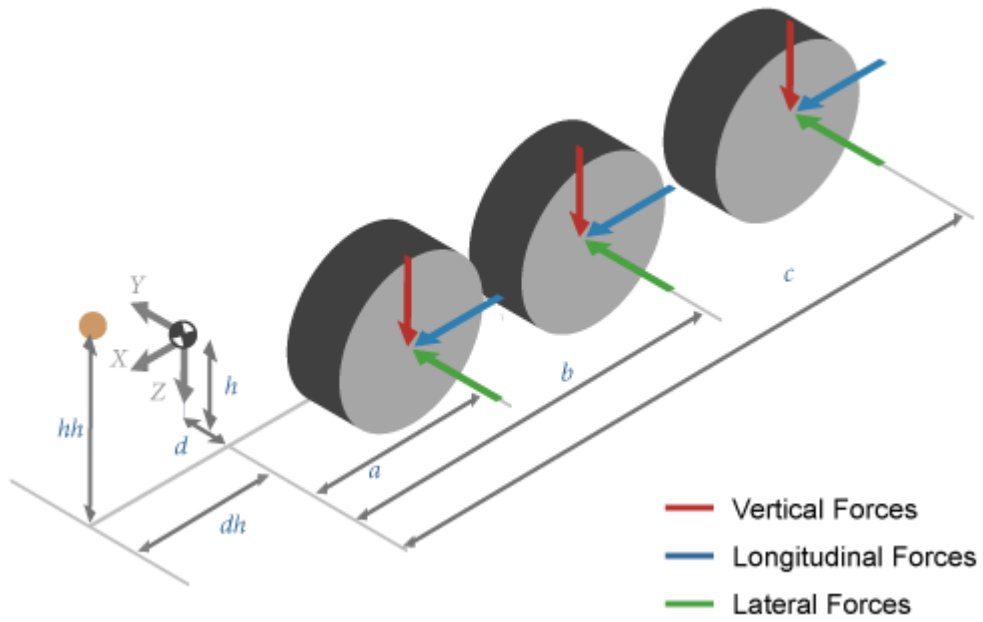
Input Signals Pane Parameter	Input Port	Description
<b>Hitch moments</b>	Mh	Hitch moment at the hitch location, $Mh_x$ , $Mh_y$ , and $Mh_z$ , about the vehicle-fixed frame
<b>Initial longitudinal position</b>	X_o	Initial vehicle CG displacement along the earth-fixed X-axis
<b>Initial yaw angle</b>	psi_o	Initial rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw)
<b>Initial longitudinal velocity</b>	xdot_o	Initial vehicle CG velocity along the vehicle-fixed x-axis
<b>Initial yaw rate</b>	r_o	Initial vehicle angular velocity about the vehicle-fixed z-axis (yaw rate)
<b>Initial lateral position</b>	Y_o	Initial vehicle CG displacement along the earth-fixed Y-axis
<b>Air temperature</b>	AirTemp	Ambient air temperature. Consider this option if you want to vary the temperature during run time.
<b>Initial lateral velocity</b>	ydot_o	Initial vehicle CG velocity along the vehicle-fixed y-axis

### Theory

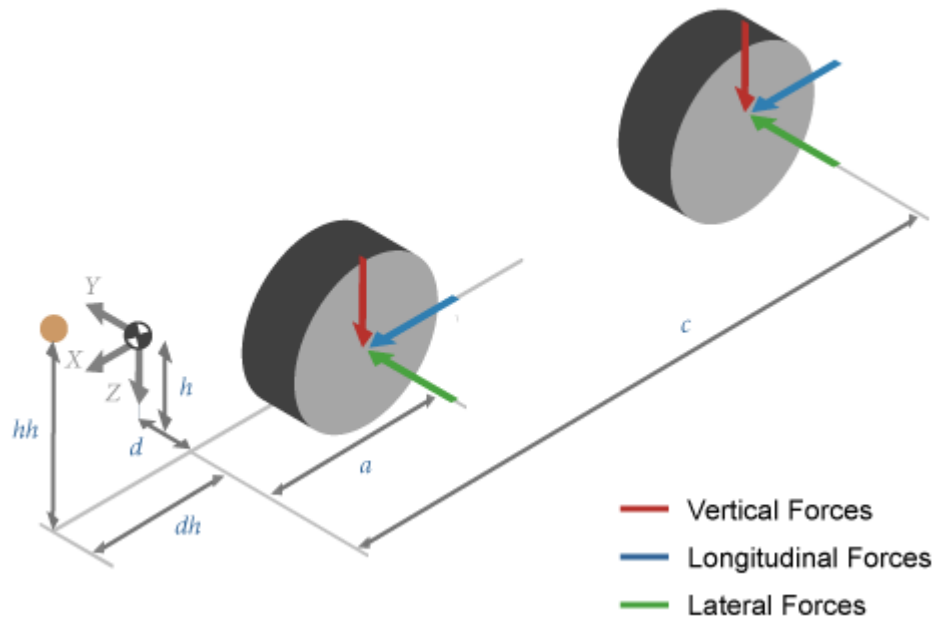
To determine the vehicle motion, the block solves the rigid body planar dynamics equations of motion.

Calculation	Description
<i>Dynamics</i>	The block solves the rigid-body planar dynamics equations to determine the vehicle longitudinal motion. If you set <b>Axle forces</b> to <b>External longitudinal velocity</b> , the block assumes a quasi-steady state for the longitudinal acceleration.
<i>External forces</i>	External forces include both drag and external force inputs. The forces act on the vehicle CG.  The block divides the normal forces by the nominal normal load to vary the effective friction parameters during weight and load transfer. The block maintains pitch and roll equilibrium.
<i>Tire forces</i>	The block uses the ratio of the local, longitudinal, and lateral velocities to determine the slip angles.  The block uses the steering angles to transform the tire forces to the vehicle-fixed frame.  If you set <b>Axle forces</b> to <b>External forces</b> , the block assumes that the externally provided forces are in the vehicle-fixed frame at the axle-wheel location.

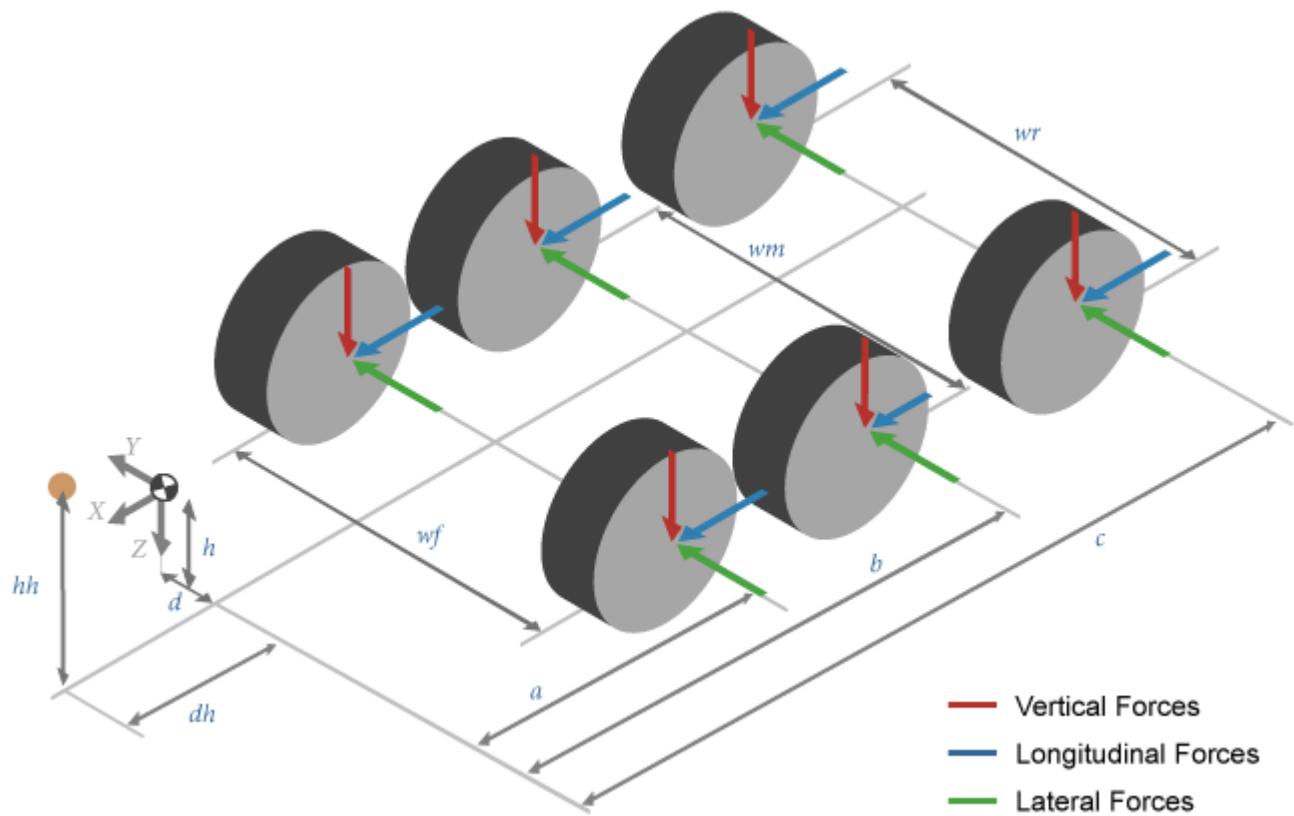
Single Track – Three Axles



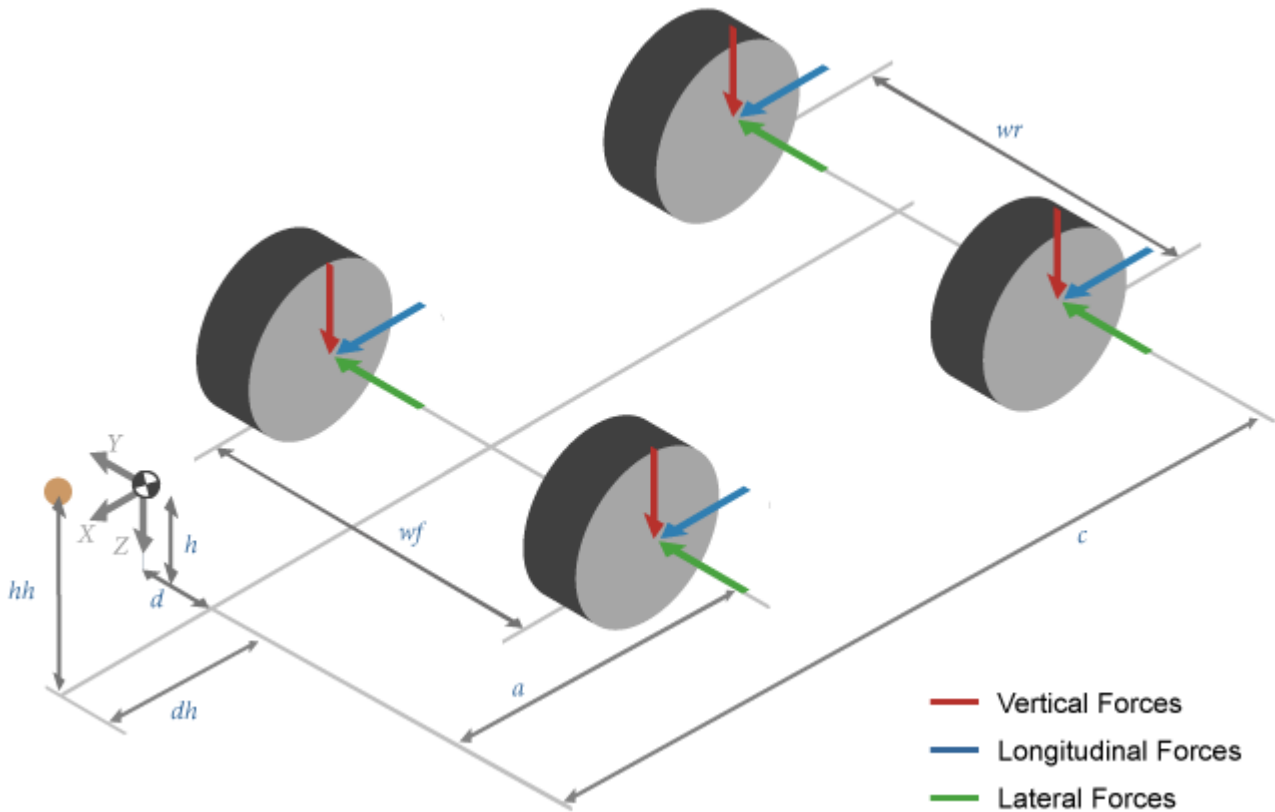
Single Track – Two Axles



## Dual Track – Three Axes



**Dual Track – Two Axles**



The illustrations use these variables.

- $a, b, c$  Longitudinal distance of the front, middle, and rear axles, respectively, from the normal projection point of the vehicle CG onto the common axle plane
- $h$  Height of the tractor CG above the axle plane along the vehicle-fixed z-axis
- $d$  Lateral distance from the geometric centerline to the center of mass along the vehicle-fixed y-axis
- $hh$  Height of the hitch above the axle plane along the vehicle-fixed z-axis
- $dh$  Longitudinal distance of the hitch from the normal projection point of tractor CG onto the common axle plane
- $hl$  Lateral distance from center of mass to hitch along the vehicle-fixed y-axis.
- $wf, wm, wr$  Front, middle, and rear track width, respectively

**Drag**

This table summarizes the block implementation for the drag calculation.

Calculation	Description
Coordinate transformation	The block transforms the wind speeds from the inertial frame to the vehicle-fixed frame.

Calculation	Description
<i>Drag forces</i>	To determine a relative airspeed, the block subtracts the wind speed from the CG vehicle velocity. Using the relative airspeed, the block determines the drag forces.
<i>Drag moments</i>	Using the relative airspeed, the block determines the drag moments.

### Lateral Corner Stiffness and Relaxation Dynamics

To enable the mapped corner stiffness and relaxation length dynamic parameters, set **Axle forces** to External longitudinal forces or External longitudinal velocity.

Parameter Settings		Description
Mapped Corner Stiffness	Include Relaxation Length Dynamics	
Off (default)	On (default)	The block uses constant corner stiffness values.  The slip angles include the relaxation length dynamic settings. The relaxation length approximates an effective corner stiffness force that is a function of wheel travel.
On	On (default)	The block uses lookup tables that are functions of the corner stiffness data and slip angles.  The slip angles include the relaxation length dynamic settings. The relaxation length approximates an effective corner stiffness force that is a function of wheel travel.
Off (default)	Off	The block uses constant corner stiffness values.

## Ports

### Input

#### WhlAngF – Front wheel steering angles

scalar | array

Front wheel steering angles,  $\delta_F$ , in rad.

Vehicle Track Setting	Variable	Signal Dimension
Single 2-axle	$\delta_F$	Scalar - 1
Single 3-axle		
Dual 2-axle	$\delta_F = [\delta_{fl} \ \delta_{fr}]$ or $\begin{bmatrix} \delta_{fl} \\ \delta_{fr} \end{bmatrix}$	Array - [1x2] or [2x1]
Dual 3-axle		

### Dependencies

To enable this port, under **Input signals**, select **Front wheel steering**.

**WhlAngM — Middle wheel steering angles**

scalar | array

Middle wheel steering angles,  $\delta_M$ , in rad.

Vehicle Track Setting	Variable	Signal Dimension
Single 3-axle	$\delta_M$	Scalar - 1
Dual 3-axle	$\delta_M = [\delta_{ml} \ \delta_{mr}]$ or $\begin{bmatrix} \delta_{ml} \\ \delta_{mr} \end{bmatrix}$	Array - [1x2] or [2x1]

**Dependencies**

To enable this port:

- Set **Vehicle track** to Single 3-axle or Dual 3-axle.
- To enable this port, under **Input signals**, select **Middle wheel steering**.

**WhlAngR — Rear wheel steering angles**

scalar | array

Rear wheel steering angles,  $\delta_R$ , in rad.

Vehicle Track Setting	Variable	Signal Dimension
Single 2-axle	$\delta_R$	Scalar - 1
Single 3-axle		
Dual 2-axle	$\delta_R = [\delta_{rl} \ \delta_{rr}]$ or $\begin{bmatrix} \delta_{rl} \\ \delta_{rr} \end{bmatrix}$	Array - [1x2] or [2x1]
Dual 3-axle		

**Dependencies**

To enable this port, under **Input signals**, select **Rear wheel steering**.

**xdotin — Longitudinal velocity**

scalar

Vehicle CG velocity along the vehicle-fixed x-axis, in m/s.

**Dependencies**

To enable this port, set **Axle forces** to External longitudinal velocity.

**FwF — Total force on the front wheels**

scalar | array

Force on the front wheels,  $F_{W_F}$ , along the vehicle-fixed axis, in N.

Vehicle Track Setting	Axle Forces Setting	Description	Variable	Signal Dimension
Single 2-axle	External longitudinal forces	Longitudinal force on the front wheel	$F_{wF} = F_{x_f}$	Scalar - 1
Single 3-axle	External forces	Longitudinal and lateral forces on the front wheel	$F_{wF} = [F_{x_f} \ F_{y_f}]$ or $\begin{bmatrix} F_{x_f} \\ F_{y_f} \end{bmatrix}$	Array - [1x2] or [2x1]
Dual 2-axle	External longitudinal forces	Longitudinal force on the front wheels	$F_{wF} = [F_{x_{fl}} \ F_{x_{fr}}]$ or $\begin{bmatrix} F_{x_{fl}} \\ F_{x_{fr}} \end{bmatrix}$	Array - [1x2] or [2x1]
Dual 3-axle	External forces	Longitudinal and lateral forces on the front wheels	$F_{wF} = \begin{bmatrix} F_{x_{fl}} & F_{x_{fr}} \\ F_{y_{fl}} & F_{y_{fr}} \end{bmatrix}$	Array - [2x2]

#### Dependencies

To enable this port, set **Axle forces** to one of these options:

- External longitudinal forces
- External forces

#### F<sub>wM</sub> – Total force on the middle wheels

scalar | array

Force on the middle wheels,  $F_{wM}$ , along the vehicle-fixed axis, in N.

Vehicle Track Setting	Axle Forces Setting	Description	Variable	Signal Dimension
Single 3-axle	External longitudinal forces	Longitudinal force on the middle wheel	$F_{wM} = F_{x_r}$	Scalar - 1
	External forces	Longitudinal and lateral forces on the middle wheel	$F_{wM} = [F_{x_m} \ F_{y_m}]$ or $\begin{bmatrix} F_{x_m} \\ F_{y_m} \end{bmatrix}$	Array - [1x2] or [2x1]
Dual 3-axle	External longitudinal forces	Longitudinal force on the middle wheels	$F_{wM} = [F_{x_{ml}} \ F_{x_{mr}}]$ or $\begin{bmatrix} F_{x_{ml}} \\ F_{x_{mr}} \end{bmatrix}$	Array - [1x2] or [2x1]

Vehicle Track Setting	Axle Forces Setting	Description	Variable	Signal Dimension
	External forces	Longitudinal and lateral forces on the middle wheels	$FwM = \begin{bmatrix} F_{xml} & F_{xmr} \\ F_{yml} & F_{ymr} \end{bmatrix}$	Array - [2x2]

**Dependencies**

To enable this port, set:

- **Vehicle track** to Single 3-axle or Dual 3-axle.
- **Axle forces** to External longitudinal forces or External forces.

**FwR — Total force on the rear wheels**

scalar | array

Force on the rear wheels,  $FwR$ , along the vehicle-fixed axis, in N.

Vehicle Track Setting	Axle Forces Setting	Description	Variable	Signal Dimension
Single 2-axle	External longitudinal forces	Longitudinal force on the rear wheel	$FwR = F_{x_r}$	Scalar - 1
Single 3-axle	External forces	Longitudinal and lateral forces on the rear wheel	$FwR = [F_{x_r} \ F_{y_r}]$ or $\begin{bmatrix} F_{x_r} \\ F_{y_r} \end{bmatrix}$	Array - [1x2] or [2x1]
Dual 2-axle	External longitudinal forces	Longitudinal force on the rear wheels	$FwR = [F_{x_{rl}} \ F_{x_{rr}}]$ or $\begin{bmatrix} F_{x_{rl}} \\ F_{x_{rr}} \end{bmatrix}$	Array - [1x2] or [2x1]
Dual 3-axle	External forces	Longitudinal and lateral forces on the rear wheels	$FwR = \begin{bmatrix} F_{x_{rl}} & F_{x_{rr}} \\ F_{y_{rl}} & F_{y_{rr}} \end{bmatrix}$	Array - [2x2]

**Dependencies**

To enable this port, set **Axle forces** to one of these options:

- External longitudinal forces
- External forces

**FExt — External force on the vehicle CG**

array

External forces applied to the vehicle CG,  $F_{x_{ext}}, F_{y_{ext}}, F_{z_{ext}}$ , in vehicle-fixed frame, in N. The signal vector dimensions are [1x3] or [3x1].



**Dependencies**

To enable this port, under **Input signals**, select **External forces**.

**MExt — External moment about vehicle CG**

array

External moment about the vehicle CG,  $M_x$ ,  $M_y$ ,  $M_z$ , in the vehicle-fixed frame, in N·m. The signal vector dimensions are [1x3] or [3x1].

**Dependencies**

To enable this port, under **Input signals**, select **External moments**.

**Fh — Hitch force on the body**

array

Hitch force applied to the body at the hitch location,  $Fh_x$ ,  $Fh_y$ ,  $Fh_z$ , in the vehicle-fixed frame, in N, specified as a 1-by-3 or 3-by-1 array.

**Dependencies**

To enable this port, under **Input signals**, select **Hitch forces**.

**Mh — Hitch moment about body**

array

Hitch moment at the hitch location,  $Mh_x$ ,  $Mh_y$ ,  $Mh_z$ , about the vehicle-fixed frame, in N·m, specified as a 1-by-3 or 3-by-1 array.

**Dependencies**

To enable this port, under **Input signals**, select **Hitch moments**.

**WindXYZ — Wind speed**

array

Wind speed,  $W_x$ ,  $W_y$ ,  $W_z$ , along the inertial X-, Y-, and Z-axes, in m/s. The signal vector dimensions are 1-by-3 or 3-by-1.

**Dependencies**

To enable this port, under **Input signals**, select **External wind**.

**Mu — Tire friction coefficient**

array

Tire friction coefficient,  $\mu$ . The value is dimensionless.

Vehicle Track Setting	Description	Variable	Signal Dimension
Single 2-axle	Friction coefficient on the wheels	$Mu = [\mu_f \ \mu_r]$ or $\begin{bmatrix} \mu_f \\ \mu_r \end{bmatrix}$	Array - [1x2] or [2x1]
Dual 2-axle	Friction coefficient on the wheels	$Mu = \begin{bmatrix} \mu_{fl} & \mu_{fr} \\ \mu_{rl} & \mu_{rr} \end{bmatrix}$	Array - [2x2]

Vehicle Track Setting	Description	Variable	Signal Dimension
Single 3-axle	Friction coefficient on the wheels	$Mu = [\mu_f \ \mu_m \ \mu_r] \text{ or}$ $\begin{bmatrix} \mu_f \\ \mu_m \\ \mu_r \end{bmatrix}$	Array - [1x3] or [3x1]
Dual 3-axle	Friction coefficient on the wheels	$Mu = \begin{bmatrix} \mu_{fl} & \mu_{fr} \\ \mu_{ml} & \mu_{mr} \\ \mu_{rl} & \mu_{rr} \end{bmatrix}$	Array - [3x2]

**Dependencies**

To enable this port, under **Input signals**, select **External friction**.

**AirTemp – Ambient air temperature**

scalar

Ambient air temperature, in K.

**Dependencies**

To enable this port, under **Input signals**, select **Air temperature**.

**X\_o – Initial longitudinal position**

scalar

Initial vehicle CG displacement along the earth-fixed X-axis, in m.

**Dependencies**

To enable this port, under **Input signals**, select **Initial longitudinal position**.

**Y\_o – Initial lateral position**

scalar

Initial vehicle CG displacement along the earth-fixed Y-axis, in m.

**Dependencies**

To enable this port, under **Input signals**, select **Initial lateral position**.

**xdot\_o – Initial longitudinal position**

scalar

Initial vehicle CG velocity along the vehicle-fixed x-axis, in m/s.

**Dependencies**

To enable this port:

- 1 Set **Axle forces** to one of these options:

- External longitudinal forces
- External forces

2 Under **Input signals**, select **Initial longitudinal velocity**

### **ydot\_o — Initial lateral position**

scalar

Initial vehicle CG velocity along the vehicle-fixed  $y$ -axis, in m/s.

#### **Dependencies**

To enable this port, under **Input signals**, select **Initial lateral velocity**.

### **psi\_o — Initial yaw angle**

scalar

Rotation of the vehicle-fixed frame about the earth-fixed  $Z$ -axis (yaw), in rad.

#### **Dependencies**

To enable this port, under **Input signals**, select **Initial yaw angle**.

### **r\_o — Initial yaw rate**

scalar

Vehicle angular velocity about the vehicle-fixed  $z$ -axis (yaw rate), in rad/s.

#### **Dependencies**

To enable this port, under **Input signals**, select **Initial yaw rate**.

#### **Output**

#### **Info — Trailer data**

bus

Trailer data, returned as a bus signal containing these block values.

Signal				Description	Value	Units
InertFrm	Cg	Disp	X	Vehicle CG displacement along the earth-fixed $X$ -axis	Computed	m
			Y	Vehicle CG displacement along the earth-fixed $Y$ -axis	Computed	m
			Z	Vehicle CG displacement along the earth-fixed $Z$ -axis	0	m
	Vel	Xdot	Vehicle CG velocity along the earth-fixed $X$ -axis	Computed	m/s	
		Ydot	Vehicle CG velocity along the earth-fixed $Y$ -axis	Computed	m/s	

Signal			Description		Value	Units		
			Zdot		Vehicle CG velocity along the earth-fixed Z-axis	0	m/s	
		Ang	phi		Rotation of the vehicle-fixed frame about the earth-fixed X-axis (roll)	0	rad	
			theta		Rotation of the vehicle-fixed frame about the earth-fixed Y-axis (pitch)	0	rad	
			psi		Rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw)	Computed	rad	
	FrntAxl	Lft	Disp	X		Front left wheel displacement along the earth-fixed X-axis	Computed	m
				Y		Front left wheel displacement along the earth-fixed Y-axis	Computed	m
				Z		Front left wheel displacement along the earth-fixed Z-axis	0	m
			Vel	Xdot		Front left wheel velocity along the earth-fixed X-axis	Computed	m/s
				Ydot		Front left wheel velocity along the earth-fixed Y-axis	Computed	m/s
				Zdot		Front left wheel velocity along the earth-fixed Z-axis	0	m/s
		Rght	Disp	X		Front right wheel displacement along the earth-fixed X-axis	Computed	m
				Y		Front right wheel displacement along the earth-fixed Y-axis	Computed	m
				Z		Front right wheel displacement along the earth-fixed Z-axis	0	m
			Vel	Xdot		Front right wheel velocity along the earth-fixed X-axis	Computed	m/s
				Ydot		Front right wheel velocity along the earth-fixed Y-axis	Computed	m/s

Signal				Description	Value	Units	
			Zdot	Front right wheel velocity along the earth-fixed Z-axis	0	m/s	
	MidlAxl	Lft	Disp	X	Middle left wheel displacement along the earth-fixed X-axis	Computed	m
				Y	Middle left wheel displacement along the earth-fixed Y-axis	Computed	m
				Z	Middle left wheel displacement along the earth-fixed Z-axis	0	m
			Vel	Xdot	Middle left wheel velocity along the earth-fixed X-axis	Computed	m/s
				Ydot	Middle left wheel velocity along the earth-fixed Y-axis	Computed	m/s
				Zdot	Middle left wheel velocity along the earth-fixed Z-axis	0	m/s
		Rght	Disp	X	Middle right wheel displacement along the earth-fixed X-axis	Computed	m
				Y	Middle right wheel displacement along the earth-fixed Y-axis	Computed	m
				Z	Middle right wheel displacement along the earth-fixed Z-axis	0	m
			Vel	Xdot	Middle right wheel velocity along the earth-fixed X-axis	Computed	m/s
				Ydot	Middle right wheel velocity along the earth-fixed Y-axis	Computed	m/s
				Zdot	Middle right wheel velocity along the earth-fixed Z-axis	0	m/s
	RearAxl	Lft	Disp	X	Rear left wheel displacement along the earth-fixed X-axis	Computed	m
				Y	Rear left wheel displacement along the earth-fixed Y-axis	Computed	m

Signal				Description	Value	Units	
		Left	Z	Rear left wheel displacement along the earth-fixed Z-axis	0	m	
			Vel	Xdot	Rear left wheel velocity along the earth-fixed X-axis	Computed	m/s
				Ydot	Rear left wheel velocity along the earth-fixed Y-axis	Computed	m/s
		Zdot		Rear left wheel velocity along the earth-fixed Z-axis	0	m/s	
		Right	Disp	X	Rear right wheel displacement along the earth-fixed X-axis	Computed	m
				Y	Rear right wheel displacement along the earth-fixed Y-axis	Computed	m
				Z	Rear right wheel displacement along the earth-fixed Z-axis	0	m
		Vel	Xdot	Rear right wheel velocity along the earth-fixed X-axis	Computed	m/s	
			Ydot	Rear right wheel velocity along the earth-fixed Y-axis	Computed	m/s	
	Zdot		Rear right wheel velocity along the earth-fixed Z-axis	0	m/s		
	Geom	Disp	X	Trailer body offset from the axle plane along the earth-fixed X-axis	Computed	m	
			Y	Trailer body offset from the center plane along the earth-fixed Y-axis	Computed	m	
Z			Trailer body offset from the axle plane along the earth-fixed Z-axis	Computed	m		
Vel		Xdot	Trailer body offset velocity along the earth-fixed X-axis	Computed	m/s		
		Ydot	Trailer body offset velocity along the earth-fixed Y-axis	Computed	m/s		

Signal			Description	Value	Units				
	Hitch	Disp	Zdot	Trailer body offset velocity along the earth-fixed Z-axis	Computed	m/s			
			X	Trailer hitch offset from the axle plane along the earth-fixed X-axis	Computed	m			
			Y	Trailer hitch offset from the center plane along the earth-fixed Y-axis	Computed	m			
		Vel	Z	Trailer hitch offset from the axle plane along the earth-fixed Z-axis	Computed	m			
			Xdot	Trailer hitch offset velocity along the earth-fixed X-axis	Computed	m/s			
			Ydot	Trailer hitch offset velocity along the earth-fixed Y-axis	Computed	m/s			
			Zdot	Trailer hitch offset velocity along the earth-fixed Z-axis	Computed	m/s			
			BdyFrm	Cg	Vel	xdot	Vehicle CG velocity along the vehicle-fixed x-axis	Computed	m/s
						ydot	Vehicle CG velocity along the vehicle-fixed y-axis	Computed	m/s
		zdot				Vehicle CG velocity along the vehicle-fixed z-axis	0	m/s	
Ang	Beta	Body slip angle, $\beta$ $\beta = \frac{V_y}{V_x}$	Computed	rad					
AngVel	p	Vehicle angular velocity about the vehicle-fixed x-axis (roll rate)	0	rad/s					
	q	Vehicle angular velocity about the vehicle-fixed y-axis (pitch rate)	0	rad/s					
	r	Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate)	Computed	rad/s					
Acc	ax	Vehicle CG acceleration along the vehicle-fixed x-axis	Computed	gn					

Signal			Description	Value	Units	
			ay	Vehicle CG acceleration along the vehicle-fixed y-axis	Computed	gn
			az	Vehicle CG acceleration along the vehicle-fixed z-axis	0	gn
			xddot	Vehicle CG acceleration along the vehicle-fixed x-axis	Computed	m/s <sup>2</sup>
			yddot	Vehicle CG acceleration along the vehicle-fixed y-axis	Computed	m/s <sup>2</sup>
			zddot	Vehicle CG acceleration along the vehicle-fixed z-axis	0	m/s <sup>2</sup>
		AngAcc	pdot	Vehicle angular acceleration about the vehicle-fixed x-axis	0	rad/s
			qdot	Vehicle angular acceleration about the vehicle-fixed y-axis	0	rad/s
			rdot	Vehicle angular acceleration about the vehicle-fixed z-axis	Computed	rad/s
		Forces	Body	Fx	Net force on the vehicle CG along the vehicle-fixed x-axis	Computed
	Fy			Net force on the vehicle CG along the vehicle-fixed y-axis	Computed	N
	Fz			Net force on the vehicle CG along the vehicle-fixed z-axis	0	N
	Ext		Fx	External force on the vehicle CG along the vehicle-fixed x-axis	Computed	N
			Fy	External force on the vehicle CG along the vehicle-fixed y-axis	Computed	N
			Fz	External force on the vehicle CG along the vehicle-fixed z-axis	0	N



Signal			Description		Value	Units	
	Hitch	Fx	Hitch force applied to the body at the hitch location along the vehicle-fixed x-axis		Computed	N	
			Fy	Hitch force applied to the body at the hitch location along the vehicle-fixed y-axis		Computed	N
				Fz	Hitch force applied to the body at the hitch location along the vehicle-fixed z-axis		Computed
	FrntAxl	Lft	Fx	Longitudinal force on the left front wheel along the vehicle-fixed x-axis		Computed	N
			Fy	Lateral force on the left front wheel along the vehicle-fixed y-axis		Computed	N
			Fz	Normal force on the left front wheel along the vehicle-fixed z-axis		Computed	N
		Rght	Fx	Longitudinal force on the right front wheel along the vehicle-fixed x-axis		Computed	N
			Fy	Lateral force on the right front wheel along the vehicle-fixed y-axis		Computed	N
			Fz	Normal force on the right front wheel along the vehicle-fixed z-axis		Computed	N
	MidlAxl	Lft	Fx	Longitudinal force on the left middle wheel along the vehicle-fixed x-axis		Computed	N
			Fy	Lateral force on the left middle wheel along the vehicle-fixed y-axis		Computed	N
			Fz	Normal force on the left middle wheel along the vehicle-fixed z-axis		Computed	N
		Rght	Fx	Longitudinal force on the right middle wheel along the vehicle-fixed x-axis		Computed	N
			Fy	Lateral force on the right middle wheel along the vehicle-fixed y-axis		Computed	N

Signal				Description	Value	Units	
				Fz	Normal force on the right middle wheel along the vehicle-fixed z-axis	Computed N	
		RearAx1	Lft	Fx	Longitudinal force on the left rear wheel along the vehicle-fixed x-axis	Computed N	
				Fy	Lateral force on the left rear wheel along the vehicle-fixed y-axis	Computed N	
				Fz	Normal force on the left rear wheel along the vehicle-fixed z-axis	Computed N	
			Rght	Fx	Longitudinal force on the right rear wheel along the vehicle-fixed x-axis	Computed N	
				Fy	Lateral force on the right rear wheel along the vehicle-fixed y-axis	Computed N	
				Fz	Normal force on the right rear wheel along the vehicle-fixed z-axis	Computed N	
		Tires	FrntTires	L	F Front left tire force along the vehicle-fixed x-axis	Computed N	
				f		Computed N	
				t		Computed N	
			RghtTires	R	F Front right tire force along the vehicle-fixed x-axis	Computed N	
				g		Computed N	
				h		Computed N	
			FrntTires	t	F	Front right tire force along the vehicle-fixed y-axis	Computed N
					y		Computed N
					z		Computed N
			RearTires	Lft	L	F Rear left tire force along the vehicle-fixed x-axis	Computed N
					f		Computed N
					t		Computed N
		Rght		R	F Rear right tire force along the vehicle-fixed x-axis	Computed N	

Signal					Description	Value	Units
				F <sub>y</sub>	Rear right tire force along the vehicle-fixed y-axis	Computed	N
				F <sub>z</sub>	Rear right tire force along the vehicle-fixed z-axis	Computed	
		Drag	F <sub>x</sub>		Drag force on the vehicle CG along the vehicle-fixed x-axis	Computed	N
			F <sub>y</sub>		Drag force on the vehicle CG along the vehicle-fixed y-axis	Computed	N
			F <sub>z</sub>		Drag force on the vehicle CG along the vehicle-fixed z-axis	Computed	N
		Grvty	F <sub>x</sub>		Gravity force on the vehicle CG along the vehicle-fixed x-axis	Computed	N
			F <sub>y</sub>		Gravity force on the vehicle CG along the vehicle-fixed y-axis	Computed	N
			F <sub>z</sub>		Gravity force on the vehicle CG along the vehicle-fixed z-axis	Computed	N
		Moments	Body	M <sub>x</sub>		Body moment on the vehicle CG about the vehicle-fixed x-axis	0
	M <sub>y</sub>			Body moment on the vehicle CG about the vehicle-fixed y-axis	Computed	N·m	
	M <sub>z</sub>			Body moment on the vehicle CG about the vehicle-fixed z-axis	0	N·m	
	Drag		M <sub>x</sub>		Drag moment on the vehicle CG about the vehicle-fixed x-axis	0	N·m
			M <sub>y</sub>		Drag moment on the vehicle CG about the vehicle-fixed y-axis	Computed	N·m
			M <sub>z</sub>		Drag moment on the vehicle CG about the vehicle-fixed z-axis	0	N·m
	Ext		M <sub>x</sub>		External moment on the vehicle CG about the vehicle-fixed x-axis	0	N·m

Signal			Description		Value	Units		
			My		External moment on the vehicle CG about the vehicle-fixed y-axis	Computed	N·m	
			Mz		External moment on the vehicle CG about the vehicle-fixed z-axis	0	N·m	
		Hitch	Mx		Hitch moment at the hitch location about vehicle-fixed x-axis	0	N·m	
			My		Hitch moment at the hitch location about vehicle-fixed y-axis	Computed	N·m	
			Mz		Hitch moment at the hitch location about vehicle-fixed z-axis	0	N·m	
	FrntAxl	Lft	Disp	x		Front left wheel displacement along the vehicle-fixed x-axis	Computed	m
				y		Front left wheel displacement along the vehicle-fixed y-axis	Computed	m
				z		Front left wheel displacement along the vehicle-fixed z-axis	Computed	m
			Vel	xdo	t	Front left wheel velocity along the vehicle-fixed x-axis	Computed	m/s
				ydo	t	Front left wheel velocity along the vehicle-fixed y-axis	Computed	m/s
				zdo	t	Front left wheel velocity along the vehicle-fixed z-axis	0	m/s
		Rght	Disp	x		Front right wheel displacement along the vehicle-fixed x-axis	Computed	m
				y		Front right wheel displacement along the vehicle-fixed y-axis	Computed	m
				z		Front right wheel displacement along the vehicle-fixed z-axis	Computed	m
			Vel	xdo	t	Front right wheel velocity along the vehicle-fixed x-axis	Computed	m/s

Signal					Description	Value	Units
				ydot	Front right wheel velocity along the vehicle-fixed y-axis	Computed	m/s
				zdot	Front right wheel velocity along the vehicle-fixed z-axis	0	m/s
			Steer	WhlAngFL	Front left wheel steering angle	Computed	rad
				WhlAngFR	Front right wheel steering angle	Computed	rad
	MidlAxl	Lft	Disp	x	Middle left wheel displacement along the vehicle-fixed x-axis	Computed	m
				y	Middle left wheel displacement along the vehicle-fixed y-axis	Computed	m
				z	Middle left wheel displacement along the vehicle-fixed z-axis	Computed	m
			Vel	xdot	Middle left wheel velocity along the vehicle-fixed x-axis	Computed	m/s
				ydot	Middle left wheel velocity along the vehicle-fixed y-axis	Computed	m/s
				zdot	Middle left wheel velocity along the vehicle-fixed z-axis	0	m/s
		Rght	Disp	x	Middle right wheel displacement along the vehicle-fixed x-axis	Computed	m
				y	Middle right wheel displacement along the vehicle-fixed y-axis	Computed	m
				z	Middle right wheel displacement along the vehicle-fixed z-axis	Computed	m
			Vel	xdot	Middle right wheel velocity along the vehicle-fixed x-axis	Computed	m/s
ydot	Middle right wheel velocity along the vehicle-fixed y-axis	Computed		m/s			

Signal					Description	Value	Units		
		Steer	WhlAngRL	zdot	Middle right wheel velocity along the vehicle-fixed z-axis	0	m/s		
				WhlAngRR	Middle right wheel steering angle	Computed	rad		
				WhlAngRR	Middle left wheel steering angle	Computed	rad		
		RearAxl	Lft	Disp	x	Rear left wheel displacement along the vehicle-fixed x-axis	Computed	m	
					y	Rear left wheel displacement along the vehicle-fixed y-axis	Computed	m	
					z	Rear left wheel displacement along the vehicle-fixed z-axis	Computed	m	
				Vel	xdot	Rear left wheel velocity along the vehicle-fixed x-axis	Computed	m/s	
					ydot	Rear left wheel velocity along the vehicle-fixed y-axis	Computed	m/s	
					zdot	Rear left wheel velocity along the vehicle-fixed z-axis	0	m/s	
				Rght	Disp	x	Rear right wheel displacement along the vehicle-fixed x-axis	Computed	m
						y	Rear right wheel displacement along the vehicle-fixed y-axis	Computed	m
						z	Rear right wheel displacement along the vehicle-fixed z-axis	Computed	m
			Vel		xdot	Rear right wheel velocity along the vehicle-fixed x-axis	Computed	m/s	
					ydot	Rear right wheel velocity along the vehicle-fixed y-axis	Computed	m/s	
					zdot	Rear right wheel velocity along the vehicle-fixed z-axis	0	m/s	

Signal			Description	Value	Units	
	Steer	WhlAngRL	Rear left wheel steering angle	Computed	rad	
		WhlAngRR	Rear right wheel steering angle	Computed	rad	
	Hitch	Disp	x	Hitch offset from axle plane along the vehicle-fixed x-axis	Input	m
			y	Hitch offset from center plane along the vehicle-fixed y-axis	Input	m
			z	Hitch offset from axle plane along the earth-fixed z-axis	Input	m
		Vel	xdo t	Hitch offset velocity along the vehicle-fixed x-axis	Computed	m/s
			ydo t	Hitch offset velocity along the vehicle-fixed y-axis	Computed	m/s
			zdo t	Hitch offset velocity along the vehicle-fixed z-axis	0	m/s
	Pwr	Ext		Applied external power	Computed	W
		Hitch		Hitch power	Computed	
		Drag		Power loss due to drag	Computed	W
	Geom	Disp	x	Trailer offset from axle plane along the vehicle-fixed x-axis	Input	m
			y	Trailer offset from center plane along the vehicle-fixed y-axis	Input	m
			z	Trailer offset from axle plane along the earth-fixed z-axis	Input	m
		Vel	xdo t	Trailer offset velocity along the vehicle-fixed x-axis	Computed	m/s
ydo t			Trailer offset velocity along the vehicle-fixed y-axis	Computed	m/s	
zdo t			Trailer offset velocity along the vehicle-fixed z-axis	0	m/s	

Signal				Description	Value	Units
		Ang	Beta	Body slip angle, $\beta$ $\beta = \frac{V_y}{V_x}$	Computed	rad

Signal			Description	Value	Units
PwrInfo	PwrTrnsfrd	PwrFxExt	Externally applied longitudinal force power	Computed	W
		PwrFyExt	Externally applied lateral force power	Computed	W
		PwrMzExt	Externally applied yaw moment power	Computed	W
		PwrFwFLx	Longitudinal force applied at the front left axle power	Computed	W
		PwrFwFLy	Lateral force applied at the front left axle power	Computed	W
		PwrFwFRx	Longitudinal force applied at the front right axle power	Computed	W
		PwrFwFRy	Lateral force applied at the front right axle power	Computed	W
		PwrFwMLx	Longitudinal force applied at the middle left axle power	Computed	W
		PwrFwMLy	Lateral force applied at the middle left axle power	Computed	W
		PwrFwMRx	Longitudinal force applied at the middle right axle power	Computed	W
		PwrFwMRy	Lateral force applied at the middle right axle power	Computed	W
		PwrFwRLx	Longitudinal force applied at the rear left axle power	Computed	W
		PwrFwRLy	Lateral force applied at the rear left axle power	Computed	W
		PwrFwRRx	Longitudinal force applied at the rear right axle power	Computed	W
	PwrFwRRy	Lateral force applied at the rear right axle power	Computed	W	
	PwrNotTrnsfrd	PwrFxDrag	Longitudinal drag force power	Computed	W
		PwrFyDrag	Lateral drag force power	Computed	W
		PwrMzDrag	Drag pitch moment power	Computed	W



Signal		Description	Value	Units	
	PwrStored	PwrStoredGrvty	Rate change in gravitational potential energy	Computed	W
		PwrStoredxdot	Rate of change of longitudinal kinetic energy	Computed	W
		PwrStoredydot	Rate of change of lateral kinetic energy	Computed	W
		PwrStoredr	Rate of change of rotational yaw kinetic energy	Computed	W

**xdot – Trailer longitudinal velocity**

scalar

Trailer CG velocity along the vehicle-fixed  $x$ -axis, in m/s.**ydot – Trailer lateral velocity**

scalar

Trailer CG velocity along the vehicle-fixed  $y$ -axis, in m/s.**psi – Yaw**

scalar

Rotation of the vehicle-fixed frame about the earth-fixed  $Z$ -axis (yaw), in rad.**r – Yaw rate**

scalar

Vehicle angular velocity,  $r$ , about the vehicle-fixed  $z$ -axis (yaw rate), in rad/s.**FzF – Normal force on the front wheels**

scalar | array

Normal force on the front wheels,  $Fz_F$ , along the vehicle-fixed  $z$ -axis, in N.

Vehicle Track Setting	Description	Variable	Signal Dimension
Single 2-axle Single 3-axle	Normal force on the front axle	$FzF = Fz_f$	Scalar - 1
Dual 2-axle Dual 3-axle	Normal force on the front wheels	$FzF = [Fz_{fl} \ Fz_{fr}]$	Array - [1x2]

**FzM – Normal force on the middle wheels**

scalar | array

Normal force on the middle wheels,  $Fz_M$ , along the vehicle-fixed  $z$ -axis, in N.

Vehicle Track Setting	Description	Variable	Signal Dimension
Single 3-axle	Normal force on the middle axle	$FzM = Fz_m$	Scalar - 1
Dual 3-axle	Normal force on the right and left middle wheels	$FzM = [Fz_{ml} \ Fz_{rl}]$	Array - [1x2]

**Dependencies**

To enable this port, set **Vehicle track** to Single 3-axle or Dual 3-axle.

**FzR – Normal force on the rear wheels**

scalar | array

Normal force on the rear wheels,  $Fz_R$ , along the vehicle-fixed z-axis, in N.

Vehicle Track Setting	Description	Variable	Signal Dimension
Single 2-axle	Normal force on the rear wheel	$FzR = Fz_r$	Scalar - 1
Single 3-axle			
Dual 2-axle	Normal force on the rear wheels	$FzR = [Fz_{rl} \ Fz_{rr}]$	Array - [1x2]
Dual 3-axle			

**Fhz – Normal component of hitch force on the body**

scalar

Normal hitch force applied to the body at the hitch location,  $Fh_z$ , in the vehicle-fixed frame z-axis, in N.

If you enable the **Hitch forces** parameter, the block offsets the normal hitch force,  $Fh_z$ , with the value of the  $Fh$  input port component along the vehicle-fixed z-axis.

**Parameters**

**Options**

**Vehicle track – Type of vehicle track**

Dual 3-axle (default) | Single 2-axle | Single 3-axle | Dual 2-axle

Use the **Vehicle track** parameter to specify the number of tracks.

Vehicle Track Setting	Implementation
Single 2-axle	Trailer with a single track and two axles. <ul style="list-style-type: none"> <li>Forces act along the center line of the axles.</li> <li>No lateral load transfer.</li> </ul>

Vehicle Track Setting	Implementation
Dual 2-axle	Trailer with a dual track and two axles. Forces act at the axle hard-point locations.
Single 3-axle	Trailer with a single track and three axles. <ul style="list-style-type: none"> <li>Forces act along the center line of the axles.</li> <li>No lateral load transfer.</li> </ul>
Dual 3-axle (default)	Trailer with a dual track and three axles. Forces act at the axle hard-point locations.

### Axle forces – Type of axle force

External forces (default) | External longitudinal velocity | External longitudinal forces

Use the **Axle forces** parameter to specify the type of force.

Axle Forces Setting	Implementation
External longitudinal velocity	<ul style="list-style-type: none"> <li>The block assumes that the external longitudinal velocity is in a quasi-steady state, and the longitudinal acceleration is approximately zero.</li> <li>Because the motion is quasi-steady, the block calculates lateral forces using the tire slip angles and linear cornering stiffness.</li> <li>Consider this setting when you want to: <ul style="list-style-type: none"> <li>Generate virtual sensor signal data.</li> <li>Conduct high-level software studies that are not impacted by driveline or nonlinear tire responses.</li> </ul> </li> </ul>
External longitudinal forces	<ul style="list-style-type: none"> <li>The block uses the external longitudinal force to accelerate or brake the vehicle.</li> <li>The block calculates lateral forces using the tire slip angles and linear cornering stiffness.</li> <li>Consider this setting when you want to: <ul style="list-style-type: none"> <li>Account for changes in the longitudinal velocity on the lateral and yaw motion.</li> <li>Specify the external longitudinal motion through a force instead of an external longitudinal velocity.</li> <li>Connect the block to tractive actuators, wheels, brakes, and hitches.</li> </ul> </li> </ul>
External forces	<ul style="list-style-type: none"> <li>The block uses the external lateral and longitudinal forces to steer, accelerate, or brake the vehicle.</li> <li>The block does not use the steering input to calculate vehicle motion.</li> <li>Consider this setting when you need tire models with more accurate nonlinear combined lateral and longitudinal slip.</li> </ul>

**Input Signals****Front wheel steering — WhlAngF input port**

off (default) | on

Select to create input port WhlAngF.

**Middle wheel steering — WhlAngM input port**

off (default) | on

Select to create input port WhlAngM.

**Dependencies**To enable this parameter, set **Vehicle track** to Single 3-axle or Dual 3-axle.**Rear wheel steering — WhlAngR input port**

off (default) | on

Select to create input port WhlAngR.

**External wind — WindXYZ input port**

off (default) | on

Select to create input port WindXYZ.

**External friction — Mu input port**

off (default) | on

Select to create input port Mu.

**Dependencies**To enable this parameter, set **Axle forces** to one of these options:

- External longitudinal forces
- External forces

**External forces — FExt input port**

off (default) | on

Select to create input port FExt.

**External moments — MExt input port**

off (default) | on

Select to create input port MExt.

**Hitch forces — Fh input port**

on (default) | off

Select to create input port Fh.

**Hitch moments — Mh input port**

on (default) | off

Select to create input port Mh.

**Initial longitudinal position – X\_o input port**

off (default) | on

Select to create input port X\_o.

**Initial yaw angle – psi\_o input port**

off (default) | on

Select to create input port psi\_o.

**Initial longitudinal velocity – xdot\_o input port**

off (default) | on

Select to create input port xdot\_o.

**Dependencies**

To enable this parameter, set **Axle forces** to External longitudinal forces or External forces.

**Initial yaw rate – r\_o input port**

off (default) | on

Select to create input port r\_o.

**Initial lateral position – Y\_o input port**

off (default) | on

Select to create input port Y\_o.

**Air temperature – AirTemp input port**

off (default) | on

Select to create input port AirTemp.

**Initial lateral velocity – ydot\_o input port**

off (default) | on

Select to create input port ydot\_o.

**Longitudinal****Number of wheels on front axle, NF – Front wheel count**

2 (default) | scalar

Number of wheels on the front axle,  $N_F$ . The value is dimensionless.**Number of wheels on middle axle, NM – Middle wheel count**

2 (default) | scalar

Number of wheels on the middle axle,  $N_M$ . The value is dimensionless.**Dependencies**

To enable this parameter, set **Vehicle track** to Single 3-axle or Dual 3-axle.

**Number of wheels on rear axle,  $N_R$  – Rear wheel count**

2 (default) | scalar

Number of wheels on the rear axle,  $N_R$ . The value is dimensionless.

**Vehicle mass,  $m$  – Vehicle mass**

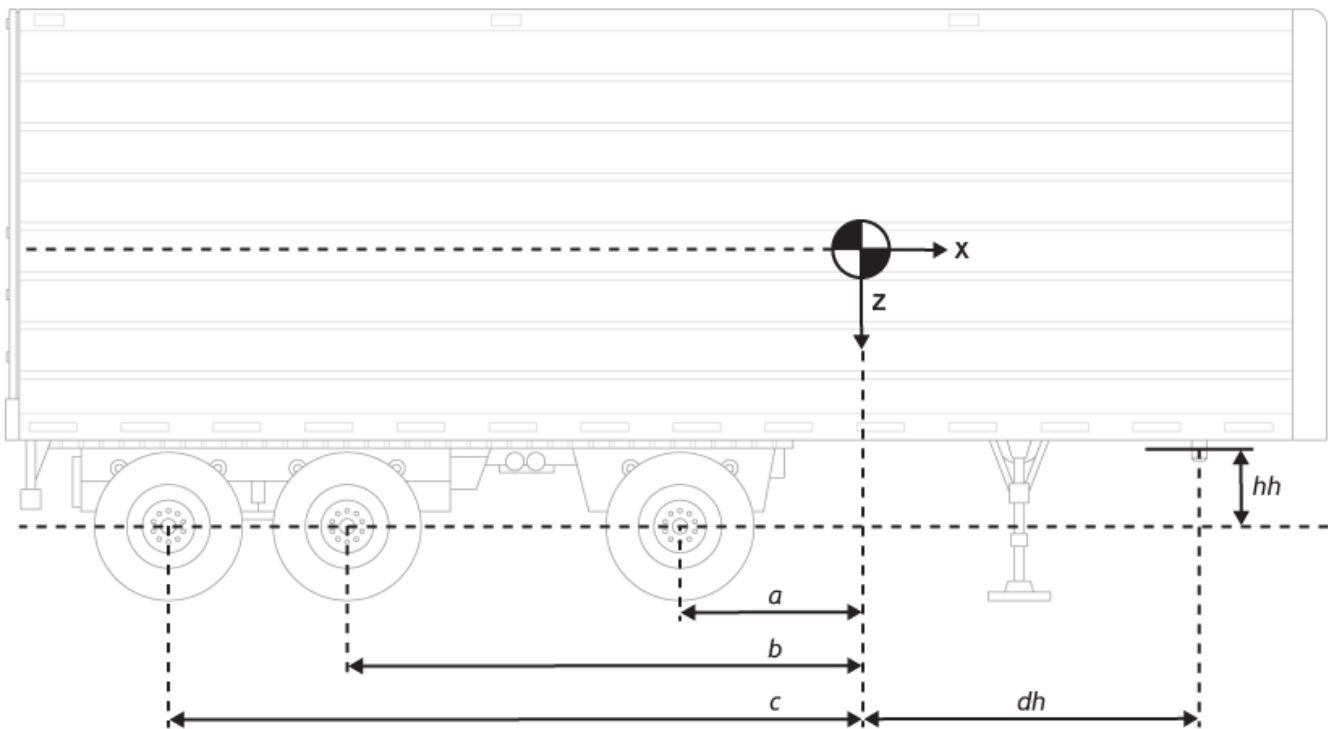
26000 (default) | scalar

Vehicle mass,  $m$ , in kg.

**Longitudinal distance from center of mass to front axle,  $a$  – Distance from CM to front axle**

4 (default) | scalar

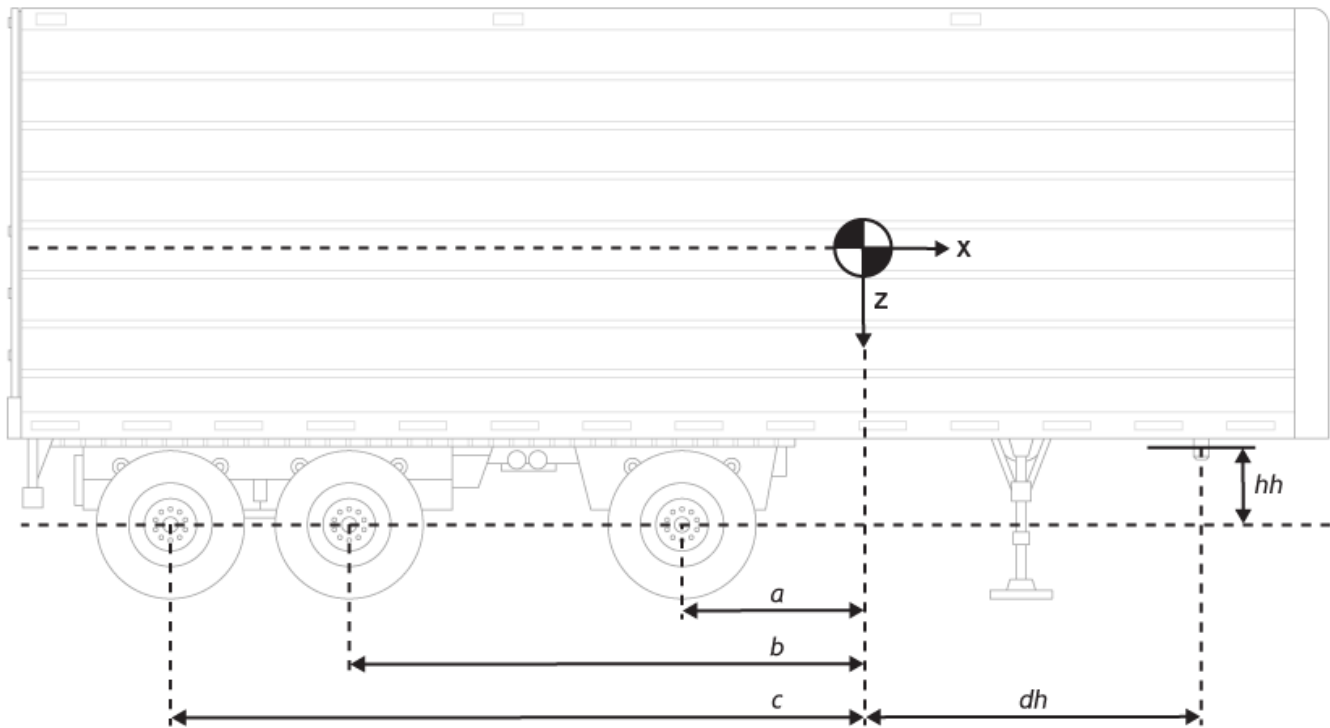
Distance from the vehicle CM to the front axle,  $a$ , in m.



**Longitudinal distance from center of mass to middle axle,  $b$  – Distance from CM to middle axle**

4.5 (default) | scalar

Distance from vehicle CM to middle axle,  $b$ , in m.



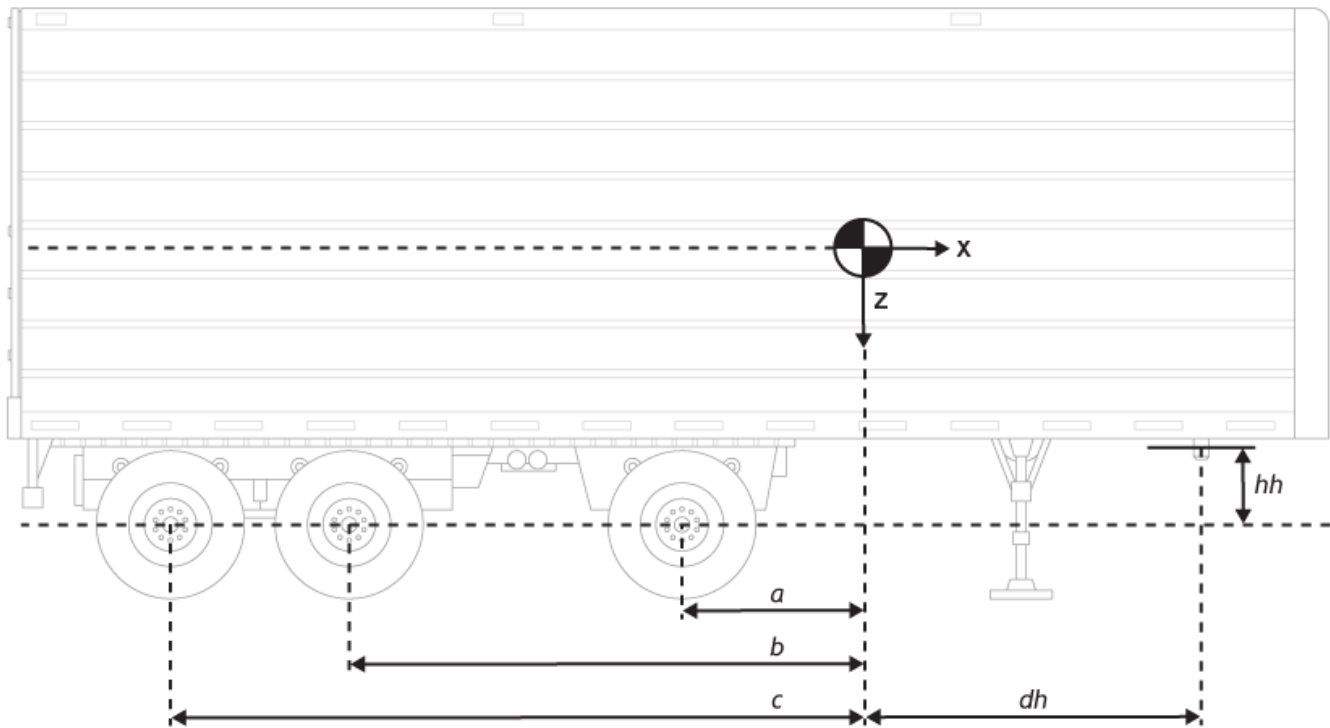
### Dependencies

To enable this parameter, set **Vehicle track** to Single 3-axle or Dual 3-axle.

**Longitudinal distance from center of mass to rear axle, c – Distance from CM to rear axle**

5 (default) | scalar

Distance from vehicle CM to the front axle,  $c$ , in m.

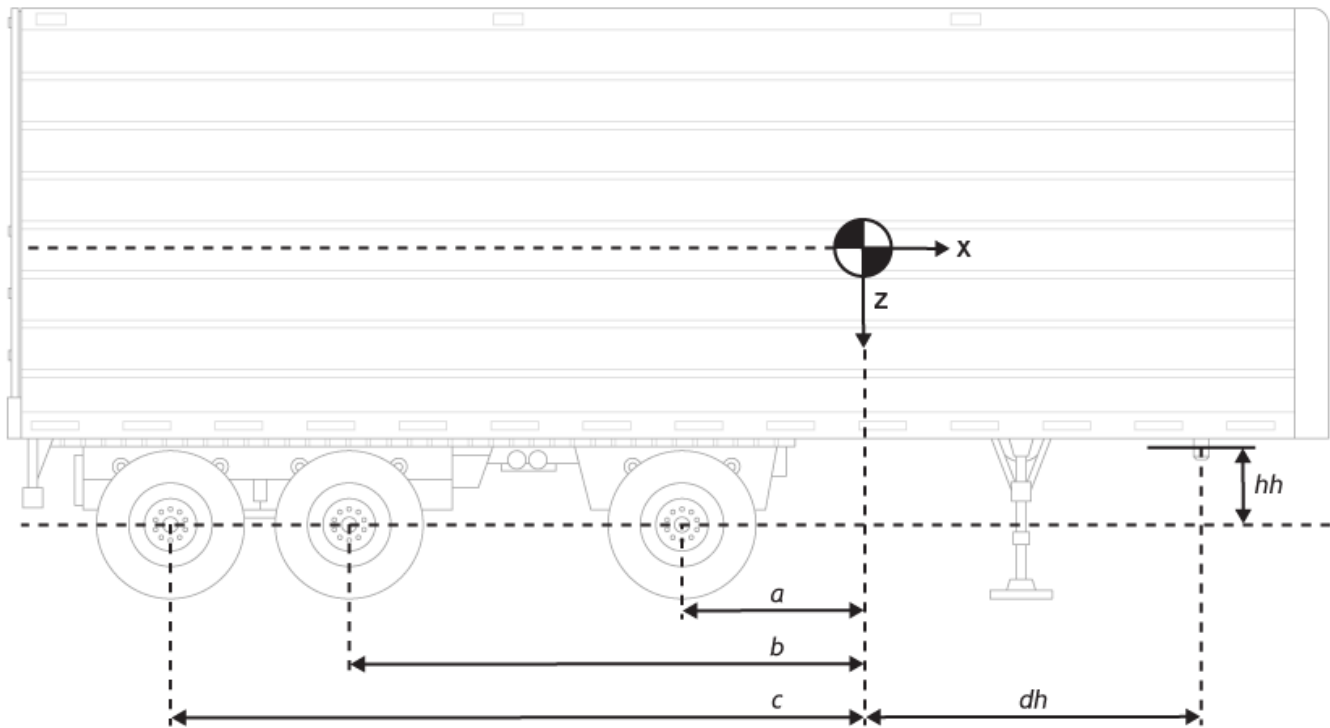


**Vertical distance from center of mass to axle plane,  $h$  – Distance from CM to axle plane**

2 (default) | scalar

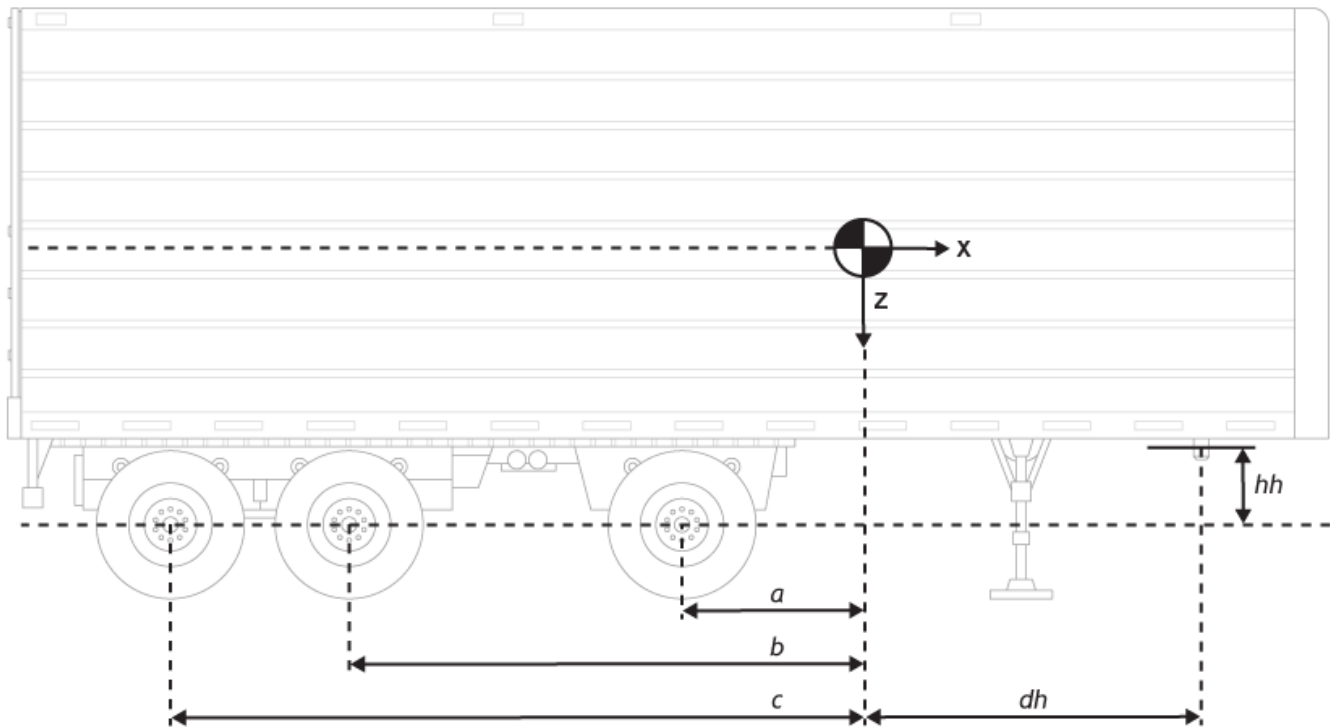
Vertical distance from vehicle CM to the axle plane,  $h$ , in m.





**Vertical distance from hitch to axle plane,  $hh$  – Distance from hitch to axle plane**  
0.6 (default) | scalar

Vertical distance from the hitch to the axle plane,  $hh$ , in m.



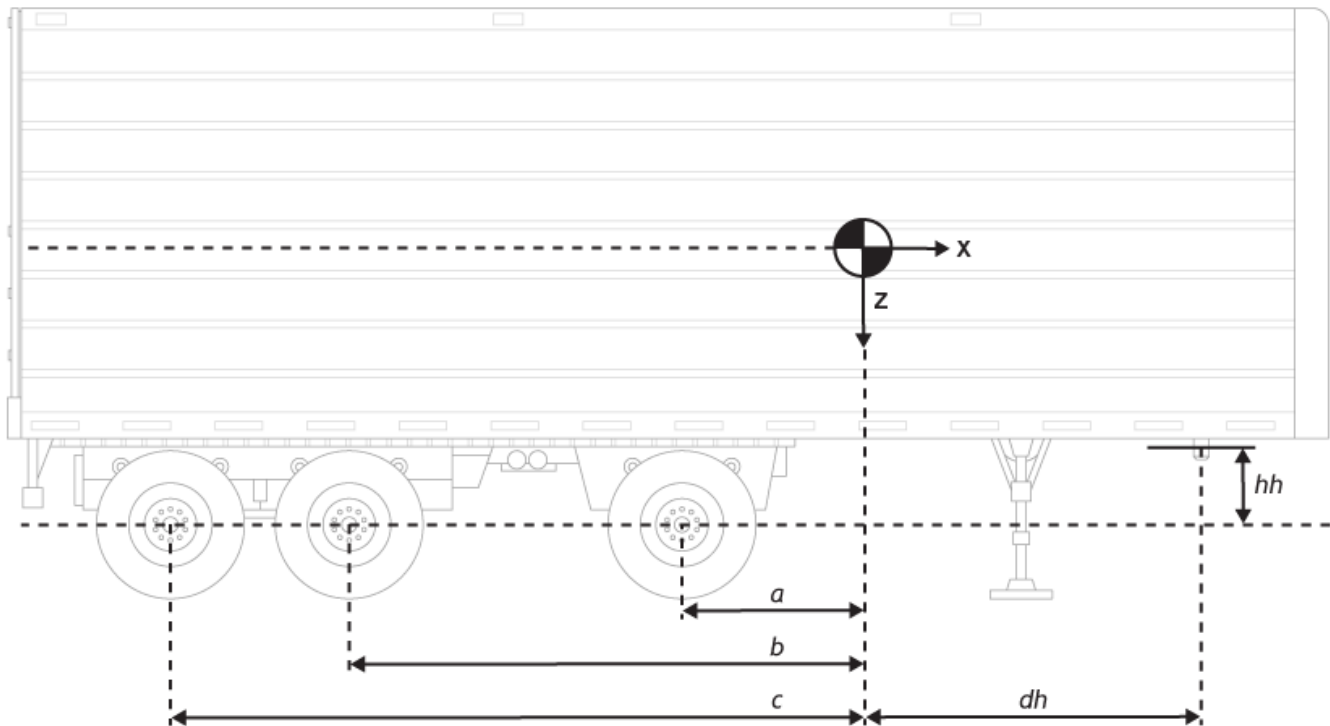
**Dependencies**

To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.

**Longitudinal distance from center of mass to hitch,  $dh$  – Distance to hitch**

7.5 (default) | scalar

Longitudinal distance from the center of mass to the hitch,  $dh$ , in m.



### Dependencies

To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.

### Initial inertial frame longitudinal position, $X_o$ – Initial inertial X location

0 (default) | scalar

Initial vehicle CG displacement along the earth-fixed X-axis, in m.

### Initial longitudinal velocity, $\dot{x}_o$ – Initial velocity

0 (default) | scalar

Initial vehicle CG velocity along the vehicle-fixed x-axis, in m/s.

### Dependencies

To enable this parameter, set **Axle forces** to one of these options:

- External longitudinal forces
- External forces

### Lateral

### Mapped corner stiffness – Selection

off (default) | on

Enables mapped corner stiffness calculation.

### Dependencies

To enable this parameter, set **Axle forces** to one of these options:

- External longitudinal velocity
- External longitudinal forces

### Include relaxation length dynamics — Enable relaxation length dynamics

on (default) | off

Enables relaxation length dynamics.

### Dependencies

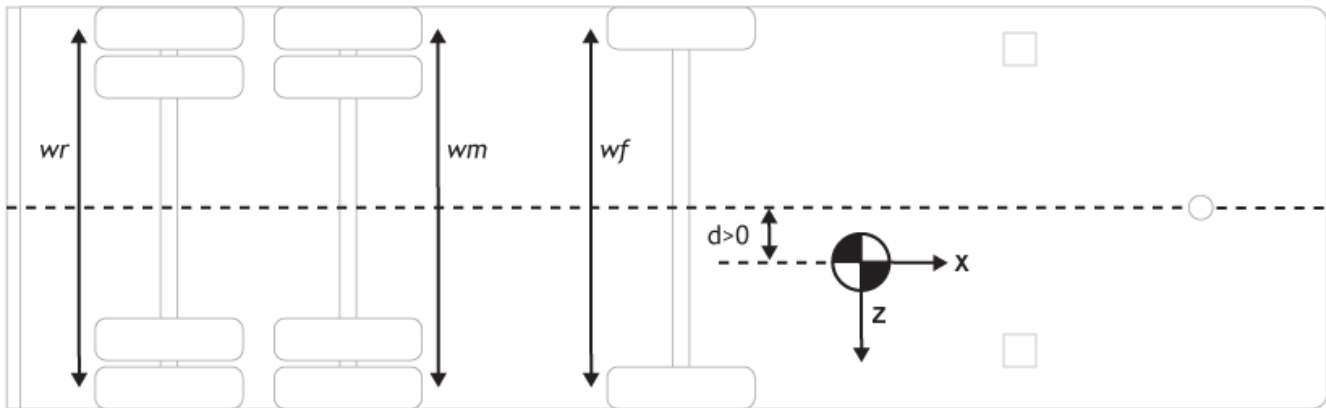
To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Clear **Mapped corner stiffness**.

### Lateral distance from geometric centerline to center of mass, $d$ — Distance from centerline to CM

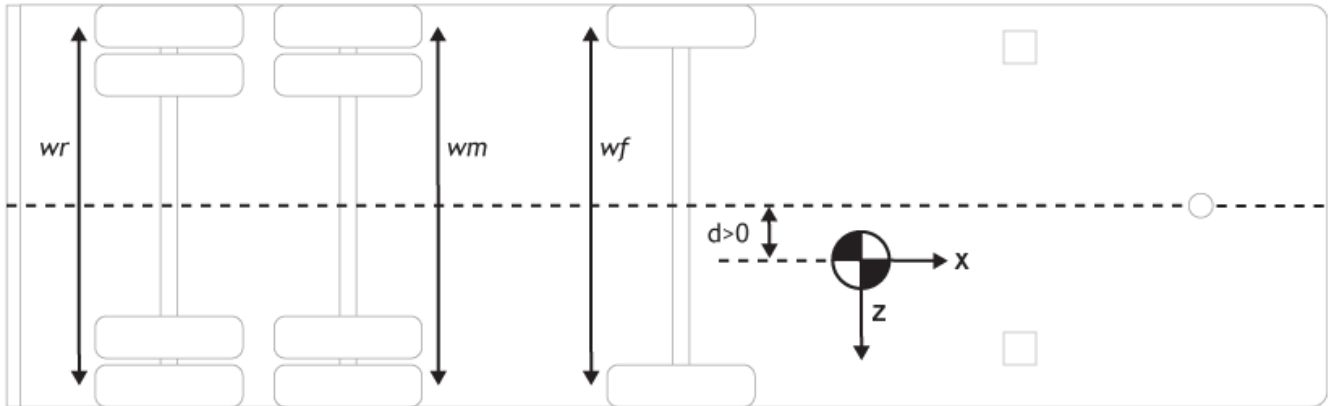
0 (default) | scalar

Lateral distance from the geometric centerline to the center of mass,  $d$ , in m, along the vehicle-fixed  $y$ . Positive values indicate that the trailer CM is to the right of the geometric centerline. Negative values indicate that the trailer CM is to the left of the geometric centerline.

**Front track width,  $w_f$  – Front track width**

1.82 (default) | scalar

Front track width,  $w_f$ , in m.



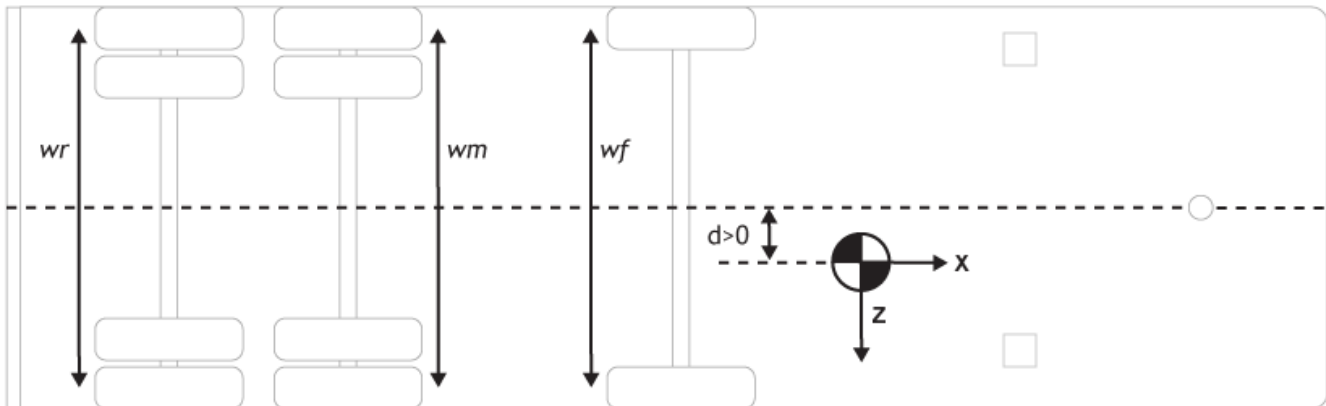
**Dependencies**

To enable this parameter, set **Vehicle track** to Dual 2-axle or Dual 3-axle.

**Middle track width,  $w_m$  – Middle track width**

1.82 (default) | scalar

Middle track width,  $w_m$ , in m.



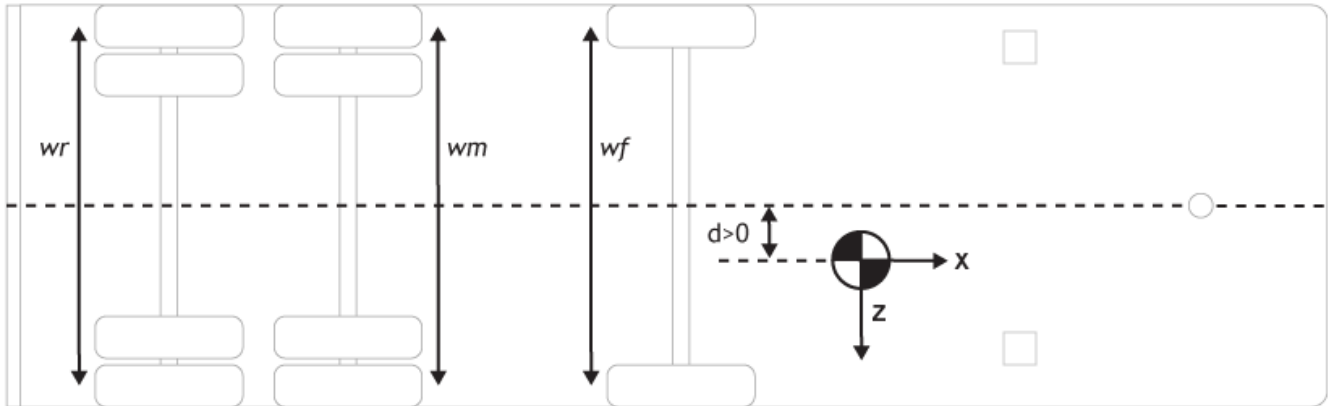
### Dependencies

To enable this parameter, set **Vehicle track** to Dual 3-axle.

### Rear track width, $w_r$ – Rear track width

1.82 (default) | scalar

Rear track width,  $w_r$ , in m.



**Dependencies**

To enable this parameter, set **Vehicle track** to Dual 2-axle or Dual 3-axle.

**Front axle tire corner stiffness,  $Cy_f$  – Front axle tire stiffness**

12.3 (default) | scalar

Front tire corner stiffness,  $Cy_f$ , in N/rad.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Clear **Mapped corner stiffness**.

**Middle axle tire corner stiffness,  $Cy_m$  – Middle axle tire stiffness**

11.3 (default) | scalar

Middle tire corner stiffness,  $Cy_m$ , in N/rad.

**Dependencies**

To enable this parameter:



1 Set **Vehicle track** to one of these options:

- Single 3-axle
- Dual 3-axle

2 Set **Axle forces** to one of these options:

- External longitudinal velocity
- External longitudinal forces

3 Clear **Mapped corner stiffness**.

### Rear axle tire corner stiffness, $Cy_r$ – Rear axle tire stiffness

11.3 (default) | scalar

Rear tire corner stiffness,  $Cy_r$ , in N/rad.

#### Dependencies

To enable this parameter:

1 Set **Axle forces** to one of these options:

- External longitudinal velocity
- External longitudinal forces

2 Clear **Mapped corner stiffness**.

### Front tire(s) relaxation length, $\sigma_f$ – Relaxation length

.1 (default) | scalar

Front tire relaxation length,  $\sigma_f$ , in m.

#### Dependencies

To enable this parameter:

1 Set **Axle forces** to one of these options:

- External longitudinal velocity
- External longitudinal forces

2 Do either of these:

- Select **Mapped corner stiffness**.
- Clear **Mapped corner stiffness** and select **Include relaxation length dynamics**.

### Middle tire(s) relaxation length, $\sigma_m$ – Relaxation length

.1 (default) | scalar

Middle tire relaxation length,  $\sigma_m$ , in m.

#### Dependencies

To enable this parameter:

1 Set **Vehicle track** to one of these options:

- Single 3-axle
  - Dual 3-axle
- 2 Set **Axle forces** to one of these options:
    - External longitudinal velocity
    - External longitudinal forces
  - 3 Do either of these:
    - Select **Mapped corner stiffness**.
    - Clear **Mapped corner stiffness** and select **Include relaxation length dynamics**.

**Rear tire(s) relaxation length, sigma\_r – Relaxation length**

.1 (default) | scalar

Rear tire relaxation length,  $\sigma_r$ , in m.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Do either of these:
  - Select **Mapped corner stiffness**.
  - Clear **Mapped corner stiffness** and select **Include relaxation length dynamics**.

**Front axle slip angle breakpoints, alpha\_f\_brk – Breakpoints**

[-.1 .1] (default) | vector

Front axle slip angle breakpoints,  $\alpha_{fbrk}$ , in rad.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Select **Mapped corner stiffness**.

**Front axle corner data, Cy\_f\_data – Breakpoints**

[-9e3 9e3] (default) | vector

Front axle corner data,  $Cy_{fdata}$ , in N/rad.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Select **Mapped corner stiffness**.

**Middle axle slip angle breakpoints, alpha\_m\_brk — Breakpoints**  
 [-.1 .1] (default) | vector

Middle axle slip angle breakpoints,  $\alpha_{mbrk}$ , in rad.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Select **Mapped corner stiffness**.

**Middle axle corner data, Cy\_m\_data — Breakpoints**  
 [-9e3 9e3] (default) | vector

Middle axle corner data,  $Cy_{mdata}$ , in N/rad.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Select **Mapped corner stiffness**.

**Rear axle slip angle breakpoints, alpha\_r\_brk — Breakpoints**  
 [-.1 .1] (default) | vector

Rear axle slip angle breakpoints,  $\alpha_{rbrk}$ , in rad.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Select **Mapped corner stiffness**.

**Rear axle corner data, Cy\_r\_data — Data**  
 [-9e3 9e3] (default) | vector

Rear axle corner data,  $Cy_{rdata}$ , in N/rad.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Select **Mapped corner stiffness**.

**Initial inertial frame lateral displacement,  $Y_o$  – Position**

0 (default) | scalar

Initial vehicle CG displacement along the earth-fixed Y-axis, in m.

**Initial lateral velocity,  $ydot_o$  – Velocity**

0 (default) | scalar

Initial vehicle CG velocity along the vehicle-fixed y-axis, in m/s.

**Yaw****Yaw polar inertia,  $I_{zz}$  – Inertia**

4000 (default) | scalar

Yaw polar inertia, in  $\text{kg}\cdot\text{m}^2$ .

**Initial yaw angle,  $\psi_o$  – Psi rotation**

0 (default) | scalar

Rotation of the vehicle-fixed frame about earth-fixed Z-axis (yaw), in rad.

**Initial yaw rate,  $r_o$  – Yaw rate**

0 (default) | scalar

Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate), in rad/s.

**Aerodynamic****Longitudinal drag area,  $A_f$  – Effective vehicle cross-sectional area**

2 (default) | scalar

Effective vehicle cross-sectional area,  $A_f$ , to calculate the aerodynamic drag force on the vehicle, in  $\text{m}^2$ .

**Longitudinal drag coefficient,  $C_d$  – Air drag coefficient**

.3 (default) | scalar

Air drag coefficient,  $C_d$ . The value is dimensionless.

**Longitudinal lift coefficient,  $C_l$  – Air lift coefficient**

.1 (default) | scalar

Air lift coefficient,  $C_l$ . The value is dimensionless.

**Longitudinal drag pitch moment, C<sub>pm</sub> — Pitch drag**

.1 (default) | scalar

Longitudinal drag pitch moment coefficient,  $C_{pm}$ . The value is dimensionless.

**Relative wind angle vector, beta\_w — Wind angle**

[0:0.01:0.3] (default) | vector

Relative wind angle vector,  $\beta_w$ , in rad.

**Side force coefficient vector, C<sub>s</sub> — Side force coefficient**

[0:0.03:0.9] (default) | vector

Side force coefficient vector coefficient,  $C_s$ . The value is dimensionless.

**Yaw moment coefficient vector, C<sub>ym</sub> — Yaw moment drag**

[0:0.01:0.3] (default) | vector

Yaw moment coefficient vector coefficient,  $C_{ym}$ . The value is dimensionless.

**Environment****Absolute air pressure, P<sub>abs</sub> — Pressure**

101325 (default) | scalar

Environmental absolute pressure,  $P_{abs}$ , in Pa.

**Air temperature, T<sub>air</sub> — Temperature**

273 (default) | scalar

Environmental absolute temperature,  $T$ , in K.

**Dependencies**

To enable this parameter, clear **Air temperature**.

**Gravitational acceleration, g — Gravity**

9.81 (default) | scalar

Gravitational acceleration,  $g$ , in  $m/s^2$ .

**Nominal friction scaling factor, mu — Friction scale factor**

1 (default) | scalar

Nominal friction scale factor,  $\mu$ . The value is dimensionless.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Clear **External Friction**.

**Simulation****Longitudinal velocity tolerance, `xdot_tol` – Tolerance**`.01` (default) | scalar

Longitudinal velocity tolerance, in m/s.

**Nominal normal force, `Fznom` – Normal force**`5000` (default) | scalar

Nominal normal force, in N.

**Dependencies**

To enable this parameter, set **Axle forces** to one of these options:

- External longitudinal velocity
- External longitudinal forces

**Geometric longitudinal offset from axle plane, `longOff` – Longitudinal offset**`0` (default) | scalar

Vehicle chassis offset from the axle plane along the vehicle-fixed x-axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independently of the vehicle CG.

**Geometric lateral offset from center plane, `latOff` – Lateral offset**`0` (default) | scalar

Vehicle chassis offset from the center plane along the vehicle-fixed y-axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independently of the vehicle CG.

**Geometric vertical offset from axle plane, `vertOff` – Vertical offset**`0` (default) | scalar

Vehicle chassis offset from the axle plane along the vehicle-fixed z-axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independently of the vehicle CG.

**Wrap Euler angles, `wrapAng` – Wrap the Euler angles to the interval  $[-\pi, \pi]$** `off` (default) | on

Wrap the Euler angles to the interval  $[-\pi, \pi]$ . For vehicle maneuvers that might undergo vehicle yaw rotations that are outside of this interval, consider clearing the parameter if you want to:

- Track the total vehicle yaw rotation.
- Avoid discontinuities in the vehicle state estimators.

**References**

- [1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers (SAE), 1992.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Trailer Body 6DOF | Vehicle Body 3DOF | Vehicle Body 3DOF Three Axles

### **Topics**

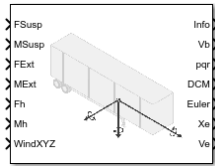
“Coordinate Systems in Vehicle Dynamics Blockset”

### **Introduced in R2020a**

## Trailer Body 6DOF

Trailer body with translational and rotational motion

**Library:** Vehicle Dynamics Blockset / Vehicle Body



### Description

The Trailer Body 6DOF block implements a rigid two-axle or three-axle trailer body model that calculates longitudinal, lateral, vertical, pitch, roll, and yaw motion. The block accounts for body mass, inertia, aerodynamic drag, road incline, and weight distribution between the axle hard-point locations due to suspension and external forces and moments.

Use the **Inertial Loads** parameters to analyze the trailer dynamics under different loading conditions. To specify the number of trailer axles, use the **Number of axles** parameter.

To create additional input ports, under **Input signals**, select these block parameters.

Parameter	Input Port	Description
<b>Hitch forces</b>	Fh	Hitch force applied to the body at the hitch location, $Fh_x$ , $Fh_y$ , and $Fh_z$ , in the vehicle-fixed frame
<b>Hitch moments</b>	Mh	Hitch moment at the hitch location, $Mh_x$ , $Mh_y$ , and $Mh_z$ , about the vehicle-fixed frame

### Inertial Loads

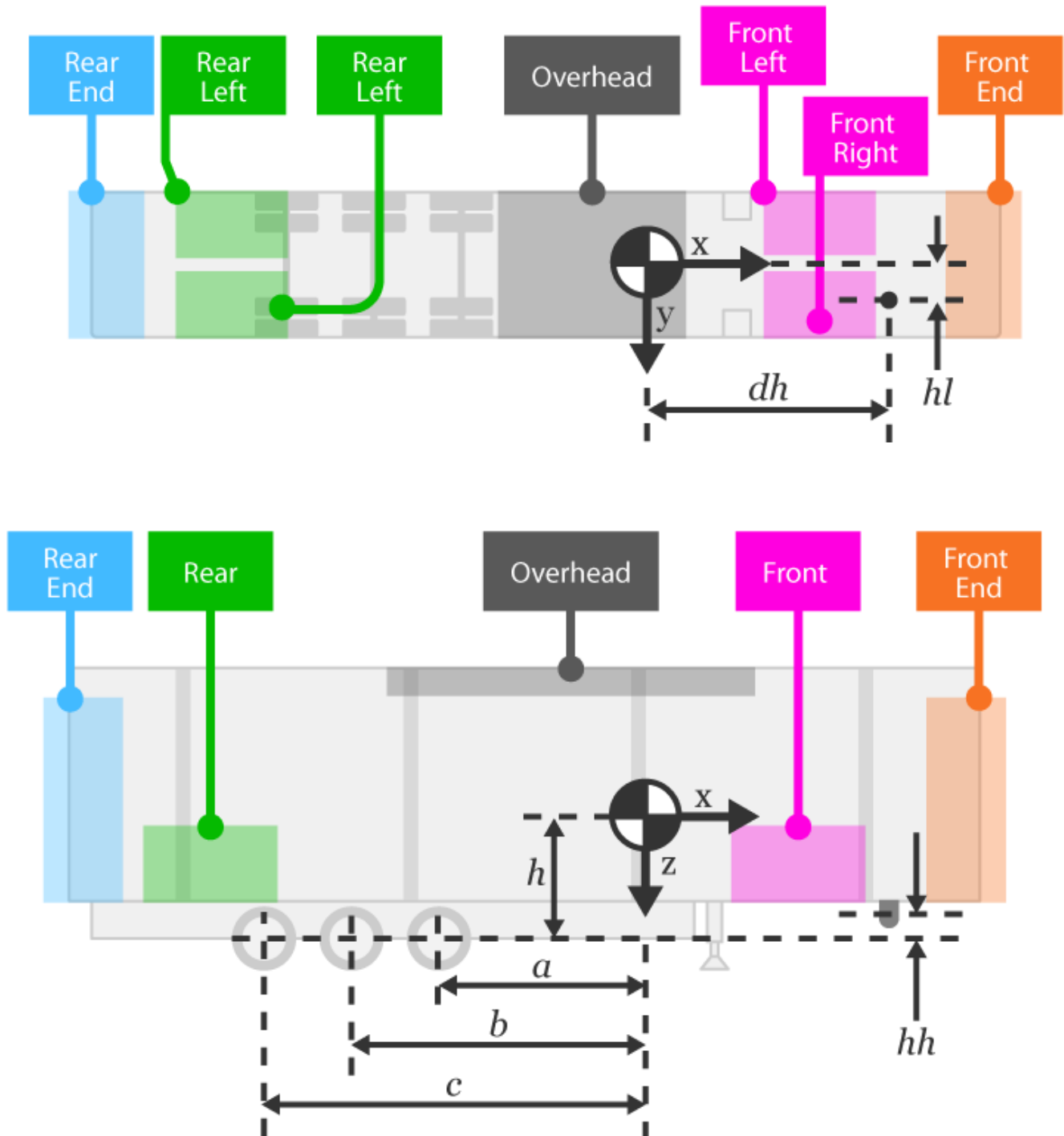
To analyze the vehicle dynamics under different loading conditions, use the **Inertial Loads** parameters. You can specify these loads:

- Front end
- Overhead
- Front left and front right
- Rear left and rear right
- Rear end

For each of the loads, you can specify the mass, location, and inertia.

The illustrations provide the load locations and vehicle parameter dimensions. The table provides the corresponding location parameter sign settings.





This table summarizes the parameter settings that specify the load locations indicated by the dots. For the location, the block uses this distance vector:

- Front axle to load, along the vehicle-fixed  $x$ -axis
- Vehicle centerline to load, along the vehicle-fixed  $y$ -axis
- Front axle to load, along the vehicle-fixed  $z$ -axis

Load	Parameter	Example Location
Front end	<b>Distance vector from front axle, <math>z1R</math></b>	<ul style="list-style-type: none"> <li>• <math>z1R(1,1) &lt; 0</math> — Forward of the front axle</li> <li>• <math>z1R(1,2) &gt; 0</math> — Right of the vehicle centerline</li> <li>• <math>z1R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Overhead	<b>Distance vector from front axle, <math>z2R</math></b>	<ul style="list-style-type: none"> <li>• <math>z2R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z2R(1,2) &lt; 0</math> — Left of the vehicle centerline</li> <li>• <math>z2R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Front left	<b>Distance vector from front axle, <math>z3R</math></b>	<ul style="list-style-type: none"> <li>• <math>z3R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z3R(1,2) &lt; 0</math> — Left of the vehicle centerline</li> <li>• <math>z3R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Front right	<b>Distance vector from front axle, <math>z4R</math></b>	<ul style="list-style-type: none"> <li>• <math>z4R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z4R(1,2) &gt; 0</math> — Right of the vehicle centerline</li> <li>• <math>z4R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Rear left	<b>Distance vector from front axle, <math>z5R</math></b>	<ul style="list-style-type: none"> <li>• <math>z5R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z5R(1,2) &lt; 0</math> — Left of the vehicle centerline</li> <li>• <math>z5R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Rear right	<b>Distance vector from front axle, <math>z6R</math></b>	<ul style="list-style-type: none"> <li>• <math>z6R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z6R(1,2) &gt; 0</math> — Right of the vehicle centerline</li> <li>• <math>z6R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Rear end	<b>Distance vector from front axle, <math>z7R</math></b>	<ul style="list-style-type: none"> <li>• <math>z7R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z7R(1,2) &gt; 0</math> — Right of the vehicle centerline</li> <li>• <math>z7R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>

### Equations of Motion

To determine the vehicle motion, the block implements calculations for the rigid body vehicle dynamics, wind drag, inertial loads, and coordinate transformations. The body-fixed and vehicle-fixed coordinate systems are the same.

The block considers the rotation of a body-fixed coordinate frame about a flat earth-fixed inertial reference frame. The origin of the body-fixed coordinate frame is the vehicle center of gravity of the body.

The block uses this equation to calculate the translational motion of the body-fixed coordinate frame, where the applied forces  $[F_x F_y F_z]^T$  are in the body-fixed frame, and the mass of the body,  $m$ , is assumed to be constant.

$$\bar{F}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m(\dot{\bar{V}}_b + \bar{\omega} \times \bar{V}_b)$$

$$\bar{M}_b = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I\dot{\bar{\omega}} + \bar{\omega} \times (I\bar{\omega})$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

To determine the relationship between the body-fixed angular velocity vector,  $[p \ q \ r]^T$ , and the rate of change of the Euler angles,  $[\dot{\phi} \ \dot{\theta} \ \dot{\psi}]^T$ , the block resolves the Euler rates into the body-fixed frame.

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} \dot{\phi} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} 0 \\ \dot{\theta} \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \dot{\psi} \end{bmatrix} \equiv J^{-1} \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

Inverting  $J$  gives the required relationship to determine the Euler rate vector.

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = J \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & (\sin\phi\tan\theta) & (\cos\phi\tan\theta) \\ 0 & \cos\phi & -\sin\phi \\ 0 & \frac{\sin\phi}{\cos\theta} & \frac{\cos\phi}{\cos\theta} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

The applied forces and moments are the sum of the drag, gravitational, external, and suspension forces.

$$\bar{F}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \begin{bmatrix} F_{d_x} \\ F_{d_y} \\ F_{d_z} \end{bmatrix} + \begin{bmatrix} F_{g_x} \\ F_{g_y} \\ F_{g_z} \end{bmatrix} + \begin{bmatrix} F_{ext_x} \\ F_{ext_y} \\ F_{ext_z} \end{bmatrix} + \begin{bmatrix} F_{FL_x} \\ F_{FL_y} \\ F_{FL_z} \end{bmatrix} + \begin{bmatrix} F_{FR_x} \\ F_{FR_y} \\ F_{FR_z} \end{bmatrix} + \begin{bmatrix} F_{ML_x} \\ F_{ML_y} \\ F_{ML_z} \end{bmatrix} + \begin{bmatrix} F_{MR_x} \\ F_{MR_y} \\ F_{MR_z} \end{bmatrix} + \begin{bmatrix} F_{RL_x} \\ F_{RL_y} \\ F_{RL_z} \end{bmatrix} + \begin{bmatrix} F_{RR_x} \\ F_{RR_y} \\ F_{RR_z} \end{bmatrix}$$

$$\bar{M}_b = \begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} M_{d_x} \\ M_{d_y} \\ M_{d_z} \end{bmatrix} + \begin{bmatrix} M_{ext_x} \\ M_{ext_y} \\ M_{ext_z} \end{bmatrix} + \begin{bmatrix} M_{FL_x} \\ M_{FL_y} \\ M_{FL_z} \end{bmatrix} + \begin{bmatrix} M_{FR_x} \\ M_{FR_y} \\ M_{FR_z} \end{bmatrix} + \begin{bmatrix} M_{ML_x} \\ M_{ML_y} \\ M_{ML_z} \end{bmatrix} + \begin{bmatrix} M_{MR_x} \\ M_{MR_y} \\ M_{MR_z} \end{bmatrix} + \begin{bmatrix} M_{RL_x} \\ M_{RL_y} \\ M_{RL_z} \end{bmatrix} + \begin{bmatrix} M_{RR_x} \\ M_{RR_y} \\ M_{RR_z} \end{bmatrix} + \bar{M}_F$$

Calculation	Implementation
Load masses and inertias	The block uses the parallel axis theorem to resolve the individual load masses and inertias with the vehicle mass and inertia. $J_{ij} = I_{ij} + m( R ^2\delta_{ij} - R_iR_j)$

Calculation	Implementation
Gravitational forces, $F_g$	The block uses the direction cosine matrix (DCM) to transform the gravitational vector in the inertial-fixed frame to the body-fixed frame.
Drag forces, $F_d$ , and moments, $M_d$	<p>To determine a relative airspeed, the block subtracts the wind speed from the vehicle center of mass (CM) velocity. Using the relative airspeed, the block determines the drag forces.</p> $\bar{w} = \sqrt{(\dot{x}_b - w_x)^2 + (\dot{x}_y - w_y)^2 + (w_z)^2}$ $F_{dx} = -\frac{1}{2TR} C_d A_f P_{abs}(\bar{w})$ $F_{dy} = -\frac{1}{2TR} C_s A_f P_{abs}(\bar{w})$ $F_{dz} = -\frac{1}{2TR} C_l A_f P_{abs}(\bar{w})$ <p>Using the relative airspeed, the block determines the drag moments.</p> $M_{dr} = -\frac{1}{2TR} C_{rm} A_f P_{abs}(\bar{w})(a + c)$ $M_{dp} = -\frac{1}{2TR} C_{pm} A_f P_{abs}(\bar{w})(a + c)$ $M_{dy} = -\frac{1}{2TR} C_{ym} A_f P_{abs}(\bar{w})(a + c)$
External forces, $F_{in}$ , and moments, $M_{in}$	The external forces and moments are input via ports <b>FExt</b> and <b>MExt</b> .
Suspension forces and moments	<p>The block assumes that the suspension forces and moments act on these hardpoint locations:</p> <ul style="list-style-type: none"> <li>• <math>F_{FL}, M_{FL}</math> — Front left</li> <li>• <math>F_{FR}, M_{FR}</math> — Front right</li> <li>• <math>F_{ML}, M_{ML}</math> — Middle left</li> <li>• <math>F_{MR}, M_{MR}</math> — Middle right</li> <li>• <math>F_{RL}, M_{RL}</math> — Rear left</li> <li>• <math>F_{RR}, M_{RR}</math> — Rear right</li> </ul>

The equations use these variables.

$x, \dot{x}, \ddot{x}$	Vehicle CM displacement, velocity, and acceleration along the vehicle-fixed x-axis
$y, \dot{y}, \ddot{y}$	Vehicle CM displacement, velocity, and acceleration along the vehicle-fixed y-axis
$z, \dot{z}, \ddot{z}$	Vehicle CM displacement, velocity, and acceleration along the vehicle-fixed z-axis
$\varphi$	Rotation of the vehicle-fixed frame about the earth-fixed X-axis (roll)
$\theta$	Rotation of the vehicle-fixed frame about the earth-fixed Y-axis (pitch)

$\psi$	Rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw)
$F_{FLx}, F_{FLy}, F_{FLz}$	Suspension forces applied to the front left hardpoint along the vehicle-fixed x-, y-, and z-axes
$F_{FRx}, F_{FRy}, F_{FRz}$	Suspension forces applied to the front right hardpoint along the vehicle-fixed x-, y-, and z-axes
$F_{MLx}, F_{MLy}, F_{MLz}$	Suspension forces applied to the middle left hardpoint along the vehicle-fixed x-, y-, and z-axes
$F_{MRx}, F_{MRy}, F_{MRz}$	Suspension forces applied to the middle right hardpoint along the vehicle-fixed x-, y-, and z-axes
$F_{RLx}, F_{RLy}, F_{RLz}$	Suspension forces applied to the rear left hardpoint along the vehicle-fixed x-, y-, and z-axes
$F_{RRx}, F_{RRy}, F_{RRz}$	Suspension forces applied to the rear right hardpoint along the vehicle-fixed x-, y-, and z-axes
$M_{FLx}, M_{FLy}, M_{FLz}$	Suspension moment applied to the front left hardpoint about the vehicle-fixed x-, y-, and z-axes
$M_{FRx}, M_{FRy}, M_{FRz}$	Suspension moment applied to the front right hardpoint about the vehicle-fixed x-, y-, and z-axes
$M_{MLx}, M_{MLy}, M_{MLz}$	Suspension moment applied to the middle left hardpoint about the vehicle-fixed x-, y-, and z-axes
$M_{MRx}, M_{MRy}, M_{MRz}$	Suspension moment applied to the middle right hardpoint about the vehicle-fixed x-, y-, and z-axes
$M_{RLx}, M_{RLy}, M_{RLz}$	Suspension moment applied to the rear left hardpoint about the vehicle-fixed x-, y-, and z-axes
$M_{RRx}, M_{RRy}, M_{RRz}$	Suspension moment applied to the rear right hardpoint about the vehicle-fixed x-, y-, and z-axes
$F_{extx}, F_{exty}, F_{extz}$	External forces applied to the vehicle CM along the vehicle-fixed x-, y-, and z-axes
$F_{dx}, F_{dy}, F_{dz}$	Drag forces applied to the vehicle CM along the vehicle-fixed x-, y-, and z-axes
$M_{extx}, M_{exty}, M_{extz}$	External moment about the vehicle CM about the vehicle-fixed x-, y-, and z-axes
$M_{dx}, M_{dy}, M_{dz}$	Drag moment about the vehicle CM about the vehicle-fixed x-, y-, and z-axes
$I$	Vehicle body moments of inertia
$a, b, c$	Distance of the front, middle, and rear axles, respectively, from the normal projection point of the vehicle CM onto the common axle plane
$h$	Height of the vehicle CM above the axle plane
$d$	Lateral distance from the geometric centerline to the center of mass along the vehicle-fixed y-axis
$hh$	Height of the hitch above the axle plane along the vehicle-fixed z-axis
$dh$	Longitudinal distance of the hitch from the normal projection point of the vehicle CM onto the common axle plane
$hl$	Lateral distance from center of mass to the hitch along the vehicle-fixed y-axis.

$w_F, w_M, w_R$	Front, middle, and rear track widths, respectively
$C_d$	Air drag coefficient acting along the vehicle-fixed x-axis
$C_s$	Air drag coefficient acting along the vehicle-fixed y-axis
$C_l$	Air drag coefficient acting along the vehicle-fixed z-axis
$C_{rm}$	Air drag roll moment acting about the vehicle-fixed x-axis
$C_{pm}$	Air drag pitch moment acting about the vehicle-fixed y-axis
$C_{ym}$	Air drag yaw moment acting about the vehicle-fixed z-axis
$A_f$	Frontal area
$R$	Atmospheric specific gas constant
$T$	Environmental air temperature
$P_{abs}$	Environmental absolute pressure
$w_x, w_y, w_z$	Wind speed along the vehicle-fixed x-, y-, and z-axes
$W_x, W_y, W_z$	Wind speed along inertial X-, Y-, and Z-axes

## Ports

### Input

#### FSusp — Suspension forces on trailer

3-by-4 array (default) | 3-by-6 array

Suspension longitudinal, lateral, and vertical suspension forces, FSusp, applied to the trailer at the hardpoint location, in N, specified as a 3-by-4 or 3-by-6 array, depending on the **Number of axles** parameter.

Number of axles Setting	Variable	Signal Dimension
2	$FSusp = \begin{bmatrix} F_{FLx} & F_{FRx} & F_{RLx} & F_{RRx} \\ F_{FLy} & F_{FRy} & F_{RLy} & F_{RRy} \\ F_{FLz} & F_{FRz} & F_{RLz} & F_{RRz} \end{bmatrix}$	Array - 3-by-4
3	$FSusp = \begin{bmatrix} F_{FLx} & F_{FRx} & F_{MLx} & F_{MRx} & F_{RLx} & F_{RRx} \\ F_{FLy} & F_{FRy} & F_{MLy} & F_{MRy} & F_{RLy} & F_{RRy} \\ F_{FLz} & F_{FRz} & F_{MLz} & F_{MRz} & F_{RLz} & F_{RRz} \end{bmatrix}$	Array - 3-by-6

The arrays use these variables.

$F_{FLx}, F_{FLy}, F_{FLz}$	Suspension forces applied to front left hardpoint along the vehicle-fixed x-, y-, and z-axes
$F_{FRx}, F_{FRy}, F_{FRz}$	Suspension forces applied to front right hardpoint along the vehicle-fixed x-, y-, and z-axes

$F_{MLx}, F_{MLy}, F_{MLz}$	Suspension forces applied to middle left hardpoint along the vehicle-fixed x-, y-, and z-axes
$F_{MRx}, F_{MRy}, F_{MRz}$	Suspension forces applied to middle right hardpoint along the vehicle-fixed x-, y-, and z-axes
$F_{RLx}, F_{RLy}, F_{RLz}$	Suspension forces applied to rear left hardpoint along the vehicle-fixed x-, y-, and z-axes
$F_{RRx}, F_{RRy}, F_{RRz}$	Suspension forces applied to rear right hardpoint along the vehicle-fixed x-, y-, and z-axes

### MSusp — Suspension moments on trailer

3-by-4 array (default) | 3-by-6 array

Suspension longitudinal, lateral, and vertical suspension moments, MSusp, applied about the vehicle at the hardpoint location, in N·m, specified as a 3-by-4 or 3-by-6 array, depending on the **Number of axles** parameter.

Number of axles Setting	Variable	Signal Dimension
2	$MSusp = \begin{bmatrix} M_{FLx} & M_{FRx} & M_{RLx} & M_{RRx} \\ M_{FLy} & M_{FRy} & M_{RLy} & M_{RRy} \\ M_{FLz} & M_{FRz} & M_{RLz} & M_{RRz} \end{bmatrix}$	Array - 3-by-4
3	$MSusp = \begin{bmatrix} M_{FLx} & M_{FRx} & M_{MLx} & M_{MRx} & M_{RLx} & M_{RRx} \\ M_{FLy} & M_{FRy} & M_{MLy} & M_{MRy} & M_{RLy} & M_{RRy} \\ M_{FLz} & M_{FRz} & M_{MLz} & M_{MRz} & M_{RLz} & M_{RRz} \end{bmatrix}$	Array - 3-by-6

The arrays use these variables.

$M_{FLx}, M_{FLy}, M_{FLz}$	Suspension moment applied to front left hardpoint about the vehicle-fixed x-, y-, and z-axes
$M_{FRx}, M_{FRy}, M_{FRz}$	Suspension moment applied to front right hardpoint about the vehicle-fixed x-, y-, and z-axes
$M_{MLx}, M_{MLy}, M_{MLz}$	Suspension moment applied to middle left hardpoint about the vehicle-fixed x-, y-, and z-axes
$M_{MRx}, M_{MRy}, M_{MRz}$	Suspension moment applied to middle right hardpoint about the vehicle-fixed x-, y-, and z-axes
$M_{RLx}, M_{RLy}, M_{RLz}$	Suspension moment applied to rear left hardpoint about the vehicle-fixed x-, y-, and z-axes
$M_{RRx}, M_{RRy}, M_{RRz}$	Suspension moment applied to rear right hardpoint about the vehicle-fixed x-, y-, and z-axes

### FExt — External forces acting on vehicle

vector

External forces on the vehicle, in N, specified as a 1-by-3 or 3-by-1 vector.

$$FExt = F_{ext} = [F_{ext_x} \ F_{ext_y} \ F_{ext_z}] \text{ or } \begin{bmatrix} F_{ext_x} \\ F_{ext_y} \\ F_{ext_z} \end{bmatrix}$$

Array Element	Force Axis
FExt (1, 1)	Vehicle-fixed x-axis (longitudinal)
FExt (1, 2) or FExt (2, 1)	Vehicle-fixed y-axis (lateral)
FExt (1, 3) or FExt (3, 1)	Vehicle-fixed z-axis (vertical)

**MExt – External moments acting on vehicle**  
vector

External moments acting on the vehicle, in N·m, specified as a 1-by-3 or 3-by-1 vector.

$$MExt = M_{ext} = [M_{ext_x} \ M_{ext_y} \ M_{ext_z}] \text{ or } \begin{bmatrix} M_{ext_x} \\ M_{ext_y} \\ M_{ext_z} \end{bmatrix}$$

Array Element	Force Axis
MExt (1, 1)	Vehicle-fixed x-axis (longitudinal)
MExt (1, 2) or MExt (2, 1)	Vehicle-fixed y-axis (lateral)
MExt (1, 3) or MExt (3, 1)	Vehicle-fixed z-axis (vertical)

**Fh – Hitch force on the body**  
array

Hitch force applied to the body at the hitch location,  $Fh_x, Fh_y, Fh_z$ , in the vehicle-fixed frame, in N, specified as a 1-by-3 or 3-by-1 array.

**Dependencies**

To enable this port, under **Input signals**, select **Hitch forces**.

**Mh – Hitch moment about body**  
array

Hitch moment at the hitch location,  $Mh_x, Mh_y, Mh_z$ , about the vehicle-fixed frame, in N·m, specified as a 1-by-3 or 3-by-1 array.

**Dependencies**

To enable this port, under **Input signals**, select **Hitch moments**.

**WindXYZ – Wind speed**  
array



Wind speed,  $W_x$ ,  $W_y$ ,  $W_z$  along inertial X-, Y-, and Z-axes, in m/s, specified as a 1-by-3 or 3-by-1 array.

### AirTemp – Ambient air temperature

scalar

Ambient air temperature,  $T_{air}$ , in K, specified as a scalar.

### Dependencies

To enable this port, under **Environment**, select **Air temperature**.

### Output

### Info – Trailer body information

bus

Trailer body information, returned as a bus signal containing the following values.

Signal					Description	Value	Units
InertFrm	Cg	Disp	X		Vehicle CM displacement along the earth-fixed X-axis	Computed	m
			Y		Vehicle CM displacement along the earth-fixed Y-axis	Computed	m
			Z		Vehicle CM displacement along the earth-fixed Z-axis	Computed	m
		Vel	Xdot		Vehicle CM velocity along the earth-fixed X-axis	Computed	m/s
			Ydot		Vehicle CM velocity along the earth-fixed Y-axis	Computed	m/s
			Zdot		Vehicle CM velocity along the earth-fixed Z-axis	Computed	m/s
		Ang	phi		Rotation of the vehicle-fixed frame about the earth-fixed X-axis (roll)	Computed	rad
			theta		Rotation of the vehicle-fixed frame about the earth-fixed Y-axis (pitch)	Computed	rad
			psi		Rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw)	Computed	rad
	FrntAxl	Lft	Disp	X	Front left axle displacement along the earth-fixed X-axis	Computed	m

Signal				Description	Value	Units			
				Y	Front left axle displacement along the earth-fixed Y-axis	Computed	m		
				Z	Front left axle displacement along the earth-fixed Z-axis	Computed	m		
				Vel	Xdot	Front left axle velocity along the earth-fixed X-axis	Computed	m/s	
						Ydot	Front left axle velocity along the earth-fixed Y-axis	Computed	m/s
						Zdot	Front left axle velocity along the earth-fixed Z-axis	Computed	m/s
		Rght	Disp		X	Front right axle displacement along the earth-fixed X-axis	Computed	m	
					Y	Front right axle displacement along the earth-fixed Y-axis	Computed	m	
					Z	Front right axle displacement along the earth-fixed Z-axis	Computed	m	
			Vel		Xdot	Front right axle velocity along the earth-fixed X-axis	Computed	m/s	
	Ydot				Front right axle velocity along the earth-fixed Y-axis	Computed	m/s		
	Zdot				Front right axle velocity along the earth-fixed Z-axis	Computed	m/s		
	MidlAxl	Lft	Disp	X	Middle left axle displacement along the earth-fixed X-axis	Computed	m		
				Y	Middle left axle displacement along the earth-fixed Y-axis	Computed	m		
				Z	Middle left axle displacement along the earth-fixed Z-axis	Computed	m		
			Vel	Xdot	Middle left axle velocity along the earth-fixed X-axis	Computed	m/s		

Signal				Description	Value	Units	
				Ydot	Middle left axle velocity along the earth-fixed Y-axis	Computed	m/s
				Zdot	Middle left axle velocity along the earth-fixed Z-axis	Computed	m/s
		Rght	Disp	X	Middle right axle displacement along the earth-fixed X-axis	Computed	m
				Y	Middle right axle displacement along the earth-fixed Y-axis	Computed	m
				Z	Middle right axle displacement along the earth-fixed Z-axis	Computed	m
		Vel		Xdot	Middle right axle velocity along the earth-fixed X-axis	Computed	m/s
				Ydot	Middle right axle velocity along the earth-fixed Y-axis	Computed	m/s
				Zdot	Middle right axle velocity along the earth-fixed Z-axis	Computed	m/s
	RearAxl	Lft	Disp	X	Rear left axle displacement along the earth-fixed X-axis	Computed	m
				Y	Rear left axle displacement along the earth-fixed Y-axis	Computed	m
				Z	Rear left axle displacement along the earth-fixed Z-axis	Computed	m
			Vel	Xdot	Rear left axle velocity along the earth-fixed X-axis	Computed	m/s
				Ydot	Rear left axle velocity along the earth-fixed Y-axis	Computed	m/s
				Zdot	Rear left axle velocity along the earth-fixed Z-axis	Computed	m/s
Rght		Disp	X	Rear right axle displacement along the earth-fixed X-axis	Computed	m	

Signal					Description	Value	Units
				Y	Rear right axle displacement along the earth-fixed Y-axis	Computed	m
				Z	Rear right axle displacement along the earth-fixed Z-axis	Computed	m
			Vel	Xdot	Rear right axle velocity along the earth-fixed X-axis	Computed	m/s
				Ydot	Rear right axle velocity along the earth-fixed Y-axis	Computed	m/s
				Zdot	Rear right axle velocity along the earth-fixed Z-axis	Computed	m/s
			Hitch	Disp	X		Hitch offset from the axle plane along the earth-fixed X-axis
	Y	Hitch offset from the axle plane along the earth-fixed Y-axis				Computed	m
	Z	Hitch offset from the axle plane along the earth-fixed Z-axis				Computed	m
	Vel	Xdot		Hitch velocity along the earth-fixed X-axis	Computed	m/s	
		Ydot		Hitch velocity along the earth-fixed Y-axis	Computed	m/s	
		Zdot		Hitch velocity along the earth-fixed Z-axis	Computed	m/s	
	Geom	Disp	X		Trailer offset from the axle plane along the earth-fixed X-axis	Computed	m
				Y	Trailer offset from the center plane along the earth-fixed Y-axis	Computed	m
				Z	Trailer offset from the axle plane along the earth-fixed Z-axis	Computed	m
		Vel	Xdot	Trailer offset velocity along the earth-fixed X-axis	Computed	m/s	

Signal			Description	Value	Units		
			Ydot	Trailer offset velocity along the earth-fixed Y-axis	Computed	m/s	
			Zdot	Trailer offset velocity along the earth-fixed Z-axis	Computed	m/s	
BdyFrm	Cg	Vel	xdot	Vehicle CM velocity along the vehicle-fixed x-axis	Computed	m/s	
			ydot	Vehicle CM velocity along the vehicle-fixed y-axis	Computed	m/s	
			zdot	Vehicle CM velocity along the vehicle-fixed z-axis	Computed	m/s	
		AngVel	p	Vehicle angular velocity about the vehicle-fixed x-axis (roll rate)	Computed	rad/s	
			q	Vehicle angular velocity about the vehicle-fixed y-axis (pitch rate)	Computed	rad/s	
			r	Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate)	Computed	rad/s	
		Acc	ax	Vehicle CM acceleration along the vehicle-fixed x-axis	Computed	gn	
			ay	Vehicle CM acceleration along the vehicle-fixed y-axis	Computed	gn	
			az	Vehicle CM acceleration along the vehicle-fixed z-axis	Computed	gn	
			xddot	Vehicle CM acceleration along the vehicle-fixed x-axis	Computed	m/s <sup>2</sup>	
			yddot	Vehicle CM acceleration along the vehicle-fixed y-axis	Computed	m/s <sup>2</sup>	
			zddot	Vehicle CM acceleration along the vehicle-fixed z-axis	Computed	m/s <sup>2</sup>	
		DCM	Direction cosine matrix		Computed	rad	
		Forces	Body	Fx	Net force on the vehicle CM along the vehicle-fixed x-axis	Computed	N

Signal			Description		Value	Units	
	Ext	Fy	Net force on the vehicle CM along the vehicle-fixed y-axis		Computed	N	
		Fz	Net force on the vehicle CM along the vehicle-fixed z-axis		Computed	N	
		Fx	External force on the vehicle CM along the vehicle-fixed x-axis		Input	N	
		Fy	External force on the vehicle CM along the vehicle-fixed x-axis		Input	N	
		Fz	External force on the vehicle CM along the vehicle-fixed x-axis		Input	N	
		FrntAx1	Lft	Fx	Front left axle velocity along the earth-fixed Y-axis	Computed	N
			Fy	Lateral force on the left side of the front axle left along the vehicle-fixed y-axis	Computed	N	
			Fz	Normal force on the left side of the front axle along the vehicle-fixed z-axis	Computed	N	
		Rght	Fx	Longitudinal force on the right side of the front axle along the vehicle-fixed x-axis	Computed	N	
			Fy	Lateral force on the right side of the front axle left along the vehicle-fixed y-axis	Computed	N	
			Fz	Normal force on the right side of the front axle along the vehicle-fixed z-axis	Computed	N	
		MidlAx1	Lft	Fx	Longitudinal force on the left side of the middle axle along the vehicle-fixed x-axis	Computed	N

Signal				Description	Value	Units	
				Fy	Longitudinal force on the left side of the middle axle along the vehicle-fixed x-axis	Computed	N
				Fz	Normal force on the left side of the middle axle along the vehicle-fixed z-axis	Computed	N
			Rght	Fx	Longitudinal force on the right side of the middle axle along the vehicle-fixed x-axis	Computed	N
				Fy	Lateral force on the right side of the middle axle left along the vehicle-fixed y-axis	Computed	N
				Fz	Normal force on the right side of the middle axle along the vehicle-fixed z-axis	Computed	N
		RearAx1	Lft	Fx	Longitudinal force on the left side of the rear axle along the vehicle-fixed x-axis	Computed	N
				Fy	Lateral force on the left side of the rear axle left along the vehicle-fixed y-axis	Computed	N
				Fz	Normal force on the left side of the rear axle along the vehicle-fixed z-axis	Computed	N
			Rght	Fx	Longitudinal force on the right side of the rear axle along the vehicle-fixed x-axis	Computed	N
				Fy	Lateral force on the right side of the rear axle left along the vehicle-fixed y-axis	Computed	N
				Fz	Normal force on the right side of the rear axle along the vehicle-fixed z-axis	Computed	N
Hitch	Fx	Hitch force applied to the body at the hitch location along the vehicle-fixed x-axis	Computed	N			

Signal			Description			Value	Units	
			Fy		Hitch force applied to the body at the hitch location along the vehicle-fixed y-axis	Computed	N	
			Fz		Hitch force applied to the body at the hitch location along the vehicle-fixed z-axis	Computed	N	
	Tires	FrntTires	L	F	Front left tire force along the vehicle-fixed x-axis	Computed	N	
					F	Front left tire force along the vehicle-fixed y-axis	Computed	N
					F	Front left tire force along the vehicle-fixed z-axis	Computed	N
				R	F	Front right tire force along the vehicle-fixed x-axis	Computed	N
					F	Front right tire force along the vehicle-fixed y-axis	Computed	N
					F	Front right tire force along the vehicle-fixed z-axis	Computed	N
			MidlTires	L	F	Middle left tire force along the vehicle-fixed x-axis	Computed	N
					F	Middle left tire force along the vehicle-fixed y-axis	Computed	N
					F	Middle left tire force along the vehicle-fixed z-axis	Computed	N
				R	F	Middle right tire force along the vehicle-fixed x-axis	Computed	N
					F	Middle right tire force along the vehicle-fixed y-axis	Computed	N
					F	Middle right tire force along the vehicle-fixed z-axis	Computed	N
			RearTires	L	F	Rear left tire force along the vehicle-fixed x-axis	Computed	N



Signal					Description	Value	Units				
				R g h t	F y	Rear left tire force along the vehicle-fixed y-axis	Computed	N			
					F z	Rear left tire force along the vehicle-fixed z-axis	Computed	N			
					F x	Rear right tire force along the vehicle-fixed x-axis	Computed	N			
					F y	Rear right tire force along the vehicle-fixed y-axis	Computed	N			
					F z	Rear right tire force along the vehicle-fixed z-axis	Computed	N			
				Drag	Fx	Drag force on the vehicle CM along the vehicle-fixed x-axis		Computed	N		
						Fy	Drag force on the vehicle CM along the vehicle-fixed y-axis		Computed	N	
							Fz	Drag force on the vehicle CM along the vehicle-fixed z-axis		Computed	N
				Grvty	Fx	Gravity force on the vehicle CM along the vehicle-fixed x-axis		Computed	N		
						Fy	Gravity force on the vehicle CM along the vehicle-fixed y-axis		Computed	N	
							Fz	Gravity force on the vehicle CM along the vehicle-fixed z-axis		Computed	N
				Moments	Body	Mx	Body moment on the vehicle CM about the vehicle-fixed x-axis		Computed	N·m	
							My	Body moment on the vehicle CM about the vehicle-fixed y-axis		Computed	N·m
								Mz	Body moment on the vehicle CM about the vehicle-fixed z-axis		Computed
					Drag	Mx	Drag moment on the vehicle CM about the vehicle-fixed x-axis		Computed	N·m	
My	Drag moment on the vehicle CM about the vehicle-fixed y-axis		Computed				N·m				

Signal		Description		Value	Units			
		Ext	Mz	Drag moment on the vehicle CM about the vehicle-fixed z-axis	Computed	N·m		
			Mx	External moment on the vehicle CG about the vehicle-fixed x-axis	Computed	N·m		
			My	External moment on the vehicle CG about the vehicle-fixed y-axis	Computed	N·m		
		Hitch	Mz	External moment on the vehicle CG about the vehicle-fixed z-axis	Computed	N·m		
			Mx	Hitch moment at the hitch location about the vehicle-fixed x-axis	Computed	N·m		
			My	Hitch moment at the hitch location about the vehicle-fixed y-axis	Computed	N·m		
		FrntAxl	Lft	Disp	x	Front left axle displacement along the vehicle-fixed x-axis	Computed	m
					y	Front left axle displacement along the vehicle-fixed y-axis	Computed	m
					z	Front left axle displacement along the vehicle-fixed z-axis	Computed	m
	Vel			xdo t	Front left axle velocity along the vehicle-fixed x-axis	Computed	m/s	
				ydo t	Front left axle velocity along the vehicle-fixed y-axis	Computed	m/s	
				zdo t	Front left axle velocity along the vehicle-fixed z-axis	Computed	m/s	
	Rght	Disp	x	Front right axle displacement along the vehicle-fixed x-axis	Computed	m		
			y	Front right axle displacement along the vehicle-fixed y-axis	Computed	m		

Signal				Description	Value	Units	
				z	Front right axle displacement along the vehicle-fixed z-axis	Computed m	
			Vel	xdo t	Front right axle velocity along the vehicle-fixed x-axis	Computed m/s	
				ydo t	Front right axle velocity along the vehicle-fixed y-axis	Computed m/s	
				zdo t	Front right axle velocity along the vehicle-fixed z-axis	Computed m/s	
	MidlAxl	Lft	Disp	x	Middle left axle displacement along the vehicle-fixed x-axis	Computed m	
				y	Middle left axle displacement along the vehicle-fixed y-axis	Computed m	
				z	Middle left axle displacement along the vehicle-fixed z-axis	Computed m	
			Vel	xdo t	Middle left axle velocity along the vehicle-fixed x-axis	Computed m/s	
				ydo t	Middle left axle velocity along the vehicle-fixed y-axis	Computed m/s	
				zdo t	Middle left axle velocity along the vehicle-fixed z-axis	Computed m/s	
			Rght	Disp	x	Middle right axle displacement along the vehicle-fixed x-axis	Computed m
		y			Middle right axle displacement along the vehicle-fixed y-axis	Computed m	
		z			Middle right axle displacement along the vehicle-fixed z-axis	Computed m	
	Vel	xdo t		Middle right axle velocity along the vehicle-fixed x-axis	Computed m/s		
		ydo t		Middle right axle velocity along the vehicle-fixed y-axis	Computed m/s		

Signal				Description	Value	Units	
				zdot	Middle right axle velocity along the vehicle-fixed z-axis	Computed	m/s
	RearAxl	Lft	Disp	x	Rear left axle displacement along the vehicle-fixed x-axis	Computed	m
				y	Rear left axle displacement along the vehicle-fixed y-axis	Computed	m
				z	Rear left axle displacement along the vehicle-fixed z-axis	Computed	m
			Vel	xdot	Rear left axle velocity along the vehicle-fixed x-axis	Computed	m/s
				ydot	Rear left axle velocity along the vehicle-fixed y-axis	Computed	m/s
				zdot	Rear left axle velocity along the vehicle-fixed z-axis	Computed	m/s
		Rght	Disp	x	Rear right axle displacement along the vehicle-fixed x-axis	Computed	m
				y	Rear right axle displacement along the vehicle-fixed y-axis	Computed	m
				z	Rear right axle displacement along the vehicle-fixed z-axis	Computed	m
			Vel	xdot	Rear right axle velocity along the vehicle-fixed x-axis	Computed	m/s
				ydot	Rear right axle velocity along the vehicle-fixed y-axis	Computed	m/s
				zdot	Rear right axle velocity along the vehicle-fixed z-axis	Computed	m/s
	Hitch	Disp	x	Hitch offset from axle plane along the vehicle-fixed x-axis	Input	m	
			y	Hitch offset from center plane along the vehicle-fixed y-axis	Input	m	

Signal				Description	Value	Units	
	Vel		z	Hitch offset from axle plane along the vehicle-fixed z-axis	Input	m	
			xdo t	Hitch offset velocity along the vehicle-fixed x-axis	Computed	m/s	
			ydo t	Hitch offset velocity along the vehicle-fixed y-axis	Computed	m/s	
			zdo t	Hitch offset velocity along the vehicle-fixed z-axis	Computed	m/s	
	Pwr	PwrExt	Applied external power		Computed	W	
			Drag		Computed	W	
	Geom	Disp		x	Trailer offset from axle plane along the vehicle-fixed x-axis	Input	m
				y	Trailer offset from center plane along the vehicle-fixed y-axis	Input	m
				z	Trailer offset from axle plane along the vehicle-fixed z-axis	Input	m
		Vel		xdo t	Trailer chassis offset velocity along the vehicle-fixed x-axis	Computed	m/s
				ydo t	Trailer chassis offset velocity along the vehicle-fixed y-axis	Computed	m/s
				zdo t	Trailer chassis offset velocity along the vehicle-fixed z-axis	Computed	m/s
		Ang		Beta	Body slip angle, $\beta$	Computed	rad
					$\beta = \frac{V_y}{V_x}$		

**Vb – Vehicle velocity along vehicle-fixed frame**

vector

Vehicle CM velocity along the vehicle-fixed x-, y-, z-axes, respectively, in m/s, returned as a vector.

**pqr – Vehicle angular velocity about vehicle-fixed frame**

vector

Vehicle CM angular velocity about the vehicle-fixed x- (roll rate), y- (pitch rate), z-axes (yaw rate), respectively, in rad/s, returned as a vector.

**DCM – Direction cosine matrix**

array

Direction cosine matrix, in rad, returned as an array.

**Euler – Euler angles**

array

Euler angles,  $\varphi$ ,  $\theta$ , and  $\psi$ , respectively, in rad, returned as an array.

**Xe – Vehicle position in inertial reference frame**

vector

Vehicle CM position along inertial-fixed X-, Y-, Z-axes, respectively, in m, returned as a vector.

**Ve – Vehicle velocity in inertial reference frame**

vector

Vehicle CM velocity along inertial-fixed X-, Y-, Z-axes, respectively, in m/s, returned as a vector.

**Parameters****Block Options****Number of axles – Create hitch force input port**

2 (default) | 3

Specify the number of axles on the trailer.

**Input Signals****Hitch forces – Create hitch force input port**

on (default) | off

Select to create an input port,  $F_h$ , for the hitch forces.

**Hitch moments – Create hitch moment input port**

on (default) | off

Select to create an input port,  $M_h$ , for the hitch moments.

**Chassis****Vehicle mass, m – Mass**

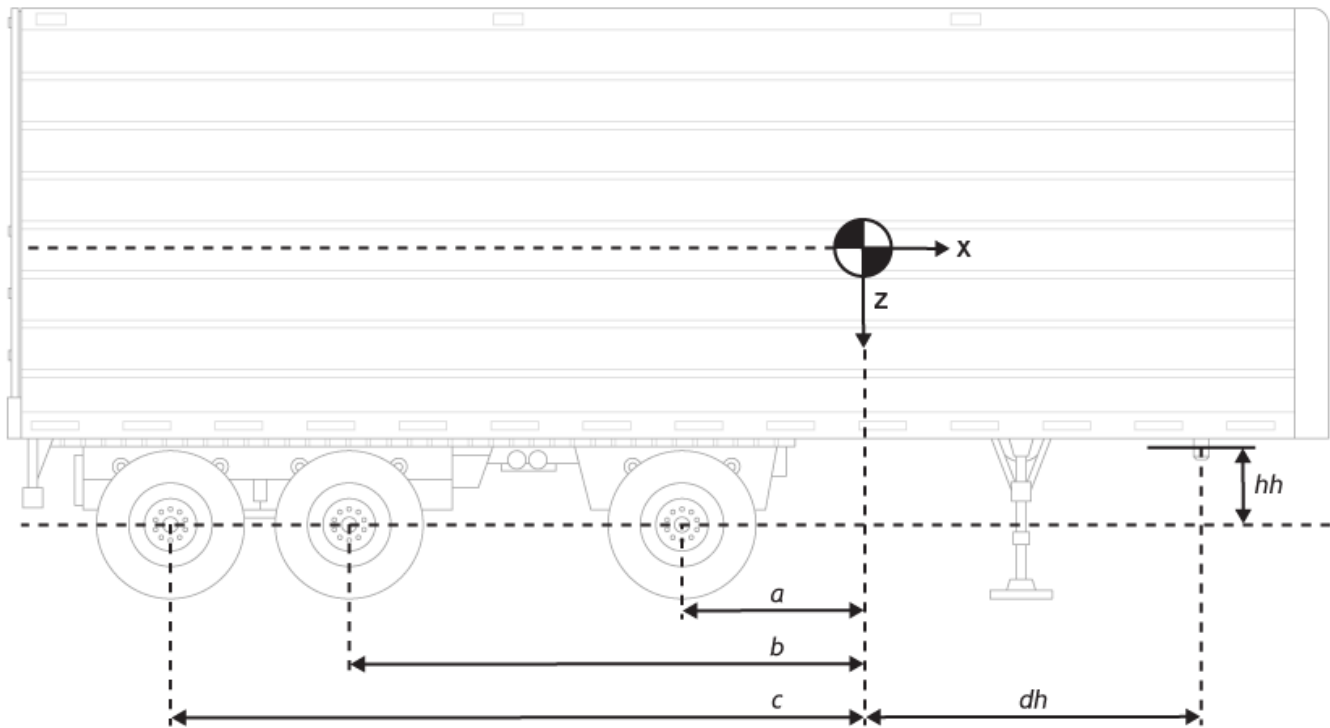
2000 (default) | scalar

Vehicle mass,  $m$ , in kg.

**Longitudinal distance from center of mass to front axle, a – Distance from center of mass to front axle**

1.4 (default) | scalar

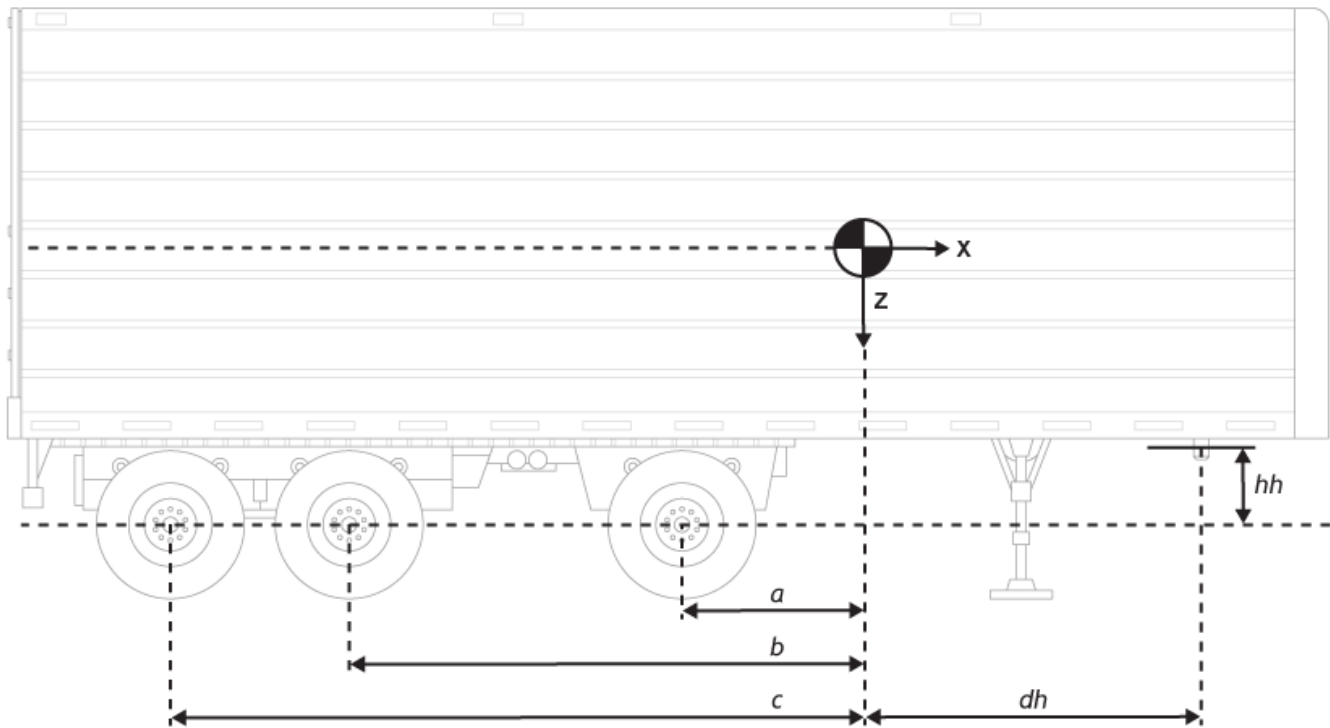
Distance from the vehicle CM to the front axle,  $a$ , in m.



**Longitudinal distance from center of mass to middle axle,  $b$  – Distance from center of mass to middle axle**

1.6 (default) | scalar

Distance from the vehicle CM to the middle axle,  $b$ , in m.



**Dependencies**

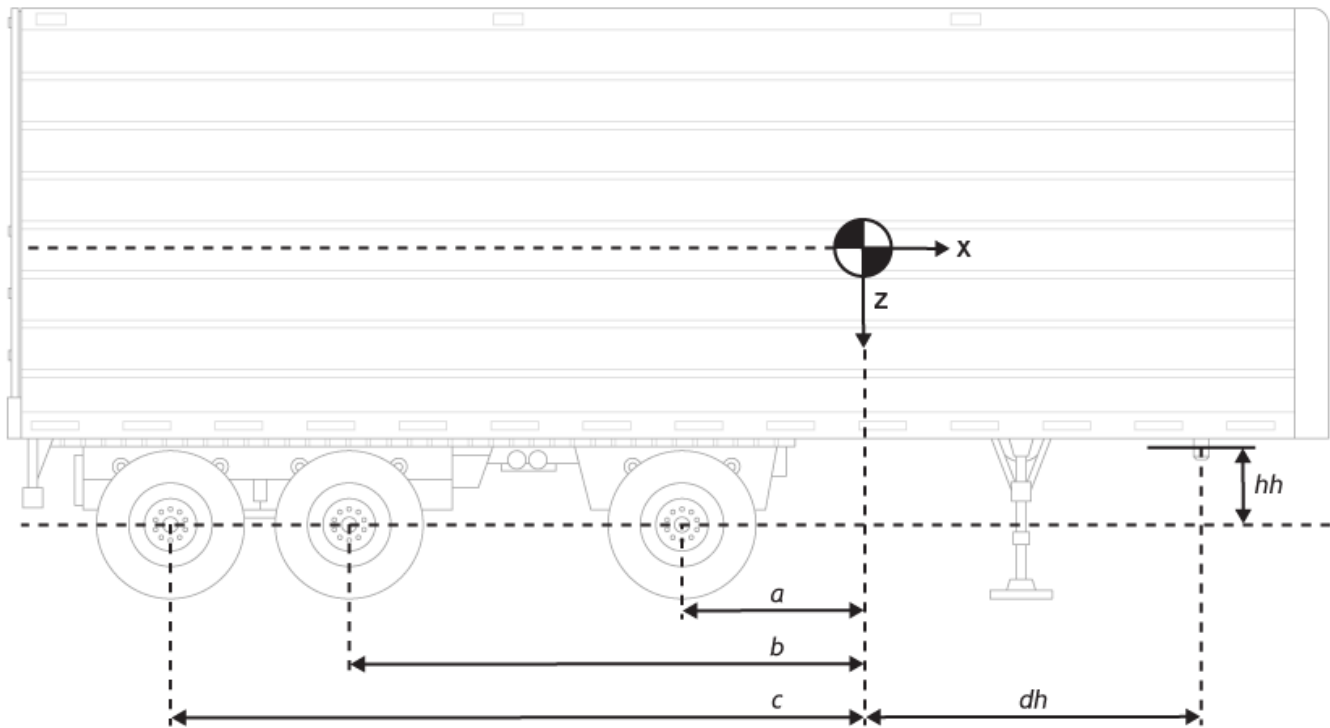
To enable this parameter, set **Number of axles** to 3.

**Longitudinal distance from center of mass to rear axle,  $c$  – Distance from center of mass to rear axle**

1.9 (default) | scalar

Distance from the vehicle CM to the middle axle,  $c$ , in m.

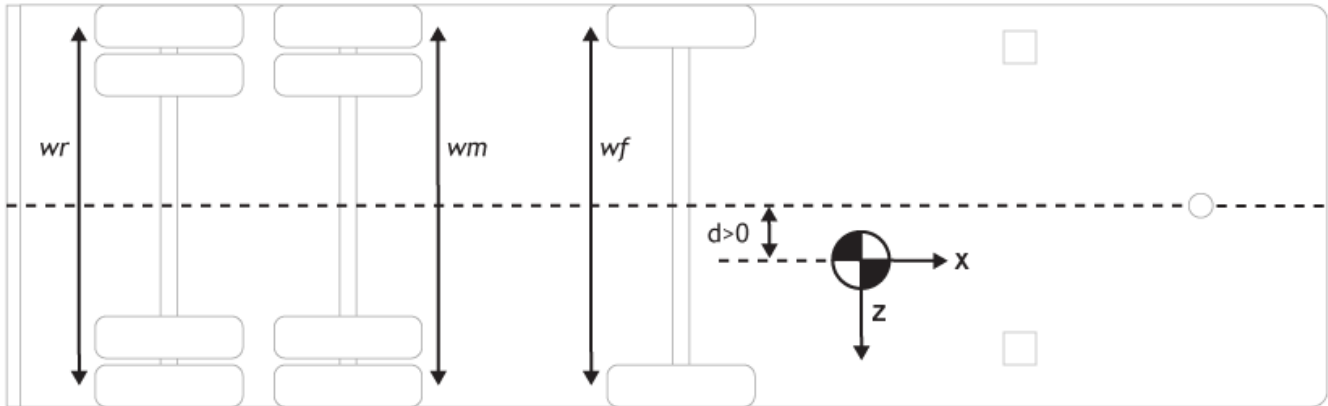




**Lateral distance from geometric centerline to center of mass,  $d$  – Distance from geometric centerline to center of mass**

$\theta$  (default) | scalar

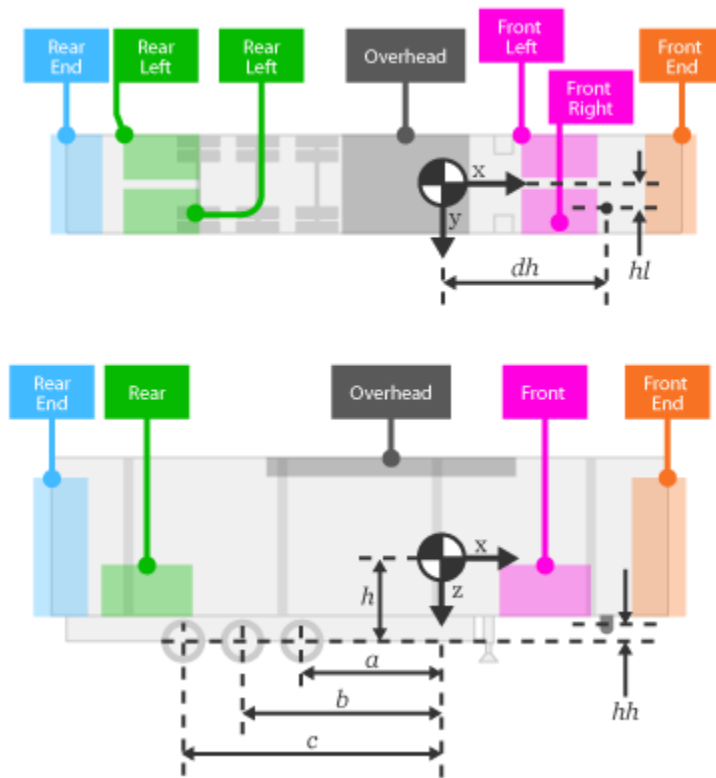
Lateral distance from the geometric centerline to the CM,  $d$ , in m, along the vehicle-fixed y-axis. Positive values indicate that the vehicle CM is to the right of the geometric centerline. Negative values indicate that the vehicle CM is to the left of the geometric centerline.



**Vertical distance from center of mass to axle plane,  $h$  – Distance from center of mass to axle plane**

.35 (default) | scalar

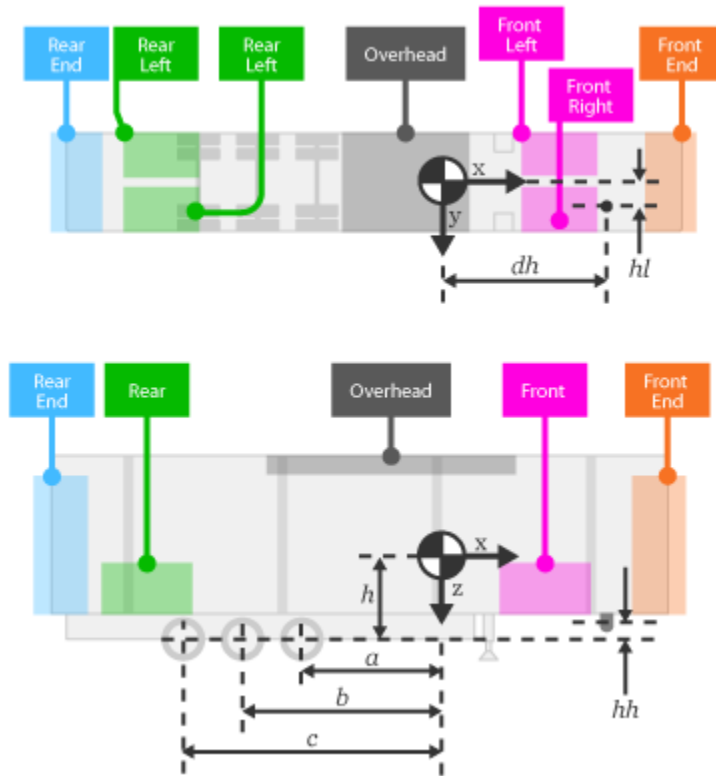
Vertical distance from the vehicle CM to the axle plane,  $h$ , in m.



**Longitudinal distance from center of mass to hitch,  $dh$  – Longitudinal distance from CM to hitch**

1 (default) | scalar

Longitudinal distance from center of mass to hitch,  $dh$ , in m.



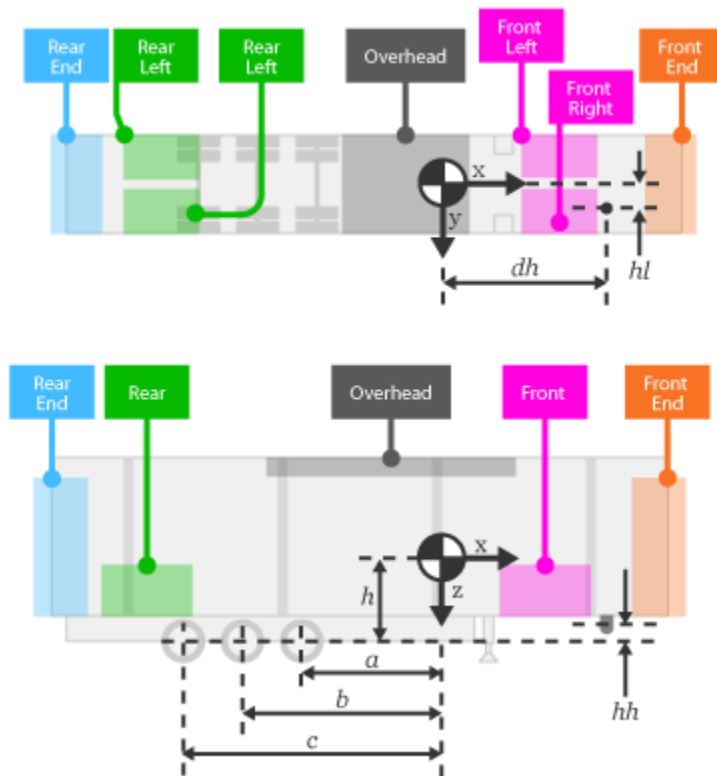
**Dependencies**

To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.

**Longitudinal distance from center of mass to hitch,  $hl$  – Lateral distance from CM to hitch**

0 (default) | scalar

Lateral distance from center of mass to hitch,  $hl$ , in m.

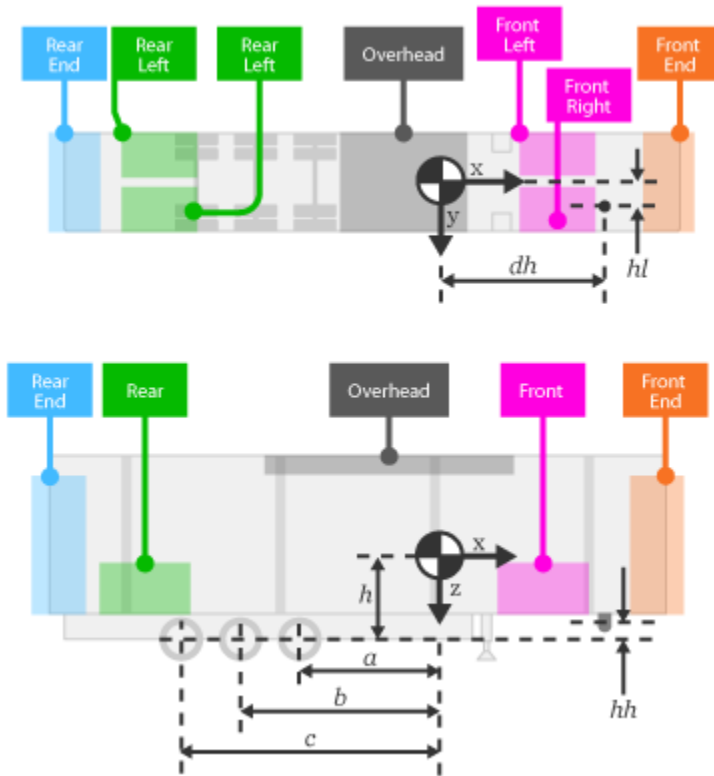


### Dependencies

To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.

**Vertical distance from hitch to axle plane, hh** — Distance from hitch to axle plane  
0.1 (default) | scalar

Vertical distance from hitch to axle plane,  $hh$ , in m.



**Dependencies**

To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.

**Initial position in the inertial frame [Xeo,Yeo,Zeo], Xe\_o – Initial position**  
 [0,0,0] (default) | vector

Initial position of the vehicle in the inertial frame,  $Xe_o$ , in m.

**Initial velocity in body axes [xdot\_o,ydot\_o,zdot\_o], xbdot\_o – Initial velocity**  
 [0,0,0] (default) | vector

Initial vehicle CM velocity along the vehicle-fixed x, y-, and z-axes, respectively, in m/s.

**Initial Euler orientation [roll, pitch, yaw], eul\_o – Rotation**  
 [0,0,0] (default) | vector

Initial Euler rotation of the vehicle-fixed frame about the earth-fixed X- (roll), Y- (pitch), Z-axes (yaw), respectively, in rad.

**Initial body rotation rates [p,q,r], p\_o – Initial rotation rate**  
 [0,0,0] (default) | vector

Initial vehicle CM angular velocity about the vehicle-fixed x- (roll rate), y- (pitch rate), z-axes (yaw rate), respectively, in rad/s.

**Chassis inertia tensor,  $I_{veh}$  – Inertia**

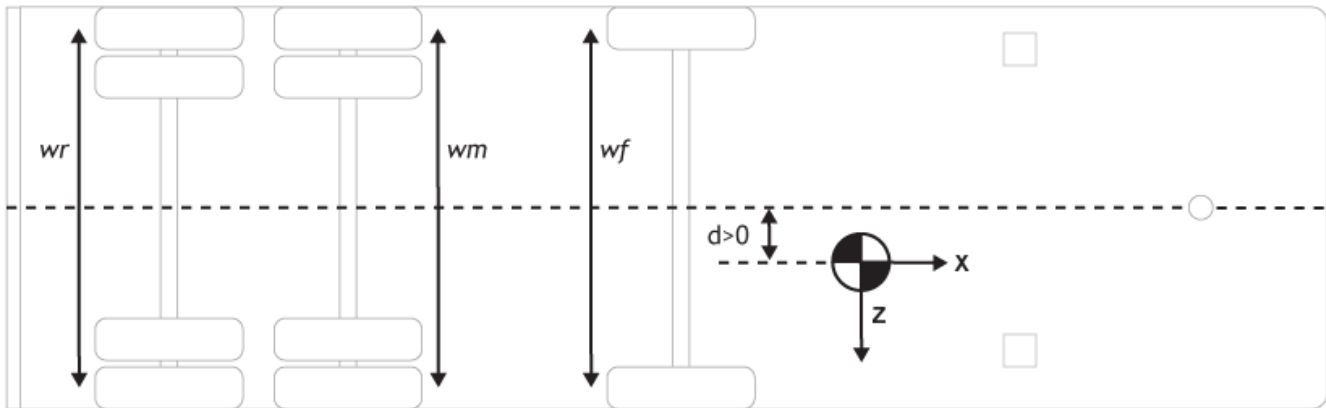
[430 0 0; 0 1900 0; 0 0 2100] (default) | array

Vehicle inertia tensor,  $I_{veh}$ , in  $\text{kg}\cdot\text{m}^2$ . Dimensions are [3-by-3].

**Front track width,  $w_f$  – Front track width**

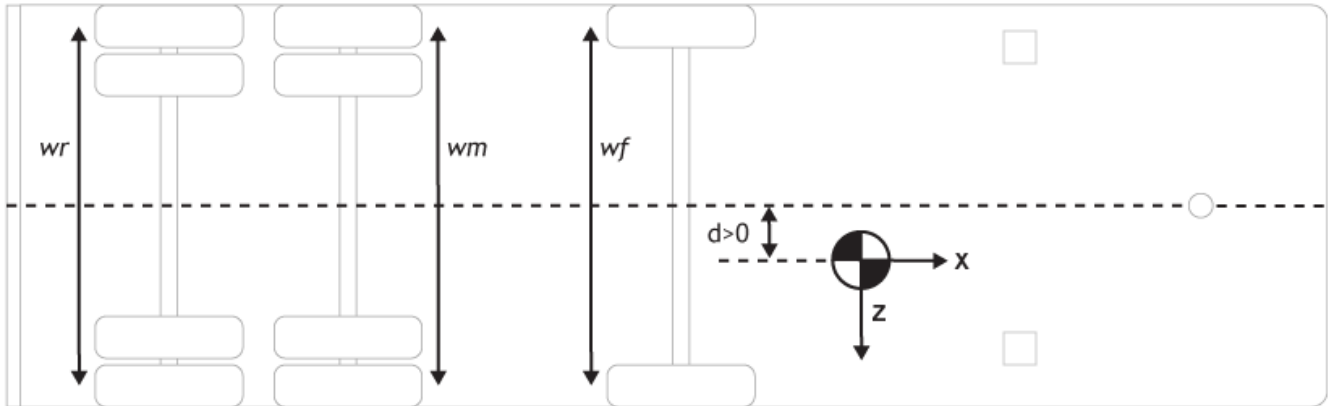
1.9 (default) | scalar

Front track width, in m.

**Middle track width,  $w_m$  – Middle track width**

1.9 (default) | scalar

Middle track width, in m.



**Dependencies**

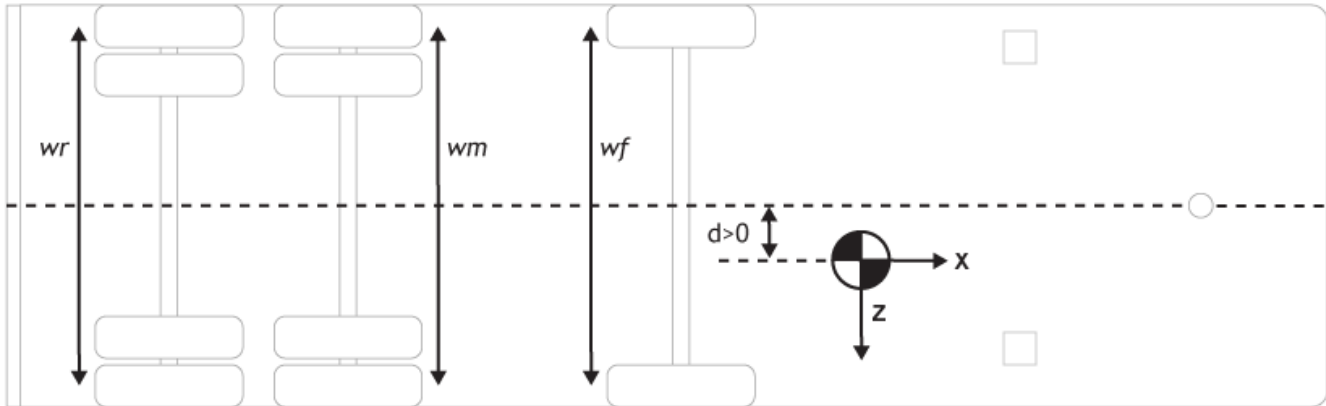
To enable this parameter, set **Number of axles** to 3.

**Rear track width,  $w_r$  – Rear track width**

1.9 (default) | scalar

Rear track width, in m.





## Inertial Loads

### Front End

#### Mass, $z1m$ – Mass

0 (default) | scalar

Mass,  $z1m$ , in kg.

#### Distance vector from front axle, $z1R$ – Distance

[-.25, .125, .15] (default) | vector

Distance vector from front axle to load,  $z1R$ , in m. Dimensions are 1-by-3.

Array Element	Description
$z1R(1,1)$	Front suspension hardpoint to load, along vehicle-fixed x-axis
$z1R(1,2)$	Vehicle centerline to load, along vehicle-fixed y-axis
$z1R(1,3)$	Front suspension hardpoint to load, along vehicle-fixed z-axis

For example, this table summarizes the parameter settings that specify the load location.

Example Location	Sign
• Forward of the front axle	• $z1R(1,1) < 0$
• Right of the vehicle centerline	• $z1R(1,2) > 0$
• Above the front axle suspension hardpoint	• $z1R(1,3) > 0$

**Inertia tensor, z1I – Inertia**

[1.4, -.2, .1; -.2, 1.4, .1; .1, .1, 2.25].\*0 (default) | array

Inertia tensor,  $z1I$ , in  $kg \cdot m^2$ . Dimensions are [3-by-3].

$$z1I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis

**Overhead**

**Mass, z2m – Mass**

0 (default) | scalar

Mass,  $z2m$ , in kg.

**Distance vector from front axle, z2R – Distance**

[1.4, 0, .8] (default) | vector

Distance vector from front axle to load,  $z2R$ , in m. Dimensions are 1-by-3.

Array Element	Description
$z2R(1,1)$	Front suspension hardpoint to load, along vehicle-fixed x-axis
$z2R(1,2)$	Vehicle centerline to load, along vehicle-fixed y-axis
$z2R(1,3)$	Front suspension hardpoint to load, along vehicle-fixed z-axis

For example, this table summarizes the parameter settings that specify the load location.

Example Location	Sign
• Rear of the front axle	• $z2R(1,1) > 0$
• Left of the vehicle centerline	• $z2R(1,2) < 0$
• Above the front axle suspension hardpoint	• $z2R(1,3) > 0$

**Inertia tensor, z2I – Inertia**

[1.4, -.2, .1; -.2, 1.4, .1; .1, .1, 2.25].\*0 (default) | array

Inertia tensor,  $z2I$ , in  $kg \cdot m^2$ . Dimensions are [3-by-3].

$$z2I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis

### Front Left

#### Mass, z3m – Mass

0 (default) | scalar

Mass, z3m, in kg.

#### Distance vector from front axle, z3R – Distance

[.75, -.5, .4] (default) | vector

Distance vector from front axle to load, z3R, in m. Dimensions are 1-by-3.

Array Element	Description
z3R(1,1)	Front suspension hardpoint to load, along vehicle-fixed x-axis
z3R(1,2)	Vehicle centerline to load, along vehicle-fixed y-axis
z3R(1,3)	Front suspension hardpoint to load, along vehicle-fixed z-axis

For example, this table summarizes the parameter settings that specify the load location.

Example Location	Sign
• Rear of the front axle	• z3R(1,1) > 0
• Left of the vehicle centerline	• z3R(1,2) < 0
• Above the front axle suspension hardpoint	• z3R(1,3) > 0

#### Inertia tensor, z3I – Inertia

[5, -.1, -2; -2, 9, .1; -.1, .1, 6].\*0 (default) | array

Inertia tensor, z3I, in kg·m<sup>2</sup>. Dimensions are [3-by-3].

$$z3I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis

- z-axis along the vehicle-fixed z-axis

**Front Right**

**Mass, z4m – Mass**

0 (default) | scalar

Mass, z4m, in kg.

**Distance vector from front axle, z4R – Distance**

[.75, .5, .4] (default) | vector

Distance vector from front axle to load, z4R, in m. Dimensions are 1-by-3.

Array Element	Description
z4R(1,1)	Front suspension hardpoint to load, along vehicle-fixed x-axis
z4R(1,2)	Vehicle centerline to load, along vehicle-fixed y-axis
z4R(1,3)	Front suspension hardpoint to load, along vehicle-fixed z-axis

For example, this table summarizes the parameter settings that specify the load location.

Example Location	Sign
• Rear of the front axle	• z4R(1,1) > 0
• Right of the vehicle centerline	• z4R(1,2) > 0
• Above the front axle suspension hardpoint	• z4R(1,3) > 0

**Inertia tensor, z4I – Inertia**

[5, -.1, -2; -2, 9, .1; -.1, .1, 6].\*0 (default) | array

Inertia tensor, z4I, in kg·m<sup>2</sup>. Dimensions are [3-by-3].

$$z4I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis

**Rear Left**

**Mass, z5m – Mass**

0 (default) | scalar

Mass, z5m, in kg.

**Distance vector from front axle, z5R – Distance**

[1.25, -.5, .4] (default) | vector

Distance vector from front axle to load,  $z5R$ , in m. Dimensions are 1-by-3.

Array Element	Description
$z5R(1,1)$	Front suspension hardpoint to load, along vehicle-fixed x-axis
$z5R(1,2)$	Vehicle centerline to load, along vehicle-fixed y-axis
$z5R(1,3)$	Front suspension hardpoint to load, along vehicle-fixed z-axis

For example, this table summarizes the parameter settings that specify the load location.

Example Location	Sign
<ul style="list-style-type: none"> <li>Rear of the front axle</li> </ul>	<ul style="list-style-type: none"> <li><math>z5R(1,1) &gt; 0</math></li> </ul>
<ul style="list-style-type: none"> <li>Left of the vehicle centerline</li> </ul>	<ul style="list-style-type: none"> <li><math>z5R(1,2) &lt; 0</math></li> </ul>
<ul style="list-style-type: none"> <li>Above the front axle suspension hardpoint</li> </ul>	<ul style="list-style-type: none"> <li><math>z5R(1,3) &gt; 0</math></li> </ul>

#### Inertia tensor, $z5I$ — Inertia

$[5, -.1, -2; -2, 9, .1; -.1, .1, 6] .* \theta$  (default) | array

Inertia tensor,  $z5I$ , in  $\text{kg}\cdot\text{m}^2$ . Dimensions are [3-by-3].

$$z5I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis

#### Rear Right

##### Mass, $z6m$ — Mass

$\theta$  (default) | scalar

Mass,  $z6m$ , in kg.

##### Distance vector from front axle, $z6R$ — Distance

$[1.25, -.5, .4]$  (default) | vector

Distance vector from front axle to load,  $z6R$ , in m. Dimensions are 1-by-3.

Array Element	Description
$z6R(1,1)$	Front suspension hardpoint to load, along vehicle-fixed x-axis
$z6R(1,2)$	Vehicle centerline to load, along vehicle-fixed y-axis
$z6R(1,3)$	Front suspension hardpoint to load, along vehicle-fixed z-axis

For example, this table summarizes the parameter settings that specify the load location.

Example Location	Sign
<ul style="list-style-type: none"> <li>Rear of the front axle</li> </ul>	<ul style="list-style-type: none"> <li><math>z6R(1,1) &gt; 0</math></li> </ul>
<ul style="list-style-type: none"> <li>Right of the vehicle centerline</li> </ul>	<ul style="list-style-type: none"> <li><math>z6R(1,2) &gt; 0</math></li> </ul>
<ul style="list-style-type: none"> <li>Above the front axle suspension hardpoint</li> </ul>	<ul style="list-style-type: none"> <li><math>z6R(1,3) &gt; 0</math></li> </ul>

**Inertia tensor, z6I – Inertia**

[5, -.1, -2; -2, 9, .1; -.1, .1, 6].\*0 (default) | array

Inertia tensor, z6I, in kg·m<sup>2</sup>. Dimensions are [3-by-3].

$$z6I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis

**Rear End**

**Mass, z7m – Mass**

0 (default) | scalar

Mass, z7m, in kg.

**Distance vector from front axle, z7R – Distance**

[2, 0, .25] (default) | vector

Distance vector from front axle to load, z7R, in m. Dimensions are 1-by-3.

Array Element	Description
z7R(1,1)	Front suspension hardpoint to load, along vehicle-fixed x-axis
z7R(1,2)	Vehicle centerline to load, along vehicle-fixed y-axis
z7R(1,3)	Front suspension hardpoint to load, along vehicle-fixed z-axis

For example, this table summarizes the parameter settings that specify the load location.

Example Location	Sign
<ul style="list-style-type: none"> <li>Rear of the front axle</li> </ul>	<ul style="list-style-type: none"> <li><math>z7R(1,1) &gt; 0</math></li> </ul>
<ul style="list-style-type: none"> <li>Right of the vehicle centerline</li> </ul>	<ul style="list-style-type: none"> <li><math>z7R(1,2) &gt; 0</math></li> </ul>
<ul style="list-style-type: none"> <li>Above the front axle suspension hardpoint</li> </ul>	<ul style="list-style-type: none"> <li><math>z7R(1,3) &gt; 0</math></li> </ul>

**Inertia tensor, z7I – Inertia**

[1.4, -.2, .1; -.2, 1.4, .1; .1, .1, 2.25].\*0 (default) | array

Inertia tensor,  $z7I$ , in  $\text{kg}\cdot\text{m}^2$ . Dimensions are [3-by-3].

$$z7I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis

## Aerodynamic

### Longitudinal drag area, $A_f$ — Drag area

2 (default) | scalar

Effective vehicle cross-sectional area,  $A_f$  to calculate the aerodynamic drag force on the vehicle, in  $\text{m}^2$ .

### Longitudinal drag coefficient, $C_d$ — Drag coefficient

.3 (default) | scalar

Air drag coefficient,  $C_d$ , dimensionless.

### Longitudinal lift coefficient, $C_l$ — Lift

.1 (default) | scalar

Air lift coefficient,  $C_l$ , dimensionless.

### Longitudinal drag pitch moment, $C_{pm}$ — Pitch drag

.1 (default) | scalar

Longitudinal drag pitch moment coefficient,  $C_{pm}$ , dimensionless.

### Relative wind angle vector, $\beta_w$ — Wind angle

[0:0.001:0.01] (default) | vector

Relative wind angle vector,  $\beta_w$ , in rad.

### Side force coefficient vector, $C_s$ — Side force drag

[0:0.01:0.1] (default) | vector

Side force coefficient vector coefficient,  $C_s$ , dimensionless.

### Yaw moment coefficient vector, $C_{ym}$ — Yaw moment drag

[0:0.001:0.01] (default) | vector

Yaw moment coefficient vector coefficient,  $C_{ym}$ , dimensionless.

## Environment

### Absolute air pressure, $P_{abs}$ — Pressure

101325 (default) | scalar

Environmental air absolute pressure,  $P_{abs}$ , in Pa.

**Air temperature,  $T_{air}$  – Ambient air temperature**

273 (default) | scalar

Ambient air temperature,  $T_{air}$ , in K.

**Dependencies**

To enable this parameter, clear **Air temperature**.

**Gravitational acceleration,  $g$  – Gravity**

9.81 (default) | scalar

Gravitational acceleration,  $g$ , in  $m/s^2$ .

**Simulation****Longitudinal velocity tolerance,  $xdot_{tol}$  – Tolerance**

.1 (default) | scalar

Longitudinal velocity tolerance,  $xdot_{tol}$ , in m/s.

The block uses this parameter to avoid a division by zero when it calculates the body slip angle,  $\beta$ .

**Geometric longitudinal offset from axle plane,  $longOff$  – Longitudinal offset**

0 (default) | scalar

Trailer offset from axle plane along body-fixed x-axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independently of the vehicle CG.

**Geometric lateral offset from center plane,  $latOff$  – Lateral offset**

0 (default) | scalar

Trailer offset from center plane along body-fixed y-axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independently of the vehicle CG.

**Geometric vertical offset from axle plane,  $vertOff$  – Vertical offset**

0 (default) | scalar

Trailer offset from axle plane along body-fixed z-axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independently of the vehicle CG.

**Wrap Euler angles,  $wrapAng$  – Selection**

on (default) | off

Wrap the Euler angles to the interval  $[-\pi, \pi]$ . For vehicle maneuvers that might undergo vehicle yaw rotations that are outside of the interval, consider clearing the parameter if you want to:

- Track the total vehicle yaw rotation.
- Avoid discontinuities in the vehicle state estimators.

**References**

- [1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers (SAE), 1992.



## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

[Trailer Body 3DOF](#) | [Vehicle Body 6DOF](#) | [Vehicle Body 3DOF Longitudinal](#)

### **Topics**

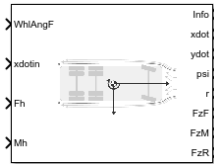
[“Coordinate Systems in Vehicle Dynamics Blockset”](#)

### **Introduced in R2020b**

## Vehicle Body 3DOF Three Axles

Three-axle vehicle body with longitudinal, lateral, and yaw motion

**Library:** Vehicle Dynamics Blockset / Vehicle Body



### Description

The Vehicle Body 3DOF Three Axles block implements a rigid, three-axle vehicle body model to calculate longitudinal, lateral, and yaw motion. The block accounts for the axle and hitch reaction forces due to the vehicle body mass acceleration, aerodynamic drag, and steering.

Use this block in vehicle dynamics and automated driving studies to model nonholonomic vehicle motion when vehicle pitch, roll, and vertical motion are not significant.

Use the **Vehicle track** parameter to specify the number of tracks.

Vehicle Track Setting	Implementation
Single (bicycle)	<ul style="list-style-type: none"> <li>Forces act along the center line of the axles.</li> <li>No lateral load transfer.</li> </ul>
Dual	Forces act at the axle hard-point locations.

Use the **Axle forces** parameter to specify the type of force.

Axle Forces Setting	Implementation
External longitudinal velocity	<ul style="list-style-type: none"> <li>The block assumes that the external longitudinal velocity is in a quasi-steady state, so the longitudinal acceleration is approximately zero.</li> <li>Because the motion is quasi-steady, the block calculates lateral forces using the tire slip angles and linear cornering stiffness.</li> <li>Consider this setting when you want to: <ul style="list-style-type: none"> <li>Generate virtual sensor signal data.</li> <li>Conduct high-level software studies that are not impacted by driveline or nonlinear tire responses.</li> </ul> </li> </ul>

Axle Forces Setting	Implementation
External longitudinal forces	<ul style="list-style-type: none"> <li>The block uses the external longitudinal force to accelerate or brake the vehicle.</li> <li>The block calculates lateral forces using the tire slip angles and linear cornering stiffness.</li> <li>Consider this setting when you want to: <ul style="list-style-type: none"> <li>Account for changes in the longitudinal velocity on the lateral and yaw motion.</li> <li>Specify the external longitudinal motion through a force instead of an external longitudinal velocity.</li> <li>Connect the block to tractive actuators, wheels, brakes, and hitches.</li> </ul> </li> </ul>
External forces	<ul style="list-style-type: none"> <li>The block uses the external lateral and longitudinal forces to steer, accelerate, or brake the vehicle.</li> <li>The block does not use the steering input to calculate vehicle motion.</li> <li>Consider this setting when you need tire models with more accurate nonlinear combined lateral and longitudinal slip.</li> </ul>

To create additional input ports, under **Input signals**, select these block parameters.

Input Signals Pane Parameter	Input Port	Description
<b>Front wheel steering</b>	WhlAngF	Front wheel angle, $\delta_F$
<b>Middle wheel steering</b>	WhlAngM	Middle wheel angle, $\delta_M$
<b>Rear wheel steering</b>	WhlAngR	Rear wheel angle, $\delta_R$
<b>External wind</b>	WindXYZ	Wind speed, $W_x$ , $W_y$ , and $W_z$ , in an inertial reference frame
<b>External friction</b>	Mu	Friction coefficient
<b>External forces</b>	FExt	External force on the vehicle center of gravity (CG), $F_x$ , $F_y$ , and $F_z$ , in the vehicle-fixed frame
<b>External moments</b>	MExt	External moment about the vehicle CG, $M_x$ , $M_y$ , and $M_z$ , in the vehicle-fixed frame
<b>Hitch forces</b>	Fh	Hitch force applied to the body at the hitch location, $Fh_x$ , $Fh_y$ , and $Fh_z$ , in the vehicle-fixed frame
<b>Hitch moments</b>	Mh	Hitch moment at the hitch location, $Mh_x$ , $Mh_y$ , and $Mh_z$ , about the vehicle-fixed frame
<b>Initial longitudinal position</b>	X_o	Initial vehicle CG displacement along the earth-fixed X-axis
<b>Initial yaw angle</b>	psi_o	Initial rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw)
<b>Initial longitudinal velocity</b>	xdot_o	Initial vehicle CG velocity along the vehicle-fixed x-axis

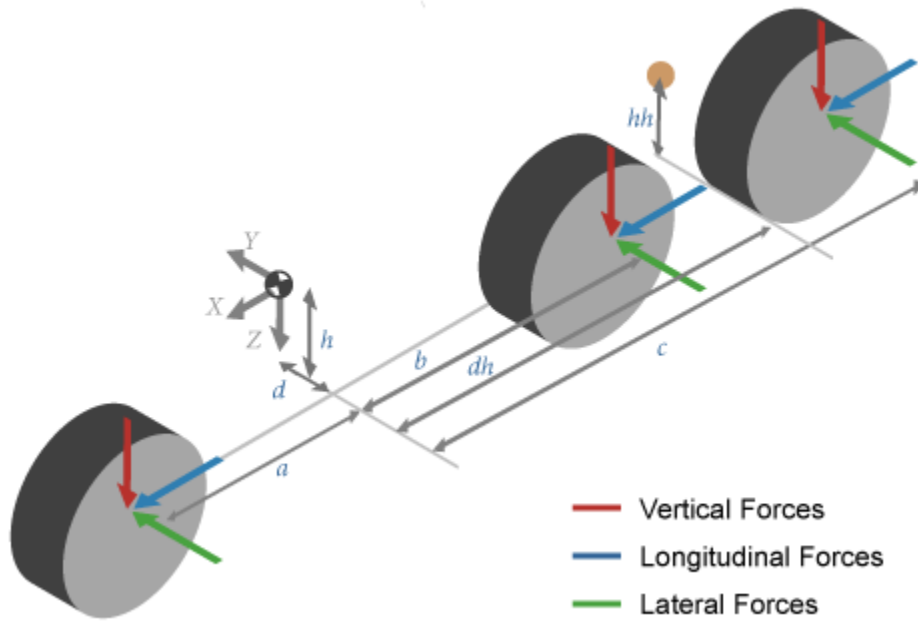
Input Signals Pane Parameter	Input Port	Description
<b>Initial yaw rate</b>	r_o	Initial vehicle angular velocity about the vehicle-fixed z-axis (yaw rate)
<b>Initial lateral position</b>	Y_o	Initial vehicle CG displacement along the earth-fixed Y-axis
<b>Air temperature</b>	AirTemp	Ambient air temperature. Consider this option if you want to vary the temperature during run time.
<b>Initial lateral velocity</b>	ydot_o	Initial vehicle CG velocity along the vehicle-fixed y-axis

### Theory

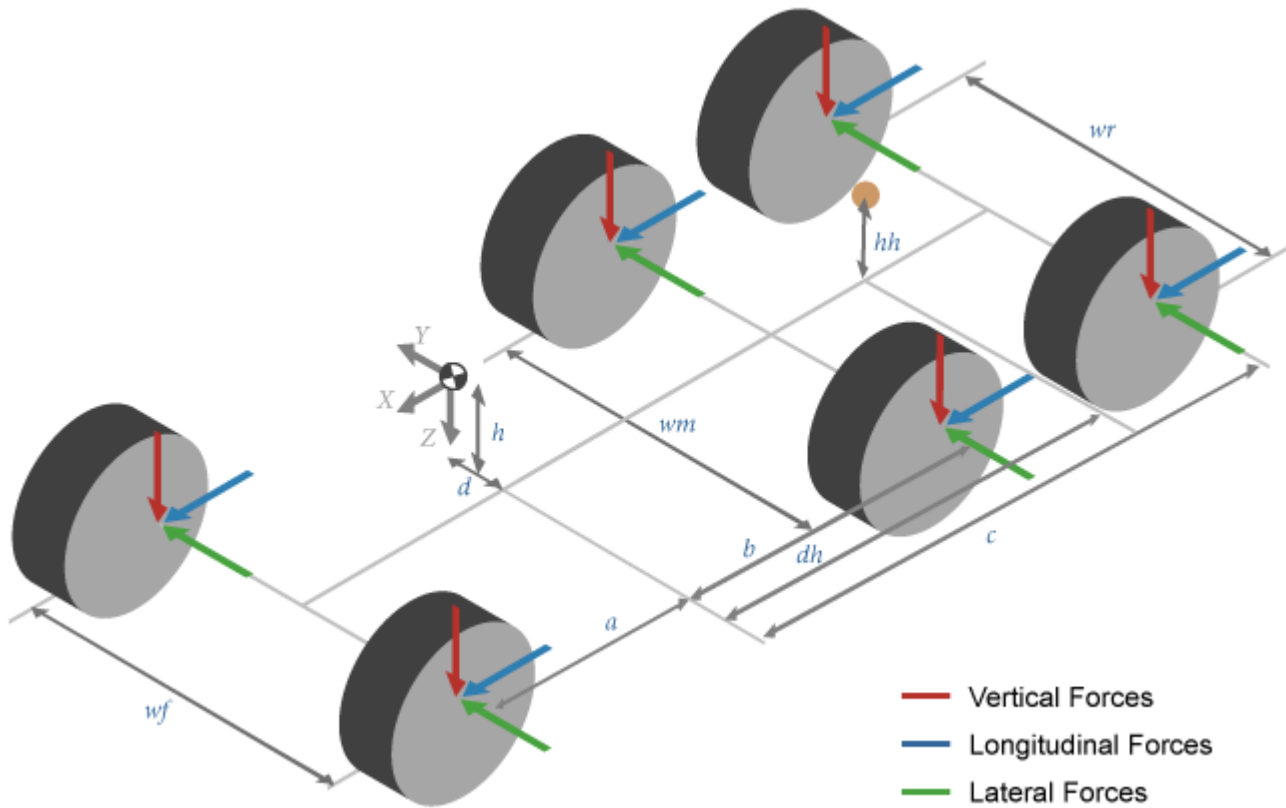
To determine the vehicle motion, the block solves the rigid body planar dynamics equations of motion.

Calculation	Description
<i>Dynamics</i>	The block solves the rigid-body planar dynamics equations to determine the vehicle longitudinal motion. If you set <b>Axle forces</b> to <b>External longitudinal velocity</b> , the block assumes a quasi-steady state for the longitudinal acceleration.
<i>External forces</i>	External forces include both drag and external force inputs. The forces act on the vehicle CG.  The block divides the normal forces by the nominal normal load to vary the effective friction parameters during weight and load transfer. The block maintains pitch and roll equilibrium.
<i>Tire forces</i>	The block uses the ratio of the local, longitudinal, and lateral velocities to determine the slip angles.  The block uses the steering angles to transform the tire forces to the vehicle-fixed frame.  If you set <b>Axle forces</b> to <b>External forces</b> , the block assumes that the externally provided forces are in the vehicle-fixed frame at the axle-wheel location.

Single Track



**Dual Track**



The illustrations use these variables.

- $a, b, c$  Longitudinal distance of the front, middle, and rear axles, respectively, from the normal projection point of the vehicle CG onto the common axle plane
- $h$  Height of vehicle CG above the axle plane along the vehicle-fixed z-axis
- $d$  Lateral distance from geometric centerline to center of mass along the vehicle-fixed y-axis
- $hh$  Height of the hitch above the axle plane along the vehicle-fixed z-axis
- $dh$  Longitudinal distance of the hitch from normal projection point of the vehicle CG onto the common axle plane
- $hl$  Lateral distance from center of mass to hitch along the vehicle-fixed y-axis.
- $wf, wm, wr$  Front, middle, and rear track width, respectively

**Drag**

This table summarizes the block implementation for the drag calculation.

Calculation	Description
Coordinate transformation	The block transforms the wind speeds from the inertial frame to the vehicle-fixed frame.

Calculation	Description
<i>Drag forces</i>	To determine a relative airspeed, the block subtracts the wind speed from the CG vehicle velocity. Using the relative airspeed, the block determines the drag forces.
<i>Drag moments</i>	Using the relative airspeed, the block determines the drag moments.

### Lateral Corner Stiffness and Relaxation Dynamics

To enable the mapped corner stiffness and relaxation length dynamic parameters, set **Axle forces** to External longitudinal force or External longitudinal velocity.

Parameter Settings		Description
Mapped Corner Stiffness	Include Relaxation Length Dynamics	
Off (default)	On (default)	The block uses constant corner stiffness values.  The slip angles include the relaxation length dynamic settings. The relaxation length approximates an effective corner stiffness force that is a function of wheel travel.
On	On (default)	The block uses lookup tables that are functions of the corner stiffness data and slip angles.  The slip angles include the relaxation length dynamic settings. The relaxation length approximates an effective corner stiffness force that is a function of wheel travel.
Off (default)	Off	The block uses constant corner stiffness values.

## Ports

### Input

#### WhlAngF – Front wheel steering angles

scalar | array

Front wheel steering angles,  $\delta_F$ , in rad.

Vehicle Track Setting	Variable	Signal Dimension
Single (bicycle)	$\delta_F$	Scalar - 1
Dual	$\delta_F = [\delta_{fl} \ \delta_{fr}]$ or $\begin{bmatrix} \delta_{fl} \\ \delta_{fr} \end{bmatrix}$	Array - [1x2] or [2x1]

### Dependencies

To enable this port, on the **Input signals** pane, select **Front wheel steering**.

#### WhlAngM – Middle wheel steering angles

scalar | array

Middle wheel steering angles,  $\delta_M$ , in rad.

Vehicle Track Setting	Variable	Signal Dimension
Single (bicycle)	$\delta_M$	Scalar - 1
Dual	$\delta_M = [\delta_{ml} \ \delta_{mr}]$ or $\begin{bmatrix} \delta_{ml} \\ \delta_{mr} \end{bmatrix}$	Array - [1x2] or [2x1]

**Dependencies**

To enable this port, on the **Input signals** pane, select **Middle wheel steering**.

**WhlAngR – Rear wheel steering angles**

scalar | array

Rear wheel steering angles,  $\delta_R$ , in rad.

Vehicle Track Setting	Variable	Signal Dimension
Single (bicycle)	$\delta_R$	Scalar - 1
Dual	$\delta_R = [\delta_{rl} \ \delta_{rr}]$ or $\begin{bmatrix} \delta_{rl} \\ \delta_{rr} \end{bmatrix}$	Array - [1x2] or [2x1]

**Dependencies**

To enable this port, on the **Input signals** pane, select **Rear wheel steering**.

**xdotin – Longitudinal velocity**

scalar

Vehicle CG velocity along the vehicle-fixed x-axis, in m/s.

**Dependencies**

To enable this port, set **Axle forces** to External longitudinal velocity.

**FwF – Total force on the front wheels**

scalar | array

Force on the front wheels,  $F_{wF}$ , along the vehicle-fixed axis, in N.

Vehicle Track Setting	Axle Forces Setting	Description	Variable	Signal Dimension
Single (bicycle)	External longitudinal forces	Longitudinal force on the front wheel	$F_{wF} = F_{x_f}$	Scalar - 1
	External forces	Longitudinal and lateral forces on the front wheel	$F_{wF} = [F_{x_f} \ F_{y_f}]$ or $\begin{bmatrix} F_{x_f} \\ F_{y_f} \end{bmatrix}$	Array - [1x2] or [2x1]



Vehicle Track Setting	Axle Forces Setting	Description	Variable	Signal Dimension
Dual	External longitudinal forces	Longitudinal force on the front wheels	$F_{wF} = [F_{xfl} \ F_{xfr}]$ or $\begin{bmatrix} F_{xfl} \\ F_{xfr} \end{bmatrix}$	Array - [1x2] or [2x1]
	External forces	Longitudinal and lateral forces on the front wheels	$F_{wF} = \begin{bmatrix} F_{xfl} & F_{xfr} \\ F_{yfl} & F_{yfr} \end{bmatrix}$	Array - [2x2]

### Dependencies

To enable this port, set **Axle forces** to one of these options:

- External longitudinal forces
- External forces

### F<sub>wM</sub> – Total force on the middle wheels

scalar | array

Force on the middle wheels,  $F_{wM}$ , along the vehicle-fixed axis, in N.

Vehicle Track Setting	Axle Forces Setting	Description	Variable	Signal Dimension
Single (bicycle)	External longitudinal forces	Longitudinal force on the middle wheel	$F_{wM} = F_{x_r}$	Scalar - 1
	External forces	Longitudinal and lateral forces on the middle wheel	$F_{wM} = [F_{x_m} \ F_{y_m}]$ or $\begin{bmatrix} F_{x_m} \\ F_{y_m} \end{bmatrix}$	Array - [1x2] or [2x1]
Dual	External longitudinal forces	Longitudinal force on the middle wheels	$F_{wM} = [F_{x_{ml}} \ F_{x_{mr}}]$ or $\begin{bmatrix} F_{x_{ml}} \\ F_{x_{mr}} \end{bmatrix}$	Array - [1x2] or [2x1]
	External forces	Longitudinal and lateral forces on the middle wheels	$F_{wM} = \begin{bmatrix} F_{x_{ml}} & F_{x_{mr}} \\ F_{y_{ml}} & F_{y_{mr}} \end{bmatrix}$	Array - [2x2]

### Dependencies

To enable this port, set **Axle forces** to one of these options:

- External longitudinal forces

- External forces

**FwR — Total force on the rear wheels**

scalar | array

Force on the rear wheels,  $F_{wR}$ , along the vehicle-fixed axis, in N.

Vehicle Track Setting	Axle Forces Setting	Description	Variable	Signal Dimension
Single (bicycle)	External longitudinal forces	Longitudinal force on the rear wheel	$F_{wR} = F_{x_r}$	Scalar - 1
	External forces	Longitudinal and lateral forces on the rear wheel	$F_{wR} = [F_{x_r} \ F_{y_r}]$ or $\begin{bmatrix} F_{x_r} \\ F_{y_r} \end{bmatrix}$	Array - [1x2] or [2x1]
Dual	External longitudinal forces	Longitudinal force on the rear wheels	$F_{wR} = [F_{x_{rl}} \ F_{x_{rr}}]$ or $\begin{bmatrix} F_{x_{rl}} \\ F_{x_{rr}} \end{bmatrix}$	Array - [1x2] or [2x1]
	External forces	Longitudinal and lateral forces on the rear wheels	$F_{wR} = \begin{bmatrix} F_{x_{rl}} & F_{x_{rr}} \\ F_{y_{rl}} & F_{y_{rr}} \end{bmatrix}$	Array - [2x2]

**Dependencies**

To enable this port, set **Axle forces** to one of these options:

- External longitudinal forces
- External forces

**FExt — External force on vehicle CG**

array

External forces applied to the vehicle CG,  $F_{x_{ext}}, F_{y_{ext}}, F_{z_{ext}}$ , in vehicle-fixed frame, in N. The signal array dimensions are [1x3] or [3x1].

**Dependencies**

To enable this port, on the **Input signals** pane, select **External forces**.

**MExt — External moment about vehicle CG**

array

External moment about the vehicle CG,  $M_x, M_y, M_z$ , in the vehicle-fixed frame, in N·m. The signal array dimensions are [1x3] or [3x1].

**Dependencies**

To enable this port, on the **Input signals** pane, select **External moments**.

**Fh — Hitch force on the body**

array

Hitch force applied to the body at the hitch location,  $Fh_x, Fh_y, Fh_z$ , in the vehicle-fixed frame, in N, specified as a 1-by-3 or 3-by-1 array.

#### Dependencies

To enable this port, under **Input signals**, select **Hitch forces**.

#### Mh — Hitch moment about body

array

Hitch moment at the hitch location,  $Mh_x, Mh_y, Mh_z$ , about the vehicle-fixed frame, in N·m, specified as a 1-by-3 or 3-by-1 array.

#### Dependencies

To enable this port, under **Input signals**, select **Hitch moments**.

#### WindXYZ — Wind speed

array

Wind speed,  $W_x, W_y, W_z$  along the inertial X-, Y-, and Z-axes, in m/s. The signal array dimensions are [1x3] or [3x1].

#### Dependencies

To enable this port, on the **Input signals** pane, select **External wind**.

#### Mu — Tire friction coefficient

array

Tire friction coefficient,  $\mu$ , dimensionless.

Vehicle Track Setting	Variable	Signal Dimension
Single (bicycle)	$Mu = [\mu_f \ \mu_m \ \mu_r] \text{ or } \begin{bmatrix} \mu_f \\ \mu_m \\ \mu_r \end{bmatrix}$	Array - [1x3] or [3x1]
Dual	$Mu = \begin{bmatrix} \mu_{fl} & \mu_{fr} \\ \mu_{ml} & \mu_{mr} \\ \mu_{rl} & \mu_{rr} \end{bmatrix}$	Array - [3x2]

#### Dependencies

To enable this port, on the **Input signals** pane, select **External friction**.

#### AirTemp — Ambient air temperature

scalar

Ambient air temperature, in K.

#### Dependencies

To enable this port, on the **Input signals** pane, select **Air temperature**.

#### X\_o — Initial longitudinal position

scalar

Initial vehicle CG displacement along the earth-fixed X-axis, in m.

**Dependencies**

To enable this port, on the **Input signals** pane, select **Initial longitudinal position**.

**Y\_o – Initial lateral position**

scalar

Initial vehicle CG displacement along the earth-fixed Y-axis, in m.

**Dependencies**

To enable this port, on the **Input signals** pane, select **Initial lateral position**.

**xdot\_o – Initial longitudinal position**

scalar

Initial vehicle CG velocity along the vehicle-fixed x-axis, in m/s.

**Dependencies**

To enable this port:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal forces
  - External forces
- 2 On the **Input signals** pane, select **Initial longitudinal velocity**

**ydot\_o – Initial lateral position**

scalar

Initial vehicle CG velocity along the vehicle-fixed y-axis, in m/s.

**Dependencies**

To enable this port, on the **Input signals** pane, select **Initial lateral velocity**.

**psi\_o – Initial yaw angle**

scalar

Rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw), in rad.

**Dependencies**

To enable this port, on the **Input signals** pane, select **Initial yaw angle**.

**r\_o – Initial yaw rate**

scalar

Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate), in rad/s.

**Dependencies**

To enable this port, on the **Input signals** pane, select **Initial yaw rate**.

**Output****Info – Vehicle data**

bus

Vehicle data, returned as a bus signal containing these block values.

Signal			Description		Value	Units		
InertFrm	Cg	Disp	X		Vehicle CG displacement along the earth-fixed X-axis	Computed	m	
			Y		Vehicle CG displacement along the earth-fixed Y-axis	Computed	m	
			Z		Vehicle CG displacement along the earth-fixed Z-axis	0	m	
		Vel	Xdot		Vehicle CG velocity along the earth-fixed X-axis	Computed	m/s	
			Ydot		Vehicle CG velocity along the earth-fixed Y-axis	Computed	m/s	
			Zdot		Vehicle CG velocity along the earth-fixed Z-axis	0	m/s	
		Ang	phi		Rotation of the vehicle-fixed frame about the earth-fixed X-axis (roll)	0	rad	
			theta		Rotation of the vehicle-fixed frame about the earth-fixed Y-axis (pitch)	0	rad	
			psi		Rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw)	Computed	rad	
	FrntAxl	Lft	Disp	X		Front left wheel displacement along the earth-fixed X-axis	Computed	m
				Y		Front left wheel displacement along the earth-fixed Y-axis	Computed	m
				Z		Front left wheel displacement along the earth-fixed Z-axis	0	m
			Vel	Xdot		Front left wheel velocity along the earth-fixed X-axis	Computed	m/s
				Ydot		Front left wheel velocity along the earth-fixed Y-axis	Computed	m/s

Signal				Description	Value	Units		
				Zdot	Front left wheel velocity along the earth-fixed Z-axis	0	m/s	
		Rght	Disp	X	Front right wheel displacement along the earth-fixed X-axis	Computed	m	
				Y	Front right wheel displacement along the earth-fixed Y-axis	Computed	m	
				Z	Front right wheel displacement along the earth-fixed Z-axis	0	m	
			Vel	Xdot	Front right wheel velocity along the earth-fixed X-axis	Computed	m/s	
				Ydot	Front right wheel velocity along the earth-fixed Y-axis	Computed	m/s	
				Zdot	Front right wheel velocity along the earth-fixed Z-axis	0	m/s	
	MidlAxl	Lft	Disp	X	Middle left wheel displacement along the earth-fixed X-axis	Computed	m	
					Y	Middle left wheel displacement along the earth-fixed Y-axis	Computed	m
					Z	Middle left wheel displacement along the earth-fixed Z-axis	0	m
				Vel	Xdot	Middle left wheel velocity along the earth-fixed X-axis	Computed	m/s
					Ydot	Middle left wheel velocity along the earth-fixed Y-axis	Computed	m/s
					Zdot	Middle left wheel velocity along the earth-fixed Z-axis	0	m/s
			Rght	Disp	X	Middle right wheel displacement along the earth-fixed X-axis	Computed	m
					Y	Middle right wheel displacement along the earth-fixed Y-axis	Computed	m

Signal				Description	Value	Units		
			Vel	Z	Middle right wheel displacement along the earth-fixed Z-axis	0	m	
				Xdot	Middle right wheel velocity along the earth-fixed X-axis	Computed	m/s	
				Ydot	Middle right wheel velocity along the earth-fixed Y-axis	Computed	m/s	
				Zdot	Middle right wheel velocity along the earth-fixed Z-axis	0	m/s	
	RearAxl	Lft	Disp		X	Rear left wheel displacement along the earth-fixed X-axis	Computed	m
					Y	Rear left wheel displacement along the earth-fixed Y-axis	Computed	m
					Z	Rear left wheel displacement along the earth-fixed Z-axis	0	m
			Vel		Xdot	Rear left wheel velocity along the earth-fixed X-axis	Computed	m/s
					Ydot	Rear left wheel velocity along the earth-fixed Y-axis	Computed	m/s
					Zdot	Rear left wheel velocity along the earth-fixed Z-axis	0	m/s
		Rght	Disp		X	Rear right wheel displacement along the earth-fixed X-axis	Computed	m
					Y	Rear right wheel displacement along the earth-fixed Y-axis	Computed	m
					Z	Rear right wheel displacement along the earth-fixed Z-axis	0	m
			Vel		Xdot	Rear right wheel velocity along the earth-fixed X-axis	Computed	m/s
					Ydot	Rear right wheel velocity along the earth-fixed Y-axis	Computed	m/s

Signal				Description	Value	Units	
			Zdot	Rear right wheel velocity along the earth-fixed Z-axis	0	m/s	
	Hitch	Disp	X	Trailer hitch offset from the axle plane along the earth-fixed X-axis	Computed	m	
			Y	Trailer hitch offset from the center plane along the earth-fixed Y-axis	Computed	m	
			Z	Trailer hitch offset from the axle plane along the earth-fixed Z-axis	Computed	m	
		Vel	Xdot	Trailer hitch offset velocity along the earth-fixed X-axis	Computed	m/s	
			Ydot	Trailer hitch offset velocity along the earth-fixed Y-axis	Computed	m/s	
			Zdot	Trailer hitch offset velocity along the earth-fixed Z-axis	Computed	m/s	
		Geom	Disp	X	Vehicle chassis offset from axle plane along the earth-fixed X-axis	Computed	m
				Y	Vehicle chassis offset from center plane along the earth-fixed Y-axis	Computed	m
				Z	Vehicle chassis offset from axle plane along the earth-fixed Z-axis	Computed	m
	Vel		Xdot	Vehicle chassis offset velocity along the earth-fixed X-axis	Computed	m/s	
			Ydot	Vehicle chassis offset velocity along the earth-fixed Y-axis	Computed	m/s	
			Zdot	Vehicle chassis offset velocity along the earth-fixed Z-axis	Computed	m/s	
BdyFrm	Cg	Vel	xdot	Vehicle CG velocity along the vehicle-fixed x-axis	Computed	m/s	
			ydot	Vehicle CG velocity along the vehicle-fixed y-axis	Computed	m/s	



Signal			Description	Value	Units	
			zdot	Vehicle CG velocity along the vehicle-fixed z-axis	0	m/s
	Ang	Beta		Body slip angle, $\beta$ $\beta = \frac{V_y}{V_x}$	Computed	rad
	AngVel	p		Vehicle angular velocity about the vehicle-fixed x-axis (roll rate)	0	rad/s
		q		Vehicle angular velocity about the vehicle-fixed y-axis (pitch rate)	0	rad/s
		r		Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate)	Computed	rad/s
	Acc	ax		Vehicle CG acceleration along the vehicle-fixed x-axis	Computed	gn
		ay		Vehicle CG acceleration along the vehicle-fixed y-axis	Computed	gn
		az		Vehicle CG acceleration along the vehicle-fixed z-axis	0	gn
		xddot		Vehicle CG acceleration along the vehicle-fixed x-axis	Computed	m/s <sup>2</sup>
		yddot		Vehicle CG acceleration along the vehicle-fixed y-axis	Computed	m/s <sup>2</sup>
		zddot		Vehicle CG acceleration along the vehicle-fixed z-axis	0	m/s <sup>2</sup>
	AngAcc	pdot		Vehicle angular acceleration about the vehicle-fixed x-axis	0	rad/s
		qdot		Vehicle angular acceleration about the vehicle-fixed y-axis	0	rad/s
		rdot		Vehicle angular acceleration about the vehicle-fixed z-axis	Computed	rad/s
	Forces	Body	Fx	Net force on vehicle CG along the vehicle-fixed x-axis	Computed	N

Signal			Description	Value	Units		
			Fy	Net force on vehicle CG along the vehicle-fixed y-axis	Computed	N	
			Fz	Net force on vehicle CG along the vehicle-fixed z-axis	0	N	
		Ext	Fx	External force on vehicle CG along the vehicle-fixed x-axis	Computed	N	
			Fy	External force on vehicle CG along the vehicle-fixed y-axis	Computed	N	
			Fz	External force on vehicle CG along the vehicle-fixed z-axis	0	N	
		Hitch	Fx	Hitch force applied to body at the hitch location along the vehicle-fixed x-axis	Computed	N	
			Fy	Hitch force applied to body at the hitch location along the vehicle-fixed y-axis	Computed	N	
			Fz	Hitch force applied to body at the hitch location along the vehicle-fixed z-axis	Computed	N	
		FrntAxl	Lft	Fx	Longitudinal force on left front wheel along the vehicle-fixed x-axis	Computed	N
				Fy	Lateral force on left front wheel along the vehicle-fixed y-axis	Computed	N
				Fz	Normal force on left front wheel along the vehicle-fixed z-axis	Computed	N
			Rght	Fx	Longitudinal force on right front wheel along the vehicle-fixed x-axis	Computed	N
				Fy	Lateral force on right front wheel along the vehicle-fixed y-axis	Computed	N
				Fz	Normal force on right front wheel along the vehicle-fixed z-axis	Computed	N

Signal				Description	Value	Units	
	MidlAxl	Lft	Fx	Longitudinal force on left middle wheel along the vehicle-fixed x-axis	Computed	N	
			Fy	Lateral force on left middle wheel along the vehicle-fixed y-axis	Computed	N	
			Fz	Normal force on left middle wheel along the vehicle-fixed z-axis	Computed	N	
		Rght	Fx	Longitudinal force on right middle wheel along the vehicle-fixed x-axis	Computed	N	
			Fy	Lateral force on right middle wheel along the vehicle-fixed y-axis	Computed	N	
			Fz	Normal force on right middle wheel along the vehicle-fixed z-axis	Computed	N	
		RearAxl	Lft	Fx	Longitudinal force on left rear wheel along the vehicle-fixed x-axis	Computed	N
				Fy	Lateral force on left rear wheel along the vehicle-fixed y-axis	Computed	N
				Fz	Normal force on left rear wheel along the vehicle-fixed z-axis	Computed	N
	Rght		Fx	Longitudinal force on right rear wheel along the vehicle-fixed x-axis	Computed	N	
			Fy	Lateral force on right rear wheel along the vehicle-fixed y-axis	Computed	N	
			Fz	Normal force on right rear wheel along the vehicle-fixed z-axis	Computed	N	
	Tires	FrntTires	L	F	Front left tire force along the vehicle-fixed x-axis	Computed	N
			f	F	Front left tire force along the vehicle-fixed y-axis	Computed	N
			t	F	Front left tire force along the vehicle-fixed z-axis	Computed	N

Signal				Description	Value	Units			
			R g h t	F	Front right tire force along the vehicle-fixed x-axis	Computed	N		
				F	Front right tire force along the vehicle-fixed y-axis	Computed	N		
				F	Front right tire force along the vehicle-fixed z-axis	Computed	N		
				RearTires	L	Rear left tire force along the vehicle-fixed x-axis	Computed	N	
					F	Rear left tire force along the vehicle-fixed y-axis	Computed	N	
					F	Rear left tire force along the vehicle-fixed z-axis	Computed	N	
				R g h t	F	Rear right tire force along the vehicle-fixed x-axis	Computed	N	
					F	Rear right tire force along the vehicle-fixed y-axis	Computed	N	
					F	Rear right tire force along the vehicle-fixed z-axis	Computed		
			Drag	Fx	Drag force on vehicle CG along the vehicle-fixed x-axis		Computed	N	
					Drag force on vehicle CG along the vehicle-fixed y-axis		Computed	N	
					Drag force on vehicle CG along the vehicle-fixed z-axis		Computed	N	
					Grvty	Fx	Gravity force on vehicle CG along the vehicle-fixed x-axis	Computed	N
						Fy	Gravity force on vehicle CG along the vehicle-fixed y-axis	Computed	N
						Fz	Gravity force on vehicle CG along the vehicle-fixed z-axis	Computed	N
Moments	Body	Mx	Body moment on vehicle CG about the vehicle-fixed x-axis	0	N·m				

Signal				Description	Value	Units		
			My	Body moment on vehicle CG about the vehicle-fixed y-axis	Computed	N·m		
				Mz	Body moment on vehicle CG about the vehicle-fixed z-axis	0	N·m	
			Drag	Mx	Drag moment on vehicle CG about the vehicle-fixed x-axis	0	N·m	
				My	Drag moment on vehicle CG about the vehicle-fixed y-axis	Computed	N·m	
				Mz	Drag moment on vehicle CG about the vehicle-fixed z-axis	0	N·m	
			Ext	Mx	External moment on vehicle CG about the vehicle-fixed x-axis	0	N·m	
				My	External moment on vehicle CG about the vehicle-fixed y-axis	Computed	N·m	
				Mz	External moment on vehicle CG about the vehicle-fixed z-axis	0	N·m	
			Hitch	Mx	Hitch moment at the hitch location about vehicle-fixed x-axis	0	N·m	
		My		Hitch moment at the hitch location about vehicle-fixed y-axis	Computed	N·m		
		Mz		Hitch moment at the hitch location about vehicle-fixed z-axis	0	N·m		
		FrntAxl	Lft	Disp	x	Front left wheel displacement along the vehicle-fixed x-axis	Computed	m
					y	Front left wheel displacement along the vehicle-fixed y-axis	Computed	m
					z	Front left wheel displacement along the vehicle-fixed z-axis	Computed	m
				Vel	xdot	Front left wheel velocity along the vehicle-fixed x-axis	Computed	m/s

Signal				Description	Value	Units		
		Right	Disp	ydot	Front left wheel velocity along the vehicle-fixed y-axis	Computed	m/s	
				zdot	Front left wheel velocity along the vehicle-fixed z-axis	0	m/s	
			x	Front right wheel displacement along the vehicle-fixed x-axis	Computed	m		
				y	Front right wheel displacement along the vehicle-fixed y-axis	Computed	m	
				z	Front right wheel displacement along the vehicle-fixed z-axis	Computed	m	
			Vel	xdot	Front right wheel velocity along the vehicle-fixed x-axis	Computed	m/s	
		ydot		Front right wheel velocity along the vehicle-fixed y-axis	Computed	m/s		
		zdot		Front right wheel velocity along the vehicle-fixed z-axis	0	m/s		
		Steer	WhlAngFL		Front left wheel steering angle	Computed	rad	
			WhlAngFR		Front right wheel steering angle	Computed	rad	
		MidlAxl	Lft	Disp	x	Middle left wheel displacement along the vehicle-fixed x-axis	Computed	m
					y	Middle left wheel displacement along the vehicle-fixed y-axis	Computed	m
					z	Middle left wheel displacement along the vehicle-fixed z-axis	Computed	m
				Vel	xdot	Middle left wheel velocity along the vehicle-fixed x-axis	Computed	m/s
ydot	Middle left wheel velocity along the vehicle-fixed y-axis				Computed	m/s		
zdot	Middle left wheel velocity along the vehicle-fixed z-axis				Computed	m/s		

Signal				Description	Value	Units			
			zdot	Middle left wheel velocity along the vehicle-fixed z-axis	0	m/s			
		Rght	Disp	x	Middle right wheel displacement along the vehicle-fixed x-axis	Computed	m		
				y	Middle right wheel displacement along the vehicle-fixed y-axis	Computed	m		
				z	Middle right wheel displacement along the vehicle-fixed z-axis	Computed	m		
			Vel	xdot	Middle right wheel velocity along the vehicle-fixed x-axis	Computed	m/s		
					ydot	Middle right wheel velocity along the vehicle-fixed y-axis	Computed	m/s	
						zdot	Middle right wheel velocity along the vehicle-fixed z-axis	0	m/s
			Steer	WhlAngRL		Middle left wheel steering angle	Computed	rad	
				WhlAngRR		Middle right wheel steering angle	Computed	rad	
	RearAxl		Lft	Disp	x	Rear left wheel displacement along the vehicle-fixed x-axis	Computed	m	
					y	Rear left wheel displacement along the vehicle-fixed y-axis	Computed	m	
					z	Rear left wheel displacement along the vehicle-fixed z-axis	Computed	m	
				Vel	xdot	Rear left wheel velocity along the vehicle-fixed x-axis	Computed	m/s	
						ydot	Rear left wheel velocity along the vehicle-fixed y-axis	Computed	m/s
							zdot	Rear left wheel velocity along the vehicle-fixed z-axis	0

Signal				Description	Value	Units	
	Right	Disp	x	Rear right wheel displacement along the vehicle-fixed x-axis	Computed	m	
			y	Rear right wheel displacement along the vehicle-fixed y-axis	Computed	m	
			z	Rear right wheel displacement along the vehicle-fixed z-axis	Computed	m	
		Vel	xdot	Rear right wheel velocity along the vehicle-fixed x-axis	Computed	m/s	
			ydot	Rear right wheel velocity along the vehicle-fixed y-axis	Computed	m/s	
			zdot	Rear right wheel velocity along the vehicle-fixed z-axis	0	m/s	
		Steer	WhlAngRL		Rear left wheel steering angle	Computed	rad
			WhlAngRR		Rear right wheel steering angle	Computed	rad
		Hitch	Disp	x	Hitch offset from axle plane along the vehicle-fixed x-axis	Input	m
	y			Hitch offset from center plane along the vehicle-fixed y-axis	Input	m	
z	Hitch offset from axle plane along the earth-fixed z-axis			Input	m		
Vel	xdot		Hitch offset velocity along the vehicle-fixed x-axis	Computed	m/s		
	ydot		Hitch offset velocity along the vehicle-fixed y-axis	Computed	m/s		
	zdot		Hitch offset velocity along the vehicle-fixed z-axis	0	m/s		
Pwr	Ext		Applied external power	Computed	W		
	Hitch		Power loss due to hitch	Computed	W		
	Drag		Power loss due to drag	Computed	W		
Geom	Disp	x	Vehicle chassis offset from axle plane along the vehicle-fixed x-axis	Input	m		



Signal				Description	Value	Units
			y	Vehicle chassis offset from center plane along the vehicle-fixed y-axis	Input	m
			z	Vehicle chassis offset from axle plane along the earth-fixed z-axis	Input	m
	Vel		xdo t	Vehicle chassis offset velocity along the vehicle-fixed x-axis	Computed	m/s
			ydo t	Vehicle chassis offset velocity along the vehicle-fixed y-axis	Computed	m/s
			zdo t	Vehicle chassis offset velocity along the vehicle-fixed z-axis	0	m/s
	Ang		Beta	Body slip angle, $\beta$  $\beta = \frac{V_y}{V_x}$	Computed	rad

Signal			Description	Value	Units
PwrInfo	PwrTrnsfrd	PwrFxExt	Externally applied longitudinal force power	Computed	W
		PwrFyExt	Externally applied lateral force power	Computed	W
		PwrMzExt	Externally applied yaw moment power	Computed	W
		PwrFwFLx	Longitudinal force applied at the front left axle power	Computed	W
		PwrFwFLy	Lateral force applied at the front left axle power	Computed	W
		PwrFwFRx	Longitudinal force applied at the front right axle power	Computed	W
		PwrFwFRy	Lateral force applied at the front right axle power	Computed	W
		PwrFwMLx	Longitudinal force applied at the middle left axle power	Computed	W
		PwrFwMLy	Lateral force applied at the middle left axle power	Computed	W
		PwrFwMRx	Longitudinal force applied at the middle right axle power	Computed	W
		PwrFwMRy	Lateral force applied at the middle right axle power	Computed	W

Signal		Description	Value	Units	
		PwrFwRLx	Longitudinal force applied at the rear left axle power	Computed	W
		PwrFwRLy	Lateral force applied at the rear left axle power	Computed	W
		PwrFwRRx	Longitudinal force applied at the rear right axle power	Computed	W
		PwrFwRRy	Lateral force applied at the rear right axle power	Computed	W
	PwrNotTrnsfrd	PwrFxDrag	Longitudinal drag force power	Computed	W
		PwrFyDrag	Lateral drag force power	Computed	W
		PwrMzDrag	Drag pitch moment power	Computed	W
	PwrStored	PwrStoredGrvty	Rate change in gravitational potential energy	Computed	W
		PwrStoredxdot	Rate of change of longitudinal kinetic energy	Computed	W
		PwrStoredydot	Rate of change of lateral kinetic energy	Computed	W
		PwrStoredr	Rate of change of rotational yaw kinetic energy	Computed	W

**xdot – Vehicle longitudinal velocity**

scalar

Vehicle CG velocity along the vehicle-fixed x-axis, in m/s.

**ydot – Vehicle lateral velocity**

scalar

Vehicle CG velocity along the vehicle-fixed y-axis, in m/s.

**psi – Yaw**

scalar

Rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw), in rad.

**r – Yaw rate**

scalar

Vehicle angular velocity,  $r$ , about the vehicle-fixed z-axis (yaw rate), in rad/s.

**FzF – Normal force on front wheels**

scalar | array

Normal force on the front wheels,  $F_{zF}$ , along the vehicle-fixed z-axis, in N.

Vehicle Track Setting	Description	Variable	Signal Dimension
Single (bicycle)	Normal force on front axle	$FzF = Fz_f$	Scalar - 1
Dual	Normal force on the right and left front wheels	$FzF = [Fz_{fl} \ Fz_{fr}]$	Array - [1x2]

### FzM – Normal force on middle wheels

scalar | array

Normal force on the middle wheels,  $Fz_M$ , along the vehicle-fixed z-axis, in N.

Vehicle Track Setting	Description	Variable	Signal Dimension
Single (bicycle)	Normal force on middle axle	$FzM = Fz_m$	Scalar - 1
Dual	Normal force on the right and left middle wheels	$FzM = [Fz_{ml} \ Fz_{rl}]$	Array - [1x2]

### FzR – Normal force on rear wheels

scalar | array

Normal force on the rear wheels,  $Fz_R$ , along the vehicle-fixed z-axis, in N.

Vehicle Track Setting	Description	Variable	Signal Dimension
Single (bicycle)	Normal force on rear wheel	$FzR = Fz_r$	Scalar - 1
Dual	Normal force on the right and left rear wheels	$FzR = [Fz_{rl} \ Fz_{rr}]$	Array - [1x2]

## Parameters

### Options

#### Vehicle track – Number of vehicle tracks

Dual (default) | Single (bicycle)

Use the **Vehicle track** parameter to specify the number of tracks.

Vehicle Track Setting	Implementation
Single (bicycle)	<ul style="list-style-type: none"> <li>Forces act along the center line of the axles.</li> <li>No lateral load transfer.</li> </ul>
Dual	Forces act at the axle hard-point locations.

**Axle forces – Type of axle force**

External longitudinal velocity (default) | External longitudinal forces | External forces

Use the **Axle forces** parameter to specify the type of force.

Axle Forces Setting	Implementation
External longitudinal velocity	<ul style="list-style-type: none"> <li>• The block assumes that the external longitudinal velocity is in a quasi-steady state, so the longitudinal acceleration is approximately zero.</li> <li>• Because the motion is quasi-steady, the block calculates lateral forces using the tire slip angles and linear cornering stiffness.</li> <li>• Consider this setting when you want to:                             <ul style="list-style-type: none"> <li>• Generate virtual sensor signal data.</li> <li>• Conduct high-level software studies that are not impacted by driveline or nonlinear tire responses.</li> </ul> </li> </ul>
External longitudinal forces	<ul style="list-style-type: none"> <li>• The block uses the external longitudinal force to accelerate or brake the vehicle.</li> <li>• The block calculates lateral forces using the tire slip angles and linear cornering stiffness.</li> <li>• Consider this setting when you want to:                             <ul style="list-style-type: none"> <li>• Account for changes in the longitudinal velocity on the lateral and yaw motion.</li> <li>• Specify the external longitudinal motion through a force instead of an external longitudinal velocity.</li> <li>• Connect the block to tractive actuators, wheels, brakes, and hitches.</li> </ul> </li> </ul>
External forces	<ul style="list-style-type: none"> <li>• The block uses the external lateral and longitudinal forces to steer, accelerate, or brake the vehicle.</li> <li>• The block does not use the steering input to calculate vehicle motion.</li> <li>• Consider this setting when you need tire models with more accurate nonlinear combined lateral and longitudinal slip.</li> </ul>

**Input Signals**

**Front wheel steering – WhlAngF input port**

on (default) | off

Select to create input port WhlAngF.

**Middle wheel steering – WhlAngM input port**

off (default) | on

Select to create input port WhlAngM.

**Rear wheel steering – WhlAngR input port**

off (default) | on

Select to create input port WhlAngR.

**External wind — WindXYZ input port**

off (default) | on

Select to create input port WindXYZ.

**External friction — Mu input port**

off (default) | on

Select to create input port Mu.

**Dependencies**

To enable this parameter, set **Axle forces** to External longitudinal forces or External forces.

**External forces — FExt input port**

off (default) | on

Select to create input port FExt.

**External moments — MExt input port**

off (default) | on

Select to create input port MExt.

**Hitch forces — Fh input port**

on (default) | off

Select to create input port Fh.

**Hitch moments — Mh input port**

on (default) | off

Specify to create input port Mh.

**Initial longitudinal position — X\_o input port**

off (default) | on

Specify to create input port X\_o.

**Initial yaw angle — psi\_o input port**

off (default) | on

Specify to create input port psi\_o.

**Initial longitudinal velocity — xdot\_o input port**

off (default) | on

Specify to create input port xdot\_o.

**Dependencies**

To enable this parameter, set **Axle forces** to External longitudinal forces or External forces.

**Initial yaw rate — r\_o input port**

off (default) | on

Specify to create input port r\_o.

**Initial lateral position — Y\_o input port**

off (default) | on

Specify to create input port Y\_o.

**Air temperature — AirTemp input port**

off (default) | on

Specify to create input port AirTemp.

**Initial lateral velocity — ydot\_o input port**

off (default) | on

Specify to create input port ydot\_o.

**Longitudinal**

**Number of wheels on front axle, NF — Front wheel count**

2 (default) | scalar

Number of wheels on the front axle,  $N_F$ , dimensionless.

**Number of wheels on middle axle, NM — Middle wheel count**

2 (default) | scalar

Number of wheels on the middle axle,  $N_M$ , dimensionless.

**Number of wheels on rear axle, NR — Rear wheel count**

2 (default) | scalar

Number of wheels on the rear axle,  $N_R$ , dimensionless.

**Vehicle mass, m — Vehicle mass**

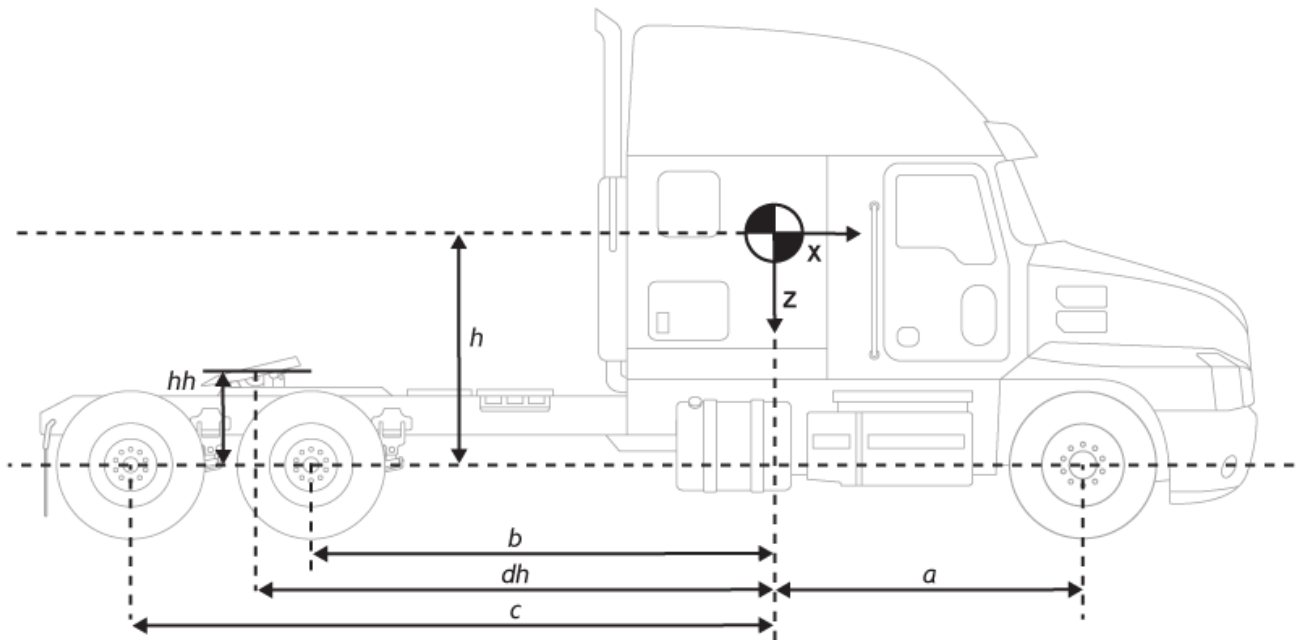
47000 (default) | scalar

Vehicle mass,  $m$ , in kg.

**Longitudinal distance from center of mass to front axle, a — Distance from CM to front axle**

0.5 (default) | scalar

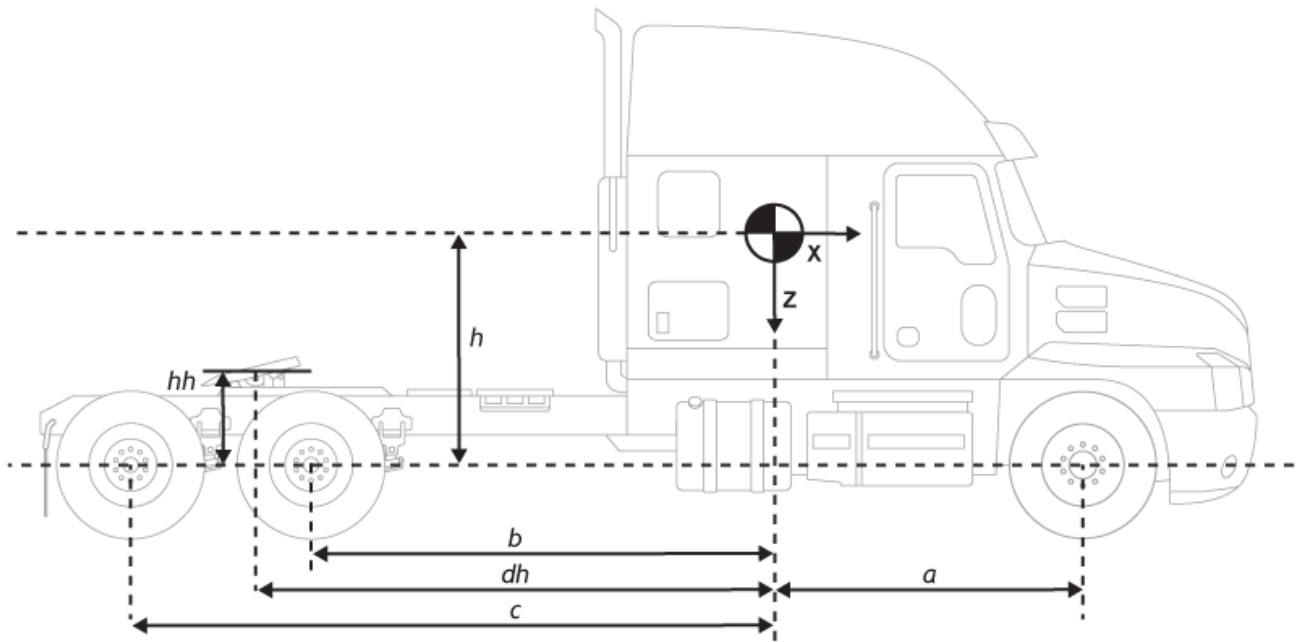
Distance from vehicle CM to front axle,  $a$ , in m.



**Longitudinal distance from center of mass to middle axle,  $b$  – Distance from CM to middle axle**

4.5 (default) | scalar

Distance from vehicle CM to middle axle,  $b$ , in m.

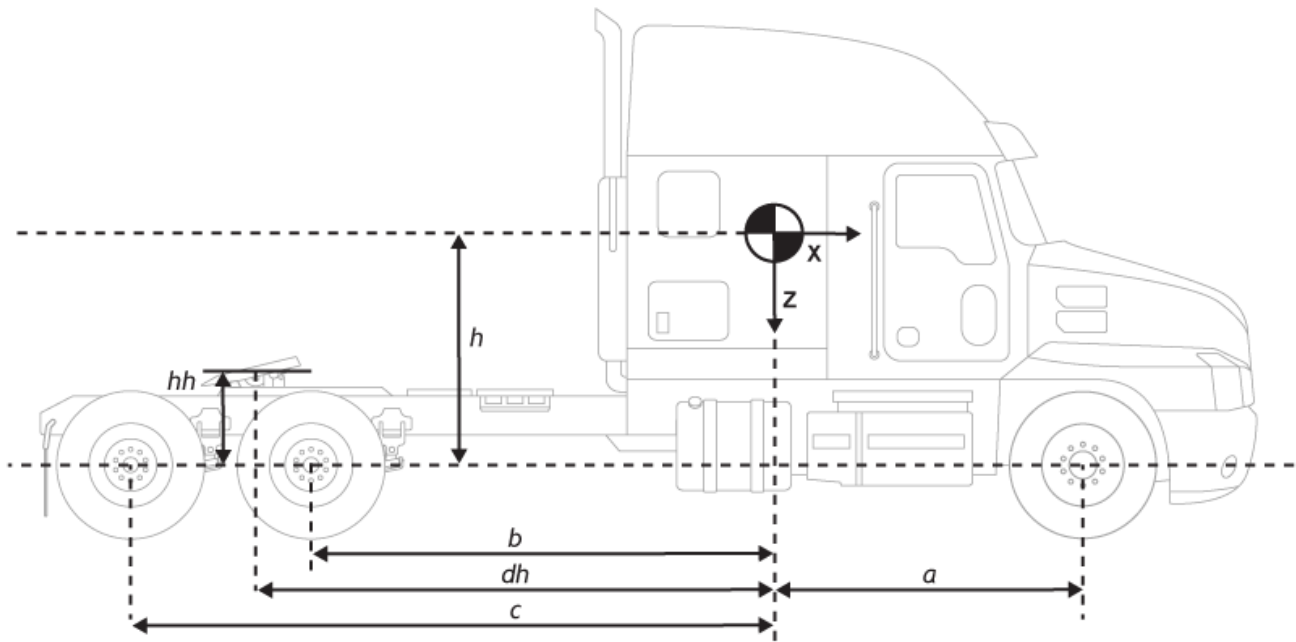


**Longitudinal distance from center of mass to rear axle,  $c$  – Distance from CM to rear axle**

5.7 (default) | scalar

Distance from vehicle CM to rear axle,  $c$ , in m.

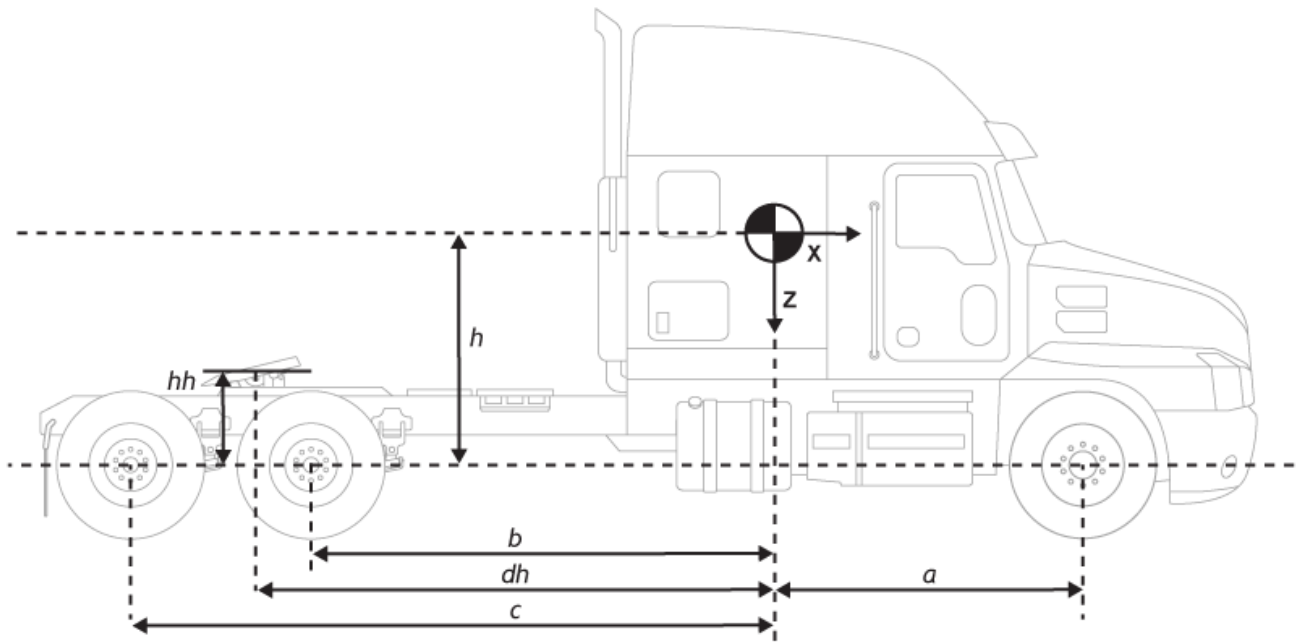




**Vertical distance from center of mass to axle plane,  $h$  – Distance from CM to axle plane**

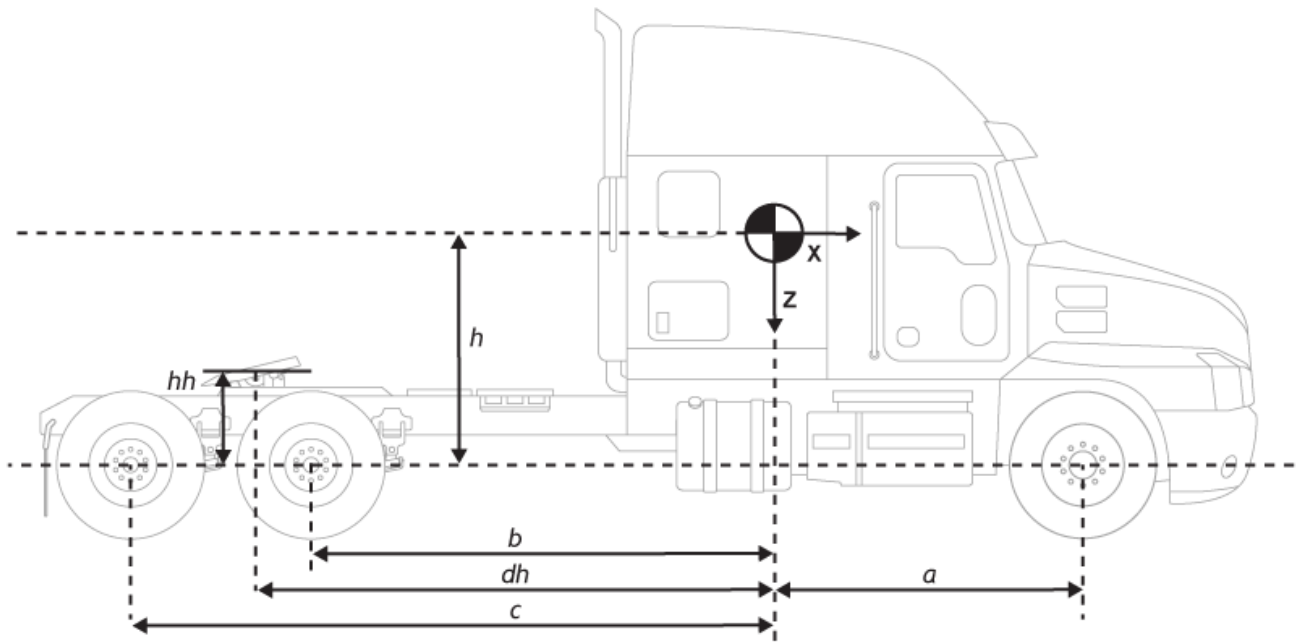
0.3 (default) | scalar

Vertical distance from vehicle CM to axle plane,  $h$ , in m.



**Vertical distance from hitch to axle plane,  $hh$  – Distance from hitch to axle plane**  
0.5 (default) | scalar

Vertical distance from hitch to axle plane,  $hh$ , in m.



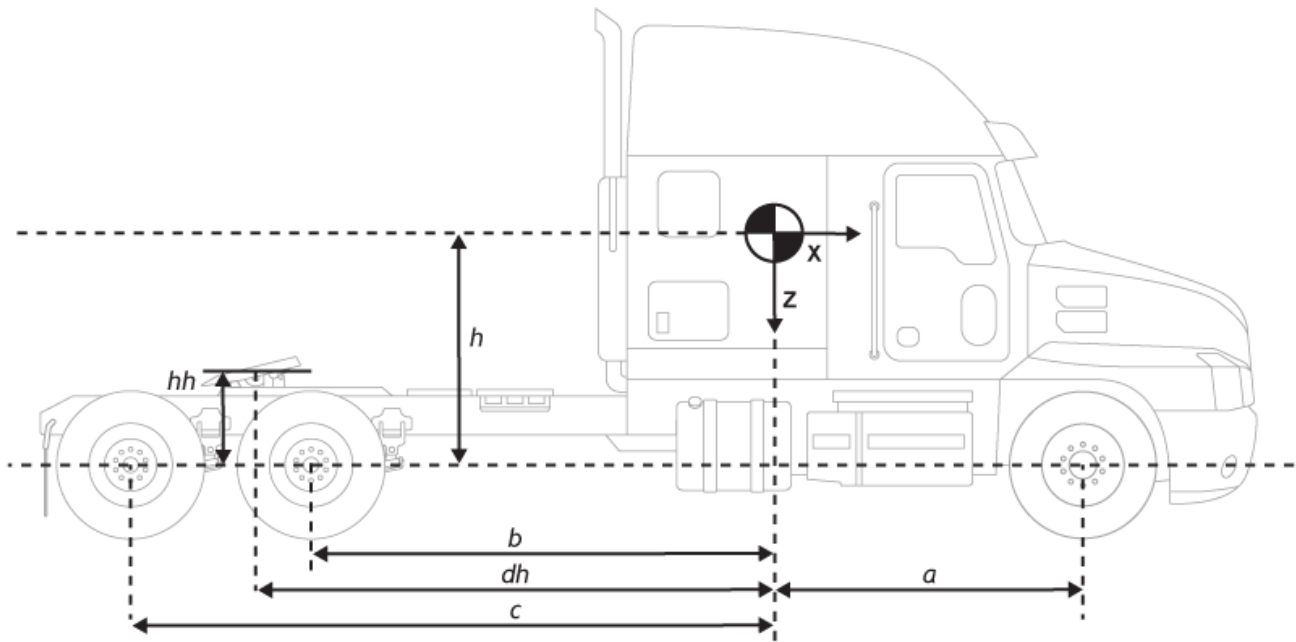
### Dependencies

To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.

**Longitudinal distance from center of mass to hitch,  $dh$  – Distance from CM to hitch**

5 (default) | scalar

Longitudinal distance from center of mass to hitch,  $dh$ , in m.



**Dependencies**

To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.

**Initial inertial frame longitudinal position,  $X_o$  – Initial longitudinal displacement**

0 (default) | scalar

Initial vehicle CG displacement along the earth-fixed X-axis, in m.

**Initial longitudinal velocity,  $\dot{x}_o$  – Initial longitudinal velocity**

0 (default) | scalar

Initial vehicle CG velocity along the vehicle-fixed x-axis, in m/s.

**Dependencies**

To enable this parameter, set **Axle forces** to one of these options:

- External longitudinal forces
- External forces

**Lateral**

**Mapped corner stiffness – Enable mapped corner stiffness**

off (default) | on

Enables mapped corner stiffness calculation.

**Dependencies**

To enable this parameter, set **Axle forces** to one of these options:

- External longitudinal velocity
- External longitudinal forces

**Include relaxation length dynamics — Enable relaxation length dynamics**

on (default) | off

Enables relaxation length dynamics.

**Dependencies**

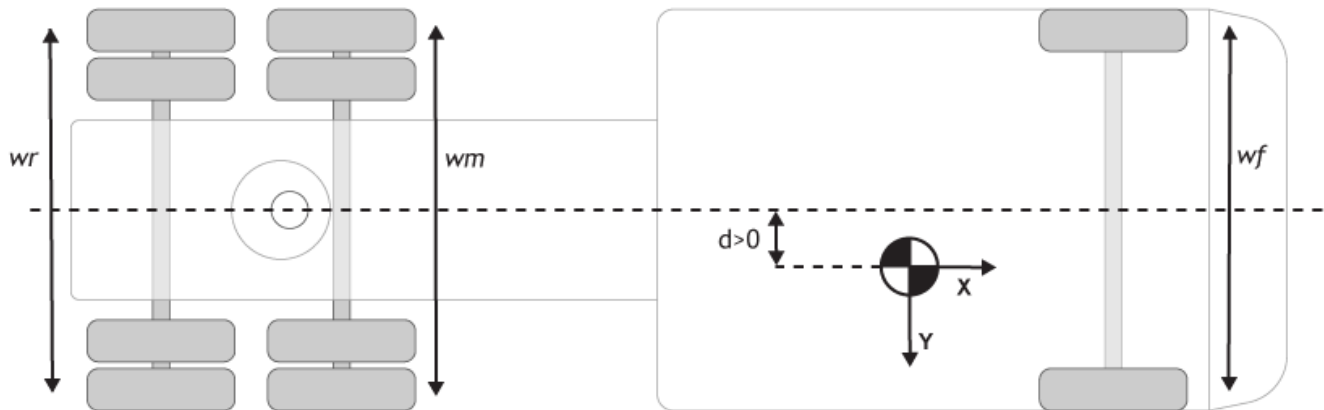
To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Clear **Mapped corner stiffness**.

**Lateral distance from geometric centerline to center of mass,  $d$  — Distance from centerline to CM**

0 (default) | scalar

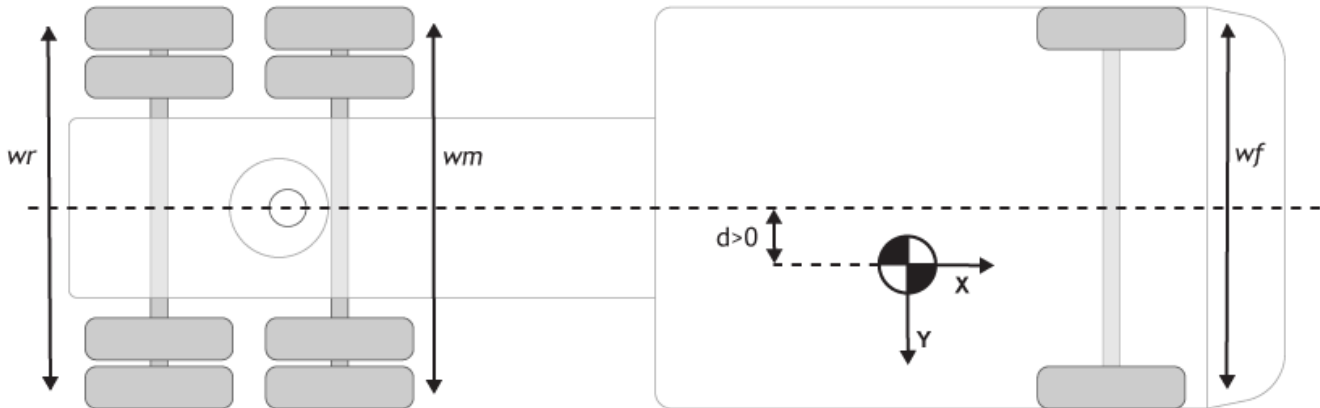
Lateral distance from the geometric centerline to the center of mass,  $d$ , in m, along the vehicle-fixed  $y$ -axis. Positive values indicate that the vehicle CM is to the right of the geometric centerline. Negative values indicate that the vehicle CM is to the left of the geometric centerline.



**Track width,  $w$  – Front, middle, and rear track widths**

[1.82, 1.82, 1.82] (default) | vector

Front, middle, and rear track widths,  $w_f$ ,  $w_m$ , and,  $w_r$ , respectively, in m. Dimensions are 1-by-3.



### Dependencies

To enable this parameter, set **Vehicle track** to Dual.

### Front axle tire corner stiffness, $C_{y_f}$ – Front tire corner stiffness

12e3 | scalar

Front tire corner stiffness,  $C_{y_f}$ , in N/rad.

### Dependencies

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Clear **Mapped corner stiffness**.

### Middle axle tire corner stiffness, $C_{y_m}$ – Middle tire corner stiffness

11e3 | scalar

Middle axle tire corner stiffness,  $C_{y_m}$ , in N/rad.

### Dependencies

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces

- 2 Clear **Mapped corner stiffness**.

**Rear axle tire corner stiffness,  $Cy_r$  – Rear tire corner stiffness**  
11e3 | scalar

Rear axle tire corner stiffness,  $Cy_r$ , in N/rad.

#### Dependencies

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces

- 2 Clear **Mapped corner stiffness**.

**Front tire(s) relaxation length,  $\sigma_f$  – Front tire relaxation length**  
.1 (default) | scalar

Front tire relaxation length,  $\sigma_f$ , in m.

#### Dependencies

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Do either of these:
  - Select **Mapped corner stiffness**.
  - Clear **Mapped corner stiffness** and select **Include relaxation length dynamics**.

**Middle tire(s) relaxation length,  $\sigma_m$  – Middle tire relaxation length**  
.1 (default) | scalar

Middle tire relaxation length,  $\sigma_m$ , in m.

#### Dependencies

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces

- 2 Do either of these:



- Select **Mapped corner stiffness**.
- Clear **Mapped corner stiffness** and select **Include relaxation length dynamics**.

**Rear tire(s) relaxation length, sigma\_r — Rear tire relaxation length**

.1 (default) | scalar

Rear tire relaxation length,  $\sigma_r$ , in m.**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Do either of these:
  - Select **Mapped corner stiffness**.
  - Clear **Mapped corner stiffness** and select **Include relaxation length dynamics**.

**Front axle slip angle breakpoints, alpha\_f\_brk — Breakpoints**

[-.1 .1] (default) | vector

Front axle slip angle breakpoints,  $\alpha_{fbrk}$ , in rad.**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Select **Mapped corner stiffness**.

**Front axle tire corner data, Cy\_f\_data — Front axle tire corner data**

[-9e3 9e3] (default) | vector

Front axle tire corner data,  $C_{y_{fdata}}$ , in N/rad.**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Select **Mapped corner stiffness**.

**Middle axle slip angle breakpoints, alpha\_m\_brk — Breakpoints**

[-.1 .1] (default) | vector

Middle axle slip angle breakpoints,  $\alpha_{mbrk}$ , in rad.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Select **Mapped corner stiffness**.

**Middle axle tire corner data,  $Cy\_m\_data$  — Middle axle tire corner data**

$[-9e3\ 9e3]$  (default) | vector

Middle axle tire corner data,  $Cy_{mdata}$ , in N/rad.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Select **Mapped corner stiffness**.

**Rear axle slip angle breakpoints,  $\alpha\_r\_brk$  — Breakpoints**

$[-.1\ .1]$  (default) | vector

Rear axle slip angle breakpoints,  $\alpha_{rbrk}$ , in rad.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Select **Mapped corner stiffness**.

**Rear axle tire corner data,  $Cy\_r\_data$  — Rear axle tire corner data**

$[-9e3\ 9e3]$  (default) | vector

Rear axle tire corner data,  $Cy_{rdata}$ , in N/rad.

**Dependencies**

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Select **Mapped corner stiffness**.

**Initial inertial frame lateral displacement,  $Y_o$  – Initial lateral displacement** $0$  (default) | scalarInitial vehicle CG displacement along the earth-fixed  $Y$ -axis, in m.**Initial lateral velocity,  $ydot_o$  – Initial lateral velocity** $0$  (default) | scalarInitial vehicle CG velocity along the vehicle-fixed  $y$ -axis, in m/s.**Yaw****Yaw polar inertia,  $I_{zz}$  – Inertia**

4000 (default) | scalar

Yaw polar inertia, in  $kg \cdot m^2$ .**Initial yaw angle,  $psi_o$  – Psi rotation** $0$  (default) | scalarRotation of the vehicle-fixed frame about earth-fixed  $Z$ -axis (yaw), in rad.**Initial yaw rate,  $r_o$  – Yaw rate** $0$  (default) | scalarVehicle angular velocity about the vehicle-fixed  $z$ -axis (yaw rate), in rad/s.**Aerodynamic****Longitudinal drag area,  $A_f$  – Effective vehicle cross-sectional area**

2 (default) | scalar

Effective vehicle cross-sectional area,  $A_f$ , to calculate the aerodynamic drag force on the vehicle, in  $m^2$ .**Longitudinal drag coefficient,  $C_d$  – Air drag coefficient**

.3 (default) | scalar

Air drag coefficient,  $C_d$ . The value is dimensionless.**Longitudinal lift coefficient,  $C_l$  – Air lift coefficient**

.1 (default) | scalar

Air lift coefficient,  $C_l$ . The value is dimensionless.**Longitudinal drag pitch moment,  $C_{pm}$  – Pitch drag**

.1 (default) | scalar

Longitudinal drag pitch moment coefficient,  $C_{pm}$ . The value is dimensionless.**Relative wind angle vector,  $beta_w$  – Wind angle**

[0:0.01:0.3] (default) | vector

Relative wind angle vector,  $\beta_w$ , in rad.**Side force coefficient vector,  $C_s$  – Side force coefficient**

[0:0.03:0.9] (default) | vector

Side force coefficient vector coefficient,  $C_s$ . The value is dimensionless.

**Yaw moment coefficient vector,  $C_{ym}$  — Yaw moment drag**  
[0:0.01:0.3] (default) | vector

Yaw moment coefficient vector coefficient,  $C_{ym}$ . The value is dimensionless.

#### Environment

**Absolute air pressure,  $P_{abs}$  — Pressure**  
101325 (default) | scalar

Environmental absolute pressure,  $P_{abs}$ , in Pa.

**Air temperature,  $T_{air}$  — Temperature**  
273 (default) | scalar

Environmental absolute temperature,  $T$ , in K.

#### Dependencies

To enable this parameter, clear **Air temperature**.

**Gravitational acceleration,  $g$  — Gravity**  
9.81 (default) | scalar

Gravitational acceleration,  $g$ , in  $m/s^2$ .

**Nominal friction scaling factor,  $\mu$  — Friction scale factor**  
1 (default) | scalar

Nominal friction scale factor,  $\mu$ . The value is dimensionless.

#### Dependencies

To enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Clear **External Friction**.

#### Simulation

**Longitudinal velocity tolerance,  $x_{dot\_tol}$  — Tolerance**  
.01 (default) | scalar

Longitudinal velocity tolerance, in m/s.

**Nominal normal force,  $F_{znom}$  — Normal force**  
5000 (default) | scalar

Nominal normal force, in N.

#### Dependencies

To enable this parameter, set **Axle forces** to one of these options:

- External longitudinal velocity
- External longitudinal forces

#### **Geometric longitudinal offset from axle plane, longOff – Longitudinal offset**

0 (default) | scalar

Vehicle chassis offset from the axle plane along the vehicle-fixed  $x$ -axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independently of the vehicle CG.

#### **Geometric lateral offset from center plane, latOff – Lateral offset**

0 (default) | scalar

Vehicle chassis offset from the center plane along the vehicle-fixed  $y$ -axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independently of the vehicle CG.

#### **Geometric vertical offset from axle plane, vertOff – Vertical offset**

0 (default) | scalar

Vehicle chassis offset from the axle plane along the vehicle-fixed  $z$ -axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independently of the vehicle CG.

#### **Wrap Euler angles, wrapAng – Wrap the Euler angles to the interval $[-\pi, \pi]$**

off (default) | on

Wrap the Euler angles to the interval  $[-\pi, \pi]$ . For vehicle maneuvers that might undergo vehicle yaw rotations that are outside of this interval, consider clearing the parameter if you want to:

- Track the total vehicle yaw rotation.
- Avoid discontinuities in the vehicle state estimators.

## **References**

- [1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers (SAE), 1992.

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

## **See Also**

Trailer Body 3DOF

## **Topics**

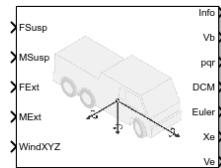
“Coordinate Systems in Vehicle Dynamics Blockset”

## **Introduced in R2020a**

## Vehicle Body 6DOF Three Axles

Three-axle vehicle tractor body with translational and rotational motion

**Library:** Vehicle Dynamics Blockset / Vehicle Body



### Description

The Vehicle Body 6DOF Three Axles block implements a six degrees-of-freedom (DOF) rigid three-axle vehicle body model that calculates longitudinal, lateral, vertical, pitch, roll, and yaw motion. Use the block to model three-axle vehicles like a tractor. The block accounts for body mass, inertia, aerodynamic drag, road incline, and weight distribution between the axle hard-point locations due to suspension and external forces and moments. Use the **Inertial Loads** parameters to analyze the vehicle dynamics under different loading conditions.

Connect the block to virtual sensors, suspension systems, or external systems like body control actuators. Use the Vehicle Body 6DOF Three Axles block in ride and handling studies to model the effects of drag forces, passenger loading, and suspension hardpoint locations.

To create additional input ports, under **Input signals**, select these block parameters.

Parameter	Input Port	Description
<b>Hitch forces</b>	Fh	Hitch force applied to the body at the hitch location, $Fh_x$ , $Fh_y$ , and $Fh_z$ , in the vehicle-fixed frame
<b>Hitch moments</b>	Mh	Hitch moment at the hitch location, $Mh_x$ , $Mh_y$ , and $Mh_z$ , about the vehicle-fixed frame

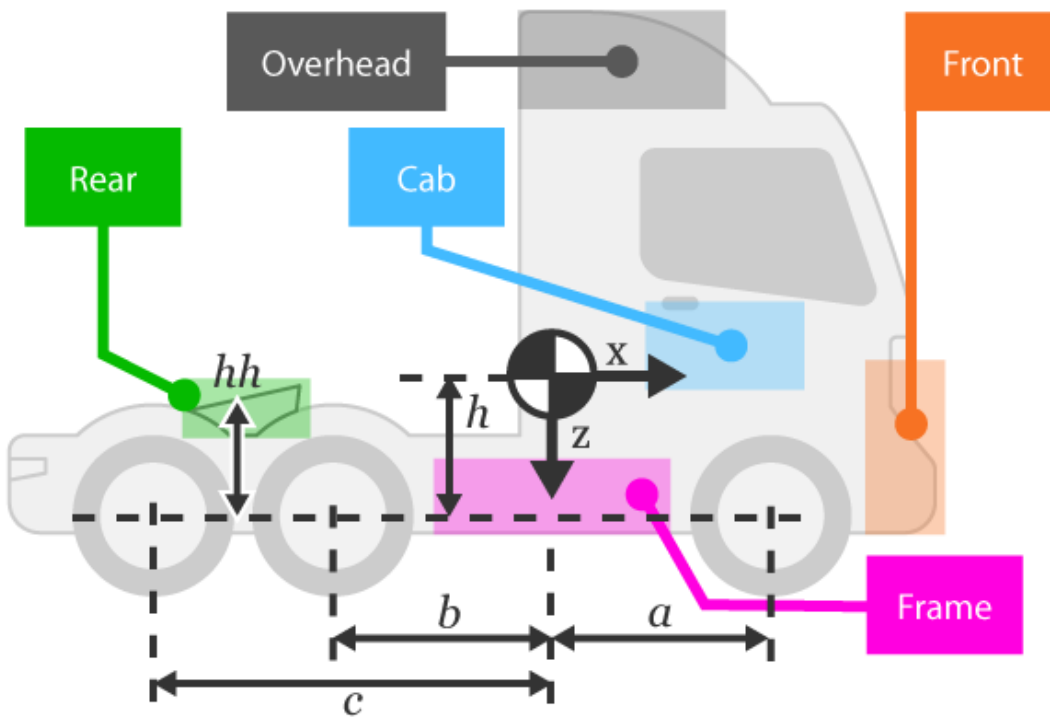
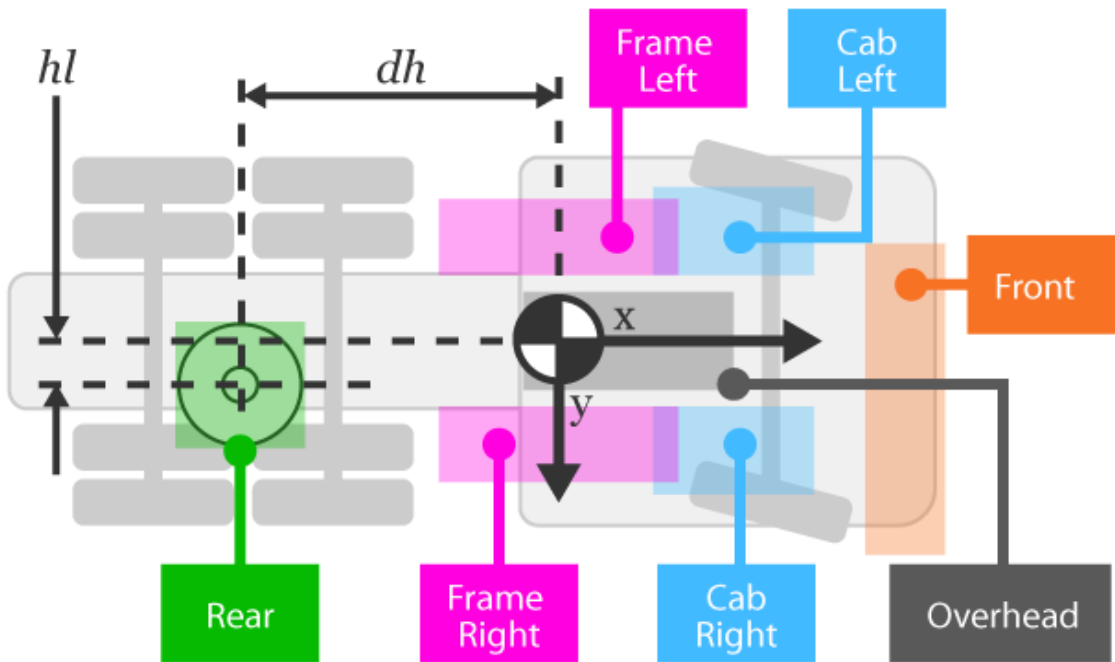
### Inertial Loads

To analyze the vehicle dynamics under different loading conditions, use the **Inertial Loads** parameters. You can specify these loads:

- Tractor front
- Cab overhead
- Tractor frame left and frame right
- Cab left and cab right
- Tractor rear

For each of the loads, you can specify the mass, location, and inertia.

The illustrations provide the load locations and vehicle parameter dimensions. The table provides the corresponding location parameter sign settings.



This table summarizes the parameter settings that specify the load locations indicated by the dots. For the location, the block uses this distance vector:

- Front axle to load, along the vehicle-fixed  $x$ -axis
- Vehicle centerline to load, along the vehicle-fixed  $y$ -axis
- Front axle to load, along the vehicle-fixed  $z$ -axis

Load	Parameter	Example Location
Tractor front	<b>Distance vector from front axle, <math>z1R</math></b>	<ul style="list-style-type: none"> <li>• <math>z1R(1,1) &lt; 0</math> — Forward of the front axle</li> <li>• <math>z1R(1,2) &gt; 0</math> — Right of the vehicle centerline</li> <li>• <math>z1R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Cab overhead	<b>Distance vector from front axle, <math>z2R</math></b>	<ul style="list-style-type: none"> <li>• <math>z2R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z2R(1,2) &lt; 0</math> — Left of the vehicle centerline</li> <li>• <math>z2R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Tractor frame left	<b>Distance vector from front axle, <math>z3R</math></b>	<ul style="list-style-type: none"> <li>• <math>z3R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z3R(1,2) &lt; 0</math> — Left of the vehicle centerline</li> <li>• <math>z3R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Tractor frame right	<b>Distance vector from front axle, <math>z4R</math></b>	<ul style="list-style-type: none"> <li>• <math>z4R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z4R(1,2) &gt; 0</math> — Right of the vehicle centerline</li> <li>• <math>z4R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Cab left	<b>Distance vector from front axle, <math>z5R</math></b>	<ul style="list-style-type: none"> <li>• <math>z5R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z5R(1,2) &lt; 0</math> — Left of the vehicle centerline</li> <li>• <math>z5R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Cab right	<b>Distance vector from front axle, <math>z6R</math></b>	<ul style="list-style-type: none"> <li>• <math>z6R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z6R(1,2) &gt; 0</math> — Right of the vehicle centerline</li> <li>• <math>z6R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>
Tractor rear	<b>Distance vector from front axle, <math>z7R</math></b>	<ul style="list-style-type: none"> <li>• <math>z7R(1,1) &gt; 0</math> — Rear of the front axle</li> <li>• <math>z7R(1,2) &gt; 0</math> — Right of the vehicle centerline</li> <li>• <math>z7R(1,3) &gt; 0</math> — Above the front axle suspension hardpoint</li> </ul>

### Equations of Motion

To determine the vehicle motion, the block implements calculations for the rigid body vehicle dynamics, wind drag, inertial loads, and coordinate transformations. The body-fixed and vehicle-fixed coordinate systems are the same.

The block considers the rotation of a body-fixed coordinate frame about a flat earth-fixed inertial reference frame. The origin of the body-fixed coordinate frame is the vehicle center of gravity of the body.



The block uses this equation to calculate the translational motion of the body-fixed coordinate frame, where the applied forces  $[F_x F_y F_z]^T$  are in the body-fixed frame, and the mass of the body,  $m$ , is assumed to be constant.

$$\bar{F}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = m(\dot{\bar{V}}_b + \bar{\omega} \times \bar{V}_b)$$

$$\bar{M}_b = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = I\dot{\bar{\omega}} + \bar{\omega} \times (I\bar{\omega})$$

$$I = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix}$$

To determine the relationship between the body-fixed angular velocity vector,  $[p \ q \ r]^T$ , and the rate of change of the Euler angles,  $[\dot{\phi} \ \dot{\theta} \ \dot{\psi}]^T$ , the block resolves the Euler rates into the body-fixed frame.

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} \dot{\phi} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} 0 \\ \dot{\theta} \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \dot{\psi} \end{bmatrix} \equiv J^{-1} \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}$$

Inverting  $J$  gives the required relationship to determine the Euler rate vector.

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = J \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & (\sin\phi\tan\theta) & (\cos\phi\tan\theta) \\ 0 & \cos\phi & -\sin\phi \\ 0 & \frac{\sin\phi}{\cos\theta} & \frac{\cos\phi}{\cos\theta} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

The applied forces and moments are the sum of the drag, gravitational, external, and suspension forces.

$$\bar{F}_b = \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \begin{bmatrix} F_{d_x} \\ F_{d_y} \\ F_{d_z} \end{bmatrix} + \begin{bmatrix} F_{g_x} \\ F_{g_y} \\ F_{g_z} \end{bmatrix} + \begin{bmatrix} F_{ext_x} \\ F_{ext_y} \\ F_{ext_z} \end{bmatrix} + \begin{bmatrix} F_{FL_x} \\ F_{FL_y} \\ F_{FL_z} \end{bmatrix} + \begin{bmatrix} F_{FR_x} \\ F_{FR_y} \\ F_{FR_z} \end{bmatrix} + \begin{bmatrix} F_{ML_x} \\ F_{ML_y} \\ F_{ML_z} \end{bmatrix} + \begin{bmatrix} F_{MR_x} \\ F_{MR_y} \\ F_{MR_z} \end{bmatrix} + \begin{bmatrix} F_{RL_x} \\ F_{RL_y} \\ F_{RL_z} \end{bmatrix} + \begin{bmatrix} F_{RR_x} \\ F_{RR_y} \\ F_{RR_z} \end{bmatrix}$$

$$\bar{M}_b = \begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} M_{d_x} \\ M_{d_y} \\ M_{d_z} \end{bmatrix} + \begin{bmatrix} M_{ext_x} \\ M_{ext_y} \\ M_{ext_z} \end{bmatrix} + \begin{bmatrix} M_{FL_x} \\ M_{FL_y} \\ M_{FL_z} \end{bmatrix} + \begin{bmatrix} M_{FR_x} \\ M_{FR_y} \\ M_{FR_z} \end{bmatrix} + \begin{bmatrix} M_{ML_x} \\ M_{ML_y} \\ M_{ML_z} \end{bmatrix} + \begin{bmatrix} M_{MR_x} \\ M_{MR_y} \\ M_{MR_z} \end{bmatrix} + \begin{bmatrix} M_{RL_x} \\ M_{RL_y} \\ M_{RL_z} \end{bmatrix} + \begin{bmatrix} M_{RR_x} \\ M_{RR_y} \\ M_{RR_z} \end{bmatrix} + \bar{M}_F$$

Calculation	Implementation
Load masses and inertias	The block uses the parallel axis theorem to resolve the individual load masses and inertias with the vehicle mass and inertia. $J_{ij} = I_{ij} + m( R ^2\delta_{ij} - R_iR_j)$

Calculation	Implementation
Gravitational forces, $F_g$	The block uses the direction cosine matrix (DCM) to transform the gravitational vector in the inertial-fixed frame to the body-fixed frame.
Drag forces, $F_d$ , and moments, $M_d$	<p>To determine a relative airspeed, the block subtracts the wind speed from the vehicle center of mass (CM) velocity. Using the relative airspeed, the block determines the drag forces.</p> $\bar{w} = \sqrt{(\dot{x}_b - w_x)^2 + (\dot{x}_y - w_y)^2 + (w_z)^2}$ $F_{dx} = -\frac{1}{2TR} C_d A_f P_{abs}(\bar{w})$ $F_{dy} = -\frac{1}{2TR} C_s A_f P_{abs}(\bar{w})$ $F_{dz} = -\frac{1}{2TR} C_l A_f P_{abs}(\bar{w})$ <p>Using the relative airspeed, the block determines the drag moments.</p> $M_{dr} = -\frac{1}{2TR} C_{rm} A_f P_{abs}(\bar{w})(a + c)$ $M_{dp} = -\frac{1}{2TR} C_{pm} A_f P_{abs}(\bar{w})(a + c)$ $M_{dy} = -\frac{1}{2TR} C_{ym} A_f P_{abs}(\bar{w})(a + c)$
External forces, $F_{in}$ , and moments, $M_{in}$	The external forces and moments are input via ports <b>FExt</b> and <b>MExt</b> .
Suspension forces and moments	<p>The block assumes that the suspension forces and moments act on these hardpoint locations:</p> <ul style="list-style-type: none"> <li>• <math>F_{FL}, M_{FL}</math> — Front left</li> <li>• <math>F_{FR}, M_{FR}</math> — Front right</li> <li>• <math>F_{ML}, M_{ML}</math> — Middle left</li> <li>• <math>F_{MR}, M_{MR}</math> — Middle right</li> <li>• <math>F_{RL}, M_{RL}</math> — Rear left</li> <li>• <math>F_{RR}, M_{RR}</math> — Rear right</li> </ul>

The equations use these variables.

$x, \dot{x}, \ddot{x}$	Vehicle CM displacement, velocity, and acceleration along the vehicle-fixed x-axis
$y, \dot{y}, \ddot{y}$	Vehicle CM displacement, velocity, and acceleration along the vehicle-fixed y-axis
$z, \dot{z}, \ddot{z}$	Vehicle CM displacement, velocity, and acceleration along the vehicle-fixed z-axis
$\varphi$	Rotation of the vehicle-fixed frame about the earth-fixed X-axis (roll)
$\theta$	Rotation of the vehicle-fixed frame about the earth-fixed Y-axis (pitch)

$\psi$	Rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw)
$F_{FLx}, F_{FLy}, F_{FLz}$	Suspension forces applied to the front left hardpoint along the vehicle-fixed x-, y-, and z-axes
$F_{FRx}, F_{FRy}, F_{FRz}$	Suspension forces applied to the front right hardpoint along the vehicle-fixed x-, y-, and z-axes
$F_{MLx}, F_{MLy}, F_{MLz}$	Suspension forces applied to the middle left hardpoint along the vehicle-fixed x-, y-, and z-axes
$F_{MRx}, F_{MRy}, F_{MRz}$	Suspension forces applied to the middle right hardpoint along the vehicle-fixed x-, y-, and z-axes
$F_{RLx}, F_{RLy}, F_{RLz}$	Suspension forces applied to the rear left hardpoint along the vehicle-fixed x-, y-, and z-axes
$F_{RRx}, F_{RRy}, F_{RRz}$	Suspension forces applied to the rear right hardpoint along the vehicle-fixed x-, y-, and z-axes
$M_{FLx}, M_{FLy}, M_{FLz}$	Suspension moment applied to the front left hardpoint about the vehicle-fixed x-, y-, and z-axes
$M_{FRx}, M_{FRy}, M_{FRz}$	Suspension moment applied to the front right hardpoint about the vehicle-fixed x-, y-, and z-axes
$M_{MLx}, M_{MLy}, M_{MLz}$	Suspension moment applied to the middle left hardpoint about the vehicle-fixed x-, y-, and z-axes
$M_{MRx}, M_{MRy}, M_{MRz}$	Suspension moment applied to the middle right hardpoint about the vehicle-fixed x-, y-, and z-axes
$M_{RLx}, M_{RLy}, M_{RLz}$	Suspension moment applied to the rear left hardpoint about the vehicle-fixed x-, y-, and z-axes
$M_{RRx}, M_{RRy}, M_{RRz}$	Suspension moment applied to the rear right hardpoint about the vehicle-fixed x-, y-, and z-axes
$F_{extx}, F_{exty}, F_{extz}$	External forces applied to the vehicle CM along the vehicle-fixed x-, y-, and z-axes
$F_{dx}, F_{dy}, F_{dz}$	Drag forces applied to the vehicle CM along the vehicle-fixed x-, y-, and z-axes
$M_{extx}, M_{exty}, M_{extz}$	External moment about the vehicle CM about the vehicle-fixed x-, y-, and z-axes
$M_{dx}, M_{dy}, M_{dz}$	Drag moment about the vehicle CM about the vehicle-fixed x-, y-, and z-axes
$I$	Vehicle body moments of inertia
$a, b, c$	Distance of the front, middle, and rear axles, respectively, from the normal projection point of the vehicle CM onto the common axle plane
$h$	Height of the vehicle CM above the axle plane
$d$	Lateral distance from the geometric centerline to the center of mass along the vehicle-fixed y-axis
$hh$	Height of the hitch above the axle plane along the vehicle-fixed z-axis
$dh$	Longitudinal distance of the hitch from the normal projection point of the vehicle CM onto the common axle plane
$hl$	Lateral distance from center of mass to the hitch along the vehicle-fixed y-axis.

$w_F, w_M, w_R$	Front, middle, and rear track widths, respectively
$C_d$	Air drag coefficient acting along the vehicle-fixed x-axis
$C_s$	Air drag coefficient acting along the vehicle-fixed y-axis
$C_l$	Air drag coefficient acting along the vehicle-fixed z-axis
$C_{rm}$	Air drag roll moment acting about the vehicle-fixed x-axis
$C_{pm}$	Air drag pitch moment acting about the vehicle-fixed y-axis
$C_{ym}$	Air drag yaw moment acting about the vehicle-fixed z-axis
$A_f$	Frontal area
$R$	Atmospheric specific gas constant
$T$	Environmental air temperature
$P_{abs}$	Environmental absolute pressure
$w_x, w_y, w_z$	Wind speed along the vehicle-fixed x-, y-, and z-axes
$W_x, W_y, W_z$	Wind speed along inertial X-, Y-, and Z-axes

## Ports

### Input

#### FSusp — Suspension forces on vehicle

3-by-6 array

Suspension longitudinal, lateral, and vertical suspension forces applied to the vehicle at the hardpoint location, in N, specified as a 3-by-6 array.

$$FSusp = \begin{bmatrix} F_{FLx} & F_{FRx} & F_{MLx} & F_{MRx} & F_{RLx} & F_{RRx} \\ F_{FLy} & F_{FRy} & F_{MLy} & F_{MRy} & F_{RLy} & F_{RRy} \\ F_{FLz} & F_{FRz} & F_{MLz} & F_{MRz} & F_{RLz} & F_{RRz} \end{bmatrix}$$

Array Element	Axle	Track	Force Axis
FSusp(1,1)	Front	Left	Vehicle-fixed x-axis (longitudinal)
FSusp(1,2)	Front	Right	
FSusp(1,3)	Middle	Left	
FSusp(1,4)	Middle	Right	
FSusp(1,5)	Rear	Left	
FSusp(1,6)	Rear	Right	
FSusp(2,1)	Front	Left	Vehicle-fixed y-axis (lateral)
FSusp(2,2)	Front	Right	
FSusp(2,3)	Middle	Left	
FSusp(2,4)	Middle	Right	
FSusp(2,5)	Rear	Left	
FSusp(2,6)	Rear	Right	
FSusp(3,1)	Front	Left	Vehicle-fixed z-axis (vertical)

Array Element	Axle	Track	Force Axis
FSusp(3,2)	Front	Right	
FSusp(3,3)	Middle	Left	
FSusp(3,4)	Middle	Right	
FSusp(3,5)	Rear	Left	
FSusp(3,6)	Rear	Right	

### MSusp – Suspension moment on vehicle

3-by-6 array

Suspension longitudinal, lateral, and vertical suspension moments applied about the vehicle at the hardpoint location, in N, specified as a 3-by-6 array.

$$MSusp = \begin{bmatrix} M_{FLx} & M_{FRx} & M_{MLx} & M_{MRx} & M_{RLx} & M_{RRx} \\ M_{FLy} & M_{FRy} & M_{MLy} & M_{MRy} & M_{RLy} & M_{RRy} \\ M_{FLz} & M_{FRz} & M_{MLz} & M_{MRz} & M_{RLz} & M_{RRz} \end{bmatrix}$$

Array Element	Axle	Track	Moment Axis
MSusp(1,1)	Front	Left	Vehicle-fixed x-axis (longitudinal)
MSusp(1,2)	Front	Right	
MSusp(1,3)	Middle	Left	
MSusp(1,4)	Middle	Right	
MSusp(1,5)	Rear	Left	
MSusp(1,6)	Rear	Right	
MSusp(2,1)	Front	Left	Vehicle-fixed y-axis (lateral)
MSusp(2,2)	Front	Right	
MSusp(2,3)	Middle	Left	
MSusp(2,4)	Middle	Right	
MSusp(2,5)	Rear	Left	
MSusp(2,6)	Rear	Right	
MSusp(3,1)	Front	Left	Vehicle-fixed z-axis (vertical)
MSusp(3,2)	Front	Right	
MSusp(3,3)	Middle	Left	
MSusp(3,4)	Middle	Right	
MSusp(3,5)	Rear	Left	
MSusp(3,6)	Rear	Right	

### FExt – External forces acting on vehicle

vector

External forces on the vehicle, in N, specified as a 1-by-3 or 3-by-1 vector.

$$FExt = F_{ext} = [F_{ext_x} \ F_{ext_y} \ F_{ext_z}] \text{ or } \begin{bmatrix} F_{ext_x} \\ F_{ext_y} \\ F_{ext_z} \end{bmatrix}$$

Array Element	Force Axis
FExt (1, 1)	Vehicle-fixed x-axis (longitudinal)
FExt (1, 2) or FExt (2, 1)	Vehicle-fixed y-axis (lateral)
FExt (1, 3) or FExt (3, 1)	Vehicle-fixed z-axis (vertical)

**MExt – External moments acting on vehicle**  
vector

External moments acting on the vehicle, in N·m, specified as a 1-by-3 or 3-by-1 vector.

$$MExt = M_{ext} = [M_{ext_x} \ M_{ext_y} \ M_{ext_z}] \text{ or } \begin{bmatrix} M_{ext_x} \\ M_{ext_y} \\ M_{ext_z} \end{bmatrix}$$

Array Element	Force Axis
MExt (1, 1)	Vehicle-fixed x-axis (longitudinal)
MExt (1, 2) or MExt (2, 1)	Vehicle-fixed y-axis (lateral)
MExt (1, 3) or MExt (3, 1)	Vehicle-fixed z-axis (vertical)

**Fh – Hitch force on the body**  
array

Hitch force applied to the body at the hitch location,  $Fh_x, Fh_y, Fh_z$ , in the vehicle-fixed frame, in N, specified as a 1-by-3 or 3-by-1 array.

**Dependencies**

To enable this port, under **Input signals**, select **Hitch forces**.

**Mh – Hitch moment about body**  
array

Hitch moment at the hitch location,  $Mh_x, Mh_y, Mh_z$ , about the vehicle-fixed frame, in N·m, specified as a 1-by-3 or 3-by-1 array.

**Dependencies**

To enable this port, under **Input signals**, select **Hitch moments**.

**WindXYZ – Wind speed**  
array

Wind speed,  $W_x$ ,  $W_y$ ,  $W_z$  along inertial X-, Y-, and Z-axes, in m/s, specified as a 1-by-3 or 3-by-1 array.

### AirTemp – Ambient air temperature

scalar

Ambient air temperature,  $T_{air}$ , in K, specified as a scalar.

#### Dependencies

To enable this port, under **Environment**, select **Air temperature**.

#### Output

### Info – Vehicle body information

bus

Vehicle body information, returned as a bus signal containing the following values.

Signal				Description	Value	Units
InertFrm	Cg	Disp	X	Vehicle CM displacement along the earth-fixed X-axis	Computed	m
			Y	Vehicle CM displacement along the earth-fixed Y-axis	Computed	m
			Z	Vehicle CM displacement along the earth-fixed Z-axis	Computed	m
		Vel	Xdot	Vehicle CM velocity along the earth-fixed X-axis	Computed	m/s
			Ydot	Vehicle CM velocity along the earth-fixed Y-axis	Computed	m/s
			Zdot	Vehicle CM velocity along the earth-fixed Z-axis	Computed	m/s
		Ang	phi	Rotation of the vehicle-fixed frame about the earth-fixed X-axis (roll)	Computed	rad
			theta	Rotation of the vehicle-fixed frame about the earth-fixed Y-axis (pitch)	Computed	rad
			psi	Rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw)	Computed	rad
	FrntAxl	Lft	Disp	X	Front left axle displacement along the earth-fixed X-axis	Computed

Signal				Description	Value	Units			
				Y	Front left axle displacement along the earth-fixed Y-axis	Computed	m		
				Z	Front left axle displacement along the earth-fixed Z-axis	Computed	m		
				Vel	Xdot	Front left axle velocity along the earth-fixed X-axis	Computed	m/s	
						Ydot	Front left axle velocity along the earth-fixed Y-axis	Computed	m/s
						Zdot	Front left axle velocity along the earth-fixed Z-axis	Computed	m/s
		Rght	Disp		X	Front right axle displacement along the earth-fixed X-axis	Computed	m	
					Y	Front right axle displacement along the earth-fixed Y-axis	Computed	m	
					Z	Front right axle displacement along the earth-fixed Z-axis	Computed	m	
			Vel		Xdot	Front right axle velocity along the earth-fixed X-axis	Computed	m/s	
	Ydot				Front right axle velocity along the earth-fixed Y-axis	Computed	m/s		
	Zdot				Front right axle velocity along the earth-fixed Z-axis	Computed	m/s		
	MidlAxl	Lft	Disp	X	Middle left axle displacement along the earth-fixed X-axis	Computed	m		
				Y	Middle left axle displacement along the earth-fixed Y-axis	Computed	m		
				Z	Middle left axle displacement along the earth-fixed Z-axis	Computed	m		
			Vel	Xdot	Middle left axle velocity along the earth-fixed X-axis	Computed	m/s		



Signal				Description	Value	Units		
				Ydot	Middle left axle velocity along the earth-fixed Y-axis	Computed	m/s	
				Zdot	Middle left axle velocity along the earth-fixed Z-axis	Computed	m/s	
		Rght	Disp		X	Middle right axle displacement along the earth-fixed X-axis	Computed	m
					Y	Middle right axle displacement along the earth-fixed Y-axis	Computed	m
					Z	Middle right axle displacement along the earth-fixed Z-axis	Computed	m
				Vel	Xdot	Middle right axle velocity along the earth-fixed X-axis	Computed	m/s
					Ydot	Middle right axle velocity along the earth-fixed Y-axis	Computed	m/s
					Zdot	Middle right axle velocity along the earth-fixed Z-axis	Computed	m/s
	RearAxl	Lft	Disp	X	Rear left axle displacement along the earth-fixed X-axis	Computed	m	
				Y	Rear left axle displacement along the earth-fixed Y-axis	Computed	m	
				Z	Rear left axle displacement along the earth-fixed Z-axis	Computed	m	
			Vel	Xdot	Rear left axle velocity along the earth-fixed X-axis	Computed	m/s	
				Ydot	Rear left axle velocity along the earth-fixed Y-axis	Computed	m/s	
				Zdot	Rear left axle velocity along the earth-fixed Z-axis	Computed	m/s	
Rght		Disp	X	Rear right axle displacement along the earth-fixed X-axis	Computed	m		

Signal				Description	Value	Units	
			Y	Rear right axle displacement along the earth-fixed Y-axis	Computed	m	
			Z	Rear right axle displacement along the earth-fixed Z-axis	Computed	m	
			Vel	Xdot	Rear right axle velocity along the earth-fixed X-axis	Computed	m/s
				Ydot	Rear right axle velocity along the earth-fixed Y-axis	Computed	m/s
				Zdot	Rear right axle velocity along the earth-fixed Z-axis	Computed	m/s
			Hitch	Disp	X	Hitch offset from the axle plane along the earth-fixed X-axis	Computed
	Y	Hitch offset from the axle plane along the earth-fixed Y-axis			Computed	m	
	Z	Hitch offset from the axle plane along the earth-fixed Z-axis			Computed	m	
	Vel	Xdot		Hitch velocity along the earth-fixed X-axis	Computed	m/s	
		Ydot		Hitch velocity along the earth-fixed Y-axis	Computed	m/s	
		Zdot		Hitch velocity along the earth-fixed Z-axis	Computed	m/s	
	Geom	Disp	X	Vehicle chassis offset from the axle plane along the earth-fixed X-axis	Computed	m	
			Y	Vehicle chassis offset from center plane along the earth-fixed Y-axis	Computed	m	
			Z	Vehicle chassis offset from the axle plane along the earth-fixed Z-axis	Computed	m	
		Vel	Xdot	Vehicle chassis offset velocity along the earth-fixed X-axis	Computed	m/s	

Signal			Description	Value	Units		
			Ydot	Vehicle chassis offset velocity along the earth-fixed Y-axis	Computed	m/s	
			Zdot	Vehicle chassis offset velocity along the earth-fixed Z-axis	Computed	m/s	
BdyFrm	Cg	Vel	xdot	Vehicle CM velocity along the vehicle-fixed x-axis	Computed	m/s	
			ydot	Vehicle CM velocity along the vehicle-fixed y-axis	Computed	m/s	
			zdot	Vehicle CM velocity along the vehicle-fixed z-axis	Computed	m/s	
		AngVel	p	Vehicle angular velocity about the vehicle-fixed x-axis (roll rate)	Computed	rad/s	
			q	Vehicle angular velocity about the vehicle-fixed y-axis (pitch rate)	Computed	rad/s	
			r	Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate)	Computed	rad/s	
		Acc	ax	Vehicle CM acceleration along the vehicle-fixed x-axis	Computed	gn	
			ay	Vehicle CM acceleration along the vehicle-fixed y-axis	Computed	gn	
			az	Vehicle CM acceleration along the vehicle-fixed z-axis	Computed	gn	
			xddot	Vehicle CM acceleration along the vehicle-fixed x-axis	Computed	m/s <sup>2</sup>	
			yddot	Vehicle CM acceleration along the vehicle-fixed y-axis	Computed	m/s <sup>2</sup>	
			zddot	Vehicle CM acceleration along the vehicle-fixed z-axis	Computed	m/s <sup>2</sup>	
		DCM	Direction cosine matrix		Computed	rad	
		Forces	Body	Fx	Net force on the vehicle CM along the vehicle-fixed x-axis	Computed	N

Signal			Description		Value	Units
	Ext	Fy	Net force on the vehicle CM along the vehicle-fixed y-axis		Computed	N
			Net force on the vehicle CM along the vehicle-fixed z-axis		Computed	N
		Fx	External force on the vehicle CM along the vehicle-fixed x-axis		Input	N
			External force on the vehicle CM along the vehicle-fixed x-axis		Input	N
			External force on the vehicle CM along the vehicle-fixed x-axis		Input	N
		FrntAx1	Lft	Fx	Front left axle velocity along the earth-fixed Y-axis	Computed
	Fy			Lateral force on the left side of the front axle left along the vehicle-fixed y-axis	Computed	N
	Fz			Normal force on the left side of the front axle along the vehicle-fixed z-axis	Computed	N
	Rght		Fx	Longitudinal force on the right side of the front axle along the vehicle-fixed x-axis	Computed	N
			Fy	Lateral force on the right side of the front axle left along the vehicle-fixed y-axis	Computed	N
			Fz	Normal force on the right side of the front axle along the vehicle-fixed z-axis	Computed	N
	MidlAx1	Lft	Fx	Longitudinal force on the left side of the middle axle along the vehicle-fixed x-axis	Computed	N

Signal				Description	Value	Units		
				Fy	Longitudinal force on the left side of the middle axle along the vehicle-fixed x-axis	Computed	N	
				Fz	Normal force on the left side of the middle axle along the vehicle-fixed z-axis	Computed	N	
				Rght	Fx	Longitudinal force on the right side of the middle axle along the vehicle-fixed x-axis	Computed	N
					Fy	Lateral force on the right side of the middle axle left along the vehicle-fixed y-axis	Computed	N
					Fz	Normal force on the right side of the middle axle along the vehicle-fixed z-axis	Computed	N
				RearAx1	Lft	Fx	Longitudinal force on the left side of the rear axle along the vehicle-fixed x-axis	Computed
			Fy			Lateral force on the left side of the rear axle left along the vehicle-fixed y-axis	Computed	N
			Fz			Normal force on the left side of the rear axle along the vehicle-fixed z-axis	Computed	N
			Rght		Fx	Longitudinal force on the right side of the rear axle along the vehicle-fixed x-axis	Computed	N
					Fy	Lateral force on the right side of the rear axle left along the vehicle-fixed y-axis	Computed	N
					Fz	Normal force on the right side of the rear axle along the vehicle-fixed z-axis	Computed	N
					Hitch	Fx	Hitch force applied to the body at the hitch location along the vehicle-fixed x-axis	Computed

Signal			Description			Value	Units	
			Fy		Hitch force applied to the body at the hitch location along the vehicle-fixed y-axis	Computed	N	
			Fz		Hitch force applied to the body at the hitch location along the vehicle-fixed z-axis	Computed	N	
	Tires	FrntTires	L	F	Front left tire force along the vehicle-fixed x-axis	Computed	N	
					F	Front left tire force along the vehicle-fixed y-axis	Computed	N
					F	Front left tire force along the vehicle-fixed z-axis	Computed	N
				R	F	Front right tire force along the vehicle-fixed x-axis	Computed	N
					F	Front right tire force along the vehicle-fixed y-axis	Computed	N
					F	Front right tire force along the vehicle-fixed z-axis	Computed	N
			MidlTires	L	F	Middle left tire force along the vehicle-fixed x-axis	Computed	N
					F	Middle left tire force along the vehicle-fixed y-axis	Computed	N
					F	Middle left tire force along the vehicle-fixed z-axis	Computed	N
				R	F	Middle right tire force along the vehicle-fixed x-axis	Computed	N
					F	Middle right tire force along the vehicle-fixed y-axis	Computed	N
					F	Middle right tire force along the vehicle-fixed z-axis	Computed	N
			RearTires	L	F	Rear left tire force along the vehicle-fixed x-axis	Computed	N

Signal					Description	Value	Units	
			R g h t	F y	Rear left tire force along the vehicle-fixed y-axis	Computed	N	
				F z	Rear left tire force along the vehicle-fixed z-axis	Computed	N	
				F x	Rear right tire force along the vehicle-fixed x-axis	Computed	N	
				F y	Rear right tire force along the vehicle-fixed y-axis	Computed	N	
				F z	Rear right tire force along the vehicle-fixed z-axis	Computed	N	
				Drag	Fx	Drag force on the vehicle CM along the vehicle-fixed x-axis	Computed	N
				Fy	Drag force on the vehicle CM along the vehicle-fixed y-axis	Computed	N	
				Fz	Drag force on the vehicle CM along the vehicle-fixed z-axis	Computed	N	
			Grvty	Fx	Gravity force on the vehicle CM along the vehicle-fixed x-axis	Computed	N	
				Fy	Gravity force on the vehicle CM along the vehicle-fixed y-axis	Computed	N	
				Fz	Gravity force on the vehicle CM along the vehicle-fixed z-axis	Computed	N	
			Moments	Body	Mx	Body moment on the vehicle CM about the vehicle-fixed x-axis	Computed	N·m
					My	Body moment on the vehicle CM about the vehicle-fixed y-axis	Computed	N·m
					Mz	Body moment on the vehicle CM about the vehicle-fixed z-axis	Computed	N·m
				Drag	Mx	Drag moment on the vehicle CM about the vehicle-fixed x-axis	Computed	N·m
					My	Drag moment on the vehicle CM about the vehicle-fixed y-axis	Computed	N·m

Signal		Description		Value	Units			
		Ext	Mz	Drag moment on the vehicle CM about the vehicle-fixed z-axis	Computed	N·m		
			Mx	External moment on the vehicle CG about the vehicle-fixed x-axis	Computed	N·m		
			My	External moment on the vehicle CG about the vehicle-fixed y-axis	Computed	N·m		
		Hitch	Mz	External moment on the vehicle CG about the vehicle-fixed z-axis	Computed	N·m		
			Mx	Hitch moment at the hitch location about vehicle-fixed x-axis	Computed	N·m		
			My	Hitch moment at the hitch location about vehicle-fixed y-axis	Computed	N·m		
		FrntAxl	Lft	Disp	x	Front left axle displacement along the vehicle-fixed x-axis	Computed	m
					y	Front left axle displacement along the vehicle-fixed y-axis	Computed	m
					z	Front left axle displacement along the vehicle-fixed z-axis	Computed	m
	Vel			xdo t	Front left axle velocity along the vehicle-fixed x-axis	Computed	m/s	
				ydo t	Front left axle velocity along the vehicle-fixed y-axis	Computed	m/s	
				zdo t	Front left axle velocity along the vehicle-fixed z-axis	Computed	m/s	
	Rght	Disp	x	Front right axle displacement along the vehicle-fixed x-axis	Computed	m		
			y	Front right axle displacement along the vehicle-fixed y-axis	Computed	m		



Signal				Description	Value	Units		
				z	Front right axle displacement along the vehicle-fixed z-axis	Computed	m	
			Vel	xdo t	Front right axle velocity along the vehicle-fixed x-axis	Computed	m/s	
				ydo t	Front right axle velocity along the vehicle-fixed y-axis	Computed	m/s	
				zdo t	Front right axle velocity along the vehicle-fixed z-axis	Computed	m/s	
	MidlAxl	Lft	Disp	x	Middle left axle displacement along the vehicle-fixed x-axis	Computed	m	
				y	Middle left axle displacement along the vehicle-fixed y-axis	Computed	m	
				z	Middle left axle displacement along the vehicle-fixed z-axis	Computed	m	
			Vel	xdo t	Middle left axle velocity along the vehicle-fixed x-axis	Computed	m/s	
				ydo t	Middle left axle velocity along the vehicle-fixed y-axis	Computed	m/s	
				zdo t	Middle left axle velocity along the vehicle-fixed z-axis	Computed	m/s	
			Rght	Disp	x	Middle right axle displacement along the vehicle-fixed x-axis	Computed	m
		y			Middle right axle displacement along the vehicle-fixed y-axis	Computed	m	
		z			Middle right axle displacement along the vehicle-fixed z-axis	Computed	m	
	Vel	xdo t		Middle right axle velocity along the vehicle-fixed x-axis	Computed	m/s		
		ydo t		Middle right axle velocity along the vehicle-fixed y-axis	Computed	m/s		

Signal				Description	Value	Units	
				zdot	Middle right axle velocity along the vehicle-fixed z-axis	Computed	m/s
	RearAxl	Lft	Disp	x	Rear left axle displacement along the vehicle-fixed x-axis	Computed	m
				y	Rear left axle displacement along the vehicle-fixed y-axis	Computed	m
				z	Rear left axle displacement along the vehicle-fixed z-axis	Computed	m
			Vel	xdot	Rear left axle velocity along the vehicle-fixed x-axis	Computed	m/s
				ydot	Rear left axle velocity along the vehicle-fixed y-axis	Computed	m/s
				zdot	Rear left axle velocity along the vehicle-fixed z-axis	Computed	m/s
		Rght	Disp	x	Rear right axle displacement along the vehicle-fixed x-axis	Computed	m
				y	Rear right axle displacement along the vehicle-fixed y-axis	Computed	m
				z	Rear right axle displacement along the vehicle-fixed z-axis	Computed	m
			Vel	xdot	Rear right axle velocity along the vehicle-fixed x-axis	Computed	m/s
				ydot	Rear right axle velocity along the vehicle-fixed y-axis	Computed	m/s
				zdot	Rear right axle velocity along the vehicle-fixed z-axis	Computed	m/s
	Hitch	Disp	x	Hitch offset from the axle plane along the vehicle-fixed x-axis	Input	m	
			y	Hitch offset from center plane along the vehicle-fixed y-axis	Input	m	

Signal				Description	Value	Units	
	Vel		z	Hitch offset from the axle plane along the vehicle-fixed z-axis	Input	m	
			xdo t	Hitch offset velocity along the vehicle-fixed x-axis	Computed	m/s	
			ydo t	Hitch offset velocity along the vehicle-fixed y-axis	Computed	m/s	
			zdo t	Hitch offset velocity along the vehicle-fixed z-axis	Computed	m/s	
	Pwr	PwrExt	Applied external power		Computed	W	
			Drag		Computed	W	
	Geom	Disp		x	Vehicle chassis offset from the axle plane along the vehicle-fixed x-axis	Input	m
				y	Vehicle chassis offset from center plane along the vehicle-fixed y-axis	Input	m
				z	Vehicle chassis offset from the axle plane along the vehicle-fixed z-axis	Input	m
		Vel		xdo t	Vehicle chassis offset velocity along the vehicle-fixed x-axis	Computed	m/s
				ydo t	Vehicle chassis offset velocity along the vehicle-fixed y-axis	Computed	m/s
				zdo t	Vehicle chassis offset velocity along the vehicle-fixed z-axis	Computed	m/s
		Ang		Beta	Body slip angle, $\beta$	Computed	rad
					$\beta = \frac{V_y}{V_x}$		

**Vb – Vehicle velocity along vehicle-fixed frame**

vector

Vehicle CM velocity along the vehicle-fixed x-, y-, z-axes, respectively, in m/s, returned as a vector.

**pqr – Vehicle angular velocity about vehicle-fixed frame**

vector

Vehicle CM angular velocity about the vehicle-fixed x- (roll rate), y- (pitch rate), z-axes (yaw rate), respectively, in rad/s, returned as a vector.

**DCM – Direction cosine matrix**

array

Direction cosine matrix, in rad, returned as an array.

**Euler – Euler angles**

array

Euler angles,  $\varphi$ ,  $\theta$ , and  $\psi$ , respectively, in rad, returned as an array.

**Xe – Vehicle position in inertial reference frame**

vector

Vehicle CM position along inertial-fixed X-, Y-, Z-axes, respectively, in m, returned as a vector.

**Ve – Vehicle velocity in inertial reference frame**

vector

Vehicle CM velocity along inertial-fixed X-, Y-, Z-axes, respectively, in m/s, returned as a vector.

**Parameters****Block Options****Input Signals****Hitch forces – Create hitch force input port**

off (default) | on

Select to create an input port, Fh, for the hitch forces.

**Hitch moments – Create hitch moment input port**

off (default) | on

Select to create an input port, Mh, for the hitch moments.

**Chassis****Vehicle mass, m – Mass**

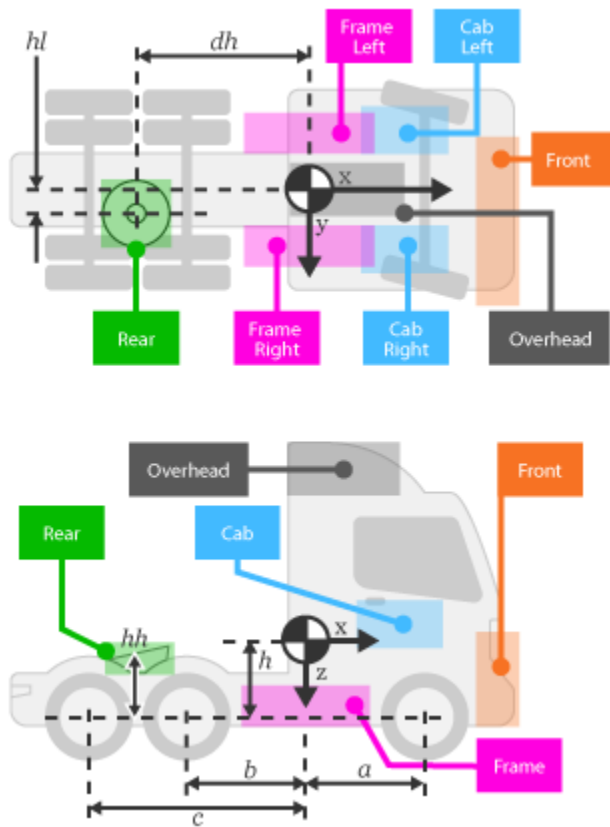
2000 (default) | scalar

Vehicle mass,  $m$ , in kg.

**Longitudinal distance from center of mass to front axle, a – Distance from center of mass to front axle**

1.4 (default) | scalar

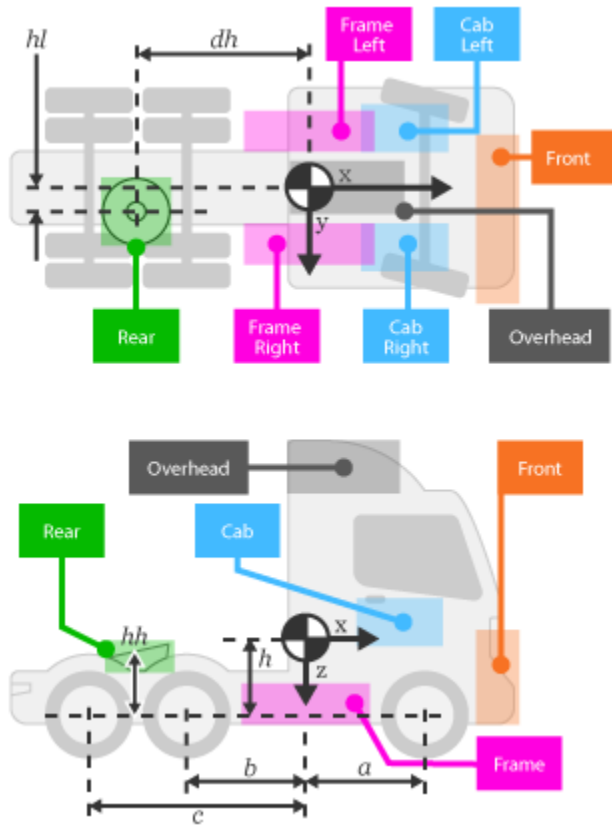
Distance from the vehicle CM to the front axle,  $a$ , in m.



**Longitudinal distance from center of mass to middle axle,  $b$  – Distance from center of mass to middle axle**

1.6 (default) | scalar

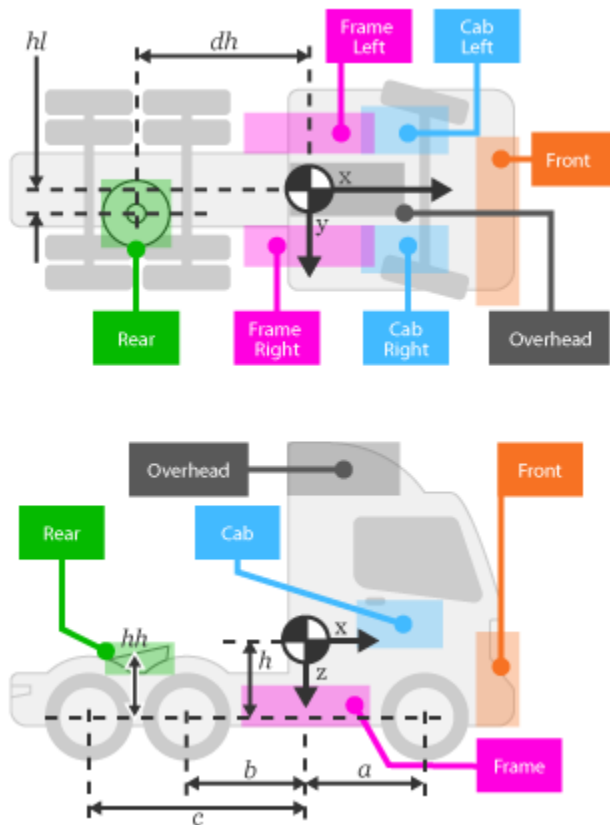
Distance from the vehicle CM to the middle axle,  $b$ , in m.



**Longitudinal distance from center of mass to rear axle,  $c$  – Distance from center of mass to rear axle**

1.8 (default) | scalar

Distance from the vehicle CM to the rear axle,  $c$ , in m.



**Lateral distance from geometric centerline to center of mass,  $d$  – Distance from geometric centerline to center of mass**

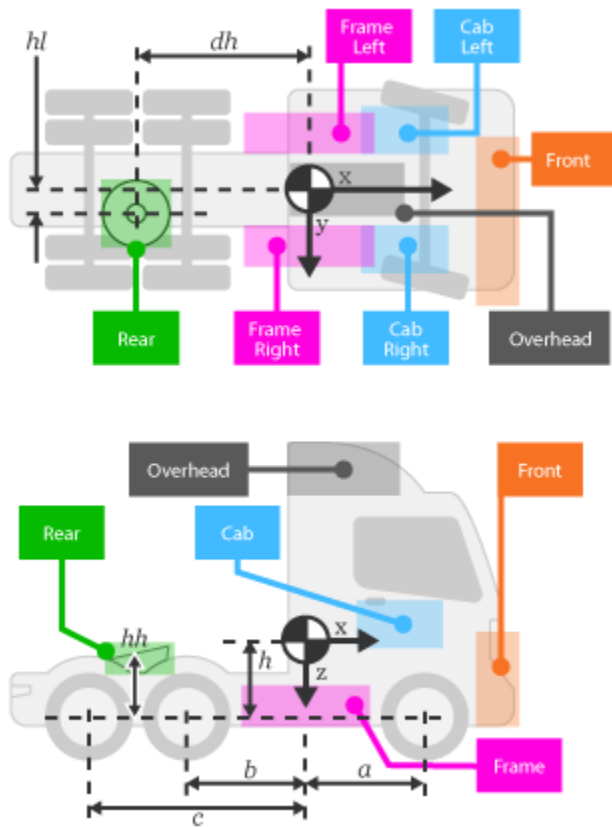
0 (default) | scalar

Lateral distance from the geometric centerline to the CM,  $d$ , in m, along the vehicle-fixed  $y$ . Positive values indicate that the vehicle CM is to the right of the geometric centerline. Negative values indicate that the vehicle CM is to the left of the geometric centerline.

**Vertical distance from center of mass to axle plane,  $h$  – Distance**

.35 (default) | scalar

Vertical distance from the vehicle CM to the axle plane,  $h$ , in m.

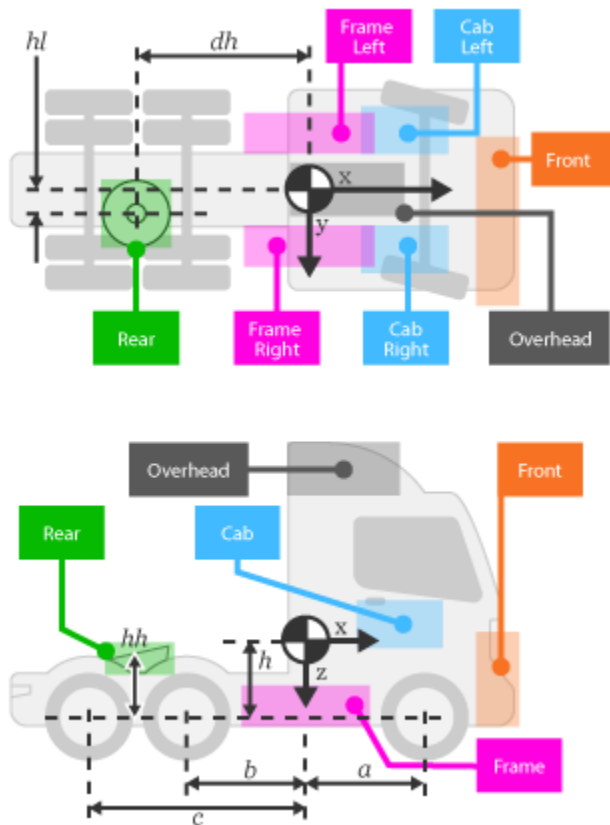


**Longitudinal distance from center of mass to hitch,  $dh$  – Longitudinal distance from CM to hitch**

1 (default) | scalar

Longitudinal distance from the CM to the hitch,  $dh$ , in m.





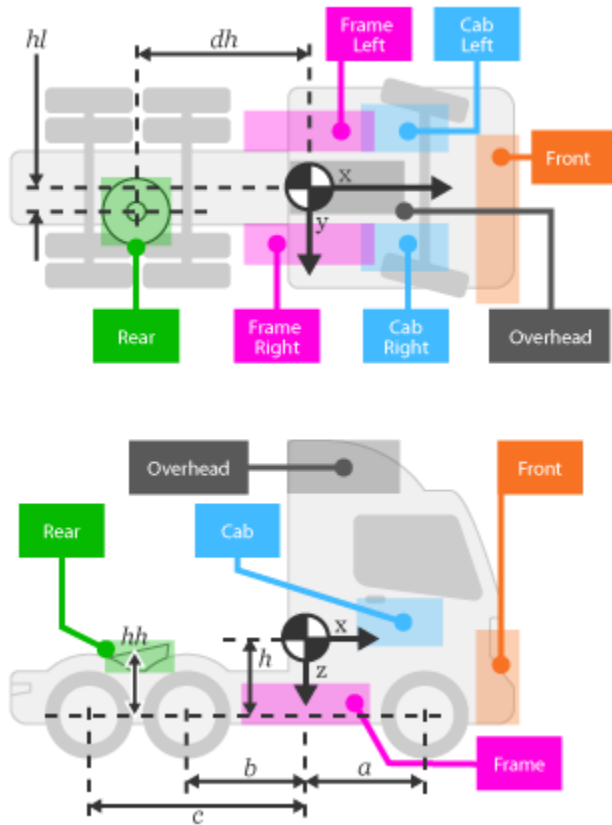
### Dependencies

To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.

**Longitudinal distance from center of mass to hitch,  $hl$  – Lateral distance from CM to hitch**

0 (default) | scalar

Lateral distance from the CM to the hitch,  $hl$ , in m.

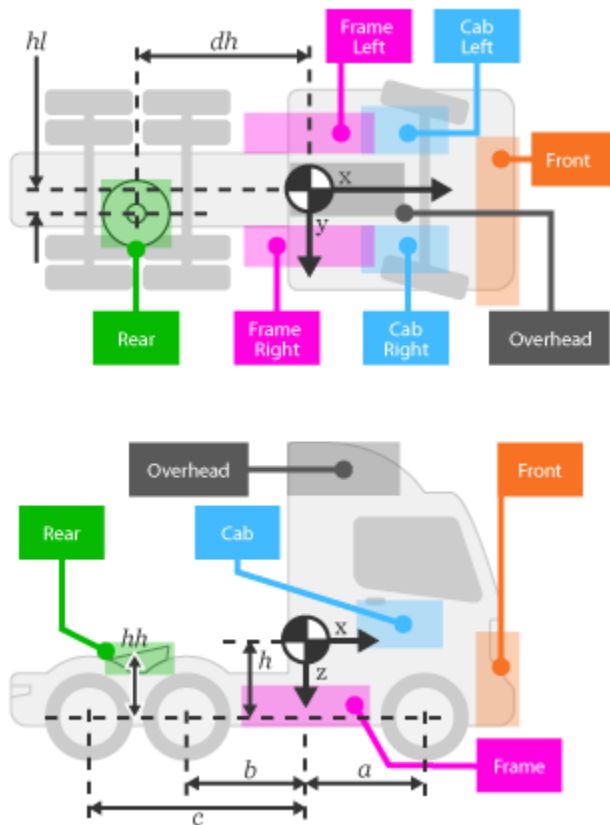


**Dependencies**

To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.

**Vertical distance from hitch to axle plane, hh** — Distance from hitch to axle plane  
 0.1 (default) | scalar

Vertical distance from the hitch to the axle plane,  $hh$ , in m.



### Dependencies

To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.

**Initial position in the inertial frame [Xeo, Yeo, Zeo], Xe\_o – Initial position**  
[0, 0, 0] (default) | vector

Initial position of the vehicle in the inertial frame,  $Xe_o$ , in m.

**Initial velocity in body axes [xdot\_o, ydot\_o, zdot\_o], xbdot\_o – Initial velocity**  
[0, 0, 0] (default) | vector

Initial vehicle CM velocity along the vehicle-fixed  $x$ ,  $y$ -, and  $z$ -axes, respectively, in m/s.

**Initial Euler orientation [roll, pitch, yaw], eul\_o – Initial Euler rotation**  
[0, 0, 0] (default) | vector

Initial Euler rotation of the vehicle-fixed frame about the earth-fixed  $X$ - (roll),  $Y$ - (pitch),  $Z$ -axes (yaw), respectively, in rad.

**Initial body rotation rates [p, q, r], p\_o – Initial rotation rate**  
[0, 0, 0] (default) | vector

Initial vehicle CM angular velocity about the vehicle-fixed  $x$ - (roll rate),  $y$ - (pitch rate),  $z$ -axes (yaw rate), respectively, in rad/s.

**Chassis inertia tensor,  $I_{veh}$  – Inertia**

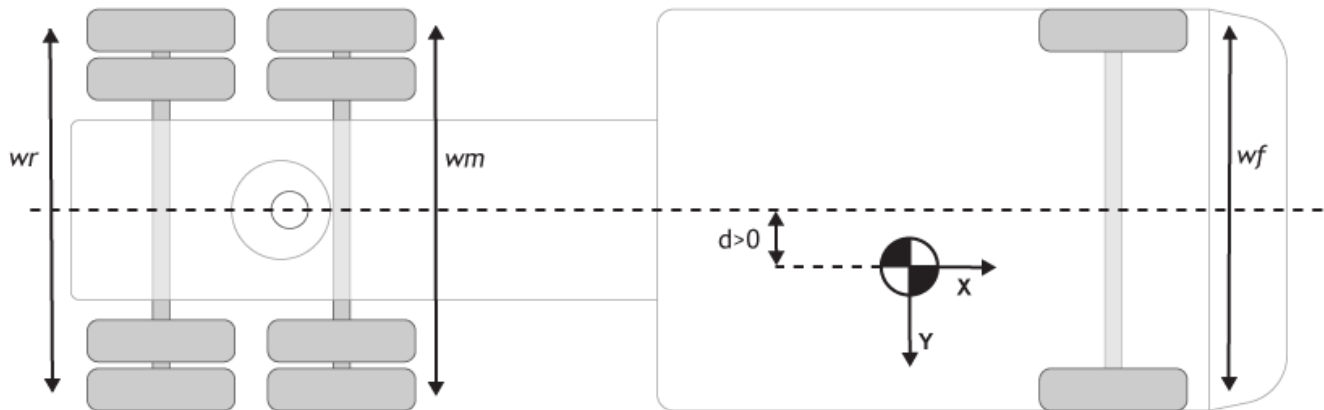
[430 0 0; 0 1900 0; 0 0 2100] (default) | array

Vehicle inertia tensor,  $I_{veh}$ , in  $kg \cdot m^2$ . Dimensions are 3-by-3.

**Track widths [front,rear],  $w$  – Widths**

[1.9,1.9,1.9] (default) | vector

Front, middle, and rear track widths,  $w_f$ ,  $w_m$ , and,  $w_r$ , respectively, in m. Dimensions are 1-by-3.



**Inertial Loads**

**Tractor Front**

**Mass,  $z1m$  – Tractor front mass**

0 (default) | scalar

Mass,  $z1m$ , in kg.

**Distance vector from front axle,  $z1R$  – Tractor front distance from front axle**

[-.25, .125, .15] (default) | vector

Distance vector from front axle to load,  $z1R$ , in m. Dimensions are 1-by-3.

Array Element	Description
z1R(1,1)	Front suspension hardpoint to load, along the vehicle-fixed x-axis
z1R(1,2)	Vehicle centerline to load, along the vehicle-fixed y-axis
z1R(1,3)	Front suspension hardpoint to load, along the vehicle-fixed z-axis

For example, this table summarizes the parameter settings that specify the load location.

Example Location	Sign
<ul style="list-style-type: none"> <li>Forward of the front axle</li> </ul>	<ul style="list-style-type: none"> <li><math>z1R(1,1) &lt; 0</math></li> </ul>
<ul style="list-style-type: none"> <li>Right of the vehicle centerline</li> </ul>	<ul style="list-style-type: none"> <li><math>z1R(1,2) &gt; 0</math></li> </ul>
<ul style="list-style-type: none"> <li>Above the front axle suspension hardpoint</li> </ul>	<ul style="list-style-type: none"> <li><math>z1R(1,3) &gt; 0</math></li> </ul>

### Inertia tensor, z1I – Tractor front inertia

[1.4, -.2, .1; -.2, 1.4, .1; .1, .1, 2.25].\*0 (default) | array

Inertia tensor, z1I, in kg·m<sup>2</sup>. Dimensions are 3-by-3.

$$z1I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis

### Cab Overhead

#### Mass, z2m – Cab overhead mass

0 (default) | scalar

Mass, z2m, in kg.

#### Distance vector from front axle, z2R – Cab overhead distance from front axle

[1.4, 0, .8] (default) | vector

Distance vector from front axle to load, z2R, in m. Dimensions are 1-by-3.

Array Element	Description
z2R(1,1)	Front suspension hardpoint to load, along the vehicle-fixed x-axis
z2R(1,2)	Vehicle centerline to load, along the vehicle-fixed y-axis

Array Element	Description
z2R(1,3)	Front suspension hardpoint to load, along the vehicle-fixed z-axis

For example, this table summarizes the parameter settings that specify the load location.

Example Location	Sign
<ul style="list-style-type: none"> <li>Rear of the front axle</li> </ul>	<ul style="list-style-type: none"> <li>z2R(1,1) &gt; 0</li> </ul>
<ul style="list-style-type: none"> <li>Left of the vehicle centerline</li> </ul>	<ul style="list-style-type: none"> <li>z2R(1,2) &lt; 0</li> </ul>
<ul style="list-style-type: none"> <li>Above the front axle suspension hardpoint</li> </ul>	<ul style="list-style-type: none"> <li>z2R(1,3) &gt; 0</li> </ul>

**Inertia tensor, z2I – Cab overhead inertia**

[1.4, -.2, .1; -.2, 1.4, .1; .1, .1, 2.25].\*0 (default) | array

Inertia tensor, z2I, in kg·m<sup>2</sup>. Dimensions are 3-by-3.

$$z2I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis

**Tractor Frame Left**

**Mass, z3m – Tractor frame left mass**

0 (default) | scalar

Mass, z3m, in kg.

**Distance vector from front axle, z3R – Tractor frame left distance from front axle**

[.75, -.5, .4] (default) | vector

Distance vector from front axle to load, z3R, in m. Dimensions are 1-by-3.

Array Element	Description
z3R(1,1)	Front suspension hardpoint to load, along the vehicle-fixed x-axis
z3R(1,2)	Vehicle centerline to load, along the vehicle-fixed y-axis
z3R(1,3)	Front suspension hardpoint to load, along the vehicle-fixed z-axis

For example, this table summarizes the parameter settings that specify the load location.

Example Location	Sign
• Rear of the front axle	• $z3R(1,1) > 0$
• Left of the vehicle centerline	• $z3R(1,2) < 0$
• Above the front axle suspension hardpoint	• $z3R(1,3) > 0$

**Inertia tensor, z3I – Tractor frame left inertia**

$[5, -.1, -2; -2, 9, .1; -.1, .1, 6].*0$  (default) | array

Inertia tensor,  $z3I$ , in  $\text{kg}\cdot\text{m}^2$ . Dimensions are 3-by-3.

$$z3I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis

**Tractor Frame Right****Mass, z4m – Tractor frame right mass**

0 (default) | scalar

Mass,  $z4m$ , in kg.

**Distance vector from front axle, z4R – Tractor frame right distance from front axle**

$[.75, .5, .4]$  (default) | vector

Distance vector from front axle to load,  $z4R$ , in m. Dimensions are 1-by-3.

Array Element	Description
$z4R(1,1)$	Front suspension hardpoint to load, along the vehicle-fixed x-axis
$z4R(1,2)$	Vehicle centerline to load, along the vehicle-fixed y-axis
$z4R(1,3)$	Front suspension hardpoint to load, along the vehicle-fixed z-axis

For example, this table summarizes the parameter settings that specify the load location.

Example Location	Sign
• Rear of the front axle	• $z4R(1,1) > 0$
• Right of the vehicle centerline	• $z4R(1,2) > 0$
• Above the front axle suspension hardpoint	• $z4R(1,3) > 0$

**Inertia tensor, z4I – Tractor frame right inertia**

$[5, -.1, -2; -2, 9, .1; -.1, .1, 6].*0$  (default) | array

Inertia tensor,  $z4I$ , in  $\text{kg}\cdot\text{m}^2$ . Dimensions are 3-by-3.

$$z4I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis

**Cab Left**

**Mass, z5m – Cab left mass**

0 (default) | scalar

Mass, z5m, in kg.

**Distance vector from front axle, z5R – Cab left distance from front axle**

[1.25, -.5, .4] (default) | vector

Distance vector from front axle to load, z5R, in m. Dimensions are 1-by-3.

Array Element	Description
z5R(1,1)	Front suspension hardpoint to load, along the vehicle-fixed x-axis
z5R(1,2)	Vehicle centerline to load, along the vehicle-fixed y-axis
z5R(1,3)	Front suspension hardpoint to load, along the vehicle-fixed z-axis

For example, this table summarizes the parameter settings that specify the load location.

Example Location	Sign
• Rear of the front axle	• $z5R(1,1) > 0$
• Left of the vehicle centerline	• $z5R(1,2) < 0$
• Above the front axle suspension hardpoint	• $z5R(1,3) > 0$

**Inertia tensor, z5I – Cab left inertia**

[5, -.1, -2; -2, 9, .1; -.1, .1, 6].\*0 (default) | array

Inertia tensor, z5I, in  $\text{kg}\cdot\text{m}^2$ . Dimensions are 3-by-3.

$$z5I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.



- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis

### Cab Right

#### Mass, $z6m$ — Cab right mass

0 (default) | scalar

Mass,  $z6m$ , in kg.

#### Distance vector from front axle, $z6R$ — Cab right distance from front axle

[1.25, -.5, .4] (default) | vector

Distance vector from front axle to load,  $z6R$ , in m. Dimensions are 1-by-3.

Array Element	Description
$z6R(1,1)$	Front suspension hardpoint to load, along the vehicle-fixed x-axis
$z6R(1,2)$	Vehicle centerline to load, along the vehicle-fixed y-axis
$z6R(1,3)$	Front suspension hardpoint to load, along the vehicle-fixed z-axis

For example, this table summarizes the parameter settings that specify the load location.

Example Location	Sign
• Rear of the front axle	• $z6R(1,1) > 0$
• Right of the vehicle centerline	• $z6R(1,2) > 0$
• Above the front axle suspension hardpoint	• $z6R(1,3) > 0$

#### Inertia tensor, $z6I$ — Cab right inertia

[5, -.1, -2; -2, 9, .1; -.1, .1, 6].\*0 (default) | array

Inertia tensor,  $z6I$ , in kg-m<sup>2</sup>. Dimensions are 3-by-3.

$$z6I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis

### Tractor Rear

#### Mass, $z7m$ — Tractor rear mass

0 (default) | scalar

Mass,  $z7m$ , in kg.

**Distance vector from front axle,  $z7R$  – Tractor rear mass distance from front axle**  
 $[2, 0, .25]$  (default) | vector

Distance vector from front axle to load,  $z7R$ , in m. Dimensions are 1-by-3.

Array Element	Description
$z7R(1, 1)$	Front suspension hardpoint to load, along the vehicle-fixed x-axis
$z7R(1, 2)$	Vehicle centerline to load, along the vehicle-fixed y-axis
$z7R(1, 3)$	Front suspension hardpoint to load, along the vehicle-fixed z-axis

For example, this table summarizes the parameter settings that specify the load location.

Example Location	Sign
<ul style="list-style-type: none"> <li>Rear of the front axle</li> </ul>	<ul style="list-style-type: none"> <li><math>z7R(1, 1) &gt; 0</math></li> </ul>
<ul style="list-style-type: none"> <li>Right of the vehicle centerline</li> </ul>	<ul style="list-style-type: none"> <li><math>z7R(1, 2) &gt; 0</math></li> </ul>
<ul style="list-style-type: none"> <li>Above the front axle suspension hardpoint</li> </ul>	<ul style="list-style-type: none"> <li><math>z7R(1, 3) &gt; 0</math></li> </ul>

**Inertia tensor,  $z7I$  – Tractor rear inertia**  
 $[1.4, -.2, .1; -.2, 1.4, .1; .1, .1, 2.25] .* 0$  (default) | array

Inertia tensor,  $z7I$ , in  $\text{kg}\cdot\text{m}^2$ . Dimensions are 3-by-3.

$$z7I = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix}$$

The tensor uses a coordinate system with an origin at the load CM.

- x-axis along the vehicle-fixed x-axis
- y-axis along the vehicle-fixed y-axis
- z-axis along the vehicle-fixed z-axis

**Aerodynamic**

**Longitudinal drag area,  $A_f$  – Vehicle cross-sectional area**  
 $2$  (default) | scalar

Effective vehicle cross-sectional area,  $A_f$  to calculate the aerodynamic drag force on the vehicle, in  $\text{m}^2$ .

**Longitudinal drag coefficient,  $C_d$  – Air drag coefficient**  
 $.3$  (default) | scalar

Air drag coefficient,  $C_d$ , dimensionless.

**Longitudinal lift coefficient, Cl – Air lift coefficient**

.1 (default) | scalar

Air lift coefficient,  $C_l$ , dimensionless.**Longitudinal drag pitch moment, Cpm – Pitch drag**

.1 (default) | scalar

Longitudinal drag pitch moment coefficient,  $C_{pm}$ , dimensionless.**Relative wind angle vector, beta\_w – Wind angle**

[0:0.001:0.01] (default) | vector

Relative wind angle vector,  $\beta_w$ , in rad.**Side force coefficient vector, Cs – Side force drag**

[0:0.01:0.1] (default) | vector

Side force coefficient vector coefficient,  $C_s$ , dimensionless.**Yaw moment coefficient vector, Cym – Yaw moment drag**

[0:0.001:0.01] (default) | vector

Yaw moment coefficient vector coefficient,  $C_{ym}$ , dimensionless.**Environment****Absolute air pressure, Pabs – Pressure**

101325 (default) | scalar

Environmental air absolute pressure,  $P_{abs}$ , in Pa.**Air temperature, Tair – Ambient air temperature**

273 (default) | scalar

Ambient air temperature,  $T_{air}$ , in K.**Dependencies**To enable this parameter, clear **Air temperature**.**Gravitational acceleration, g – Gravity**

9.81 (default) | scalar

Gravitational acceleration,  $g$ , in  $\text{m/s}^2$ .**Simulation****Longitudinal velocity tolerance, xdot\_tol – Tolerance**

.1 (default) | scalar

Longitudinal velocity tolerance,  $\dot{x}_{tol}$ , in m/s.The block uses this parameter to avoid a division by zero when it calculates the body slip angle,  $\beta$ .**Geometric longitudinal offset from axle plane, longOff – Longitudinal offset**

0 (default) | scalar

Vehicle chassis offset from the axle plane along the body-fixed  $x$ -axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independently of the vehicle CG.

**Geometric lateral offset from center plane, latOff – Lateral offset**

0 (default) | scalar

Vehicle chassis offset from center plane along the body-fixed  $y$ -axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independently of the vehicle CG.

**Geometric vertical offset from axle plane, vertOff – Vertical offset**

0 (default) | scalar

Vehicle chassis offset from the axle plane along the body-fixed  $z$ -axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independently of the vehicle CG.

**Wrap Euler angles, wrapAng – Selection**

on (default) | off

Wrap the Euler angles to the interval  $[-\pi, \pi]$ . For vehicle maneuvers that might undergo vehicle yaw rotations that are outside of the interval, consider clearing the parameter if you want to:

- Track the total vehicle yaw rotation.
- Avoid discontinuities in the vehicle state estimators.

**References**

[1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers (SAE), 1992.

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Vector Concatenate, Matrix Concatenate | Vehicle Body 6DOF | Vehicle Body 3DOF Longitudinal

**Topics**

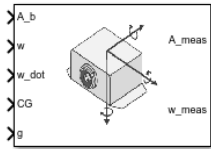
“Coordinate Systems in Vehicle Dynamics Blockset”

**Introduced in R2020b**

# Three-axis Inertial Measurement Unit

Implement three-axis inertial measurement unit (IMU)

**Library:** Vehicle Dynamics Blockset / Sensors



## Description

The Three-Axis Inertial Measurement Unit block implements an inertial measurement unit (IMU) containing a three-axis accelerometer and a three-axis gyroscope.

For a description of the equations and application of errors, see Three-axis Accelerometer (Aerospace Blockset) and Three-axis Gyroscope (Aerospace Blockset).

## Limitations

- Vibropendulous error, hysteresis affects, anisoelastic bias and aniso inertial bias are not accounted for in this block.
- This block is not intended to model the internal dynamics of different forms of the instrument.

## Ports

### Input

#### **A\_b — Actual accelerations**

three-element vector

Actual accelerations in body-fixed axes, specified as a three-element vector, in selected units.

Data Types: double

#### **w — Angular rates**

three-element vector

Angular rates in body-fixed axes, specified as a three-element vector, in radians per second.

Data Types: double

#### **w\_dot — Angular accelerations**

three-element vector

Angular accelerations in body-fixed axes, specified as a three-element vector, in radians per second squared.

Data Types: double

#### **CG — Location of center of gravity**

three-element vector

Location of the center of gravity, specified as a three-element vector, in selected units.

Data Types: double

**g – Gravity**

three-element vector

Gravity in body axis, specified as a three-element vector, in selected units.

Data Types: double

**Output**

**A\_meas – Measured accelerations**

three-element vector

Measured accelerations from the accelerometer, specified as a three-element vector, in selected units.

Data Types: double

**w\_meas – Measured angular rates**

three-element vector

Measured angular rates from the gyroscope, specified as a three-element vector, in radians per second.

Data Types: double

**Parameters**

**Main**

**Units – Units**

Metric (MKS) (default) | English

Input and output units, specified as:

Units	Acceleration	Length
Metric (MKS)	Meters per second squared	Meters
English	Feet per second squared	Feet

**Programmatic Use**

**Block Parameter:** units

**Type:** character vector

**Values:** 'Metric (MKS)' | 'English'

**Default:** 'Metric (MKS)'

**IMU location – IMU location**

[0 0 0] (default) | three-element vector

The location of the IMU, which is also the accelerometer group location, from the vehicle center of gravity, along the vehicle-fixed axis. This measurement reference is the same for the center of gravity input. The units are in selected length units.

**Programmatic Use****Block Parameter:** imu**Type:** character vector**Values:** three-element vector**Default:** '[0 0 0]'**Update rate — Update rate**

0 (default) | real, double scalar

Update rate of the accelerometer and gyroscope, specified as a real, double scalar, in seconds. An update rate of 0 creates a continuous accelerometer and continuous gyroscope. If you select the **Noise on** parameter and the update rate is 0, the block updates the noise at a rate of 0.1.

---

**Tip** If you:

- Update this parameter value to 0 (continuous)
- Configure a fixed-step solver for the model

you must also select the **Automatically handle rate transition for data transfer** check box in the **Solver** pane. This check box enables the software to handle rate transitions correctly.

---

**Programmatic Use****Block Parameter:** a\_Ts**Type:** character vector**Values:** real, double scalar**Default:** '0'**Accelerometer****Second order dynamics for accelerometer — Second-order dynamics**

on (default) | off

To apply second-order dynamics to acceleration readings, select this check box.

**Programmatic Use****Block Parameter:** dtype\_a**Type:** character vector**Values:** 'on' | 'off'**Default:** 'on'**Accelerometer natural frequency (rad/sec) — Accelerometer natural frequency**

190 (default) | real, double scalar

Natural frequency of the accelerometer, specified as a real, double scalar, in radians per second.

**Programmatic Use****Block Parameter:** w\_a**Type:** character vector**Values:** real, double scalar**Default:** '190'**Dependencies**

To enable this parameter, select **Second order dynamics for accelerometer**.

**Accelerometer damping ratio — Accelerometer damping ratio**

0.707 (default) | real, double scalar

Damping ratio of the accelerometer, specified as a real, double scalar, with no dimensions.

**Programmatic Use****Block Parameter:** z\_a**Type:** character vector**Values:** real, double scalar**Default:** '0.707'**Dependencies**

To enable this parameter, select **Second order dynamics for accelerometer**.

**Accelerometer scale factor and cross-coupling — Scale factor and cross coupling**

[1 0 0; 0 1 0; 0 0 1] (default) | 3-by-3 matrix

Scale factor and cross-coupling, specified as a 3-by-3 matrix, to skew the accelerometer from body axes and to scale accelerations along body axes.

**Programmatic Use****Block Parameter:** a\_sf\_cc**Type:** character vector**Values:** 3-by-3 matrix**Default:** '[1 0 0; 0 1 0; 0 0 1]'**Accelerometer measurement bias — Accelerometer measurement bias**

[0 0 0] (default) | three-element vector

Long-term biases along the accelerometer axes, specified as a three-element vector, in selected acceleration units.

**Programmatic Use****Block Parameter:** a\_bias**Type:** character vector**Values:** three-element vector**Default:** '[0 0 0]'**Accelerometer upper and lower limits — Minimum and maximum values of acceleration**

[-inf -inf -inf inf inf inf] (default) | six-element vector

Three minimum values and three maximum values of acceleration in each of accelerometer axes, specified as a six-element vector, in selected acceleration units.

**Programmatic Use****Block Parameter:** a\_sat**Type:** character vector**Values:** six-element vector**Default:** '[-inf -inf -inf inf inf inf]'**Gyroscope****Second-order dynamics for gyro — Gyroscope second-order dynamics**

on (default) | off



To apply second-order dynamics to gyroscope readings, select this check box.

**Programmatic Use**

**Block Parameter:** dtype\_g

**Type:** character vector

**Values:** 'on' | 'off'

**Default:** 'on'

**Gyro natural frequency (rad/sec) — Gyroscope natural frequency**

190 (default) | real, double scalar

Natural frequency of the gyroscope, specified as a real, double scalar, in radians per second.

**Programmatic Use**

**Block Parameter:** w\_g

**Type:** character vector

**Values:** real, double scalar

**Default:** '190'

**Dependencies**

To enable this parameter, select **Second-order dynamics for gyro**.

**Gyro damping ratio — Gyroscope damping ratio**

0.707 (default) | real, double scalar

Damping ratio of the gyroscope, specified as a real, double scale, with no dimensions.

**Programmatic Use**

**Block Parameter:** z\_g

**Type:** character vector

**Values:** real, double scalar

**Default:** '0.707'

**Dependencies**

To enable this parameter, select **Second-order dynamics for gyro**.

**Gyro scale factors and cross-coupling — Gyroscope scale factors and cross-coupling**

[1 0 0; 0 1 0; 0 0 1] (default) | 3-by-3 matrix

Gyroscope scale factors and cross-coupling, specified as a 3-by-3 matrix, to skew the gyroscope from body axes and to scale angular rates along body axes.

**Programmatic Use**

**Block Parameter:** g\_sf\_cc

**Type:** character vector

**Values:** 3-by-3 matrix

**Default:** '[1 0 0; 0 1 0; 0 0 1]'

**Gyro measurement bias — Gyroscope measurement bias**

[0 0 0] (default) | three-element vector

Long-term biases along the gyroscope axes, specified a three-element vector, in radians per second.

**Programmatic Use**

**Block Parameter:** g\_bias

**Type:** character vector  
**Values:** three-element vector  
**Default:** '[0 0 0]'

#### **G-sensitive bias — Maximum change in rates**

[0 0 0] (default) | three-element vector

Maximum change in rates due to linear acceleration, specified as a three-element vector, in radians per second per g-unit.

#### **Programmatic Use**

**Block Parameter:** g\_sens  
**Type:** character vector  
**Values:** three-element vector  
**Default:** '[0 0 0]'

#### **Gyro upper and lower limits — Minimum and maximum values of angular rates**

[-inf -inf -inf inf inf inf] (default) | six-element vector

Three minimum values and three maximum values of angular rates in each of the gyroscope axes, specified as a six-element vector, in radians per second.

#### **Programmatic Use**

**Block Parameter:** g\_sat  
**Type:** character vector  
**Values:** six-element vector  
**Default:** '[-inf -inf -inf inf inf inf]'

#### **Noise**

##### **Noise on — White noise**

on (default) | off

To apply white noise to acceleration and gyroscope readings, select this check box.

#### **Programmatic Use**

**Block Parameter:** a\_rand  
**Type:** character vector  
**Values:** 'on' | 'off'  
**Default:** 'on'

##### **Noise seeds — Noise seeds**

[23093 23094 23095 23096 23097 23098] (default) | six-element vector

Scalar seeds for the Gaussian noise generator for each axis of the accelerometer and gyroscope, specified as a six-element vector.

#### **Programmatic Use**

**Block Parameter:** a\_seeds  
**Type:** character vector  
**Values:** six-element vector  
**Default:** '[23093 23094 23095 23096 23097 23098]'

#### **Dependencies**

To enable this parameter, select **Noise on**.

**Noise power — Noise power**

[0.001 0.001 0.001 0.0001 0.0001 0.0001] (default) | six-element vector

Height of the power spectral density (PSD) of the white noise for each axis of the accelerometer and gyroscope, specified as a six-element vector, in:

- (m/s<sup>2</sup>)/Hz for Metric (MKS)
- (ft/s<sup>2</sup>)/Hz for English

**Programmatic Use**

**Block Parameter:** a\_pow

**Type:** character vector

**Values:** six-element vector

**Default:** '[0.001 0.001 0.001 0.0001 0.0001 0.0001]'

**Dependencies**

To enable this parameter, select **Noise on**.

**References**

[1] Rogers, R. M., *Applied Mathematics in Integrated Navigation Systems*, AIAA Education Series, 2000.

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Three-axis Accelerometer | Three-axis Gyroscope

**Introduced in R2020a**



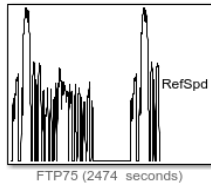
# Vehicle Scenario Blocks

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## Drive Cycle Source

Standard or specified longitudinal drive cycle

**Library:** Powertrain Blockset / Vehicle Scenario Builder  
Vehicle Dynamics Blockset / Vehicle Scenarios / Drive Cycle and Maneuvers



### Description

The Drive Cycle Source block generates a standard or user-specified longitudinal drive cycle. The block output is the specified vehicle longitudinal speed, which you can use to:

- Predict the engine torque and fuel consumption that a vehicle requires to achieve desired speed and acceleration for a given gear shift reference.
- Produce realistic velocity and shift references for closed loop acceleration and braking commands for vehicle control and plant models.
- Study, tune, and optimize vehicle control, system performance, and system robustness over multiple drive cycles.
- Identify the faults within tolerances specified by standardized tests, including:
  - EPA dynamometer driving schedules<sup>1</sup>
  - Worldwide Harmonised Light Vehicle Test Procedure (WLTP) laboratory tests<sup>2</sup>

For the drive cycles, you can use:

- Drive cycles from predefined sources. By default, the block includes the FTP–75 drive cycle. To install additional drive cycles from a support package, see “Support Package For Maneuver and Drive Cycle Data”. The support package has drive cycles that include the gear shift schedules, for example JC08 and CUEDC.
- Workspace variables.
- .mat, .xls, .xlsx, or .txt files.
- Wide open throttle (WOT) parameters, including initial and nominal reference speed, deceleration start time, and final reference speed.

To achieve the goals listed in the table, use the specified Drive Cycle Source block parameter options.

Goal	Action
Repeat the drive cycle if the simulation run time exceeds the drive cycle length.	Select <b>Repeat cyclically</b> .

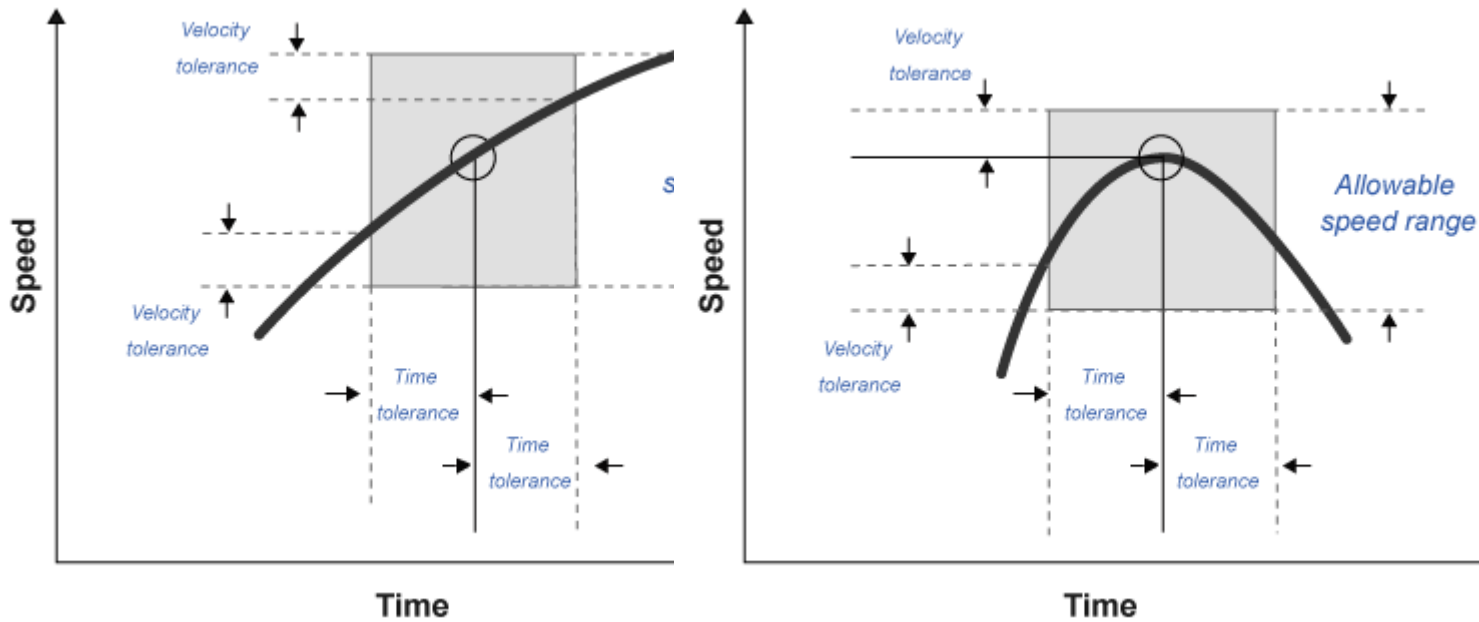
Goal	Action
Output the acceleration, as calculated by Savitzky-Golay differentiation.	Select <b>Output acceleration</b> .
Specify a sample period for discrete applications.	Specify a <b>Output sample period (0 for continuous)</b> , <b>dt</b> parameter.
Update the simulation run time so that it equals the length of the drive cycle.	Click <b>Update simulation time</b> . If a model configuration reference exists, the block does not enable this option.
Plot the drive cycle in a MATLAB® figure.	Click <b>Plot drive cycle</b> .
Specify the drive cycle using a workspace variable.	Click <b>Specify variable</b> . The block: <ul style="list-style-type: none"> <li>• Sets the <b>Drive cycle source</b> parameter to <b>Workspace variable</b>.</li> <li>• Enables the <b>From workspace</b> parameter.</li> </ul> Specify the workspace variable so that it contains time, velocity, and, optionally, the gear shift schedule.
Specify the drive cycle using a file.	Click <b>Select file</b> . The block: <ul style="list-style-type: none"> <li>• Sets the <b>Drive cycle source</b> parameter to <b>.mat</b>, <b>.xls</b>, <b>.xlsx</b> or <b>.txt</b> file.</li> <li>• Enables the <b>Drive cycle source file</b> parameter.</li> </ul> Specify a file that contains time, velocity, and, optionally, the gear shift schedule.
Output drive cycle gear.	Specify a drive cycle that contains a gear shift schedule. You can use: <ul style="list-style-type: none"> <li>• A support package to install standard drive cycles that include the gear shift schedules, for example <b>JC08</b> and <b>CUEDC</b>.</li> <li>• Workspace variables.</li> <li>• <b>.mat</b>, <b>.xls</b>, <b>.xlsx</b>, or <b>.txt</b> files.</li> </ul> Click <b>Output gear shift data</b> .
Install additional drive cycles from a support package.	Click <b>Install additional drive cycles</b> . The block enables the parameter if you can install additional drive cycles from a support package.
Identify drive cycle faults within tolerances specified by standardized tests.	On the <b>Fault Tracking</b> tab, use the parameters to specify the fault tolerances. If the vehicle speed is not within the allowable speed range, the block sets a fault condition.

### Fault and Failure Tracking

On the **Fault Tracking** tab, use the parameters to specify the fault tolerances. If the vehicle speed or time is not within the allowable range, the block sets a fault condition.

Parameter	Description	Setting	
		EPA Standard <sup>1</sup>	WLTP Tests <sup>2</sup>
<b>Speed tolerance</b>	Speed tolerance above the highest point and below the lowest point of the drive cycle speed trace within the time tolerance.	2.0 mph	2.0 km/h
<b>Time tolerance</b>	Time that the block uses to determine the speed tolerance.	1.0 s	1.0 s
<b>Maximum number of faults</b>	Maximum number of faults during the drive cycle.	<i>Not specified</i>	10
<b>Maximum single fault time</b>	Maximum fault duration.	2.0 s	1.0 s
<b>Maximum total fault time</b>	Maximum accumulated time spent under fault condition.	<i>Not specified</i>	<i>Not specified</i>

These figures illustrate how the block uses the velocity and time tolerances to determine the allowable speed range.





## Ports

### Input

#### VelFdbk — Vehicle longitudinal speed

scalar

Longitudinal vehicle speed.

### Dependencies

To enable this port, on the **Fault Tracking** tab, select **Enable fault tracking**. Set the **Velocity feedback units, inUnit** parameter to the VelFdbk input port signal units.

### Output

#### Info — Bus signal

bus

Bus signal containing these block calculations.

Signal		Description
Reference Speed		Vehicle reference speed
Reference Accel		Vehicle reference acceleration
Gear		Vehicle gear
Fault	UpprBnd	Upper bound of allowable vehicle speed range.
	LowerBnd	Lower bound of allowable vehicle speed range.
	Fault	Boolean value indicating fault condition: <ul style="list-style-type: none"> <li>• 1 — Fault</li> <li>• 0 — No fault</li> </ul> <p>If the vehicle speed is not within the allowable speed range, the block sets a fault condition.</p>
	FaultCnt	Number of faults.
	CumFaultTime	Cumulative time spent in fault condition.
	SnglFaultTime	Tim spent in a single fault.
	Fail	Boolean value indicating fault failure: <ul style="list-style-type: none"> <li>• 1 — Failure</li> <li>• 0 — No failure</li> </ul> <p>If the fault conditions exceed the maximum number of faults, maximum single fault time, or maximum total fault time, the block sets a fault failure.</p>

### Dependencies

To enable this port, on the **Fault Tracking** tab, select **Enable fault tracking**.

**RefSpd — Vehicle reference speed**

scalar

Vehicle reference speed, in units that you specify. To specify the units, use the **Output velocity units** parameter.

**RefAcc — Vehicle reference acceleration**

scalar

To calculate the acceleration, the block implements Savitzky-Golay differentiation using a second-order polynomial with a three-sample point filter.

**Dependencies**

To create the output acceleration port, select **Output acceleration**. Selecting **Output acceleration** enables the **Output acceleration units** parameter.

**Gear — Vehicle gear**

scalar

**Dependencies**

To enable this port:

- 1 Specify a drive cycle that contains a gear shift schedule. You can use:
  - A support package to install standard drive cycles that include the gear shift schedules, for example JC08 and CUEDC.
  - Workspace variables.
  - .mat, .xls, .xlsx, or .txt files.
- 2 Select **Output gear shift** data.

**Parameters****Cycle Setup****Setup****Drive cycle source — Select the drive cycle source**

FTP75 (default) | Wide Open Throttle (WOT) | Workspace variable | .mat, .xls, .xlsx or .txt file

- **FTP75** — Load the FTP75 drive cycle from a .mat file into a 1-D Lookup Table block. The FTP75 represents a city drive cycle that you can use to determine tailpipe emissions and fuel economy of passenger cars. To install additional drive cycles from a support package, see “Support Package For Maneuver and Drive Cycle Data”.
- **Wide Open Throttle (WOT)** — Use WOT parameters to specify a drive cycle for performance testing.
- **Workspace variable** — Specify time, speed, and, optionally, gear data as a structure, 2-D array, or time series object.
- **.mat, .xls, .xlsx or .txt file** — Specify a file that contains time, speed and, optionally, gear data in column format.

Once you have installed additional cycles, you can use `set_param` to set the drive cycle. For example, to use drive cycle US06:

```
set_param([gcs '/Drive Cycle Source'], 'cycleVar', 'US06')
```

### Dependencies

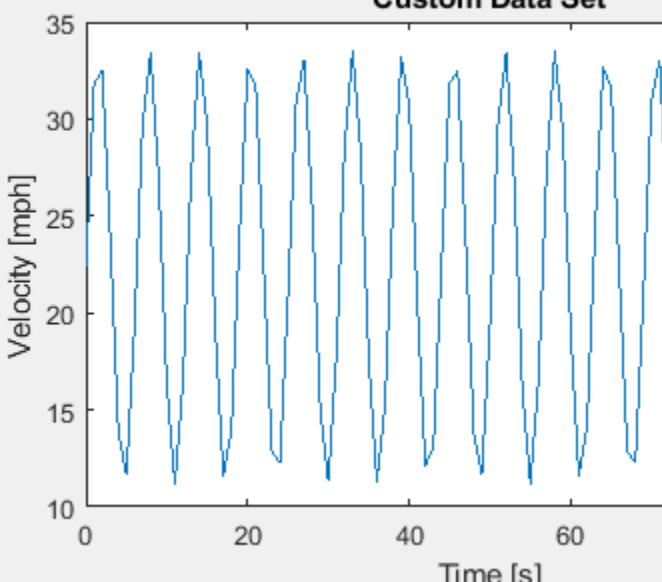
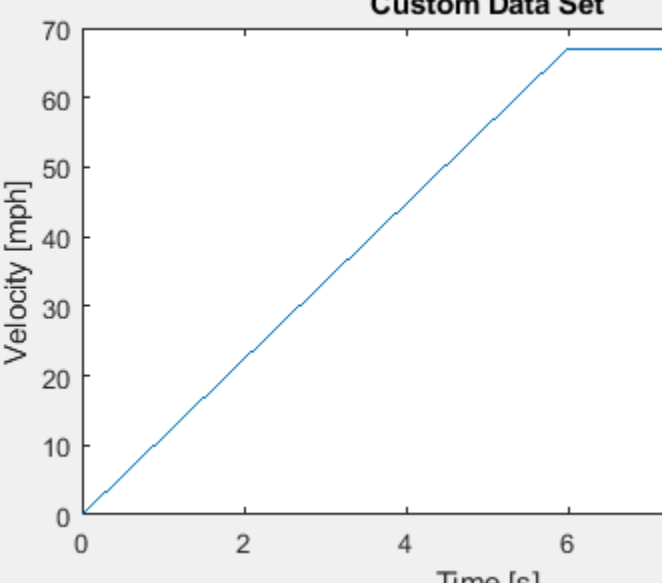
The table summarizes the parameter dependencies.

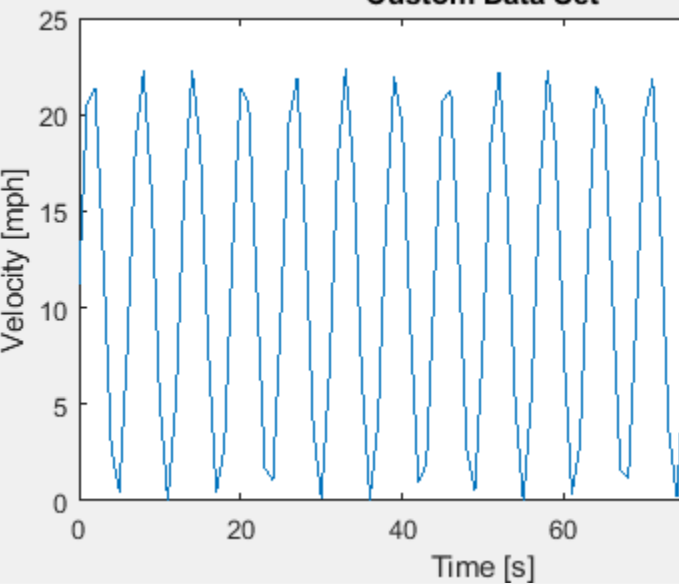
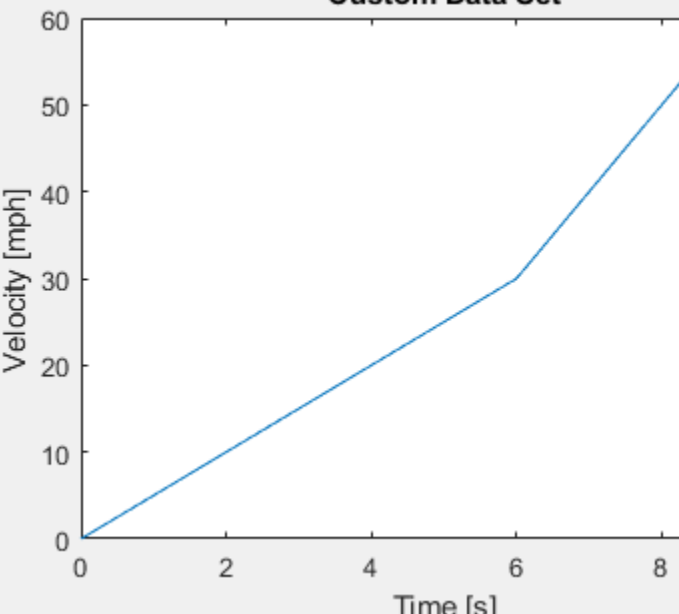
Drive Cycle Source	Enables Parameter
Wide Open Throttle (WOT)	Start time, <code>t_wot1</code>
	Initial reference speed, <code>xdot_woto</code>
	Nominal reference speed, <code>xdot_wot1</code>
	Time to start deceleration, <code>wot2</code>
	Final reference speed, <code>xdot_wot2</code>
	WOT simulation time, <code>t_wotend</code>
	Source velocity units
Workspace variable	From workspace
	Source velocity units
	Output gear shift data, if drive cycle includes gear shift schedule
.mat, .xls, .xlsx or .txt file	Drive cycle source file
	Source velocity units
	Output gear shift data, if drive cycle includes gear shift schedule

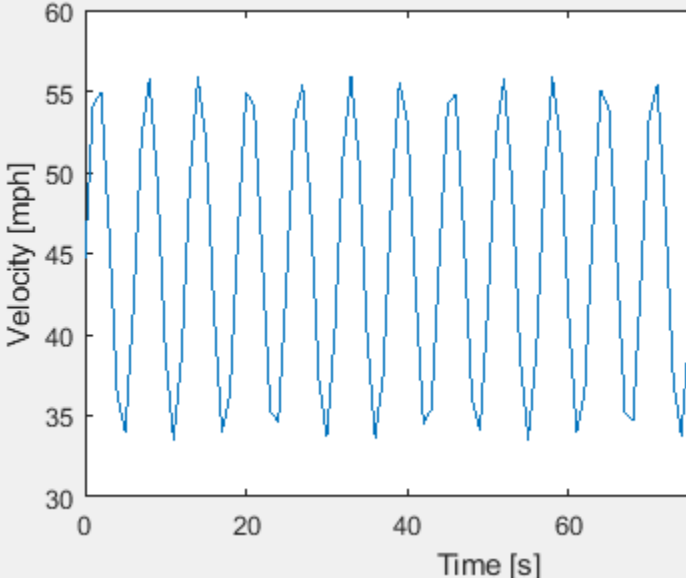
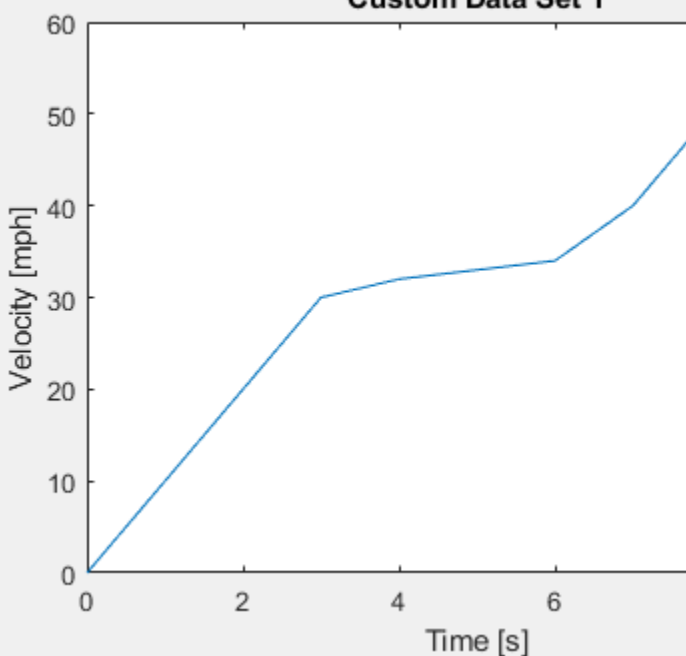
### From workspace – Workspace variable

Monotonically increasing time, velocity, and, optionally, gear data, specified by a structure, 2-D array, or time series object. Enter units for velocity in the **Source velocity units** parameter field.

A valid point must exist for each corresponding time value. You cannot specify `inf`, empty, or `NaN`.

Workspace Variable	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot
<p>Structure without a gear shift schedule. <b>From workspace</b> set to myCycleS.</p> <pre>t = 0:1:100; xdot = 5.*sin(t)+10; myCycleS.time = t'; myCycleS.signals.values = xdot';</pre>	m/s	mph	
<p>Structure with a gear shift schedule. <b>From workspace</b> set to myCycleS.</p> <pre>gears=[0, 1, 2, 3, 3, 4, 4, 4, 4, 4, 4]; t=0:1:10; xdot=[0,5,10,15,20,25,30,30,30,30,30]; myCycleS.time=t'; myCycleS.signals.values=[xdot',gears'];</pre>	m/s	mph	

Workspace Variable	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot
<p>2-D array without a gear shift schedule. <b>From workspace</b> set to myCycleA.</p> <pre>t = 0:1:100; xdot = 5.*sin(t)+5; myCycleA = [t',xdot'];</pre>	m/s	mph	
<p>2-D array with a gear shift schedule. <b>From workspace</b> set to myCycleA.</p> <pre>gears=[0, 1, 2, 3, 4, 4, 4, 5, 5, 5, 5]; t=0:1:10; xdot=[0,5,10,15,20,25,30,40,50,60,60]; myCycleA=[t',xdot',gears'];</pre>	mph	mph	

Workspace Variable	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot
<p>Time series object without a gear shift schedule. <b>From workspace</b> set to myCycleT.</p> <pre>myCycleT = timeseries; t = 0:1:100; xdot = 5.*sin(t)+20; myCycleT.Data = xdot'; myCycleT.Time = t;</pre>	m/s	mph	
<p>Time series object without a gear shift schedule. <b>From workspace</b> set to myCycleT.</p> <pre>myCycleT = timeseries; gears=[0, 1, 2, 3, 4, 4, 4, 5, 5, 5, 5]; t=0:1:10; xdot=[0,10,20,30,32,33,34,40,50,60,60]; myCycleT.Data = [xdot',gears']; myCycleT.Time = t';</pre>	mph	mph	

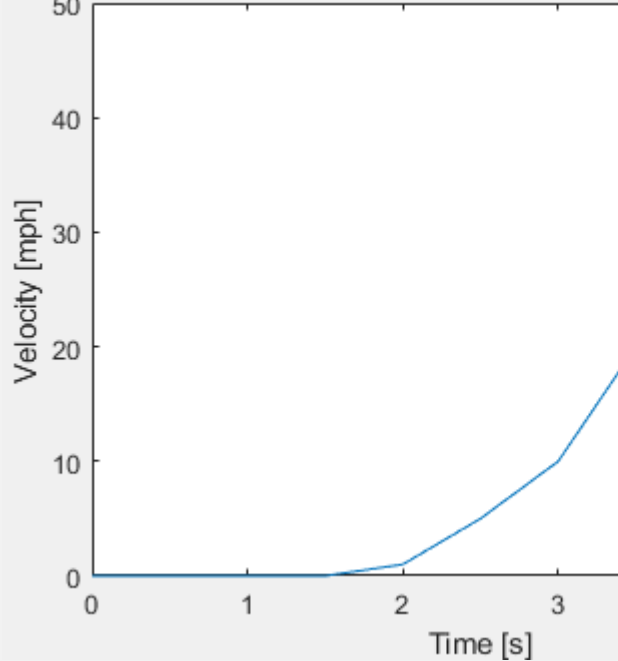
**Dependencies**

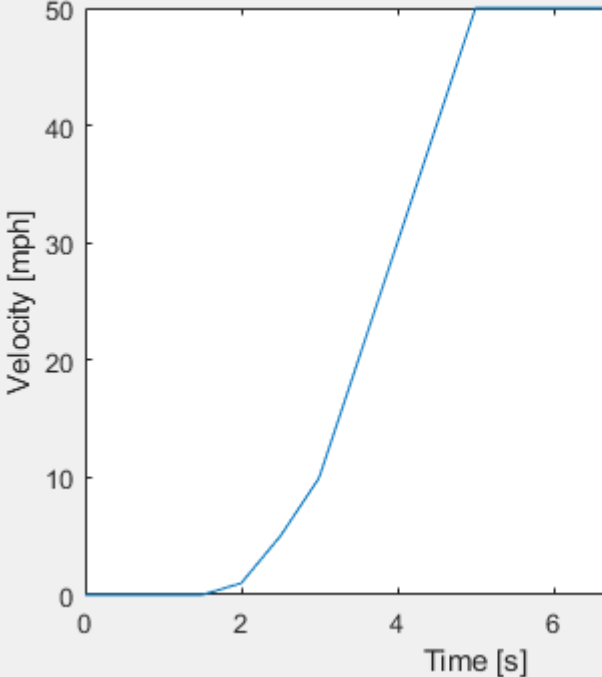
To enable this parameter, select Workspace variable from **Drive cycle source**.

**Drive cycle source file – File name**

.mat, .xls, .xlsx or .txt

File containing monotonically increasing time, velocity, and, optionally, gear in column or comma-separated format. The block ignores units in the file. Enter units for velocity in the **Source velocity units** parameter field.

File	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot																																				
<p>An .xls or .xlsx file with time in column A and velocity in column B.</p> <table border="1"> <thead> <tr> <th></th> <th>A</th> <th>B</th> </tr> </thead> <tbody> <tr><td>1</td><td>0</td><td>0</td></tr> <tr><td>2</td><td>0.5</td><td>0</td></tr> <tr><td>3</td><td>1</td><td>0</td></tr> <tr><td>4</td><td>1.5</td><td>0</td></tr> <tr><td>5</td><td>2</td><td>1</td></tr> <tr><td>6</td><td>2.5</td><td>5</td></tr> <tr><td>7</td><td>3</td><td>10</td></tr> <tr><td>8</td><td>3.5</td><td>20</td></tr> <tr><td>9</td><td>4</td><td>30</td></tr> <tr><td>10</td><td>4.5</td><td>40</td></tr> <tr><td>11</td><td>5</td><td>50</td></tr> </tbody> </table>		A	B	1	0	0	2	0.5	0	3	1	0	4	1.5	0	5	2	1	6	2.5	5	7	3	10	8	3.5	20	9	4	30	10	4.5	40	11	5	50	mph	mph	<p><b>Custom Data Set</b></p> 
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9	4	30																																					
10	4.5	40																																					
11	5	50																																					

File	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot																																																				
<p>An .xls or .xlsx file with time in column A, velocity in column B, and gear in column C. The block:</p> <ul style="list-style-type: none"> <li>• Ignores the units in the file.</li> <li>• Converts the gear information to integers:                             <ul style="list-style-type: none"> <li>• N to 0</li> <li>• D to 2</li> </ul> </li> </ul> <table border="1"> <thead> <tr> <th></th> <th>A</th> <th>B</th> <th>C</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>sec</td> <td>mph</td> <td>gear</td> </tr> <tr> <td>2</td> <td>0</td> <td>0</td> <td>N</td> </tr> <tr> <td>3</td> <td>0.5</td> <td>0</td> <td>N</td> </tr> <tr> <td>4</td> <td>1</td> <td>0</td> <td>N</td> </tr> <tr> <td>5</td> <td>1.5</td> <td>0</td> <td>N</td> </tr> <tr> <td>6</td> <td>2</td> <td>1</td> <td>D</td> </tr> <tr> <td>7</td> <td>2.5</td> <td>5</td> <td>D</td> </tr> <tr> <td>8</td> <td>3</td> <td>10</td> <td>D</td> </tr> <tr> <td>9</td> <td>3.5</td> <td>20</td> <td>D</td> </tr> <tr> <td>10</td> <td>4</td> <td>30</td> <td>D</td> </tr> <tr> <td>11</td> <td>4.5</td> <td>40</td> <td>D</td> </tr> <tr> <td>12</td> <td>5</td> <td>50</td> <td>D</td> </tr> </tbody> </table>		A	B	C	1	sec	mph	gear	2	0	0	N	3	0.5	0	N	4	1	0	N	5	1.5	0	N	6	2	1	D	7	2.5	5	D	8	3	10	D	9	3.5	20	D	10	4	30	D	11	4.5	40	D	12	5	50	D	mph	mph	<p style="text-align: center;"><b>Custom Data Set</b></p> 
	A	B	C																																																				
1	sec	mph	gear																																																				
2	0	0	N																																																				
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10	4	30	D																																																				
11	4.5	40	D																																																				
12	5	50	D																																																				



File	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot
<p>A .txt with time in column 1 and velocity in column 2. The block ignores the header and units information.</p> <pre> Time   Speed sec    mph 0      0 1      0 2      0 3      0 4      0 5      5 6      10 7      15 8      20 9      30 10     35 11     40 12     45 13     50 14     55 15     60 16     60 17     60 18     60 19     60 20     60                     </pre>	mph	mph	

If you provide the gear schedule using **P, R, N, D, L, OD**, the block maps the gears to integers.

Gear	Integer
P	80
R	- 1
N	0
L	1
D	2
OD	Next integer after highest specified gear.

For example, the block converts the gear schedule P P N L D 3 4 5 6 5 4 5 6 7 OD 7 to 80 80 0 1 2 3 4 5 6 5 4 5 6 7 8 7.

**Dependencies**

To enable this parameter, select **.mat, .xls, .xlsx** or **.txt** file from **Drive cycle source**.

**Repeat cyclically – Repeat drive cycle**

off (default) | on

Repeat the drive cycle if the simulation run time exceeds the length of the drive cycle.

### Output acceleration – Output the acceleration

off (default)

To calculate the acceleration, the block implements Savitzky-Golay differentiation using a second-order polynomial with a three-sample point filter.

#### Dependencies

To create the output acceleration port, select **Output acceleration**. Selecting **Output acceleration** enables the **Output acceleration units** parameter.

### Output gear shift data – Output the gear

off (default) | on

#### Dependencies

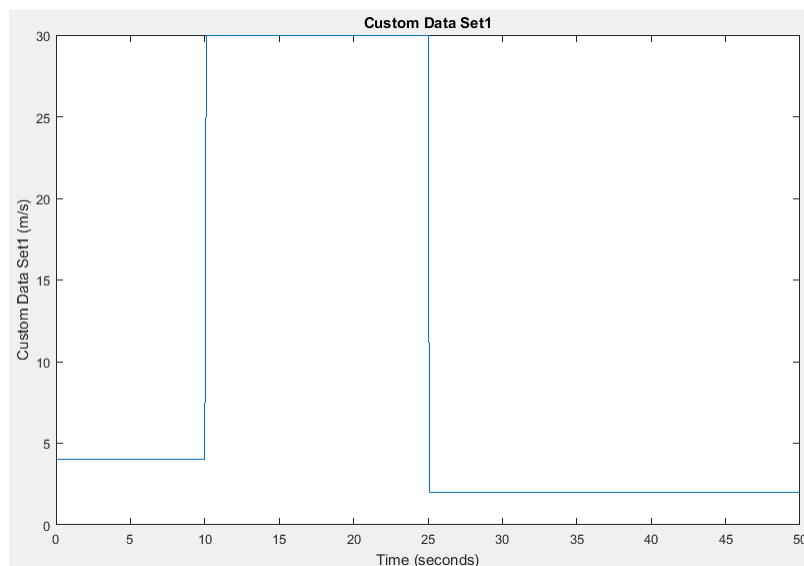
- Specify a drive cycle that contains a gear shift schedule. You can use:
  - A support package to install standard drive cycles that include the gear shift schedules, for example JC08 and CUEDC.
  - Workspace variables.
  - .mat, .xls, .xlsx, or .txt files.
- Clicking this parameter creates input port **Gear**.

#### WOT

### Start time, t\_wot1 – Drive cycle start time

5 (default) | scalar

Drive cycle start time, in s. For example, this plot shows a drive cycle with a start time of 10 s.

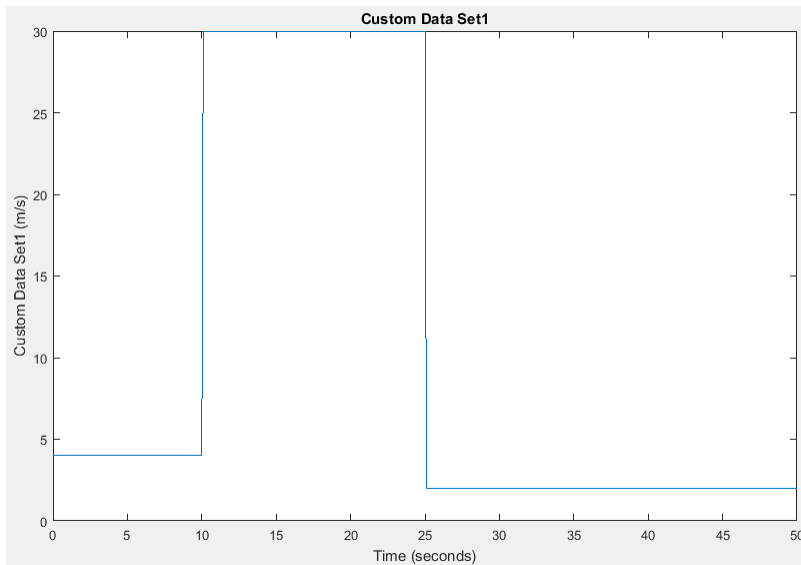


#### Dependencies

To enable this parameter, select the **Drive cycle source** parameter Wide Open Throttle (WOT).

**Initial reference speed, `xdot_woto` – Speed** $0$  (default) | scalar

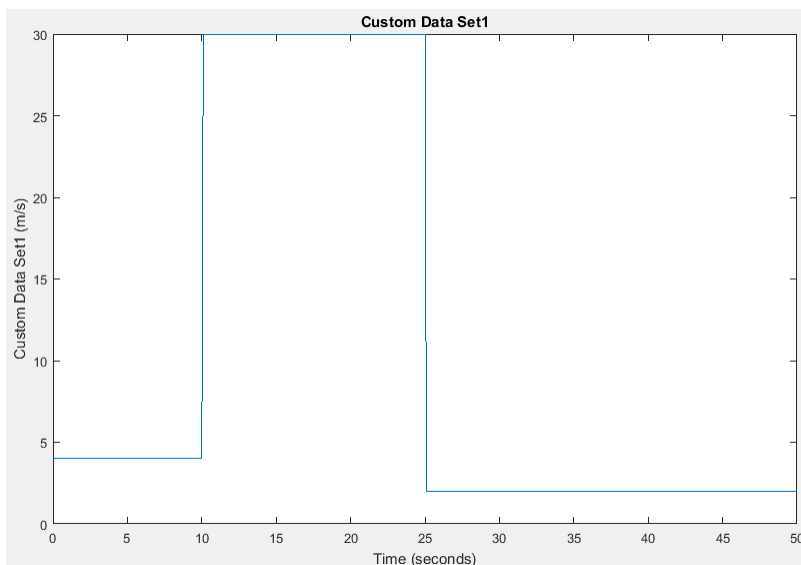
Initial reference speed, in units that you specify with the **Source velocity units** parameter. For example, this plot shows a drive cycle with an initial reference speed of 4 m/s.

**Dependencies**

To enable this parameter, select the **Drive cycle source** parameter Wide Open Throttle (WOT).

**Nominal reference speed, `xdot_wot1` – Speed** $30$  (default) | scalar

Nominal reference speed, in units that you specify with the **Source velocity units** parameter. For example, this plot shows a drive cycle with a nominal reference speed of 30 m/s.



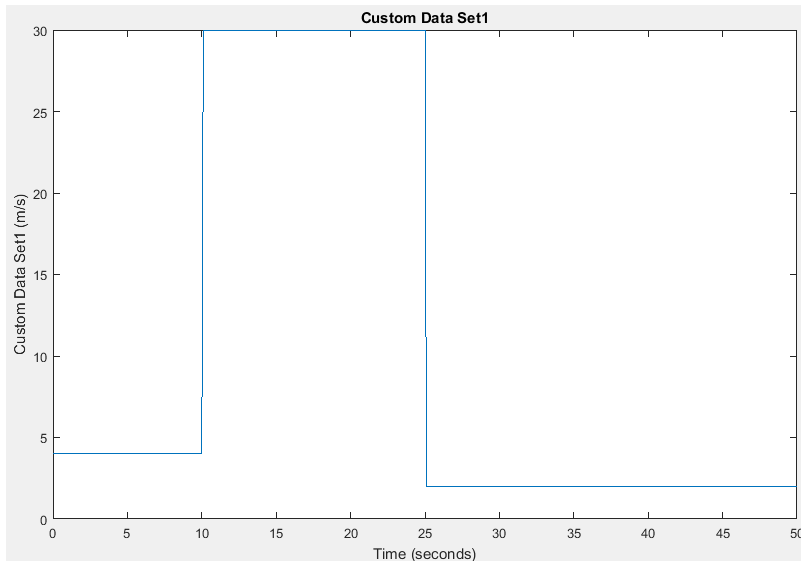
### Dependencies

To enable this parameter, select the **Drive cycle source** parameter Wide Open Throttle (WOT).

### Time to start deceleration, wot2 – Time

20 (default) | scalar

Time to start vehicle deceleration, in s. For example, this plot shows a drive cycle with vehicle deceleration starting at 25 s.



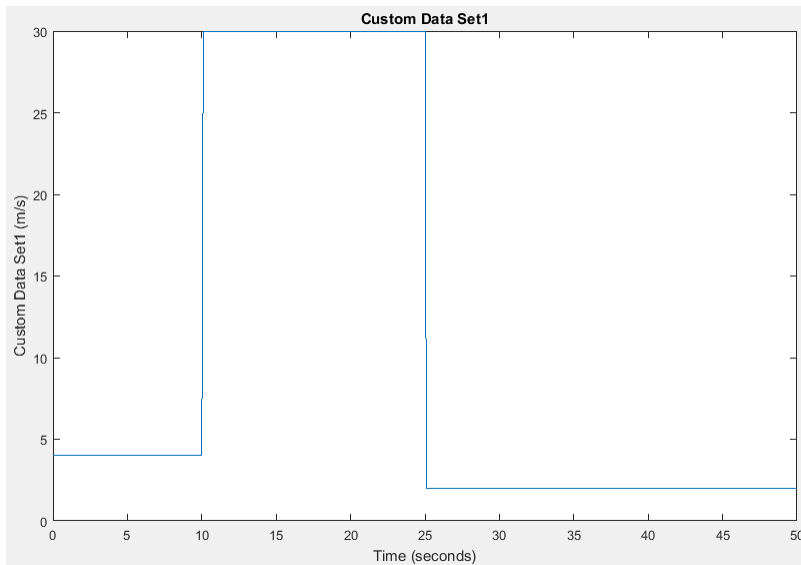
### Dependencies

To enable this parameter, select the **Drive cycle source** parameter Wide Open Throttle (WOT).

### Final reference speed, xdot\_wot2 – Speed

0 (default) | scalar

Final reference speed, in units that you specify with the **Source velocity units** parameter. For example, this plot shows a drive cycle with a final reference speed of 2 m/s.



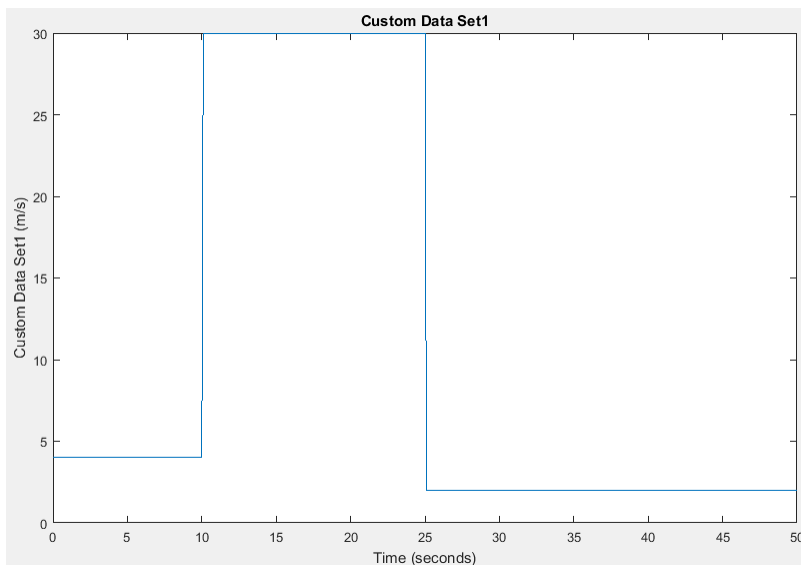
### Dependencies

To enable this parameter, select the **Drive cycle source** parameter Wide Open Throttle (WOT).

### WOT simulation time, $t_{\text{wotend}}$ — Time

30 (default) | scalar

Drive cycle WOT simulation time, in s. For example, this plot shows a drive cycle with a simulation time of 50 s.



### Dependencies

To enable this parameter, select the **Drive cycle source** parameter Wide Open Throttle (WOT).

**Units and Sample Period****Source velocity units — Specify velocity units**

m/s (default)

Input velocity units.

**Dependencies**

To enable this parameter, select the **Drive cycle source** parameter Wide Open Throttle (WOT), Workspace variable, or .mat, .xls, .xlsx or .txt file.

**Output velocity units — Specify velocity units**

m/s (default)

Output velocity units.

**Output acceleration units — Specify acceleration units**m/s<sup>2</sup> (default)

Specify the output acceleration units.

**Dependencies**

To enable this parameter, select **Output acceleration**.

**Output sample period (θ) for continuous — Sample rate**

θ (default) | scalar

Sample rate. Set to θ for continuous sample period. For a discrete period, specify a non-zero rate.

**Fault Tracking****Fault Settings****Enable fault tracking — Enable fault tracking**

off (default) | on

Select this parameter to enable drive cycle fault tracking. Use the parameters to specify the fault tolerances. If the vehicle speed is not within the allowable speed range, the block sets a fault condition.

**Dependencies**

Selecting this parameter enables these parameters:

- **Speed tolerance, velBnd**
- **Speed tolerance units, velBndUnit**
- **Velocity feedback units, inUnit**
- **Time tolerance, timeBnd**

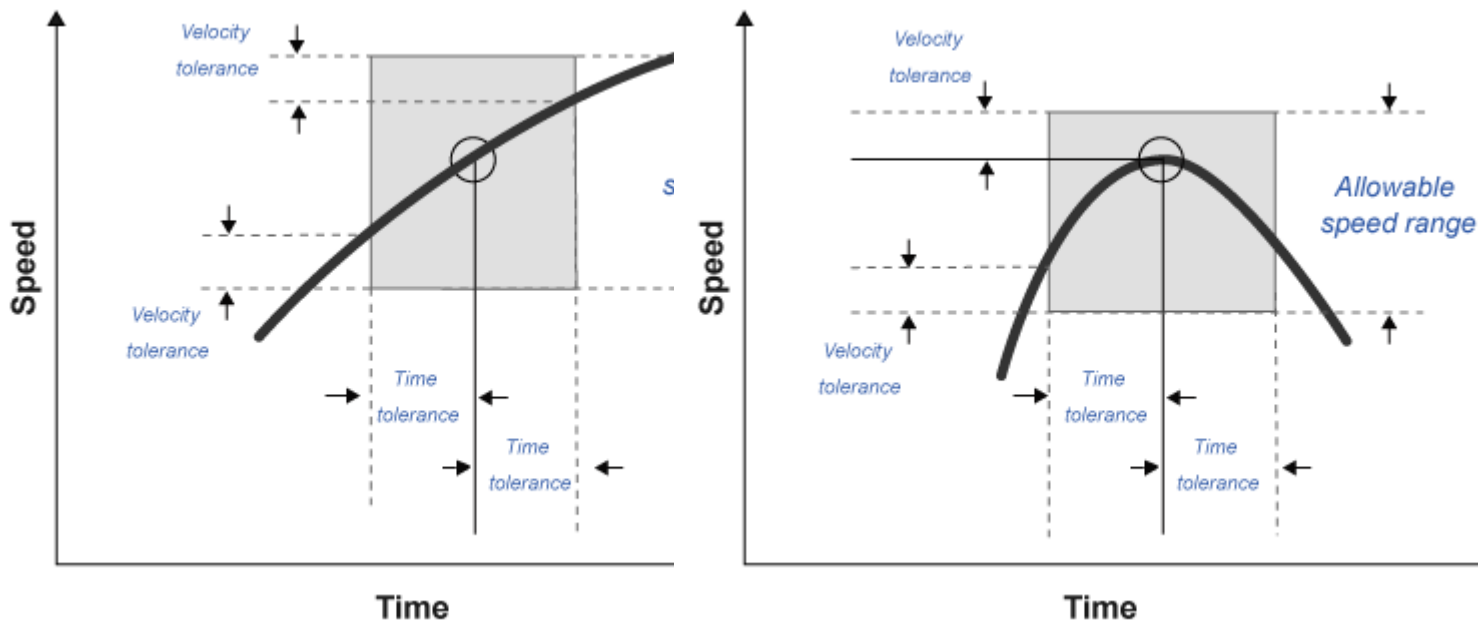
**Speed tolerance, velBnd — Drive cycle speed tolerance**

2.0 (default) | scalar

The speed tolerance above the highest point and below the lowest point of the drive cycle speed trace within the time tolerance. If the vehicle speed is not within the allowable speed range, the block sets a fault condition. For the tolerances specified by the standardized tests, use these settings:

- EPA dynamometer driving schedules — 2.0
- WLTP tests — 2.0

These figures illustrate how the block uses the velocity and time tolerances to determine the allowable speed range.



### Dependencies

To enable this parameter, on the **Fault Tracking** tab, select **Enable fault tracking**.

### Speed tolerance units, `velBndUnit` — Set units

mph (default)

Speed tolerance units. For the units specified by the standardized tests, use these units:

- EPA dynamometer driving schedules — m/s
- WLTP tests — km/h

### Dependencies

To enable this parameter, on the **Fault Tracking** tab, select **Enable fault tracking**.

### Velocity feedback units, `inUnit` — Set velocity feedback units

m/s (default)

Velocity feedback units. Set the value to the `VelFdbk` input port signal units.

### Dependencies

To enable this parameter, on the **Fault Tracking** tab, select **Enable fault tracking**.

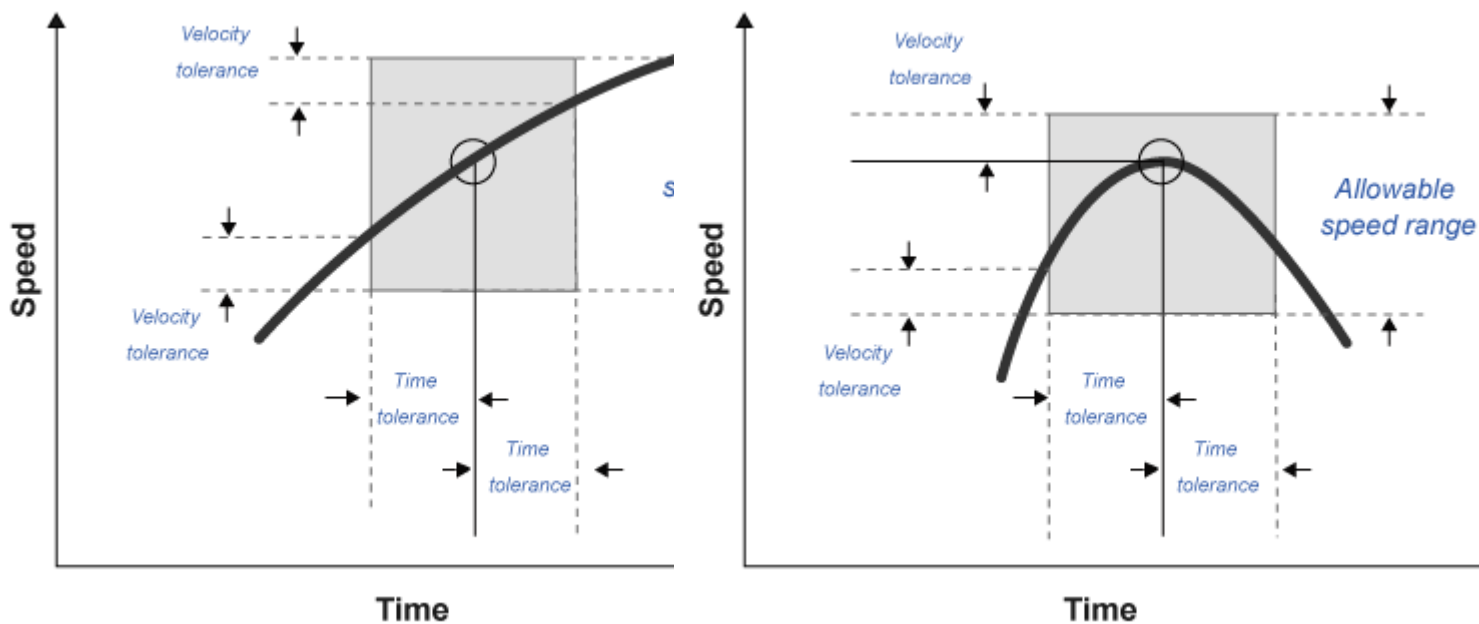
**Time tolerance, timeBnd – Time tolerance**

1.0 (default) | scalar

Time that the block uses to determine the speed tolerance. If the vehicle speed is not within the allowable speed range, the block sets a fault condition. For the time tolerances specified by the standardized tests, use these settings:

- EPA dynamometer driving schedules — 1.0
- WLTP tests — 1.0

These figures illustrate how the block uses the velocity and time tolerances to determine the allowable speed range.

**Dependencies**

To enable this parameter, on the **Fault Tracking** tab, select **Enable fault tracking**.

**Failure Settings****Enable failure tracking – Enable failure tracking**

off (default) | on

Select this parameter to enable drive cycle failure tracking.

**Dependencies**

To enable this parameter, select **Enable fault tracking**. Selecting **Enable failure tracking** parameter enables these parameters:

- **Stop simulation when trace fails, stopSim**
- **Maximum number of faults, maxFaultCnt**



- **Maximum single fault time, maxFaultTime**
- **Maximum total fault time, maxTotFaultTime**

**Maximum number of faults, maxFaultCnt — Maximum number of faults**

10 (default) | scalar

Maximum number of faults during the drive cycle. For the number specified by the standardized tests, use these settings:

- EPA dynamometer driving schedules — *Not specified*
- WLTP tests — 10

If the number of faults exceeds the maximum number of faults, the block sets a fault failure.

**Dependencies**

To enable this parameter, on the **Fault Tracking** tab, select **Enable failure tracking**.

**Maximum single fault time, maxFaultTime — Maximum duration of single fault**

2.0 (default) | scalar

Maximum duration of single fault, in s. For the time specified by the standardized tests, use these settings:

- EPA dynamometer driving schedules — 2.0
- WLTP tests — 1.0

If the fault duration exceeds the maximum single fault time, the block sets a fault failure.

**Dependencies**

To enable this parameter, on the **Fault Tracking** tab, select **Enable failure tracking**.

**Maximum total fault time, maxTotFaultTime — Maximum total fault time**

15.0 (default) | scalar

Maximum accumulated time spent under fault condition, in s.

If the accumulated time spent under fault condition exceeds the maximum total fault time, the block sets a fault failure.

**Dependencies**

To enable this parameter, on the **Fault Tracking** tab, select **Enable failure tracking**.

**Simulation Trace**

**Display simulation trace — Display velocity trace**

off (default) | on

Select this parameter to display a velocity trace window. Selecting this parameter can slow the simulation time.

**Dependencies**

Selecting this parameter enables these parameters:

- **Simulation trace update rate, dtTrace**
- **Simulation trace display window, traceWindow**

**Simulation trace update rate, dtTrace — Trace update rate**

1 (default) | scalar

Simulation trace update rate, in s. Set to 0 for continuous sample period. For a discrete period, specify a non-zero rate.

**Dependencies**

To enable this parameter, on the **Fault Tracking** tab, select **Display simulation trace**.

**Simulation trace display window, traceWindow — Trace window update rate**

10 (default) | scalar

Simulation trace window update rate, in s.

**Dependencies**

To enable this parameter, on the **Fault Tracking** tab, select **Display simulation trace**.

**References**

[1] Environmental Protection Agency (EPA). *EPA urban dynamometer driving schedule*. 40 CFR 86.115-78, July 1, 2001.

[2] European Union Commission. "Speed trace tolerances". *European Union Commission Regulation*. 32017R1151, Sec 1.2.6.6, June 1, 2017.

**Extended Capabilities****C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

**See Also**

Lateral Driver | Longitudinal Driver | Predictive Driver

**Topics**

"Support Package For Maneuver and Drive Cycle Data"

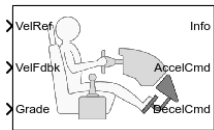
"Time Series Objects and Collections"

**Introduced in R2017a**

# Longitudinal Driver

Longitudinal speed-tracking controller

**Library:** Powertrain Blockset / Vehicle Scenario Builder  
Vehicle Dynamics Blockset / Vehicle Scenarios / Driver



## Description

The Longitudinal Driver block implements a longitudinal speed-tracking controller. Based on reference and feedback velocities, the block generates normalized acceleration and braking commands that can vary from 0 through 1. You can use the block to model the dynamic response of a driver or to generate the commands necessary to track a longitudinal drive cycle.

## Configurations

### External Actions

Use the **External Actions** parameters to create input ports for signals that can disable, hold, or override the closed-loop acceleration or deceleration commands. The block uses this priority order for the input commands: disable (highest), hold, override.

This table summarizes the external action parameters.

Goal	External Action Parameter	Input Ports	Data Type
Override the accelerator command with an input acceleration command.	<b>Accelerator override</b>	EnablAccelOvr	Boolean
		AccelOvrCmd	double
Hold the acceleration command at the current value.	<b>Accelerator hold</b>	AccelHld	Boolean
Disable the acceleration command.	<b>Accelerator disable</b>	AccelZero	Boolean
Override the decelerator command with an input deceleration command.	<b>Decelerator override</b>	EnablDecelOvr	Boolean
		DecelOvrCmd	double
Hold the decelerator command at current value.	<b>Decelerator hold</b>	DecelHld	Boolean
Disable the decelerator command.	<b>Decelerator disable</b>	DecelZero	Boolean

### Controller

Use the **Control type**, **cntrlType** parameter to specify one of these control options.

Setting	Block Implementation
PI	Proportional-integral (PI) control with tracking windup and feed-forward gains.
Scheduled PI	PI control with tracking windup and feed-forward gains that are a function of vehicle velocity.
Predictive	<p>Optimal single-point preview (look ahead) control model developed by C. C. MacAdam<sup>1, 2, 3</sup>. The model represents driver steering control behavior during path-following and obstacle avoidance maneuvers. Drivers preview (look ahead) to follow a predefined path. To implement the MacAdam model, the block:</p> <ul style="list-style-type: none"> <li>• Represents the dynamics as a linear single track (bicycle) vehicle</li> <li>• Minimizes the previewed error signal at a single point <math>T^*</math> seconds ahead in time</li> <li>• Accounts for the driver lag deriving from perceptual and neuromuscular mechanisms</li> </ul>

**Shift**

Use the **Shift type**, **shftType** parameter to specify one of these shift options.

Setting	Block Implementation
None	<p>No transmission. Block outputs a constant gear of 1.</p> <p>Use this setting to minimize the number of parameters you need to generate acceleration and braking commands to track forward vehicle motion. This setting does not allow reverse vehicle motion.</p>
Reverse, Neutral, Drive	<p>Block uses a Stateflow<sup>®</sup> chart to model reverse, neutral, and drive gear shift scheduling.</p> <p>Use this setting to generate acceleration and braking commands to track forward and reverse vehicle motion using simple reverse, neutral, and drive gear shift scheduling. Depending on the vehicle state and vehicle velocity feedback, the block uses the initial gear and time required to shift to shift the vehicle up into drive or down into reverse or neutral.</p> <p>For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.</p>

Setting	Block Implementation
Scheduled	<p>Block uses a Stateflow chart to model reverse, neutral, park, and N-speed gear shift scheduling.</p> <p>Use this setting to generate acceleration and braking commands to track forward and reverse vehicle motion using reverse, neutral, park, and N-speed gear shift scheduling. Depending on the vehicle state and vehicle velocity feedback, the block uses these parameters to determine the:</p> <ul style="list-style-type: none"> <li>• Initial gear</li> <li>• Upshift and downshift accelerator pedal positions</li> <li>• Upshift and downshift velocity</li> <li>• Timing for shifting and engaging forward and reverse from neutral</li> </ul> <p>For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.</p>
External	<p>Block uses the input gear, vehicle state, and velocity feedback to generate acceleration and braking commands to track forward and reverse vehicle motion.</p> <p>For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.</p>

### Gear Signal

Use the **Output gear signal** parameter to create the GearCmd output port. The GearCmd signal contains the integer value of the commanded vehicle gear.

Gear	Integer
Park	80
Reverse	-1
Neutral	0
Drive	1
Gear	Gear number

### Controller: PI Speed-Tracking

If you set the control type to PI or Scheduled PI, the block implements proportional-integral (PI) control with tracking windup and feed-forward gains. For the Scheduled PI configuration, the block uses feed forward gains that are a function of vehicle velocity.

To calculate the speed control output, the block uses these equations.

Setting	Equation
PI	$y = \frac{K_{ff}}{v_{nom}} v_{ref} + \frac{K_p e_{ref}}{v_{nom}} + \int \left( \frac{K_i e_{ref}}{v_{nom}} + K_{aw} e_{out} \right) dt + K_g \theta$

Setting	Equation
Scheduled PI	$y = \frac{K_{ff}(v)}{v_{nom}}v_{ref} + \frac{K_p(v)e_{ref}}{v_{nom}} + \int \left( \frac{K_i(v)e_{ref}}{v_{nom}} + K_{aw}e_{out} \right) e_{ref} dt + K_g(v)\theta$

where:

$$e_{ref} = v_{ref} - v$$

$$e_{out} = y_{sat} - y$$

$$y_{sat} = \begin{cases} -1 & y < -1 \\ y & -1 \leq y \leq 1 \\ 1 & 1 < y \end{cases}$$

The velocity error low-pass filter uses this transfer function.

$$H(s) = \frac{1}{\tau_{err}s + 1} \quad \text{for } \tau_{err} > 0$$

To calculate the acceleration and braking commands, the block uses these equations.

$$y_{acc} = \begin{cases} 0 & y_{sat} < 0 \\ y_{sat} & 0 \leq y_{sat} \leq 1 \\ 1 & 1 < y_{sat} \end{cases}$$

$$y_{dec} = \begin{cases} 0 & y_{sat} > 0 \\ -y_{sat} & -1 \leq y_{sat} \leq 0 \\ 1 & y_{sat} < -1 \end{cases}$$

The equations use these variables.

$v_{nom}$	Nominal vehicle speed
$K_p$	Proportional gain
$K_i$	Integral gain
$K_{aw}$	Anti-windup gain
$K_{ff}$	Velocity feed-forward gain
$K_g$	Grade angle feed-forward gain
$\theta$	Grade angle
$\tau_{err}$	Error filter time constant
$y$	Nominal control output magnitude
$y_{sat}$	Saturated control output magnitude
$e_{ref}$	Velocity error
$e_{out}$	Difference between saturated and nominal control outputs
$y_{acc}$	Acceleration signal
$y_{dec}$	Braking signal
$v$	Velocity feedback signal

$v_{ref}$  Reference velocity signal

### Controller: Predictive Speed-Tracking

If you set the **Control type**, **cntrlType** parameter to **Predictive**, the block implements an optimal single-point preview (look ahead) control model developed by C. C. MacAdam<sup>1, 2, 3</sup>. The model represents driver steering control behavior during path-following and obstacle avoidance maneuvers. Drivers preview (look ahead) to follow a predefined path. To implement the MacAdam model, the block:

- Represents the dynamics as a linear single track (bicycle) vehicle
- Minimizes the previewed error signal at a single point  $T^*$  seconds ahead in time
- Accounts for the driver lag deriving from perceptual and neuromuscular mechanisms

### Vehicle Dynamics

For longitudinal motion, the block implements these linear dynamics.

$$x_1 = v$$

$$\dot{x}_1 = x_2 = \frac{K_{pt}}{m} - g\sin(\gamma) + F_r x_1$$

In matrix notation:

$$\dot{x} = Fx + g\bar{u}$$

where:

$$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

$$F = \begin{bmatrix} 0 & 1 \\ \frac{F_r}{m} & 0 \end{bmatrix}$$

$$g = \begin{bmatrix} 0 \\ \frac{K_{pt}}{m} \end{bmatrix}$$

$$\bar{u} = u - \frac{m^2}{K_{pt}} g\sin(\gamma)$$

The block uses this equation for the rolling resistance.

$$F_r = - \left[ \tanh(x_1) \left( \frac{a_r}{x_1} + c_r x_1 \right) + b_r \right]$$

The single-point model assumes a minimum previewed error signal at a single point  $T^*$  seconds ahead in time.  $a^*$  is the driver ability to predict the future vehicle response based on the current steering control input.  $b^*$  is the driver ability to predict the future vehicle response based on the current vehicle state. The block uses these equations.

$$a^* = (T^*)m^T \left[ I + \sum_{n=1}^{\infty} \frac{F^n (T^*)^n}{(n+1)!} \right] g e$$

$$b^* = m^T \left[ I + \sum_{n=1}^{\infty} \frac{F^n (T^*)^n}{n!} \right]$$

where:

$$m^T = [1 \ 1]$$

The equations use these variables.

$a, b$	Forward and rearward tire location, respectively
$m$	Vehicle mass
$I$	Vehicle rotational inertia
$a^*, b^*$	Driver prediction scalar and vector gain, respectively
$x$	Predicted vehicle state vector
$v$	Longitudinal velocity
$F$	System matrix
$K_{pt}$	Tractive force and brake limit
$\gamma$	Grade angle
$g$	Control coefficient vector
$g$	Gravitational constant
$T^*$	Preview time window
$f(t+T^*)$	Previewed path input $T^*$ seconds ahead
$U$	Forward vehicle velocity
$m^T$	Constant observer vector; provides vehicle lateral position
$F_r$	Rolling resistance
$a_r$	Static rolling and driveline resistance
$b_r$	Linear rolling and driveline resistance
$c_r$	Aerodynamic rolling and driveline resistance

### Optimization

The single-point model implemented by the block finds the steering command that minimizes a local performance index,  $J$ , over the current preview interval,  $(t, t+T)$ .

$$J = \frac{1}{T} \int_t^{t+T} [f(\eta) - y(\eta)]^2 d\eta$$

To minimize  $J$  with respect to the steering command, this condition must be met.

$$\frac{dJ}{du} = 0$$

You can express the optimal control solution in terms of a current non-optimal and corresponding nonzero preview output error  $T^*$  seconds ahead<sup>1, 2, 3</sup>.



$$u^o(t) = u(t) + \frac{e(t + T^*)}{a^*}$$

The block uses the preview distance and vehicle longitudinal velocity to determine the preview time window.

$$T^* = \frac{L}{U}$$

The equations use these variables.

$T^*$	Preview time window
$f(t+T^*)$	Previewed path input $T^*$ sec ahead
$y(t+T^*)$	Previewed plant output $T^*$ sec ahead
$e(t+T^*)$	Previewed error signal $T^*$ sec ahead
$u(t), u^o(t)$	Steer angle and optimal steer angle, respectively
$L$	Preview distance
$J$	Performance index
$U$	Forward (longitudinal) vehicle velocity

### Driver Lag

The single-point model implemented by the block introduces a driver lag. The driver lag accounts for the delay when the driver is tracking tasks. Specifically, it is the transport delay deriving from perceptual and neuromuscular mechanisms. To calculate the driver transport delay, the block implements this equation.

$$H(s) = e^{-s\tau}$$

The equations use these variables.

$\tau$	Driver transport delay
$y(t+T^*)$	Previewed plant output $T^*$ sec ahead
$e(t+T^*)$	Previewed error signal $T^*$ sec ahead
$u(t), u^o(t)$	Steer angle and optimal steer angle, respectively
$J$	Performance index

### Ports

#### Input

##### VelRef — Reference vehicle velocity

scalar

Reference velocity,  $v_{ref}$ , in m/s.

##### EnbAccelOvr — Enable acceleration command override

scalar

Enable acceleration command override.

**Dependencies**

To enable this port, select **Acceleration override**.

Data Types: Boolean

**AccelOvrCmd — Acceleration override command**  
scalar

Acceleration override command, normalized from 0 through 1.

**Dependencies**

To enable this port, select **Acceleration override**.

Data Types: double

**AccelHld — Acceleration hold**  
scalar

Boolean signal that holds the acceleration command at the current value.

**Dependencies**

To enable this port, select **Acceleration hold**.

Data Types: Boolean

**AccelZero — Disable acceleration command**  
scalar

Disable acceleration command.

**Dependencies**

To enable this port, select **Acceleration disable**.

Data Types: Boolean

**EnbDecelOvr — Enable deceleration command override**  
scalar

Enable deceleration command override.

**Dependencies**

To enable this port, select **Deceleration override**.

Data Types: Boolean

**DecelOvrCmd — Deceleration override command**  
scalar

Deceleration override command, normalized from 0 through 1.

**Dependencies**

To enable this port, select **Deceleration override**.

Data Types: double

**DecelHld — Deceleration hold**

scalar

Boolean signal that holds the deceleration command at the current value.

**Dependencies**

To enable this port, select **Deceleration hold**.

Data Types: Boolean

**DecelZero — Disable deceleration command**

scalar

Disable deceleration command.

**Dependencies**

To enable this port, select **Deceleration disable**.

Data Types: Boolean

**ExtGear — Gear**

scalar

<b>Gear</b>	<b>Integer</b>
Park	80
Reverse	-1
Neutral	0
Drive	1
Gear	Gear number

**Dependencies**

To enable this port, set **Shift type, shiftType** to External.

**VelFdbk — Longitudinal vehicle velocity**

scalar

Longitudinal vehicle velocity,  $U$ , in the vehicle-fixed frame, in m/s.

**Grade — Road grade angle**

scalar

Road grade angle,  $\theta$  or  $\gamma$ , in deg.

**Output****Info — Bus signal**

bus

Bus signal containing these block calculations.

Signal	Variable	Description
Accel	$y_{acc}$	Commanded vehicle acceleration, normalized from 0 through 1
Decel	$y_{dec}$	Commanded vehicle deceleration, normalized from 0 through 1
Gear		Integer value of commanded gear
Clutch		Clutch command
Err	$e_{ref}$	Difference in reference vehicle speed and vehicle speed
ErrSqrSum	$\int_0^t e_{ref}^2 dt$	Integrated square of error
ErrMax	$\max(e_{ref}(t))$	Maximum error during simulation
ErrMin	$\min(e_{ref}(t))$	Minimum error during simulation
ExtActions	EnblAccelOvr	Override the accelerator command with an input acceleration command
	AccelOvrCmd	Input accelerator override command
	AccelHld	Hold the acceleration command at the current value
	AccelZero	Disable the acceleration command
	EnblDecelOvr	Override the decelerator command with an input deceleration command
	DecelOvrCmd	Input deceleration override command
	DecelHld	Hold the decelerator command at current value
	DecelZero	Disable the decelerator command

**AccelCmd — Commanded vehicle acceleration**

scalar

Commanded vehicle acceleration,  $y_{acc}$ , normalized from 0 through 1.

**DecelCmd — Commanded vehicle deceleration**

scalar

Commanded vehicle deceleration,  $y_{dec}$ , normalized from 0 through 1.

**GearCmd — Commanded vehicle gear**

scalar

Integer value of commanded vehicle gear.

Gear	Integer
Park	80
Reverse	-1

<b>Gear</b>	<b>Integer</b>
Neutral	0
Drive	1
Gear	Gear number

**Dependencies**

To enable this port, select **Output gear signal**.

**Parameters****External Actions****Accelerator override – Override acceleration command**

off (default) | on

Select to override the acceleration command with an input acceleration command.

**Dependencies**

Selecting this parameter creates the EnblAccelOvr and AccelOvrCmd input ports.

**Accelerator hold – Hold acceleration command**

off (default) | on

Select to hold the acceleration command.

**Dependencies**

Selecting this parameter creates the AccelHld input port.

**Accelerator disable – Disable acceleration command**

off (default) | on

Select to disable the acceleration command.

**Dependencies**

Selecting this parameter creates the AccelZero input port.

**Decelerator override – Override deceleration command**

off (default) | on

Select to override the deceleration command with an input deceleration command.

**Dependencies**

Selecting this parameter creates the EnblDecelOvr and DecelOvrCmd input ports.

**Decelerator hold – Hold deceleration command**

off (default) | on

Select to hold the deceleration command.

**Dependencies**

Selecting this parameter creates the DecelHld input port.

**Decelerator disable – Disable deceleration command**

off (default) | on

Select to disable the deceleration command.

**Dependencies**

Selecting this parameter creates the DecelZero input port.

**Configuration**

**Control type, cntrlType – Longitudinal control**

PI (default) | Scheduled PI | Predictive

Type of longitudinal control.

Setting	Block Implementation
PI	Proportional-integral (PI) control with tracking windup and feed-forward gains.
Scheduled PI	PI control with tracking windup and feed-forward gains that are a function of vehicle velocity.
Predictive	Optimal single-point preview (look ahead) control model developed by C. C. MacAdam <sup>1, 2, 3</sup> . The model represents driver steering control behavior during path-following and obstacle avoidance maneuvers. Drivers preview (look ahead) to follow a predefined path. To implement the MacAdam model, the block: <ul style="list-style-type: none"> <li>• Represents the dynamics as a linear single track (bicycle) vehicle</li> <li>• Minimizes the previewed error signal at a single point <math>T^*</math> seconds ahead in time</li> <li>• Accounts for the driver lag deriving from perceptual and neuromuscular mechanisms</li> </ul>

**Shift type, shftType – Shift type**

None (default) | Reverse, Neutral, Drive | Scheduled | External

Shift type.

Setting	Block Implementation
None	No transmission. Block outputs a constant gear of 1.  Use this setting to minimize the number of parameters you need to generate acceleration and braking commands to track forward vehicle motion. This setting does not allow reverse vehicle motion.

Setting	Block Implementation
Reverse, Neutral, Drive	<p>Block uses a Stateflow chart to model reverse, neutral, and drive gear shift scheduling.</p> <p>Use this setting to generate acceleration and braking commands to track forward and reverse vehicle motion using simple reverse, neutral, and drive gear shift scheduling. Depending on the vehicle state and vehicle velocity feedback, the block uses the initial gear and time required to shift to shift the vehicle up into drive or down into reverse or neutral.</p> <p>For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.</p>
Scheduled	<p>Block uses a Stateflow chart to model reverse, neutral, park, and N-speed gear shift scheduling.</p> <p>Use this setting to generate acceleration and braking commands to track forward and reverse vehicle motion using reverse, neutral, park, and N-speed gear shift scheduling. Depending on the vehicle state and vehicle velocity feedback, the block uses these parameters to determine the:</p> <ul style="list-style-type: none"> <li>• Initial gear</li> <li>• Upshift and downshift accelerator pedal positions</li> <li>• Upshift and downshift velocity</li> <li>• Timing for shifting and engaging forward and reverse from neutral</li> </ul> <p>For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.</p>
External	<p>Block uses the input gear, vehicle state, and velocity feedback to generate acceleration and braking commands to track forward and reverse vehicle motion.</p> <p>For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.</p>

### Reference and feedback units, velUnits – Velocity units

m/s (default)

Vehicle velocity reference and feedback units.

### Dependencies

If you set **Control type**, **cntrlType** control type to Scheduled or Scheduled PI, the block uses the **Reference and feedback units, velUnits** for the **Nominal speed, vnom** parameter dimension.

If you set **Shift Type**, **shftType** to Scheduled, the block uses the **Longitudinal velocity units, velUnits** for these parameter dimensions:

- **Upshift velocity data table, upShftTbl**

- **Downshift velocity data table, dwnShftTbl**

**Output gear signal – Create GearCmd output port**

off (default) | on

Specify to create output port GearCmd.

**Control****Longitudinal****Proportional gain, Kp – Gain**

10 (default) | scalar

Proportional gain,  $K_p$ , dimensionless.

**Dependencies**

To create this parameter, set **Control type** to PI.

**Integral gain, Ki – Gain**

5 (default) | scalar

Proportional gain,  $K_i$ , dimensionless.

**Dependencies**

To create this parameter, set **Control type** to PI.

**Velocity feed-forward, Kff – Gain**

.1 (default) | scalar

Velocity feed-forward gain,  $K_{ff}$ , dimensionless.

**Dependencies**

To create this parameter, set **Control type** to PI.

**Grade angle feed-forward, Kg – Gain**

0 (default) | scalar

Grade angle feed-forward gain,  $K_g$ , in 1/deg.

**Dependencies**

To create this parameter, set **Control type** to PI.

**Velocity gain breakpoints, VehVelVec – Breakpoints**

[0 100] (default) | vector

Velocity gain breakpoints, *VehVelVec*, dimensionless.

**Dependencies**

To create this parameter, set **Control type** to Scheduled PI.

**Velocity feed-forward gain values, KffVec – Gain**

[.1 .1] (default) | vector



Velocity feed-forward gain values,  $K_{ffVec}$ , as a function of vehicle velocity, dimensionless.

**Dependencies**

To create this parameter, set **Control type** to Scheduled PI.

**Proportional gain values,  $K_pVec$  – Gain**

[10 10] (default) | vector

Proportional gain values,  $K_pVec$ , as a function of vehicle velocity, dimensionless.

**Dependencies**

To create this parameter, set **Control type** to Scheduled PI.

**Integral gain values,  $K_iVec$  – Gain**

[5 5] (default) | vector

Integral gain values,  $K_iVec$ , as a function of vehicle velocity, dimensionless.

**Dependencies**

To create this parameter, set **Control type** to Scheduled PI.

**Grade angle feed-forward values,  $K_gVec$  – Grade gain**

[0 0] (default) | vector

Grade angle feed-forward values,  $K_gVec$ , as a function of vehicle velocity, in 1/deg.

**Dependencies**

To create this parameter, set **Control type** to Scheduled PI.

**Nominal speed,  $v_{nom}$  – Nominal vehicle speed**

5 (default) | scalar

Nominal vehicle speed,  $v_{nom}$ , in units specified by the **Reference and feedback units, velUnits** parameter. The block uses the nominal speed to normalize the controller gains.

**Dependencies**

To create this parameter, set **Control type** to PI or Scheduled PI.

**Anti-windup,  $K_{aw}$  – Gain**

1 (default) | scalar

Anti-windup gain,  $K_{aw}$ , dimensionless.

**Dependencies**

To create this parameter, set **Control type** to PI or Scheduled PI.

**Error filter time constant,  $\tau_{err}$  – Filter**

.01 (default) | scalar

Error filter time constant,  $\tau_{err}$ , in s. To disable the filter, enter 0.

**Dependencies**

To create this parameter, set **Control type** to PI or Scheduled PI.

**Predictive****Vehicle mass,  $m$  – Mass**

1500 (default) | scalar

Vehicle mass,  $m$ , in kg.

**Dependencies**

To create this parameter, set **Longitudinal control type, `cntrlType`** to Predictive.

**Effective vehicle total tractive force,  $K_p$  – Tractive force**

3000 (default) | scalar

Effective vehicle total tractive force,  $K_p$ , in N.

**Dependencies**

To create this parameter, set **Longitudinal control type, `cntrlType`** to Predictive.

**Driver response time,  $\tau$  – Tau**

.1 (default) | scalar

Driver response time,  $\tau$ , in s.

**Dependencies**

To create this parameter, set **Longitudinal control type, `cntrlType`** to Predictive.

**Preview distance,  $L$  – Distance**

2 (default) | scalar

Driver preview distance,  $L$ , in m.

**Dependencies**

To create this parameter, set **Longitudinal control type, `cntrlType`** to Predictive.

**Rolling resistance coefficient,  $a_R$  – Resistance**

200 (default) | scalar

Static rolling and driveline resistance coefficient,  $a_R$ , in N. Block uses the parameter to estimate the constant acceleration or braking effort.

**Dependencies**

To create this parameter, set **Longitudinal control type, `cntrlType`** to Predictive.

**Rolling and driveline resistance coefficient,  $b_R$  – Resistance**

2.5 (default) | scalar

Rolling and driveline resistance coefficient,  $b_R$ , in N·s/m. Block uses the parameter to estimate the linear velocity-dependent acceleration or braking effort.

**Dependencies**

To create this parameter, set **Longitudinal control type, `cntrlType`** to Predictive.

**Aerodynamic drag coefficient, `cR` – Drag**

.5 (default) | scalar

Aerodynamic drag coefficient,  $c_R$ , in  $N \cdot s^2/m^2$ . Block uses the parameter to estimate the quadratic velocity-dependent acceleration or braking effort.

**Dependencies**

To create this parameter, set **Longitudinal control type, `cntrlType`** to Predictive.

**Gravitational constant, `g` – Gravitational constant**

9.81 (default) | scalar

Gravitational constant,  $g$ , in  $m/s^2$ .

**Dependencies**

To create this parameter, set **Longitudinal control type, `cntrlType`** to Predictive.

**Shift****Reverse, Neutral, Drive****Initial gear, `GearInit` – Initial gear**

0 (default) | scalar

Integer value of the initial gear. The block uses the initial gear to generate acceleration and braking commands to track forward and reverse vehicle motion.

Gear	Integer
Park	80
Reverse	-1
Neutral	0
Drive	1
Gear	Gear number

**Dependencies**

To create this parameter, set **Shift type, `shftType`** to Reverse, Neutral, Drive or Scheduled. If you specify Reverse, Neutral, Drive, the **Initial Gear, `GearInit`** parameter value can be only -1, 0, or 1.

**Time required to shift, `tShift` – Time**

.1 (default) | scalar

Time required to shift,  $t_{Shift}$ , in s. The block uses the time required to shift to generate acceleration and braking commands to track forward and reverse vehicle motion using reverse, neutral, and drive gear shift scheduling.

**Dependencies**

To create this parameter, set **Shift type, shftType** to Reverse, Neutral, Drive.

**Scheduled****Initial gear, GearInit – Initial gear**

0 (default) | scalar

Integer value of the initial gear. The block uses the initial gear to generate acceleration and braking commands to track forward and reverse vehicle motion.

Gear	Integer
Park	80
Reverse	-1
Neutral	0
Drive	1
Gear	Gear number

**Dependencies**

To create this parameter, set **Shift type, shftType** to Reverse, Neutral, Drive or Scheduled. If you specify Reverse, Neutral, Drive, the **Initial Gear, GearInit** parameter value can be only -1, 0, or 1.

**Up and down shift accelerator pedal positions, pdlVec – Pedal position breakpoints**

[0.1 0.4 0.5 0.9] (default) | [1-by-m] vector

Pedal position breakpoints for lookup tables when calculating upshift and downshift velocities, dimensionless. Vector dimensions are 1 by the number of pedal position breakpoints, m.

**Dependencies**

To create this parameter, set **Shift type, shftType** to Scheduled.

**Upshift velocity data table, upShftTbl – Table**

[m-by-n] array

Upshift velocity data as a function of pedal position and gear, in units specified by the **Reference and feedback units, velUnits** parameter. Upshift velocities indicate the vehicle velocity at which the gear should increase by 1.

The array dimensions are m pedal positions by n gears. The first column of data, when n equals 1, is the upshift velocity for the neutral gear.

**Dependencies**

To create this parameter, set **Shift type, shftType** to Scheduled.

**Downshift velocity data table, dwnShftTbl – Table**

[m-by-n] array

Downshift velocity data as a function of pedal position and gear, in units specified by the **Reference and feedback units, velUnits** parameter. Downshift velocities indicate the vehicle velocity at which the gear should decrease by 1.

The array dimensions are  $m$  pedal positions by  $n$  gears. The first column of data, when  $n$  equals 1, is the downshift velocity for the neutral gear.

#### Dependencies

To create this parameter, set **Shift type, shftType** to Scheduled.

#### Time required to shift, tClutch – Time

.5 (default) | scalar

Time required to shift,  $t_{Clutch}$ , in s.

#### Dependencies

To create this parameter, set **Shift type, shftType** to Scheduled.

#### Time required to engage reverse from neutral, tRev – Time

.5 (default) | scalar

Time required to engage reverse from neutral,  $t_{Rev}$ , in s.

#### Dependencies

To create this parameter, set **Shift type, shftType** to Scheduled.

#### Time required to engage park from neutral, tPark – Time

120 (default) | scalar

Time required to engage park from neutral,  $t_{Park}$ , in s.

#### Dependencies

To create this parameter, set **Shift type, shftType** to Scheduled.

## References

- [1] MacAdam, C. C. "An Optimal Preview Control for Linear Systems". *Journal of Dynamic Systems, Measurement, and Control*. Vol. 102, Number 3, Sept. 1980.
- [2] MacAdam, C. C. "Application of an Optimal Preview Control for Simulation of Closed-Loop Automobile Driving ". *IEEE Transactions on Systems, Man, and Cybernetics*. Vol. 11, Issue 6, June 1981.
- [3] MacAdam, C. C. *Development of Driver/Vehicle Steering Interaction Models for Dynamic Analysis*. Final Technical Report UMTRI-88-53. Ann Arbor, Michigan: The University of Michigan Transportation Research Institute, Dec. 1988.

## Extended Capabilities

### C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

**See Also**

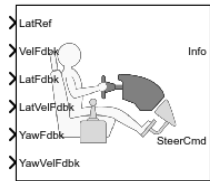
Drive Cycle Source | Lateral Driver | Predictive Driver

**Introduced in R2017a**

# Lateral Driver

Lateral path-tracking controller

**Library:** Vehicle Dynamics Blockset / Vehicle Scenarios / Driver



## Description

The Lateral Driver block implements a control model to generate normalized steering commands that track a lateral reference displacement. The normalized steering commands can vary between -1 to 1. To model the dynamics, the block uses a linear single track (bicycle) model. Use the Lateral Driver block to:

- Close the loop between a predefined path and actual vehicle motion.
- Generate steering commands that track predefined paths. You can connect the Lateral Driver block output to steering block inputs.

## Configurations

### External Actions

Use the **External Actions** parameters to create input ports for signals that can disable, hold, or override the closed-loop steering command. The block uses this priority order for the input commands: disable (highest), hold, override. The block uses this priority order for the input commands: disable (highest), hold, override.

This table summarizes the external action parameters.

Goal	External Action Parameter	Input Ports	Data Type
Override the steering command with an input steering command.	<b>Steering override</b>	EnblSteerOvr	Boolean
		SteerOvrCmd	double
Hold the steering command at the current value.	<b>Steering hold</b>	SteerHld	Boolean
Disable the steering command.	<b>Steering disable</b>	SteerZero	Boolean

Use the **Output handwheel angle** parameter to specify the units for the steering ports.

Setting	Block Implementation	Port
off (default)	Commanded steer angle, normalized from -1 through 1. The block uses the tire wheel angle saturation limit <b>Tire wheel angle limit, theta</b> parameter to normalize the command.	SteerCmd — Output
	Overrides the steering command with an input steering command normalized from -1 through 1.	SteerOvrCmd — Input
on	Commanded steer angle, in units specified by <b>Angular units, angUnits</b> .	SteerCmd — Output
	Overrides the steering command with an input steering command, in units specified by <b>Angular units, angUnits</b> .	SteerOvrCmd — Input

Also, you can specify a tire wheel angle saturation limit using the **Tire wheel angle limit, theta** parameter.

#### Control Type and Units

Use the **Lateral control type, controlTypeLat** parameter to specify the type of lateral control. The table specifies the block implementation.

Setting	Block Implementation
Predictive (default)	Optimal single-point preview (look ahead) control model developed by C. C. MacAdam <sup>1, 2, 3</sup> . The model represents driver steering control behavior during path-following and obstacle avoidance maneuvers. Drivers preview (look ahead) to follow a predefined path.



Setting	Block Implementation												
Stanley	<p>Controller that uses the Stanley<sup>4</sup> method to minimize the position error and the angle error of the current pose with respect to the reference pose.</p> <p>On the <b>Reference Control</b> pane, use the:</p> <ul style="list-style-type: none"> <li>• <b>Vector input for reference and feedback pose</b> parameter to input the to specify the input.</li> </ul> <table border="1"> <thead> <tr> <th>Setting</th> <th>Implementation</th> </tr> </thead> <tbody> <tr> <td>off (default)</td> <td>Block uses the longitudinal, lateral, and yaw reference (LongRef, LatRef, LatRef) input ports and the feedback (LongFdbk, LatFdbk, LatFdbk) input ports for the reference and feedback pose.</td> </tr> <tr> <td>on</td> <td>Block uses input ports, RefPose and CurrPose, for the reference and feedback pose, respectively.</td> </tr> </tbody> </table> <ul style="list-style-type: none"> <li>• <b>Include dynamics</b> parameter to specify the type of model for the controller to use.</li> </ul> <table border="1"> <thead> <tr> <th>Setting</th> <th>Implementation</th> </tr> </thead> <tbody> <tr> <td>off (default)</td> <td>Controller uses a kinematic bicycle model that is suitable for path following in low-speed environments such as parking lots, where inertial effects are minimal.</td> </tr> <tr> <td>on</td> <td>Controller uses a dynamic bicycle model that is suitable for path following in high-speed environments such as highways, where inertial effects are more pronounced.</td> </tr> </tbody> </table>	Setting	Implementation	off (default)	Block uses the longitudinal, lateral, and yaw reference (LongRef, LatRef, LatRef) input ports and the feedback (LongFdbk, LatFdbk, LatFdbk) input ports for the reference and feedback pose.	on	Block uses input ports, RefPose and CurrPose, for the reference and feedback pose, respectively.	Setting	Implementation	off (default)	Controller uses a kinematic bicycle model that is suitable for path following in low-speed environments such as parking lots, where inertial effects are minimal.	on	Controller uses a dynamic bicycle model that is suitable for path following in high-speed environments such as highways, where inertial effects are more pronounced.
Setting	Implementation												
off (default)	Block uses the longitudinal, lateral, and yaw reference (LongRef, LatRef, LatRef) input ports and the feedback (LongFdbk, LatFdbk, LatFdbk) input ports for the reference and feedback pose.												
on	Block uses input ports, RefPose and CurrPose, for the reference and feedback pose, respectively.												
Setting	Implementation												
off (default)	Controller uses a kinematic bicycle model that is suitable for path following in low-speed environments such as parking lots, where inertial effects are minimal.												
on	Controller uses a dynamic bicycle model that is suitable for path following in high-speed environments such as highways, where inertial effects are more pronounced.												

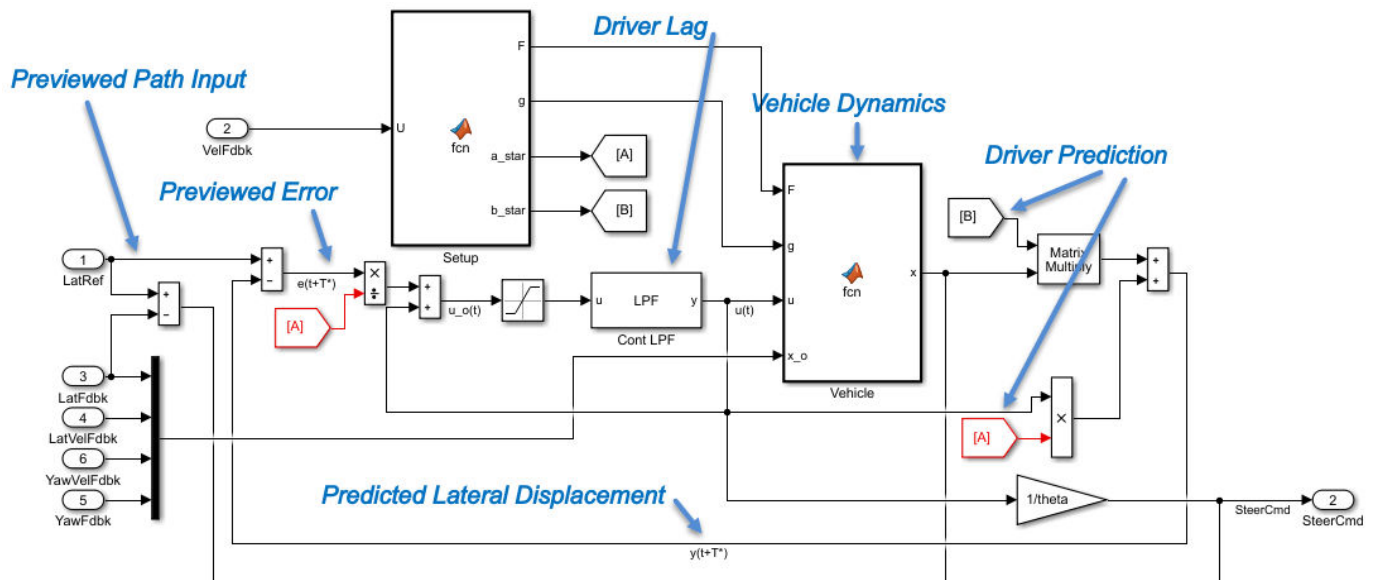
Use the **Angular units, angUnits** parameter to specify the angular units for the input and output ports.

### Controller: Predictive Lateral Path-Tracking

If you set **Lateral control type, controlTypeLat** to **Predictive**, the Lateral Driver block implements an optimal single-point preview (look ahead) control model developed by C. C. MacAdam<sup>1, 2, 3</sup>. The model represents driver steering control behavior during path-following and obstacle avoidance maneuvers. Drivers preview (look ahead) to follow a predefined path. To implement the MacAdam model, the block:

- Represents the dynamics as a linear single track (bicycle) vehicle
- Minimizes the previewed error signal at a single point  $T^*$  seconds ahead in time
- Accounts for the driver lag deriving from perceptual and neuromuscular mechanisms

This figure illustrates the block implementation of the single-point version of the driver model.



### Vehicle Dynamics

For lateral and yaw motion, the block implements these linear dynamic equations.

$$\dot{y} = v + U\psi$$

$$\dot{v} = \left[ -\frac{2(C_{\alpha F} + C_{\alpha R})}{mU} \right] v + \left[ \frac{2(bC_{\alpha R} - aC_{\alpha F})}{mU} - U \right] r + \left( \frac{2C_{\alpha F}}{m} \right) \delta_F$$

$$\dot{r} = \left[ \frac{2(bC_{\alpha R} - aC_{\alpha F})}{IU} \right] v + \left[ -\frac{2(a^2C_{\alpha F} + b^2C_{\alpha R})}{IU} \right] r + \left( \frac{2aC_{\alpha F}}{I} \right) \delta_F$$

$$\dot{\psi} = r$$

In matrix notation:

$$\dot{x} = Fx + g\delta_F$$

where:

$$x = \begin{bmatrix} y \\ v \\ r \\ \psi \end{bmatrix}$$

$$F = \begin{bmatrix} 0 & 1 & 0 & U \\ 0 & -2\frac{C_{\alpha F} + C_{\alpha R}}{mU} & 2\frac{bC_{\alpha R} - aC_{\alpha F}}{mU} - U & 0 \\ 0 & 2\frac{bC_{\alpha R} - aC_{\alpha F}}{IU} & -2\frac{a^2C_{\alpha F} + b^2C_{\alpha R}}{IU} & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$$g = \begin{bmatrix} 0 \\ \frac{2C_{\alpha F}}{m} \\ \frac{2aC_{\alpha F}}{I} \\ 0 \end{bmatrix}$$

The single-point model assumes a minimum previewed error signal at a single point  $T^*$  seconds ahead in time.  $a^*$  is the driver ability to predict the future vehicle response based on the current steering control input.  $b^*$  is the driver ability to predict the future vehicle response based on the current vehicle state. The block uses these equations.

$$a^* = T^* m^T \left[ I + \sum_{n=1}^{\infty} \frac{F^n (T^*)^n}{(n+1)!} \right] g$$

$$b^* = m^T \left[ I + \sum_{n=1}^{\infty} \frac{F^n (T^*)^n}{n!} \right]$$

where:

$$m^T = [1 \ 0 \ 0 \ 0]$$

The equations use these variables.

$a, b$	Forward and rearward tire location, respectively
$m$	Vehicle mass
$I$	Vehicle rotational inertia
$C_{\alpha F}$	Front tire cornering coefficient
$C_{\alpha R}$	Rear tire cornering coefficient
$a^*, b^*$	Driver prediction scalar and vector gain, respectively
$x$	Predicted vehicle state vector
$v$	Lateral velocity

$r$	Yaw rate
$\psi$	Front wheel heading angle
$y$	Lateral displacement
$F$	System matrix
$\delta, \delta_F$	Steer angle and front axle steer angle, respectively
$g$	Control coefficient vector
$U$	Forward (longitudinal) vehicle velocity
$T^*$	Preview time window
$f(t+T^*)$	Previewed path input $T^*$ seconds ahead
$U$	Forward vehicle velocity
$m^T$	Constant observer vector; provides vehicle lateral position

### Optimization

The single-point model implemented by the block finds the steering command that minimizes a local performance index,  $J$ , over the current preview interval,  $(t, t+T)$ .

$$J = \frac{1}{T} \int_t^{t+T} [f(\eta) - y(\eta)]^2 d\eta$$

To minimize  $J$  with respect to the steering command, this condition must be met.

$$\frac{dJ}{du} = 0$$

You can express the optimal control solution in terms of a current non-optimal and corresponding nonzero preview output error  $T^*$  seconds ahead<sup>1, 2, 3</sup>.

$$u^o(t) = u(t) + \frac{e(t + T^*)}{a^*}$$

The block uses the preview distance and vehicle longitudinal velocity to determine the preview time window.

$$T^* = \frac{L}{U}$$

The equations use these variables.

$T^*$	Preview time window
$f(t+T^*)$	Previewed path input $T^*$ sec ahead
$y(t+T^*)$	Previewed plant output $T^*$ sec ahead
$e(t+T^*)$	Previewed error signal $T^*$ sec ahead
$u(t), u^o(t)$	Steer angle and optimal steer angle, respectively
$L$	Preview distance
$J$	Performance index
$U$	Forward (longitudinal) vehicle velocity

## Driver Lag

The single-point model implemented by the block introduces a driver lag. The driver lag accounts for the delay when the driver is tracking tasks. Specifically, it is the transport delay deriving from perceptual and neuromuscular mechanisms. To calculate the driver transport delay, the block implements this equation.

$$H(s) = e^{-s\tau}$$

The equations use these variables.

$\tau$	Driver transport delay
$y(t+T^*)$	Previewed plant output $T^*$ sec ahead
$e(t+T^*)$	Previewed error signal $T^*$ sec ahead
$u(t), u^o(t)$	Steer angle and optimal steer angle, respectively
$J$	Performance index

## Controller: Stanley Lateral Path-Tracking

If you set **Lateral control type, controlTypeLat** to **Stanley**, the block implements the Stanley method<sup>4</sup>. To compute the steering angle command, the Stanley controller minimizes the position error and the angle error of the current pose with respect to the reference pose. The driving direction of the vehicle determines these error values.

To compute the steering angle command, the controller minimizes the position error and the angle error of the current pose with respect to the reference pose.

- The position error is the lateral distance from the vehicle center-of-gravity (CG) to the reference point on the path.
- The angle error is the angle of the vehicle with respect to reference path.

## Ports

### Input

#### LongRef — Longitudinal displacement reference

scalar

Longitudinal center of mass (CM) displacement reference, in the inertial reference frame, in m.

#### Dependencies

To enable this port:

- Set **Lateral control type, controlTypeLat** to **Stanley**
- Clear **Vector input for reference and feedback**

#### LatRef — Lateral displacement reference

scalar

Lateral center of mass (CM) displacement reference, in the inertial reference frame, in m.

**Dependencies**

To enable this port, do either of these:

- Set **Lateral control type, controlTypeLat** to Stanley and clear **Vector input for reference and feedback**.
- Set **Lateral control type, controlTypeLat** to Predictive.

**EnbLSteerOvr – Enable steering command override**

scalar

Enable steering command override.

**Dependencies**

To enable this port, select **Steering override**.

Data Types: Boolean

**SteerOvrCmd – Steering override command**

scalar

Steering override command.

Use the **Output handwheel angle** parameter to specify the units for the steering ports.

Setting	Block Implementation	Port
off (default)	Commanded steer angle, normalized from -1 through 1. The block uses the tire wheel angle saturation limit <b>Tire wheel angle limit, theta</b> parameter to normalize the command.	SteerCmd – Output
	Overrides the steering command with an input steering command normalized from -1 through 1.	SteerOvrCmd – Input
on	Commanded steer angle, in units specified by <b>Angular units, angUnits</b> .	SteerCmd – Output
	Overrides the steering command with an input steering command, in units specified by <b>Angular units, angUnits</b> .	SteerOvrCmd – Input

**Dependencies**

To enable this port, select **Steering override**.

Data Types: double

**SteerHld – Steering hold**

scalar

Boolean signal that holds the steering command at the current value.

**Dependencies**

To enable this port, select **Steering hold**.

Data Types: Boolean

**SteerZero – Disable steering command**

scalar

Disable steering command.

**Dependencies**

To enable this port, select **Steering disable**.

Data Types: Boolean

**YawRef – Yaw angle reference**

scalar

Vehicle yaw angle,  $\Psi_o$ , in the inertial reference frame, in units specified by **Angular units, angUnits**.

**Dependencies**

To enable this port:

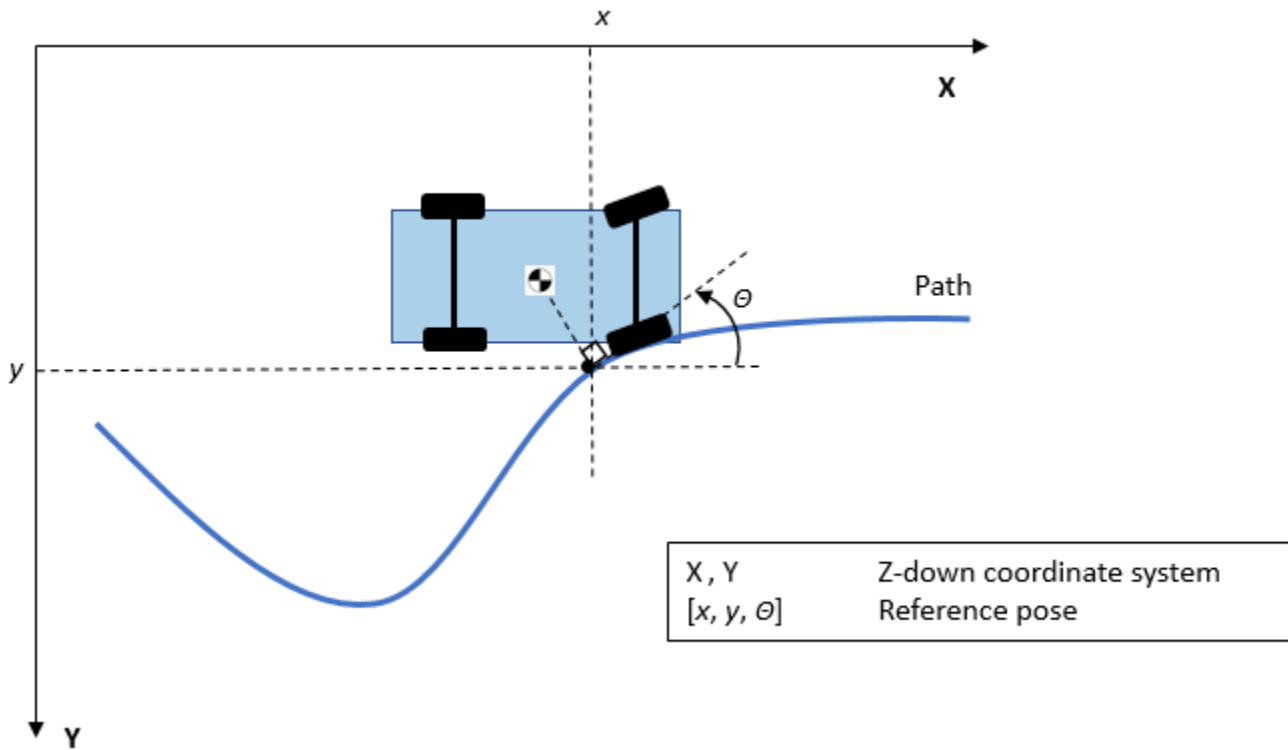
- Set **Lateral control type, controlTypeLat** to Stanley
- Clear **Vector input for reference and feedback**

**RefPose – Reference pose**[ $x$ ,  $y$ ,  $\theta$ ] vector

Reference pose, specified as an [ $x$ ,  $y$ ,  $\theta$ ] vector.  $x$  and  $y$  are in meters, and  $\theta$  are in units specified by **Angular units, angUnits**.

$x$  and  $y$  specify the reference point to steer the vehicle toward.  $\theta$  specifies the orientation angle of the path at this reference point and is positive in the counterclockwise direction.

The reference point is the point on the path that is closest to the vehicle CG. You can use either the Z-up or Z-down vehicle coordinate system, as long as you use the same coordinate system (Z-up or Z-down) for block inputs and parameters.



### Dependencies

To enable this port, set **Lateral control type**, `controlTypeLat` to Stanley and select **Vector input for reference and feedback pose**.

Data Types: single | double

### VelFdbk — Longitudinal vehicle velocity

scalar

Longitudinal vehicle velocity,  $U$ , in the vehicle-fixed frame, in m/s.

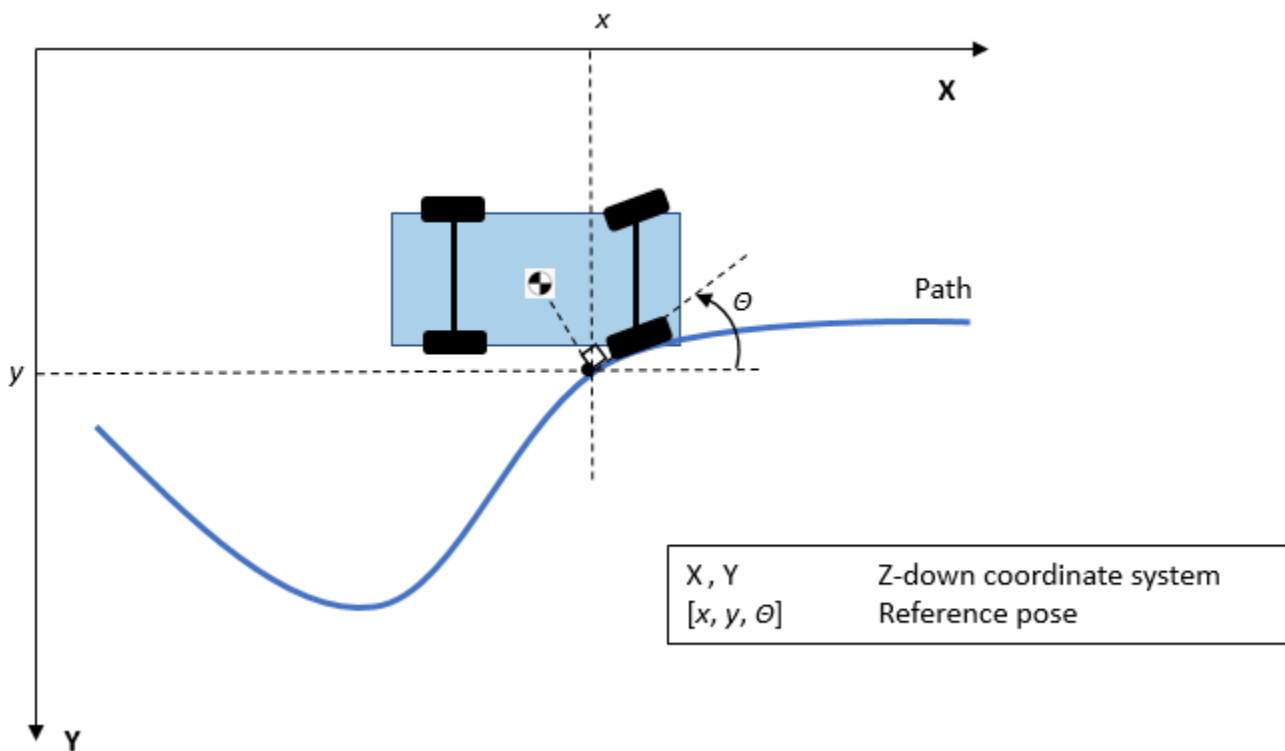
### CurrPose — Current pose

$[x, y, \theta]$  vector

Current pose of the vehicle, specified as an  $[x, y, \theta]$  vector.  $x$  and  $y$  are in meters, and  $\theta$  is in units specified by **Angular units**, `angUnits`.

$x$  and  $y$  specify the location of the vehicle, which is defined as the vehicle CG. You can use either the Z-up or Z-down vehicle coordinate system, as long you use the same coordinate system (Z-up or Z-down) for block inputs and parameters.





### Dependencies

To enable this port, set **Lateral control type, controlTypeLat** to Stanley and select **Vector input for reference and feedback pose**.

Data Types: single | double

### LatFdbk — Lateral displacement

scalar

Lateral CM displacement,  $y_o$ , in the inertial reference frame, in m.

### Dependencies

To enable this port, do either of these:

- Set **Lateral control type, controlTypeLat** to Stanley and clear **Vector input for reference and feedback**.
- Set **Lateral control type, controlTypeLat** to Predictive.

### LatVelFdbk — Lateral vehicle velocity

scalar

Lateral vehicle velocity,  $v_o$ , in the vehicle-fixed frame, in m/s.

### Dependencies

To enable this port, Set **Lateral control type, controlTypeLat** to Predictive.

**YawFdbk – Vehicle yaw angle**

scalar

Vehicle yaw angle,  $\Psi_o$ , in the inertial reference frame, in units specified by **Angular units, angUnits**.

**Dependencies**

To enable this port, do either of these:

- Set **Lateral control type, controlTypeLat** to Stanley and clear **Vector input for reference and feedback pose**.
- Set **Lateral control type, controlTypeLat** to Predictive.

**YawVelFdbk – Yaw rate**

scalar

Yaw rate,  $r_o$ , in the vehicle-fixed frame, in units specified by **Angular units, angUnits** per sec.

**Dependencies**

To enable this port, Set **Lateral control type, controlTypeLat** to Predictive.

**Output****Info – Bus signal**

bus

Bus signal containing these block calculations.

Signal		Variable	Description
Predicted	y	$y$	Predicted lateral displacement, in the vehicle-fixed frame.
	ydot	$v$	Predicted lateral velocity, in the vehicle-fixed frame.
	psi	$\Psi$	Predicted front wheel heading angle.
	r	$r$	Predicted yaw rate, in the vehicle-fixed frame.
SteerCmd		$\delta_F$	Commanded steer angle.
Err		$e_{ref}$	Difference in reference vehicle position and vehicle position.
ErrSqrSum		$\int_0^t e_{ref}^2 dt$	Integrated square of error.
ErrMax		$\max(e_{ref}(t))$	Maximum error during simulation.
ErrMin		$\min(e_{ref}(t))$	Minimum error during simulation.
ExtActions	EnblSteerOvr		Override the steering command with an input deceleration command.
	SteerOvrCmd		Input steering override command
	SteerHld		Hold the steering command at the current value
	SteerZero		Disable the steering command

**SteerCmd — Steer angle command**

scalar

Commanded steer angle,  $\delta_F$ .

Use the **Output handwheel angle** parameter to specify the units for the steering ports.

Setting	Block Implementation	Port
off (default)	Commanded steer angle, normalized from -1 through 1. The block uses the tire wheel angle saturation limit <b>Tire wheel angle limit, theta</b> parameter to normalize the command.	SteerCmd — Output
	Overrides the steering command with an input steering command normalized from -1 through 1.	SteerOvrCmd — Input
on	Commanded steer angle, in units specified by <b>Angular units, angUnits</b> .	SteerCmd — Output
	Overrides the steering command with an input steering command, in units specified by <b>Angular units, angUnits</b> .	SteerOvrCmd — Input

**Parameters****Configuration****Steering override — Override steering command**

off (default) | on

Select to override the steering command with an input steering command.

**Dependencies**

Selecting this parameter creates the Enb1SteerOvr and SteerOvrCmd input ports.

**Steering hold — Hold steering command**

off (default) | on

Select to hold the steering command.

**Dependencies**

Selecting this parameter creates the SteerHld input port.

**Steering disable — Disable steering command**

off (default) | on

Select to disable the steering command.

**Dependencies**

Selecting this parameter creates the SteerZero input port.

**Output handwheel angle — Steering port units in rad**

off (default) | on

Use the **Output handwheel angle** parameter to specify the units for the steering ports.

Setting	Block Implementation	Port
off (default)	Commanded steer angle, normalized from -1 through 1. The block uses the tire wheel angle saturation limit <b>Tire wheel angle limit, theta</b> parameter to normalize the command.	SteerCmd — Output
	Overrides the steering command with an input steering command normalized from -1 through 1.	SteerOvrCmd — Input
on	Commanded steer angle, in units specified by <b>Angular units, angUnits</b> .	SteerCmd — Output
	Overrides the steering command with an input steering command, in units specified by <b>Angular units, angUnits</b> .	SteerOvrCmd — Input

#### Dependencies

To create the SteerOvrCmd input port, select **Steering override**.

#### Lateral control type, controlTypeLat — Controller

Predictive (default) | Stanley

Use the **Lateral control type, controlTypeLat** parameter to specify the type of lateral control. The table specifies the block implementation.

Setting	Block Implementation
Predictive (default)	Optimal single-point preview (look ahead) control model developed by C. C. MacAdam <sup>1, 2, 3</sup> . The model represents driver steering control behavior during path-following and obstacle avoidance maneuvers. Drivers preview (look ahead) to follow a predefined path.

Setting	Block Implementation												
Stanley	<p>Controller that uses the Stanley<sup>4</sup> method to minimize the position error and the angle error of the current pose with respect to the reference pose.</p> <p>On the <b>Reference Control</b> pane, use the:</p> <ul style="list-style-type: none"> <li>• <b>Vector input for reference and feedback pose</b> parameter to input the to specify the input.</li> </ul> <table border="1"> <thead> <tr> <th>Setting</th> <th>Implementation</th> </tr> </thead> <tbody> <tr> <td>off (default)</td> <td>Block uses the longitudinal, lateral, and yaw reference (LongRef, LatRef, LatRef) input ports and the feedback (LongFdbk, LatFdbk, LatFdbk) input ports for the reference and feedback pose.</td> </tr> <tr> <td>on</td> <td>Block uses input ports, RefPose and CurrPose, for the reference and feedback pose, respectively.</td> </tr> </tbody> </table> <ul style="list-style-type: none"> <li>• <b>Include dynamics</b> parameter to specify the type of model for the controller to use.</li> </ul> <table border="1"> <thead> <tr> <th>Setting</th> <th>Implementation</th> </tr> </thead> <tbody> <tr> <td>off (default)</td> <td>Controller uses a kinematic bicycle model that is suitable for path following in low-speed environments such as parking lots, where inertial effects are minimal.</td> </tr> <tr> <td>on</td> <td>Controller uses a dynamic bicycle model that is suitable for path following in high-speed environments such as highways, where inertial effects are more pronounced.</td> </tr> </tbody> </table>	Setting	Implementation	off (default)	Block uses the longitudinal, lateral, and yaw reference (LongRef, LatRef, LatRef) input ports and the feedback (LongFdbk, LatFdbk, LatFdbk) input ports for the reference and feedback pose.	on	Block uses input ports, RefPose and CurrPose, for the reference and feedback pose, respectively.	Setting	Implementation	off (default)	Controller uses a kinematic bicycle model that is suitable for path following in low-speed environments such as parking lots, where inertial effects are minimal.	on	Controller uses a dynamic bicycle model that is suitable for path following in high-speed environments such as highways, where inertial effects are more pronounced.
Setting	Implementation												
off (default)	Block uses the longitudinal, lateral, and yaw reference (LongRef, LatRef, LatRef) input ports and the feedback (LongFdbk, LatFdbk, LatFdbk) input ports for the reference and feedback pose.												
on	Block uses input ports, RefPose and CurrPose, for the reference and feedback pose, respectively.												
Setting	Implementation												
off (default)	Controller uses a kinematic bicycle model that is suitable for path following in low-speed environments such as parking lots, where inertial effects are minimal.												
on	Controller uses a dynamic bicycle model that is suitable for path following in high-speed environments such as highways, where inertial effects are more pronounced.												

### Angular units, angUnits – Input and output port angular units

rad (default) | deg

Input and output port angular units.

### Reference Control

#### Predictive

### Driver response time, tau – Response time

0.1 (default) | scalar

Driver response time,  $\tau$ , in s.

### Dependencies

To enable this parameter, Set **Lateral control type, controlTypeLat** to Predictive.

### Preview distance, L – Distance

3 (default) | scalar

Driver preview distance,  $L$ , in m. Used to determine the preview time window,  $T^*$ .

#### Dependencies

To enable this parameter, Set **Lateral control type, controlTypeLat** to Predictive.

#### Stanley

#### Vector input for reference and feedback pose — Select to create RefPose and CurrPose input ports

off (default) | on

Select this parameter to create the RefPose and CurrPose input ports.

#### Dependencies

To enable this parameter, Set **Lateral control type, controlTypeLat** to Stanley.

#### Include dynamics — Select to include dynamics

off (default) | on

The controller computes this command using the Stanley method, whose control law is based on both a kinematic and dynamic bicycle model. To change between models, use this parameter.

Setting	Implementation
off	Controller uses a kinematic bicycle model that is suitable for path following in low-speed environments such as parking lots, where inertial effects are minimal.
on	Controller uses a dynamic bicycle model that is suitable for path following in high-speed environments such as highways, where inertial effects are more pronounced.

#### Dependencies

To enable this parameter, Set **Lateral control type, controlTypeLat** to Stanley.

#### Position gain of forward motion, PositionGainF — Position gain of vehicle in forward motion

2.5 (default) | positive real scalar

Position gain of the vehicle when it is in forward motion, specified as a positive scalar. This value determines how much the position error affects the steering angle. Typical values are in the range [1, 5]. Increase this value to increase the magnitude of the steering angle.

#### Dependencies

To enable this parameter, Set **Lateral control type, controlTypeLat** to Stanley.

#### Position gain of reverse motion, PositionGainF — Position gain of vehicle in reverse motion

2.5 (default) | positive real scalar

Position gain of the vehicle when it is in reverse motion, specified as a positive scalar. This value determines how much the position error affects the steering angle. Typical values are in the range [1, 5]. Increase this value to increase the magnitude of the steering angle.

**Dependencies**

To enable this parameter, Set **Lateral control type, controlTypeLat** to Stanley.

**Yaw rate feedback gain, YawRateGain — Yaw rate feedback gain**

.2 (default) | nonnegative real scalar

Yaw rate feedback gain, specified as a nonnegative real scalar. This value determines how much weight is given to the current yaw rate of the vehicle when the block computes the steering angle command.

**Dependencies**

To enable this parameter, Set **Lateral control type, controlTypeLat** to Stanley and select **Include dynamics**.

**Steering angle feedback gain, DelayGain — Steering angle feedback gain**

.2 (default) | nonnegative real scalar

Steering angle feedback gain, specified as a nonnegative real scalar. This value determines how much the difference between the current steering angle command, **SteerCmd**, and the current steering angle, **CurrSteer**, affects the next steering angle command.

**Dependencies**

To enable this parameter, Set **Lateral control type, controlTypeLat** to Stanley and select **Include dynamics**.

**Vehicle Parameters****Forward location of tire, a — Along vehicle longitudinal axis**

1.41 (default) | scalar

Forward location of tire,  $a$ , in m. Distance from vehicle cg to forward tire location, along vehicle longitudinal axis.

**Rearward location of tire, b — Along vehicle longitudinal axis**

1.41 (default) | scalar

Rearward location of tire,  $b$ , in m. Absolute value of distance from vehicle cg to rearward tire location, along vehicle longitudinal axis.

**Vehicle mass, m — Mass**

2016 (default) | scalar

Vehicle mass,  $m$ , in kg.

**Dependencies**

To enable this port, do either of these:

- Set **Lateral control type, controlTypeLat** to Stanley and select **Include dynamics**.
- Set **Lateral control type, controlTypeLat** to Predictive.

**Front tire cornering coefficient, Cy\_f — Coefficient**

25266 (default) | scalar

Cornering stiffness coefficient,  $C_{\alpha F}$ , in N/rad.

**Dependencies**

To enable this port, do either of these:

- Set **Lateral control type, controlTypeLat** to Stanley and select **Include dynamics**.
- Set **Lateral control type, controlTypeLat** to Predictive.

**Rear tire cornering coefficient, Cy\_r – Coefficient**

70933 (default) | scalar

Cornering stiffness coefficient,  $C_{\alpha R}$ , in N/rad.

**Dependencies**

To enable this port, set **Lateral control type, controlTypeLat** to Predictive.

**Vehicle rotational inertia, I – Inertia about yaw axis**

4013 (default) | scalar

Vehicle rotational inertia,  $I$ , about the vehicle yaw axis, in  $\text{N}\cdot\text{m}\cdot\text{s}^2$ .

**Dependencies**

To enable this parameter, Set **Lateral control type, controlTypeLat** to Predictive.

**Nominal steering ratio, Ksteer – Steering ratio**

18 (default) | scalar

Steering ratio,  $K_{steer}$ . The value has no dimension.

**Dependencies**

To enable this parameter, select **Output handwheel angle**.

**Tire wheel angle limit, theta – Angle limit**

$45\pi/180$  (default) | scalar

Tire wheel angle limit,  $\theta$ , in rad.

**References**

- [1] MacAdam, C. C. "An Optimal Preview Control for Linear Systems". *Journal of Dynamic Systems, Measurement, and Control*. Vol. 102, Number 3, Sept. 1980.
- [2] MacAdam, C. C. "Application of an Optimal Preview Control for Simulation of Closed-Loop Automobile Driving ". *IEEE Transactions on Systems, Man, and Cybernetics*. Vol. 11, Issue 6, June 1981.
- [3] MacAdam, C. C. *Development of Driver/Vehicle Steering Interaction Models for Dynamic Analysis*. Final Technical Report UMTRI-88-53. Ann Arbor, Michigan: The University of Michigan Transportation Research Institute, Dec. 1988.
- [4] Hoffmann, Gabriel M., Claire J. Tomlin, Michael Montemerlo, and Sebastian Thrun. "Autonomous Automobile Trajectory Tracking for Off-Road Driving: Controller Design, Experimental



Validation and Racing." *American Control Conference*. 2007, pp. 2296-2301. doi:10.1109/ACC.2007.4282788

## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

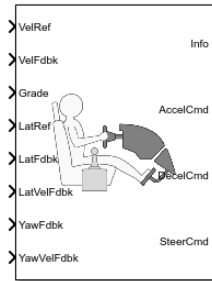
Longitudinal Driver | Predictive Driver

### **Introduced in R2018a**

## Predictive Driver

Predictive driver controller to track longitudinal speed and lateral path

**Library:** Vehicle Dynamics Blockset / Vehicle Scenarios / Driver



### Description

The Predictive Driver block implements a controller that generates normalized steering, acceleration, and braking commands to track longitudinal velocity and a lateral reference displacement. The normalized commands can vary between -1 to 1. The controller uses a single-track (bicycle) model for optimal single-point preview control.

### Configurations

#### External Actions

Use the **External Actions** parameters to create input ports for signals that you can use to simulate standard test maneuvers. The block uses this priority order for the input commands: disable (highest), hold, override.

This table summarizes the external action parameters.

Goal	External Action Parameter	Input Ports	Data Type
Override the accelerator command with an input acceleration command.	<b>Accelerator override</b>	EnablAccelOvr	Boolean
		AccelOvrCmd	double
Hold the acceleration command at the current value.	<b>Accelerator hold</b>	AccelHld	Boolean
Disable the acceleration command.	<b>Accelerator disable</b>	AccelZero	Boolean
Override the decelerator command with an input deceleration command.	<b>Decelerator override</b>	EnablDecelOvr	Boolean
		DecelOvrCmd	double
Hold the decelerator command at current value.	<b>Decelerator hold</b>	DecelHld	Boolean
Disable the decelerator command.	<b>Decelerator disable</b>	DecelZero	Boolean

Goal	External Action Parameter	Input Ports	Data Type
Override the steering command with an input steering command.	<b>Steering override</b>	EnblSteerOvr	Boolean
		SteerOvrCmd	double
Hold the steering command at the current value.	<b>Steering hold</b>	SteerHld	Boolean
Disable the steering command.	<b>Steering disable</b>	SteerZero	Boolean

**Controllers**

Use the **Longitudinal control type, cntrlType** parameter to specify one of these control options.

Setting	Block Implementation
PI	Proportional-integral (PI) control with tracking windup and feed-forward gains.
Scheduled PI	PI control with tracking windup and feed-forward gains that are a function of vehicle velocity.
Predictive	Optimal single-point preview (look ahead) control model developed by C. C. MacAdam <sup>1, 2, 3</sup> . The model represents driver steering control behavior during path-following and obstacle avoidance maneuvers. Drivers preview (look ahead) to follow a predefined path. To implement the MacAdam model, the block: <ul style="list-style-type: none"> <li>• Represents the dynamics as a linear single track (bicycle) vehicle</li> <li>• Minimizes the previewed error signal at a single point <math>T^*</math> seconds ahead in time</li> <li>• Accounts for the driver lag deriving from perceptual and neuromuscular mechanisms</li> </ul>

Use the **Lateral control type, controlTypeLat** parameter to specify the type of lateral control. The table specifies the block implementation.

Setting	Block Implementation
Predictive (default)	Optimal single-point preview (look ahead) control model developed by C. C. MacAdam <sup>1, 2, 3</sup> . The model represents driver steering control behavior during path-following and obstacle avoidance maneuvers. Drivers preview (look ahead) to follow a predefined path.

Setting	Block Implementation												
Stanley	<p>Controller that uses the Stanley<sup>4</sup> method to minimize the position error and the angle error of the current pose with respect to the reference pose.</p> <p>On the <b>Reference Control</b> pane, use the:</p> <ul style="list-style-type: none"> <li>• <b>Vector input for reference and feedback pose</b> parameter to input the to specify the input.</li> </ul> <table border="1"> <thead> <tr> <th>Setting</th> <th>Implementation</th> </tr> </thead> <tbody> <tr> <td>off (default)</td> <td>Block uses the longitudinal, lateral, and yaw reference (LongRef, LatRef, LatRef) input ports and the feedback (LongFdbk, LatFdbk, LatFdbk) input ports for the reference and feedback pose.</td> </tr> <tr> <td>on</td> <td>Block uses input ports, RefPose and CurrPose, for the reference and feedback pose, respectively.</td> </tr> </tbody> </table> <ul style="list-style-type: none"> <li>• <b>Include dynamics</b> parameter to specify the type of model for the controller to use.</li> </ul> <table border="1"> <thead> <tr> <th>Setting</th> <th>Implementation</th> </tr> </thead> <tbody> <tr> <td>off (default)</td> <td>Controller uses a kinematic bicycle model that is suitable for path following in low-speed environments such as parking lots, where inertial effects are minimal.</td> </tr> <tr> <td>on</td> <td>Controller uses a dynamic bicycle model that is suitable for path following in high-speed environments such as highways, where inertial effects are more pronounced.</td> </tr> </tbody> </table>	Setting	Implementation	off (default)	Block uses the longitudinal, lateral, and yaw reference (LongRef, LatRef, LatRef) input ports and the feedback (LongFdbk, LatFdbk, LatFdbk) input ports for the reference and feedback pose.	on	Block uses input ports, RefPose and CurrPose, for the reference and feedback pose, respectively.	Setting	Implementation	off (default)	Controller uses a kinematic bicycle model that is suitable for path following in low-speed environments such as parking lots, where inertial effects are minimal.	on	Controller uses a dynamic bicycle model that is suitable for path following in high-speed environments such as highways, where inertial effects are more pronounced.
Setting	Implementation												
off (default)	Block uses the longitudinal, lateral, and yaw reference (LongRef, LatRef, LatRef) input ports and the feedback (LongFdbk, LatFdbk, LatFdbk) input ports for the reference and feedback pose.												
on	Block uses input ports, RefPose and CurrPose, for the reference and feedback pose, respectively.												
Setting	Implementation												
off (default)	Controller uses a kinematic bicycle model that is suitable for path following in low-speed environments such as parking lots, where inertial effects are minimal.												
on	Controller uses a dynamic bicycle model that is suitable for path following in high-speed environments such as highways, where inertial effects are more pronounced.												

**Shift**

Use the **Shift type, ShftType** parameter to specify one of these shift options.

Setting	Block Implementation
None	<p>No transmission. Block outputs a constant gear of 1.</p> <p>Use this setting to minimize the number of parameters you need to generate acceleration and braking commands to track forward vehicle motion. This setting does not allow reverse vehicle motion.</p>

Setting	Block Implementation
Reverse, Neutral, Drive	<p>Block uses a Stateflow chart to model reverse, neutral, and drive gear shift scheduling.</p> <p>Use this setting to generate acceleration and braking commands to track forward and reverse vehicle motion using simple reverse, neutral, and drive gear shift scheduling. Depending on the vehicle state and vehicle velocity feedback, the block uses the initial gear and time required to shift to shift the vehicle up into drive or down into reverse or neutral.</p> <p>For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.</p>
Scheduled	<p>Block uses a Stateflow chart to model reverse, neutral, park, and N-speed gear shift scheduling.</p> <p>Use this setting to generate acceleration and braking commands to track forward and reverse vehicle motion using reverse, neutral, park, and N-speed gear shift scheduling. Depending on the vehicle state and vehicle velocity feedback, the block uses these parameters to determine the:</p> <ul style="list-style-type: none"> <li>• Initial gear</li> <li>• Upshift and downshift accelerator pedal positions</li> <li>• Upshift and downshift velocity</li> <li>• Timing for shifting and engaging forward and reverse from neutral</li> </ul> <p>For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.</p>
External	<p>Block uses the input gear, vehicle state, and velocity feedback to generate acceleration and braking commands to track forward and reverse vehicle motion.</p> <p>For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.</p>

**Units**

Use the and **Longitudinal velocity units, velUnits** and **Angular units, angUnits** parameter to specify the units for the input and output ports.

**Gear Signal**

Use the **Output gear signal** parameter to create the GearCmd output port. The GearCmd signal contains the integer value of the commanded vehicle gear.

Gear	Integer
Park	80
Reverse	-1

Gear	Integer
Neutral	0
Drive	1
Gear	Gear number

**Output Handwheel Angle**

Use the **Output handwheel angle** parameter to specify the units for the steering ports.

Setting	Block Implementation	Port
off (default)	Commanded steer angle, normalized from -1 through 1. The block uses the tire wheel angle saturation limit <b>Tire wheel angle limit, theta</b> parameter to normalize the command.	SteerCmd — Output
	Overrides the steering command with an input steering command normalized from -1 through 1.	SteerOvrCmd — Input
on	Commanded steer angle, in units specified by <b>Angular units, angUnits</b> .	SteerCmd — Output
	Overrides the steering command with an input steering command, in units specified by <b>Angular units, angUnits</b> .	SteerOvrCmd — Input

**Controller: PI Speed-Tracking**

If you set the control type to PI or Scheduled PI, the block implements proportional-integral (PI) control with tracking windup and feed-forward gains. For the Scheduled PI configuration, the block uses feed forward gains that are a function of vehicle velocity.

To calculate the speed control output, the block uses these equations.

Setting	Equation
PI	$y = \frac{K_{ff}}{v_{nom}}v_{ref} + \frac{K_p e_{ref}}{v_{nom}} + \int \left( \frac{K_i e_{ref}}{v_{nom}} + K_{aw} e_{out} \right) dt + K_g \theta$
Scheduled PI	$y = \frac{K_{ff}(v)}{v_{nom}}v_{ref} + \frac{K_p(v) e_{ref}}{v_{nom}} + \int \left( \frac{K_i(v) e_{ref}}{v_{nom}} + K_{aw} e_{out} \right) e_{ref} dt + K_g(v) \theta$

where:

$$e_{ref} = v_{ref} - v$$

$$e_{out} = y_{sat} - y$$

$$y_{sat} = \begin{cases} -1 & y < -1 \\ y & -1 \leq y \leq 1 \\ 1 & 1 < y \end{cases}$$

The velocity error low-pass filter uses this transfer function.

$$H(s) = \frac{1}{\tau_{err}s + 1} \text{ for } \tau_{err} > 0$$

To calculate the acceleration and braking commands, the block uses these equations.

$$y_{acc} = \begin{cases} 0 & y_{sat} < 0 \\ y_{sat} & 0 \leq y_{sat} \leq 1 \\ 1 & 1 < y_{sat} \end{cases}$$

$$y_{dec} = \begin{cases} 0 & y_{sat} > 0 \\ -y_{sat} & -1 \leq y_{sat} \leq 0 \\ 1 & y_{sat} < -1 \end{cases}$$

The equations use these variables.

$v_{nom}$	Nominal vehicle speed
$K_p$	Proportional gain
$K_i$	Integral gain
$K_{aw}$	Anti-windup gain
$K_{ff}$	Velocity feed-forward gain
$K_g$	Grade angle feed-forward gain
$\theta$	Grade angle
$\tau_{err}$	Error filter time constant
$y$	Nominal control output magnitude
$y_{sat}$	Saturated control output magnitude
$e_{ref}$	Velocity error
$e_{out}$	Difference between saturated and nominal control outputs
$y_{acc}$	Acceleration signal
$y_{dec}$	Braking signal
$v$	Velocity feedback signal
$v_{ref}$	Reference velocity signal

### Controller: Predictive Speed-Tracking

If you set the **Longitudinal control type, cntrlType** or **Lateral control type, cntrlType** to **Predictive**, the block implements an optimal single-point preview (look ahead) control model developed by C. C. MacAdam<sup>1, 2, 3</sup>. The model represents driver steering control behavior during path-following and obstacle avoidance maneuvers. Drivers preview (look ahead) to follow a predefined path. To implement the MacAdam model, the block:

- Represents the dynamics as a linear single track (bicycle) vehicle
- Minimizes the previewed error signal at a single point  $T^*$  seconds ahead in time
- Accounts for the driver lag deriving from perceptual and neuromuscular mechanisms

### Vehicle Dynamics

For lateral and yaw motion, the block implements these linear dynamic equations.

$$x_1 = U$$

$$\dot{x}_1 = x_2 = \frac{K_{pt}}{m} + vr - g\sin(\gamma) + F_r x_1$$

$$\dot{y} = v + U\psi$$

$$\dot{v} = \left[ -\frac{2(C_{\alpha F} + C_{\alpha R})}{mU} \right] v + \left[ \frac{2(bC_{\alpha R} - aC_{\alpha F})}{mU} - U \right] r + \left( \frac{2C_{\alpha F}}{m} \right) \delta_F$$

$$\dot{r} = \left[ \frac{2(bC_{\alpha R} - aC_{\alpha F})}{IU} \right] v + \left[ -\frac{2(a^2C_{\alpha F} + b^2C_{\alpha R})}{IU} \right] r + \left( \frac{2aC_{\alpha F}}{I} \right) \delta_F$$

$$\dot{\psi} = r$$

In matrix notation:

$$\dot{x} = Fx + gu$$

where:

$$x = \begin{bmatrix} x_1 \\ x_2 \\ y \\ v \\ r \\ \psi \end{bmatrix}$$

$$F = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ \frac{F_r}{m} & 0 & 0 & 0 & v & 0 \\ 0 & 0 & 0 & 1 & 0 & U \\ 0 & 0 & 0 & -\frac{2(C_{\alpha F} + C_{\alpha R})}{mU} & \frac{2(bC_{\alpha R} - aC_{\alpha F})}{mU} - U & 0 \\ 0 & 0 & 0 & \frac{2(bC_{\alpha R} - aC_{\alpha F})}{IU} & -\frac{2(a^2C_{\alpha F} + b^2C_{\alpha R})}{IU} & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

$$g = \begin{bmatrix} 0 & 0 \\ \frac{K_{pt}}{m} & 0 \\ 0 & 0 \\ 0 & \frac{2C_{\alpha F}}{m} \\ 0 & \frac{2aC_{\alpha F}}{I} \\ 0 & 0 \end{bmatrix}$$

$$u = \begin{bmatrix} \bar{u} \\ \delta_F \end{bmatrix}$$

$$\bar{u} = u - \frac{m^2}{K_{pt}} g \sin(\gamma)$$



The single-point model assumes a minimum previewed error signal at a single point  $T^*$  seconds ahead in time.  $a^*$  is the driver ability to predict the future vehicle response based on the current steering control input.  $b^*$  is the driver ability to predict the future vehicle response based on the current vehicle state. The block uses these equations.

$$a^* = (T^*)m^T \left[ I + \sum_{n=1}^{\infty} \frac{F^n (T^*)^n}{(n+1)!} \right] g$$

$$b^* = m^T \left[ I + \sum_{n=1}^{\infty} \frac{F^n (T^*)^n}{n!} \right]$$

$$m^T = [1 \ 1 \ 1 \ 0 \ 0 \ 0]$$

The equations use these variables.

$a, b$	Forward and rearward tire location, respectively
$m$	Vehicle mass
$I$	Vehicle rotational inertia
$C_{\alpha F}$	Front tire cornering coefficient
$C_{\alpha R}$	Rear tire cornering coefficient
$a^*, b^*$	Driver prediction scalar and vector gain, respectively
$\mathbf{x}$	Predicted vehicle state vector
$v$	Lateral velocity
$r$	Yaw rate
$\Psi$	Front wheel heading angle
$y$	Lateral displacement
$\mathbf{F}$	System matrix
$\delta, \delta_F$	Steer angle and front axle steer angle, respectively
$\gamma$	Grade angle
$\mathbf{g}$	Control coefficient vector
$U$	Forward (longitudinal) vehicle velocity
$T^*$	Preview time window
$f(t+T^*)$	Previewed path input $T^*$ seconds ahead
$\mathbf{u}$	Tractive force
$\mathbf{m}^T$	Constant observer vector; provides vehicle lateral position
$a_r$	Static rolling and driveline resistance
$b_r$	Linear rolling and driveline resistance
$c_r$	Aerodynamic rolling and driveline resistance
$F_r$	Rolling resistance

### Optimization

The single-point model implemented by the block finds the steering command that minimizes a local performance index,  $J$ , over the current preview interval,  $(t, t+T)$ .

$$J = \frac{1}{T} \int_t^{t+T} [f(\eta) - y(\eta)]^2 d\eta$$

To minimize  $J$  with respect to the steering command, this condition must be met.

$$\frac{dJ}{du} = 0$$

You can express the optimal control solution in terms of a current non-optimal and corresponding nonzero preview output error  $T^*$  seconds ahead<sup>1, 2, 3</sup>.

$$u^o(t) = u(t) + \frac{e(t + T^*)}{a^*}$$

The block uses the preview distance and vehicle longitudinal velocity to determine the preview time window.

$$T^* = \frac{L}{U}$$

The equations use these variables.

$T^*$	Preview time window
$f(t+T^*)$	Previewed path input $T^*$ sec ahead
$y(t+T^*)$	Previewed plant output $T^*$ sec ahead
$e(t+T^*)$	Previewed error signal $T^*$ sec ahead
$u(t), u^o(t)$	Steer angle and optimal steer angle, respectively
$L$	Preview distance
$J$	Performance index
$U$	Forward (longitudinal) vehicle velocity

### Driver Lag

The single-point model implemented by the block introduces a driver lag. The driver lag accounts for the delay when the driver is tracking tasks. Specifically, it is the transport delay deriving from perceptual and neuromuscular mechanisms. To calculate the driver transport delay, the block implements this equation.

$$H(s) = e^{-s\tau}$$

The equations use these variables.

$\tau$	Driver transport delay
$y(t+T^*)$	Previewed plant output $T^*$ sec ahead
$e(t+T^*)$	Previewed error signal $T^*$ sec ahead
$u(t), u^o(t)$	Steer angle and optimal steer angle, respectively
$J$	Performance index

### Controller: Stanley Lateral Path-Tracking

If you set **Lateral control type, controlTypeLat** to **Stanley**, the block implements the Stanley method<sup>4</sup>. To compute the steering angle command, the Stanley controller minimizes the position error

and the angle error of the current pose with respect to the reference pose. The driving direction of the vehicle determines these error values.

To compute the steering angle command, the controller minimizes the position error and the angle error of the current pose with respect to the reference pose.

- The position error is the lateral distance from the vehicle center-of-gravity (CG) to the reference point on the path.
- The angle error is the angle of the vehicle with respect to reference path.

## Ports

### Input

#### VelRef — Reference vehicle velocity

scalar

Reference velocity,  $v_{ref}$ , in units specified by **Longitudinal velocity units, velUnits**.

#### LongRef — Longitudinal displacement reference

scalar

Longitudinal center of mass (CM) displacement reference, in the inertial reference frame, in m.

#### Dependencies

To enable this port:

- Set **Lateral control type, controlTypeLat** to Stanley
- Clear **Vector input for reference and feedback**

#### LatRef — Lateral displacement reference

scalar

Lateral center of mass (CM) displacement reference, in the inertial reference frame, in m.

#### Dependencies

To enable this port, do either of these:

- Set **Lateral control type, controlTypeLat** to Stanley and clear **Vector input for reference and feedback**.
- Set **Lateral control type, controlTypeLat** to Predictive.

#### EnbSteerOvr — Enable steering command override

scalar

Enable steering command override.

#### Dependencies

To enable this port, select **Steering override**.

Data Types: Boolean

**SteerOvrCmd — Steering override command**

scalar

Steering override command.

Use the **Output handwheel angle** parameter to specify the units for the steering ports.

Setting	Block Implementation	Port
off (default)	Commanded steer angle, normalized from -1 through 1. The block uses the tire wheel angle saturation limit <b>Tire wheel angle limit, theta</b> parameter to normalize the command.	SteerCmd — Output
	Overrides the steering command with an input steering command normalized from -1 through 1.	SteerOvrCmd — Input
on	Commanded steer angle, in units specified by <b>Angular units, angUnits</b> .	SteerCmd — Output
	Overrides the steering command with an input steering command, in units specified by <b>Angular units, angUnits</b> .	SteerOvrCmd — Input

**Dependencies**

To enable this port, select **Steering override**.

Data Types: double

**SteerHld — Steering hold**

scalar

Boolean signal that holds the steering command at the current value.

**Dependencies**

To enable this port, select **Steering hold**.

Data Types: Boolean

**SteerZero — Disable steering command**

scalar

Disable steering command.

**Dependencies**

To enable this port, select **Steering disable**.

Data Types: Boolean

**EnbAccelOvr — Enable acceleration command override**

scalar

Enable acceleration command override.

**Dependencies**

To enable this port, select **Acceleration override**.

Data Types: Boolean

**AccelOvrCmd — Acceleration override command**

scalar

Acceleration override command, normalized from 0 through 1.

**Dependencies**

To enable this port, select **Acceleration override**.

Data Types: double

**AccelHld — Acceleration hold**

scalar

Boolean signal that holds the acceleration command at the current value.

**Dependencies**

To enable this port, select **Acceleration hold**.

Data Types: Boolean

**AccelZero — Disable acceleration command**

scalar

Disable acceleration command.

**Dependencies**

To enable this port, select **Acceleration disable**.

Data Types: Boolean

**EnbDecelOvr — Enable deceleration command override**

scalar

Enable deceleration command override.

**Dependencies**

To enable this port, select **Deceleration override**.

Data Types: Boolean

**DecelOvrCmd — Deceleration override command**

scalar

Deceleration override command, normalized from 0 through 1.

**Dependencies**

To enable this port, select **Deceleration override**.

Data Types: double

**DecelHld — Deceleration hold**

scalar

Boolean signal that holds the deceleration command at the current value.

**Dependencies**

To enable this port, select **Deceleration hold**.

Data Types: Boolean

**DecelZero — Disable deceleration command**

scalar

Disable deceleration command.

**Dependencies**

To enable this port, select **Deceleration disable**.

Data Types: Boolean

**ExtGear — Gear**

scalar

<b>Gear</b>	<b>Integer</b>
Park	80
Reverse	-1
Neutral	0
Drive	1
Gear	Gear number

**Dependencies**

To enable this port, set **Shift type, shftType** to External.

**Grade — Road grade angle**

scalar

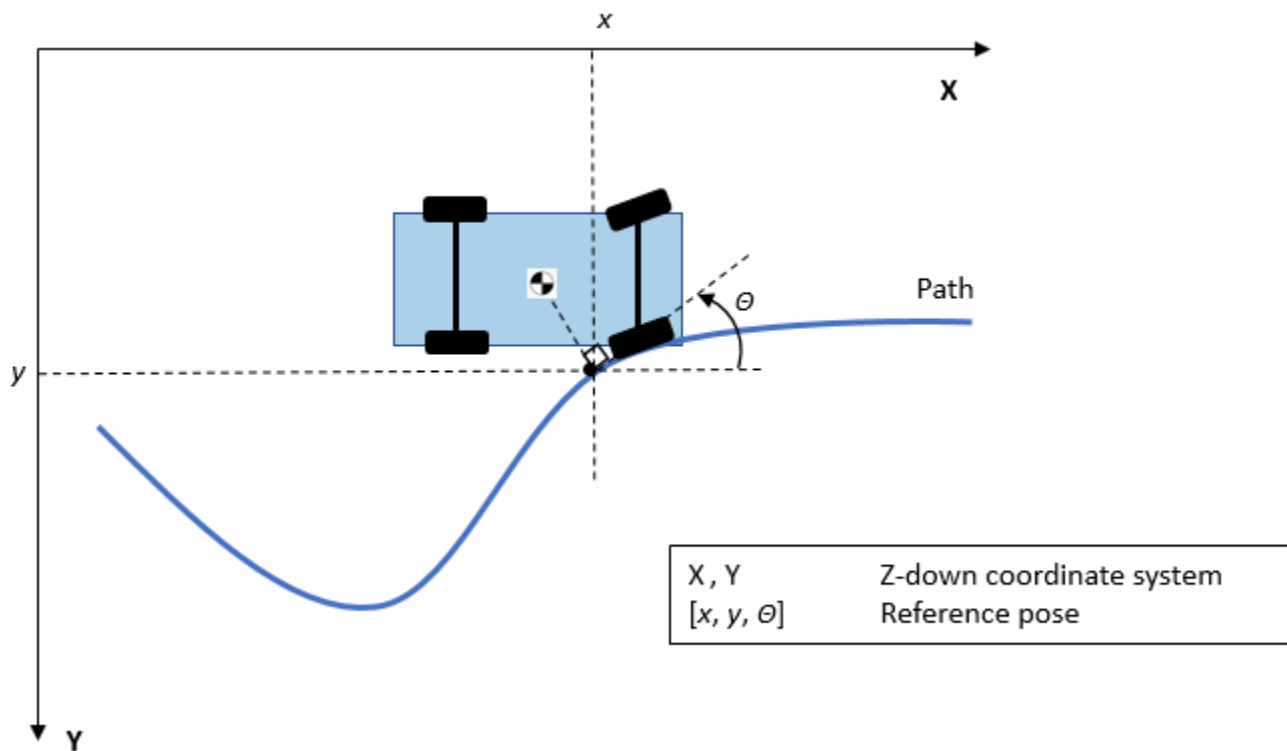
Road grade angle,  $\gamma$ , in deg.

**RefPose — Reference pose**[ $x$ ,  $y$ ,  $\theta$ ] vector

Reference pose, specified as an [ $x$ ,  $y$ ,  $\theta$ ] vector.  $x$  and  $y$  are in meters, and  $\theta$  are in units specified by **Angular units, angUnits**.

$x$  and  $y$  specify the reference point to steer the vehicle toward.  $\theta$  specifies the orientation angle of the path at this reference point and is positive in the counterclockwise direction.

The reference point is the point on the path that is closest to the vehicle CG. You can use either the Z-up or Z-down vehicle coordinate system, as long as you use the same coordinate system (Z-up or Z-down) for block inputs and parameters.



### Dependencies

To enable this port, set **Lateral control type**, `controlTypeLat` to Stanley and select **Vector input for reference and feedback pose**.

Data Types: single | double

### VelFdbk — Longitudinal vehicle velocity

scalar

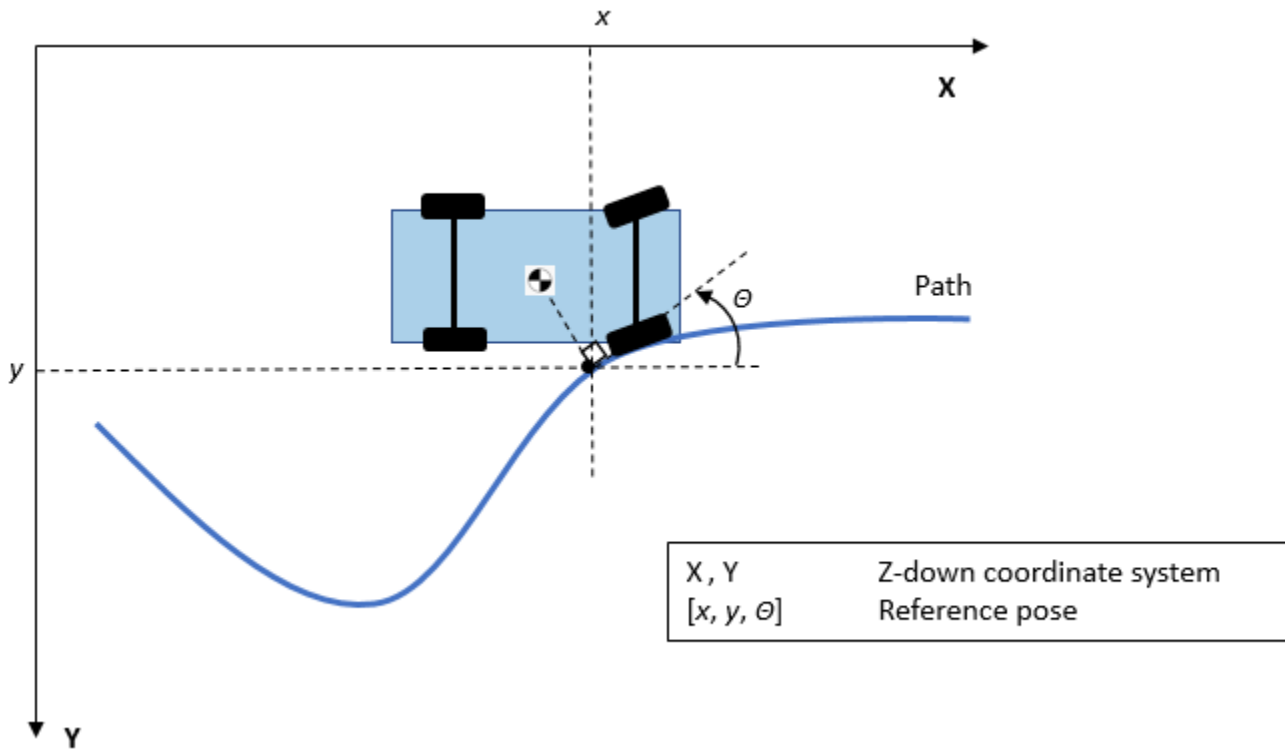
Longitudinal vehicle velocity,  $U$ , in the vehicle-fixed frame, in units specified by **Longitudinal velocity units**, `velUnits`.

### CurrPose — Current pose

[x, y,  $\theta$ ] vector

Current pose of the vehicle, specified as an [x, y,  $\theta$ ] vector. x and y are in meters, and  $\theta$  is in units specified by **Angular units**, `angUnits`.

x and y specify the location of the vehicle, which is defined as the vehicle CG. You can use either the Z-up or Z-down vehicle coordinate system, as long you use the same coordinate system (Z-up or Z-down) for block inputs and parameters.



### Dependencies

To enable this port, set **Lateral control type, controlTypeLat** to Stanley and select **Vector input for reference and feedback pose**.

Data Types: single | double

### LatFdbk — Lateral displacement

scalar

Lateral CM displacement,  $y_o$ , in the inertial reference frame, in m.

### Dependencies

To enable this port, do either of these:

- Set **Lateral control type, controlTypeLat** to Stanley and clear **Vector input for reference and feedback**.
- Set **Lateral control type, controlTypeLat** to Predictive.

### LatVelFdbk — Lateral vehicle velocity

scalar

Lateral vehicle velocity,  $v_o$ , in the vehicle-fixed frame, in m/s.

### Dependencies

To enable this port, Set **Lateral control type, controlTypeLat** to Predictive.



### YawFdbk — Vehicle yaw angle

scalar

Vehicle yaw angle,  $\Psi_o$ , in the inertial reference frame, in units specified by **Angular units, angUnits**.

#### Dependencies

To enable this port, do either of these:

- Set **Lateral control type, controlTypeLat** to Stanley and clear **Vector input for reference and feedback pose**.
- Set **Lateral control type, controlTypeLat** to Predictive.

### YawVelFdbk — Yaw rate

scalar

Yaw rate,  $r_o$ , in the vehicle-fixed frame, in units specified by **Angular units, angUnits** per sec.

#### Dependencies

To enable this port, Set **Lateral control type, controlTypeLat** to Predictive.

#### Output

#### Info — Bus signal

bus

Bus signal containing these block calculations.

Signal		Variable	Description	
Steer		$\delta_F$	Commanded steer angle, normalized from 0 through 1	
Accel		$y_{acc}$	Commanded vehicle acceleration, normalized from 0 through 1	
Decel		$y_{dec}$	Commanded vehicle deceleration, normalized from 0 through 1	
Gear			Integer value of commanded gear	
Clutch			Clutch command	
Err	LatErr	Err	$e_{ref}$	Difference in reference vehicle position and vehicle position.
		ErrSqrSum	$\int_0^t e_{ref}^2 dt$	Integrated square of error.
		ErrMax	$\max(e_{ref}(t))$	Maximum error during simulation.
		ErrMin	$\min(e_{ref}(t))$	Minimum error during simulation.
	LngErr	Err	$e_{ref}$	Difference in reference vehicle speed and vehicle speed

Signal	Variable	Description
	ErrSqrSum	$\int_0^t e_{ref}^2 dt$ Integrated square of error
	ErrMax	$\max(e_{ref}(t))$ Maximum error during simulation
	ErrMin	$\min(e_{ref}(t))$ Minimum error during simulation
ExtActions	EnblSteerOvr	Override the steering command with an input deceleration command
	SteerOvrCmd	Input steering override command
	SteerHld	Hold the steering command at the current value
	SteerZero	Disable the steering command
	EnblAccelOvr	Override the accelerator command with an input acceleration command
	AccelOvrCmd	Input accelerator override command
	AccelHld	Hold the acceleration command at the current value
	AccelZero	Disable the acceleration command
	EnblDecelOvr	Override the decelerator command with an input deceleration command
	DecelOvrCmd	Input deceleration override command
	DecelHld	Hold the decelerator command at current value
	DecelZero	Disable the decelerator command

**SteerCmd – Steer angle command**  
scalar

Commanded steer angle,  $\delta_F$ .

Use the **Output handwheel angle** parameter to specify the units for the steering ports.

Setting	Block Implementation	Port
off (default)	Commanded steer angle, normalized from -1 through 1. The block uses the tire wheel angle saturation limit <b>Tire wheel angle limit, theta</b> parameter to normalize the command.	SteerCmd – Output
	Overrides the steering command with an input steering command normalized from -1 through 1.	SteerOvrCmd – Input
on	Commanded steer angle, in units specified by <b>Angular units, angUnits</b> .	SteerCmd – Output
	Overrides the steering command with an input steering command, in units specified by <b>Angular units, angUnits</b> .	SteerOvrCmd – Input

**AccelCmd — Commanded vehicle acceleration**

scalar

Commanded vehicle acceleration,  $y_{acc}$ , normalized from 0 through 1.

**DecelCmd — Commanded vehicle deceleration**

scalar

Commanded vehicle deceleration,  $y_{dec}$ , normalized from 0 through 1.

**GearCmd — Commanded vehicle gear**

scalar

Integer value of commanded vehicle gear.

<b>Gear</b>	<b>Integer</b>
Park	80
Reverse	-1
Neutral	0
Drive	1
Gear	Gear number

**Dependencies**

To enable this port, select **Output gear signal**.

**Parameters****Configuration****External Actions****Accelerator override — Override acceleration command**

off (default) | on

Select to override the acceleration command with an input acceleration command.

**Dependencies**

Selecting this parameter creates the EnbAcceLOvr and AcceLOvrCmd input ports.

**Accelerator hold — Hold acceleration command**

off (default) | on

Select to hold the acceleration command.

**Dependencies**

Selecting this parameter creates the AcceLHld input port.

**Accelerator disable — Disable acceleration command**

off (default) | on

Select to disable the acceleration command.

**Dependencies**

Selecting this parameter creates the AccelZero input port.

**Decelerator override — Override deceleration command**

off (default) | on

Select to override the deceleration command with an input deceleration command.

**Dependencies**

Selecting this parameter creates the EnblDecelOvr and DecelOvrCmd input ports.

**Decelerator hold — Hold deceleration command**

off (default) | on

Select to hold the deceleration command.

**Dependencies**

Selecting this parameter creates the DecelHld input port.

**Decelerator disable — Disable deceleration command**

off (default) | on

Select to disable the deceleration command.

**Dependencies**

Selecting this parameter creates the DecelZero input port.

**Steering override — Override steering command**

off (default) | on

Select to override the steering command with an input steering command.

**Dependencies**

Selecting this parameter creates the EnblSteerOvr and SteerOvrCmd input ports.

**Steering hold — Hold steering command**

off (default) | on

Select to hold the steering command.

**Dependencies**

Selecting this parameter creates the SteerHld input port.

**Steering disable — Disable steering command**

off (default) | on

Select to disable the steering command.

**Dependencies**

Selecting this parameter creates the SteerZero input port.

## Control and Shift

### Longitudinal control type, `cntrlType` – Longitudinal control

PI (default) | Scheduled PI | Predictive

Type of longitudinal control.

Setting	Block Implementation
PI	Proportional-integral (PI) control with tracking windup and feed-forward gains.
Scheduled PI	PI control with tracking windup and feed-forward gains that are a function of vehicle velocity.
Predictive	<p>Optimal single-point preview (look ahead) control model developed by C. C. MacAdam<sup>1, 2, 3</sup>. The model represents driver steering control behavior during path-following and obstacle avoidance maneuvers. Drivers preview (look ahead) to follow a predefined path. To implement the MacAdam model, the block:</p> <ul style="list-style-type: none"> <li>• Represents the dynamics as a linear single track (bicycle) vehicle</li> <li>• Minimizes the previewed error signal at a single point <math>T^*</math> seconds ahead in time</li> <li>• Accounts for the driver lag deriving from perceptual and neuromuscular mechanisms</li> </ul>

### Lateral control type, `controlTypeLat` – Controller

Predictive (default) | Stanley

Use the **Lateral control type, `controlTypeLat`** parameter to specify the type of lateral control. The table specifies the block implementation.

Setting	Block Implementation
Predictive (default)	Optimal single-point preview (look ahead) control model developed by C. C. MacAdam <sup>1, 2, 3</sup> . The model represents driver steering control behavior during path-following and obstacle avoidance maneuvers. Drivers preview (look ahead) to follow a predefined path.

Setting	Block Implementation												
Stanley	<p>Controller that uses the Stanley<sup>4</sup> method to minimize the position error and the angle error of the current pose with respect to the reference pose.</p> <p>On the <b>Reference Control</b> pane, use the:</p> <ul style="list-style-type: none"> <li>• <b>Vector input for reference and feedback pose</b> parameter to input the to specify the input.</li> </ul> <table border="1"> <thead> <tr> <th>Setting</th> <th>Implementation</th> </tr> </thead> <tbody> <tr> <td>off (default)</td> <td>Block uses the longitudinal, lateral, and yaw reference (LongRef, LatRef, LatRef) input ports and the feedback (LongFdbk, LatFdbk, LatFdbk) input ports for the reference and feedback pose.</td> </tr> <tr> <td>on</td> <td>Block uses input ports, RefPose and CurrPose, for the reference and feedback pose, respectively.</td> </tr> </tbody> </table> <ul style="list-style-type: none"> <li>• <b>Include dynamics</b> parameter to specify the type of model for the controller to use.</li> </ul> <table border="1"> <thead> <tr> <th>Setting</th> <th>Implementation</th> </tr> </thead> <tbody> <tr> <td>off (default)</td> <td>Controller uses a kinematic bicycle model that is suitable for path following in low-speed environments such as parking lots, where inertial effects are minimal.</td> </tr> <tr> <td>on</td> <td>Controller uses a dynamic bicycle model that is suitable for path following in high-speed environments such as highways, where inertial effects are more pronounced.</td> </tr> </tbody> </table>	Setting	Implementation	off (default)	Block uses the longitudinal, lateral, and yaw reference (LongRef, LatRef, LatRef) input ports and the feedback (LongFdbk, LatFdbk, LatFdbk) input ports for the reference and feedback pose.	on	Block uses input ports, RefPose and CurrPose, for the reference and feedback pose, respectively.	Setting	Implementation	off (default)	Controller uses a kinematic bicycle model that is suitable for path following in low-speed environments such as parking lots, where inertial effects are minimal.	on	Controller uses a dynamic bicycle model that is suitable for path following in high-speed environments such as highways, where inertial effects are more pronounced.
Setting	Implementation												
off (default)	Block uses the longitudinal, lateral, and yaw reference (LongRef, LatRef, LatRef) input ports and the feedback (LongFdbk, LatFdbk, LatFdbk) input ports for the reference and feedback pose.												
on	Block uses input ports, RefPose and CurrPose, for the reference and feedback pose, respectively.												
Setting	Implementation												
off (default)	Controller uses a kinematic bicycle model that is suitable for path following in low-speed environments such as parking lots, where inertial effects are minimal.												
on	Controller uses a dynamic bicycle model that is suitable for path following in high-speed environments such as highways, where inertial effects are more pronounced.												

**Shift type, shftType – Shift type**

None (default) | Reverse, Neutral, Drive | Scheduled | External

Shift type.

Setting	Block Implementation
None	<p>No transmission. Block outputs a constant gear of 1.</p> <p>Use this setting to minimize the number of parameters you need to generate acceleration and braking commands to track forward vehicle motion. This setting does not allow reverse vehicle motion.</p>

Setting	Block Implementation
Reverse, Neutral, Drive	<p>Block uses a Stateflow chart to model reverse, neutral, and drive gear shift scheduling.</p> <p>Use this setting to generate acceleration and braking commands to track forward and reverse vehicle motion using simple reverse, neutral, and drive gear shift scheduling. Depending on the vehicle state and vehicle velocity feedback, the block uses the initial gear and time required to shift to shift the vehicle up into drive or down into reverse or neutral.</p> <p>For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.</p>
Scheduled	<p>Block uses a Stateflow chart to model reverse, neutral, park, and N-speed gear shift scheduling.</p> <p>Use this setting to generate acceleration and braking commands to track forward and reverse vehicle motion using reverse, neutral, park, and N-speed gear shift scheduling. Depending on the vehicle state and vehicle velocity feedback, the block uses these parameters to determine the:</p> <ul style="list-style-type: none"> <li>• Initial gear</li> <li>• Upshift and downshift accelerator pedal positions</li> <li>• Upshift and downshift velocity</li> <li>• Timing for shifting and engaging forward and reverse from neutral</li> </ul> <p>For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.</p>
External	<p>Block uses the input gear, vehicle state, and velocity feedback to generate acceleration and braking commands to track forward and reverse vehicle motion.</p> <p>For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.</p>

### Longitudinal velocity units, velUnits – Velocity units

m/s (default)

Vehicle velocity reference and feedback units.

#### Dependencies

If you set **Longitudinal control type**, **CntrlType** control type to Scheduled or Scheduled PI, the block uses the **Longitudinal velocity units, velUnits** for the **Nominal speed, vnom** parameter dimension.

If you set **Shift Type**, **shftType** to Scheduled, the block uses the **Longitudinal velocity units, velUnits** for these parameter dimensions:

- **Upshift velocity data table, upShftTbl**

- **Downshift velocity data table, dwnShftTbl**

**Angular units, angUnits — Input and output port angular units**

rad (default) | deg

Input and output port angular units.

**Output gear signal — Create GearCmd output port**

off (default) | on

Specify to create output port GearCmd.

**Output handwheel angle — Steering port units in rad**

off (default) | on

Use the **Output handwheel angle** parameter to specify the units for the steering ports.

Setting	Block Implementation	Port
off (default)	Commanded steer angle, normalized from -1 through 1. The block uses the tire wheel angle saturation limit <b>Tire wheel angle limit, theta</b> parameter to normalize the command.	SteerCmd — Output
	Overrides the steering command with an input steering command normalized from -1 through 1.	SteerOvrCmd — Input
on	Commanded steer angle, in units specified by <b>Angular units, angUnits</b> .	SteerCmd — Output
	Overrides the steering command with an input steering command, in units specified by <b>Angular units, angUnits</b> .	SteerOvrCmd — Input

**Dependencies**

To create the SteerOvrCmd input port, select **Steering override**.

**Reference Control**

**Longitudinal**

**Proportional gain, Kp — Gain**

10 (default) | scalar

Proportional gain,  $K_p$ , dimensionless.

**Dependencies**

To create this parameter, set **Control type** to PI.

**Integral gain, Ki — Gain**

5 (default) | scalar

Proportional gain,  $K_i$ , dimensionless.



**Dependencies**

To create this parameter, set **Control type** to PI.

**Velocity feed-forward, Kff – Gain**

.1 (default) | scalar

Velocity feed-forward gain,  $K_{ff}$ , dimensionless.

**Dependencies**

To create this parameter, set **Control type** to PI.

**Grade angle feed-forward, Kg – Gain**

0 (default) | scalar

Grade angle feed-forward gain,  $K_g$ , in 1/deg.

**Dependencies**

To create this parameter, set **Control type** to PI.

**Velocity gain breakpoints, VehVelVec – Breakpoints**

[0 100] (default) | vector

Velocity gain breakpoints,  $VehVelVec$ , dimensionless.

**Dependencies**

To create this parameter, set **Control type** to Scheduled PI.

**Velocity feed-forward gain values, KffVec – Gain**

[.1 .1] (default) | vector

Velocity feed-forward gain values,  $KffVec$ , as a function of vehicle velocity, dimensionless.

**Dependencies**

To create this parameter, set **Control type** to Scheduled PI.

**Proportional gain values, KpVec – Gain**

[10 10] (default) | vector

Proportional gain values,  $KpVec$ , as a function of vehicle velocity, dimensionless.

**Dependencies**

To create this parameter, set **Control type** to Scheduled PI.

**Integral gain values, KiVec – Gain**

[5 5] (default) | vector

Integral gain values,  $KiVec$ , as a function of vehicle velocity, dimensionless.

**Dependencies**

To create this parameter, set **Control type** to Scheduled PI.

**Grade angle feed-forward values,  $KgVec$  – Grade gain**

[0 0] (default) | vector

Grade angle feed-forward values,  $KgVec$ , as a function of vehicle velocity, in 1/deg.

**Dependencies**

To create this parameter, set **Control type** to Scheduled PI.

**Nominal speed,  $vnom$  – Nominal vehicle speed**

5 (default) | scalar

Nominal vehicle speed,  $v_{nom}$ , in units specified by the **Reference and feedback units, velUnits** parameter. The block uses the nominal speed to normalize the controller gains.

**Dependencies**

To create this parameter, set **Control type** to PI or Scheduled PI.

**Anti-windup,  $Kaw$  – Gain**

1 (default) | scalar

Anti-windup gain,  $K_{aw}$ , dimensionless.

**Dependencies**

To create this parameter, set **Control type** to PI or Scheduled PI.

**Error filter time constant,  $\tau_{err}$  – Filter**

.01 (default) | scalar

Error filter time constant,  $\tau_{err}$ , in s. To disable the filter, enter 0.

**Dependencies**

To create this parameter, set **Control type** to PI or Scheduled PI.

**Predictive****Driver response time,  $\tau$  – Response time**

0.1 (default) | scalar

Driver response time,  $\tau$ , in s.

**Dependencies**

To enable this parameter, Set **Longitudinal control type, cntrlType** or **Lateral control type, controlTypeLat** to Predictive.

**Preview distance,  $L$  – Distance**

3 (default) | scalar

Driver preview distance,  $L$ , in m. Used to determine the preview time window,  $T^*$ .

**Dependencies**

To enable this parameter, Set **Longitudinal control type, cntrlType** or **Lateral control type, controlTypeLat** to Predictive.

**Effective vehicle total tractive force,  $K_p$  — Tractive force**

3000 (default) | scalar

Effective vehicle total tractive force,  $K_p$ , in N.**Dependencies**To create this parameter, set **Longitudinal control type,  $ctrlType$**  to Predictive.**Rolling resistance coefficient,  $a_R$  — Resistance**

200 (default) | scalar

Static rolling and driveline resistance coefficient,  $a_R$ , in N. Block uses the parameter to estimate the constant acceleration or braking effort.**Dependencies**To create this parameter, set **Longitudinal control type,  $ctrlType$**  to Predictive.**Rolling and driveline resistance coefficient,  $b_R$  — Resistance**

2.5 (default) | scalar

Rolling and driveline resistance coefficient,  $b_R$ , in N·s/m. Block uses the parameter to estimate the linear velocity-dependent acceleration or braking effort.**Dependencies**To create this parameter, set **Longitudinal control type,  $ctrlType$**  to Predictive.**Aerodynamic drag coefficient,  $c_R$  — Drag**

.5 (default) | scalar

Aerodynamic drag coefficient,  $c_R$ , in N·s<sup>2</sup>/m<sup>2</sup>. Block uses the parameter to estimate the quadratic velocity-dependent acceleration or braking effort.**Dependencies**To create this parameter, set **Longitudinal control type,  $ctrlType$**  to Predictive.**Gravitational constant,  $g$  — Gravitational constant**

9.81 (default) | scalar

Gravitational constant,  $g$ , in m/s<sup>2</sup>.**Dependencies**To create this parameter, set **Longitudinal control type,  $ctrlType$**  to Predictive.**Stanley****Vector input for reference and feedback pose — Select to create RefPose and CurrPose input ports**

off (default) | on

Select this parameter to create the RefPose and CurrPose input ports.

**Dependencies**To enable this parameter, Set **Lateral control type,  $controlTypeLat$**  to Stanley.

**Include dynamics — Select to include dynamics**

off (default) | on

The controller computes this command using the Stanley method, whose control law is based on both a kinematic and dynamic bicycle model. To change between models, use this parameter.

Setting	Implementation
off	Controller uses a kinematic bicycle model that is suitable for path following in low-speed environments such as parking lots, where inertial effects are minimal.
on	Controller uses a dynamic bicycle model that is suitable for path following in high-speed environments such as highways, where inertial effects are more pronounced.

**Dependencies**

To enable this parameter, Set **Lateral control type, controlTypeLat** to Stanley.

**Position gain of forward motion, PositionGainF — Position gain of vehicle in forward motion**

2.5 (default) | positive real scalar

Position gain of the vehicle when it is in forward motion, specified as a positive scalar. This value determines how much the position error affects the steering angle. Typical values are in the range [1, 5]. Increase this value to increase the magnitude of the steering angle.

**Dependencies**

To enable this parameter, Set **Lateral control type, controlTypeLat** to Stanley.

**Position gain of reverse motion, PositionGainR — Position gain of vehicle in reverse motion**

2.5 (default) | positive real scalar

Position gain of the vehicle when it is in reverse motion, specified as a positive scalar. This value determines how much the position error affects the steering angle. Typical values are in the range [1, 5]. Increase this value to increase the magnitude of the steering angle.

**Dependencies**

To enable this parameter, Set **Lateral control type, controlTypeLat** to Stanley.

**Yaw rate feedback gain, YawRateGain — Yaw rate feedback gain**

.2 (default) | nonnegative real scalar

Yaw rate feedback gain, specified as a nonnegative real scalar. This value determines how much weight is given to the current yaw rate of the vehicle when the block computes the steering angle command.

**Dependencies**

To enable this parameter, Set **Lateral control type, controlTypeLat** to Stanley and select **Include dynamics**.

**Steering angle feedback gain, DelayGain — Steering angle feedback gain**

.2 (default) | nonnegative real scalar

Steering angle feedback gain, specified as a nonnegative real scalar. This value determines how much the difference between the current steering angle command, **SteerCmd**, and the current steering angle, **CurrSteer**, affects the next steering angle command.

#### Dependencies

To enable this parameter, Set **Lateral control type, controlTypeLat** to Stanley and select **Include dynamics**.

#### Vehicle Parameters

##### Forward location of tire, *a* – Along vehicle longitudinal axis

1.41 (default) | scalar

Forward location of tire, *a*, in m. Distance from vehicle cg to forward tire location, along vehicle longitudinal axis.

##### Rearward location of tire, *b* – Along vehicle longitudinal axis

1.41 (default) | scalar

Rearward location of tire, *b*, in m. Absolute value of distance from vehicle cg to rearward tire location, along vehicle longitudinal axis.

##### Vehicle mass, *m* – Mass

2016 (default) | scalar

Vehicle mass, *m*, in kg.

#### Dependencies

To enable this port, do either of these:

- Set **Lateral control type, controlTypeLat** to Stanley and select **Include dynamics**.
- Set **Lateral control type, controlTypeLat** to Predictive.

##### Front tire cornering coefficient, *C<sub>y\_f</sub>* – Coefficient

25266 (default) | scalar

Cornering stiffness coefficient, *C<sub>αF</sub>*, in N/rad.

#### Dependencies

To enable this port, do either of these:

- Set **Lateral control type, controlTypeLat** to Stanley and select **Include dynamics**.
- Set **Lateral control type, controlTypeLat** to Predictive.

##### Rear tire cornering coefficient, *C<sub>y\_r</sub>* – Coefficient

70933 (default) | scalar

Cornering stiffness coefficient, *C<sub>αR</sub>*, in N/rad.

#### Dependencies

To enable this port, set **Lateral control type, controlTypeLat** to Predictive.

**Vehicle rotational inertia, I – Inertia about yaw axis**

4013 (default) | scalar

Vehicle rotational inertia,  $I$ , about the vehicle yaw axis, in  $\text{N}\cdot\text{m}\cdot\text{s}^2$ .

**Dependencies**

To enable this parameter, Set **Lateral control type**, `controlTypeLat` to Predictive.

**Nominal steering ratio, Ksteer – Steering ratio**

18 (default) | scalar

Steering ratio,  $K_{steer}$ . The value has no dimension.

**Dependencies**

To enable this parameter, select **Output handwheel angle**.

**Tire wheel angle limit, theta – Angle limit**

45\*pi/180 (default) | scalar

Tire wheel angle limit,  $\theta$ , in rad.

**Shift****Reverse, Neutral, Drive****Initial gear, GearInit – Initial gear**

0 (default) | scalar

Integer value of the initial gear. The block uses the initial gear to generate acceleration and braking commands to track forward and reverse vehicle motion.

Gear	Integer
Park	80
Reverse	-1
Neutral	0
Drive	1
Gear	Gear number

**Dependencies**

To create this parameter, set **Shift type**, `shftType` to Reverse, Neutral, Drive or Scheduled. If you specify Reverse, Neutral, Drive, the **Initial Gear**, `GearInit` parameter value can be only -1, 0, or 1.

**Time required to shift, tShift – Time**

.1 (default) | scalar

Time required to shift,  $tShift$ , in s. The block uses the time required to shift to generate acceleration and braking commands to track forward and reverse vehicle motion using reverse, neutral, and drive gear shift scheduling.

**Dependencies**

To create this parameter, set **Shift type, shftType** to Reverse, Neutral, Drive.

**Scheduled**

**Initial gear, GearInit – Initial gear**

0 (default) | scalar

Integer value of the initial gear. The block uses the initial gear to generate acceleration and braking commands to track forward and reverse vehicle motion.

Gear	Integer
Park	80
Reverse	-1
Neutral	0
Drive	1
Gear	Gear number

**Dependencies**

To create this parameter, set **Shift type, shftType** to Reverse, Neutral, Drive or Scheduled. If you specify Reverse, Neutral, Drive, the **Initial Gear, GearInit** parameter value can be only -1, 0, or 1.

**Up and down shift accelerator pedal positions, pdlVec – Pedal position breakpoints**

[0.1 0.4 0.5 0.9] (default) | [1-by-m] vector

Pedal position breakpoints for lookup tables when calculating upshift and downshift velocities, dimensionless. Vector dimensions are 1 by the number of pedal position breakpoints, m.

**Dependencies**

To create this parameter, set **Shift type, shftType** to Scheduled.

**Upshift velocity data table, upShftTbl – Table**

[m-by-n] array

Upshift velocity data as a function of pedal position and gear, in units specified by the **Reference and feedback units, velUnits** parameter. Upshift velocities indicate the vehicle velocity at which the gear should increase by 1.

The array dimensions are m pedal positions by n gears. The first column of data, when n equals 1, is the upshift velocity for the neutral gear.

**Dependencies**

To create this parameter, set **Shift type, shftType** to Scheduled.

**Downshift velocity data table, dwnShftTbl – Table**

[m-by-n] array

Downshift velocity data as a function of pedal position and gear, in units specified by the **Reference and feedback units, velUnits** parameter. Downshift velocities indicate the vehicle velocity at which the gear should decrease by 1.

The array dimensions are  $m$  pedal positions by  $n$  gears. The first column of data, when  $n$  equals 1, is the downshift velocity for the neutral gear.

#### Dependencies

To create this parameter, set **Shift type, shftType** to Scheduled.

#### Time required to shift, tClutch – Time

.5 (default) | scalar

Time required to shift,  $t_{Clutch}$ , in s.

#### Dependencies

To create this parameter, set **Shift type, shftType** to Scheduled.

#### Time required to engage reverse from neutral, tRev – Time

.5 (default) | scalar

Time required to engage reverse from neutral,  $t_{Rev}$ , in s.

#### Dependencies

To create this parameter, set **Shift type, shftType** to Scheduled.

#### Time required to engage park from neutral, tPark – Time

120 (default) | scalar

Time required to engage park from neutral,  $t_{Park}$ , in s.

#### Dependencies

To create this parameter, set **Shift type, shftType** to Scheduled.

## References

- [1] MacAdam, C. C. "An Optimal Preview Control for Linear Systems". *Journal of Dynamic Systems, Measurement, and Control*. Vol. 102, Number 3, Sept. 1980.
- [2] MacAdam, C. C. "Application of an Optimal Preview Control for Simulation of Closed-Loop Automobile Driving ". *IEEE Transactions on Systems, Man, and Cybernetics*. Vol. 11, Issue 6, June 1981.
- [3] MacAdam, C. C. *Development of Driver/Vehicle Steering Interaction Models for Dynamic Analysis*. Final Technical Report UMTRI-88-53. Ann Arbor, Michigan: The University of Michigan Transportation Research Institute, Dec. 1988.
- [4] Hoffmann, Gabriel M., Claire J. Tomlin, Michael Montemerlo, and Sebastian Thrun. "Autonomous Automobile Trajectory Tracking for Off-Road Driving: Controller Design, Experimental Validation and Racing." *American Control Conference*. 2007, pp. 2296-2301. doi:10.1109/ACC.2007.4282788



## **Extended Capabilities**

### **C/C++ Code Generation**

Generate C and C++ code using Simulink® Coder™.

### **See Also**

Lateral Driver | Longitudinal Driver

### **Introduced in R2018a**



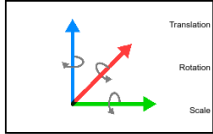
# 3D Simulation Blocks

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## Simulation 3D Actor Transform Get

Get actor translation, rotation, scale

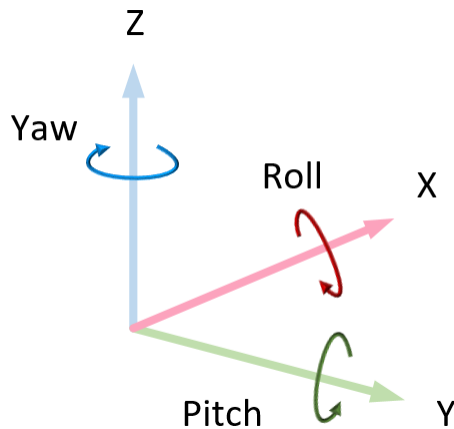
**Library:** Vehicle Dynamics Blockset / Vehicle Scenarios / Sim3D /  
Sim3D Core



### Description

The Simulation 3D Actor Transform Get block provides the actor translation, rotation, and scale for the Simulink simulation environment.

The block uses a vehicle-fixed coordinate system that is initially aligned with the inertial world coordinate system.



Axis	Description
X	Forward direction of the vehicle Roll — Right-handed rotation about X-axis
Y	Extends to the right of the vehicle, initially parallel to the ground plane Pitch — Right-handed rotation about Y-axis
Z	Extends upwards Yaw — Left-handed rotation about Z-axis

Actors are scene objects that support 3D translation, rotation, and scale. Parts are actor components. Components do not exist by themselves; they are associated with an actor.

**Tip** Verify that the Simulation 3D Scene Configuration block executes before the Simulation 3D Actor Transform Get block. That way, the Unreal Engine® 3D visualization environment prepares the data

before the Simulation 3D Actor Transform Get block receives it. To check the block execution order, right-click the blocks and select **Properties**. On the **General** tab, confirm these **Priority** settings:

- Simulation 3D Scene Configuration — 0
- Simulation 3D Actor Transform Get — 1

For more information about execution order, see “Control and Display Execution Order”.

## Ports

### Output

#### Translation — Actor translation

array

Actor translation, in m. Array dimensions are number of parts per actor-by-3.

- Translation(1,1), Translation(1,2), and Translation(1,3) — Vehicle displacement along world X-, Y, and Z- axes, respectively.
- Translation(...,1), Translation(...,2), and Translation(...,3) — Actor displacement relative to vehicle, in vehicle-fixed coordinate system initially aligned with world X-, Y, and Z- axes, respectively.

For example, consider a vehicle actor with a vehicle body and four wheels. The Translation signal:

- Dimensions are [5x3].
- Contains translation information according to the axle and wheel locations, relative to vehicle.

$$Translation = \begin{bmatrix} X_v & Y_v & Z_v \\ X_{FL} & Y_{FL} & Z_{FL} \\ X_{FR} & Y_{FR} & Z_{FR} \\ X_{RL} & Y_{RL} & Z_{RL} \\ X_{RR} & Y_{RR} & Z_{RR} \end{bmatrix}$$

Translation	Array Element
Vehicle, $X_v$	Translation(1,1)
Vehicle, $Y_v$	Translation(1,2)
Vehicle, $Z_v$	Translation(1,3)
Front left wheel, $X_{FL}$	Translation(2,1)
Front left wheel, $Y_{FL}$	Translation(2,2)
Front left wheel, $Z_{FL}$	Translation(2,3)
Front right wheel, $X_{FR}$	Translation(3,1)
Front right wheel, $Y_{FR}$	Translation(3,2)
Front right wheel, $Z_{FR}$	Translation(3,3)
Rear left wheel, $X_{RL}$	Translation(4,1)
Rear left wheel, $Y_{RL}$	Translation(4,2)

Translation	Array Element
Rear left wheel, $Z_{RL}$	Translation(4,3)
Rear right wheel, $X_{RR}$	Translation(5,1)
Rear right wheel, $Y_{RR}$	Translation(5,2)
Rear right wheel, $Z_{RR}$	Translation(5,3)

**Rotation – Actor rotation**

array

Actor rotation across a  $[-\pi/2, \pi/2]$  range, in rad. Array dimensions are number of parts per actor-by-3.

- Rotation(1,1), Rotation(1,2), and Rotation(1,3) – Vehicle rotation about vehicle-fixed pitch, roll, and yaw Y-, Z-, and X- axes, respectively.
- Rotation(...,1), Rotation(...,2), and Rotation(...,3) – Actor rotation about vehicle-fixed pitch, roll, and yaw Y-, Z-, and X- axes, respectively.

For example, consider a vehicle actor with a vehicle body and four wheels. The Rotation signal::

- Dimensions are [5x3].
- Contains rotation information according to the axle and wheel locations.

$$Rotation = \begin{bmatrix} Pitch_v & Roll_v & Yaw_v \\ Pitch_{FL} & Roll_{FL} & Yaw_{FL} \\ Pitch_{FR} & Roll_{FR} & Yaw_{FR} \\ Pitch_{RL} & Roll_{RL} & Yaw_{RL} \\ Pitch_{RR} & Roll_{RR} & Yaw_{RR} \end{bmatrix}$$

Rotation	Array Element
Vehicle, $Pitch_v$	Rotation(1,1)
Vehicle, $Roll_v$	Rotation(1,2)
Vehicle, $Yaw_v$	Rotation(1,3)
Front left wheel, $Pitch_{FL}$	Rotation(2,1)
Front left wheel, $Roll_{FL}$	Rotation(2,2)
Front left wheel, $Yaw_{FL}$	Rotation(2,3)
Front right wheel, $Pitch_{FR}$	Rotation(3,1)
Front right wheel, $Roll_{FR}$	Rotation(3,2)
Front right wheel, $Yaw_{FR}$	Rotation(3,3)
Rear left wheel, $Pitch_{RL}$	Rotation(4,1)
Rear left wheel, $Roll_{RL}$	Rotation(4,2)
Rear left wheel, $Yaw_{RL}$	Rotation(4,3)
Rear right wheel, $Pitch_{RR}$	Rotation(5,1)
Rear right wheel, $Roll_{RR}$	Rotation(5,2)

Rotation	Array Element
Rear right wheel, $Yaw_{RR}$	Rotation(5,3)

### Scale – Actor scale

array

Actor scale. Array dimensions are number of number of parts per actor-by-3.

- Scale(1,1), Scale(1,2), and Scale(1,3) – Vehicle scale along world X-, Y-, and Z- axes, respectively.
- Scale(...,1), Scale(...,2), and Scale(...,3) – Actor scale along world X-, Y-, and Z- axes, respectively.

For example, consider a vehicle actor with a vehicle body and four wheels. The Scale signal:

- Dimensions are [5x3].
- Contains scale information according to the axle and wheel locations.

$$Scale = \begin{bmatrix} X_{V_{scale}} & Y_{V_{scale}} & Z_{V_{scale}} \\ X_{FL_{scale}} & Y_{FL_{scale}} & Z_{FL_{scale}} \\ X_{FR_{scale}} & Y_{FR_{scale}} & Z_{FR_{scale}} \\ X_{RL_{scale}} & Y_{RL_{scale}} & Z_{RL_{scale}} \\ X_{RR_{scale}} & Y_{RR_{scale}} & Z_{RR_{scale}} \end{bmatrix}$$

Scale	Array Element
Vehicle, $X_{V_{scale}}$	Scale(1,1)
Vehicle, $Y_{V_{scale}}$	Scale(1,2)
Vehicle, $Z_{V_{scale}}$	Scale(1,3)
Front left wheel, $X_{FL_{scale}}$	Scale(2,1)
Front left wheel, $Y_{FL_{scale}}$	Scale(2,2)
Front left wheel, $Z_{FL_{scale}}$	Scale(2,3)
Front right wheel, $X_{FR_{scale}}$	Scale(3,1)
Front right wheel, $Y_{FR_{scale}}$	Scale(3,2)
Front right wheel, $Z_{FR_{scale}}$	Scale(3,3)
Rear left wheel, $X_{RL_{scale}}$	Scale(4,1)
Rear left wheel, $Y_{RL_{scale}}$	Scale(4,2)
Rear left wheel, $Z_{RL_{scale}}$	Scale(4,3)
Rear right wheel, $X_{RR_{scale}}$	Scale(5,1)
Rear right wheel, $Y_{RR_{scale}}$	Scale(5,2)
Rear right wheel, $Z_{RR_{scale}}$	Scale(5,3)

## Parameters

### Tag for actor in 3D scene, ActorTag — Name

SimulinkActor1 (default) | character vector

Actor name.

Actors are scene objects that support 3D translation, rotation, and scale. Parts are actor components. Components do not exist by themselves; they are associated with an actor.

The block does not support multiple instances of the same actor tag. To refer to the same scene actor when you use the 3D block pairs (e.g. Simulation 3D Actor Transform Get and Simulation 3D Actor Transform Set), specify the same **Tag for actor in 3D scene, ActorTag** parameter.

### Number of parts per actor to get, NumberOfParts — Name

1 (default) | scalar

Number of parts per actor. Actors are scene objects that support 3D translation, rotation, and scale. Parts are actor components. Components do not exist by themselves; they are associated with an actor. Typically, a vehicle actor with a body and four wheels has 5 parts.

The block does not support multiple instances of the same actor tag. To refer to the same scene actor when you use the 3D block pairs (e.g. Simulation 3D Actor Transform Get and Simulation 3D Actor Transform Set), specify the same **Tag for actor in 3D scene, ActorTag** parameter.

### Sample time — Sample time

-1 (default) | scalar

Sample time,  $T_s$ . The graphics frame rate is the inverse of the sample time.

## See Also

Simulation 3D Actor Transform Set | Simulation 3D Camera Get | Simulation 3D Scene Configuration | Vehicle Terrain Sensor

## Topics

“Coordinate Systems in Vehicle Dynamics Blockset”

“How 3D Simulation for Vehicle Dynamics Blockset Works”

“3D Visualization Engine Requirements and Limitations”

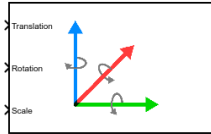
## Introduced in R2018a



# Simulation 3D Actor Transform Set

Set actor translation, rotation, scale

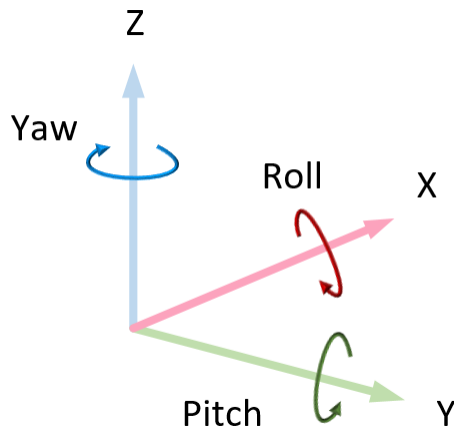
**Library:** Vehicle Dynamics Blockset / Vehicle Scenarios / Sim3D /  
Sim3D Core



## Description

The Simulation 3D Actor Transform Set block sets the actor translation, rotation, and scale in the 3D visualization environment.

The block uses a vehicle-fixed coordinate system that is initially aligned with the inertial world coordinate system.



Axis	Description
X	Forward direction of the vehicle Roll — Right-handed rotation about X-axis
Y	Extends to the right of the vehicle, initially parallel to the ground plane Pitch — Right-handed rotation about Y-axis
Z	Extends upwards Yaw — Left-handed rotation about Z-axis

Actors are scene objects that support 3D translation, rotation, and scale. Parts are actor components. Components do not exist by themselves; they are associated with an actor.

**Tip** Verify that the Simulation 3D Actor Transform Set block executes before the Simulation 3D Scene Configuration block. That way, Simulation 3D Actor Transform Set prepares the signal data

before the Unreal Engine 3D visualization environment receives it. To check the block execution order, right-click the blocks and select **Properties**. On the **General** tab, confirm these **Priority** settings:

- Simulation 3D Scene Configuration — 0
- Simulation 3D Actor Transform Set — -1

For more information about execution order, see “Control and Display Execution Order”.

## Ports

### Input

#### Translation — Actor translation

array

Actor translation, in m. Array dimensions are number of parts per actor-by-3.

- Translation(1,1), Translation(1,2), and Translation(1,3) — Vehicle displacement along world X-, Y, and Z- axes, respectively.
- Translation(...,1), Translation(...,2), and Translation(...,3) — Actor displacement relative to vehicle, in vehicle-fixed coordinate system initially aligned with world X-, Y, and Z- axes, respectively.

For example, consider a vehicle actor with a vehicle body and four wheels. The Translation signal:

- Dimensions are [5x3].
- Contains translation information according to the axle and wheel locations, relative to vehicle.

$$Translation = \begin{bmatrix} X_v & Y_v & Z_v \\ X_{FL} & Y_{FL} & Z_{FL} \\ X_{FR} & Y_{FR} & Z_{FR} \\ X_{RL} & Y_{RL} & Z_{RL} \\ X_{RR} & Y_{RR} & Z_{RR} \end{bmatrix}$$

Translation	Array Element
Vehicle, $X_v$	Translation(1,1)
Vehicle, $Y_v$	Translation(1,2)
Vehicle, $Z_v$	Translation(1,3)
Front left wheel, $X_{FL}$	Translation(2,1)
Front left wheel, $Y_{FL}$	Translation(2,2)
Front left wheel, $Z_{FL}$	Translation(2,3)
Front right wheel, $X_{FR}$	Translation(3,1)
Front right wheel, $Y_{FR}$	Translation(3,2)
Front right wheel, $Z_{FR}$	Translation(3,3)
Rear left wheel, $X_{RL}$	Translation(4,1)

Translation	Array Element
Rear left wheel, $Y_{RL}$	Translation(4,2)
Rear left wheel, $Z_{RL}$	Translation(4,3)
Rear right wheel, $X_{RR}$	Translation(5,1)
Rear right wheel, $Y_{RR}$	Translation(5,2)
Rear right wheel, $Z_{RR}$	Translation(5,3)

### Rotation – Actor rotation

array

Actor rotation across a  $[-\pi/2, \pi/2]$  range, in rad. Array dimensions are number of parts per actor-by-3.

- Rotation(1,1), Rotation(1,2), and Rotation(1,3) – Vehicle rotation about vehicle-fixed pitch, roll, and yaw  $Y$ -,  $Z$ -, and  $X$ - axes, respectively.
- Rotation(...,1), Rotation(...,2), and Rotation(...,3) – Actor rotation about vehicle-fixed pitch, roll, and yaw  $Y$ -,  $Z$ -, and  $X$ - axes, respectively.

For example, consider a vehicle actor with a vehicle body and four wheels. The Rotation signal::

- Dimensions are [5x3].
- Contains rotation information according to the axle and wheel locations.

$$Rotation = \begin{bmatrix} Pitch_v & Roll_v & Yaw_v \\ Pitch_{FL} & Roll_{FL} & Yaw_{FL} \\ Pitch_{FR} & Roll_{FR} & Yaw_{FR} \\ Pitch_{RL} & Roll_{RL} & Yaw_{RL} \\ Pitch_{RR} & Roll_{RR} & Yaw_{RR} \end{bmatrix}$$

Rotation	Array Element
Vehicle, $Pitch_v$	Rotation(1,1)
Vehicle, $Roll_v$	Rotation(1,2)
Vehicle, $Yaw_v$	Rotation(1,3)
Front left wheel, $Pitch_{FL}$	Rotation(2,1)
Front left wheel, $Roll_{FL}$	Rotation(2,2)
Front left wheel, $Yaw_{FL}$	Rotation(2,3)
Front right wheel, $Pitch_{FR}$	Rotation(3,1)
Front right wheel, $Roll_{FR}$	Rotation(3,2)
Front right wheel, $Yaw_{FR}$	Rotation(3,3)
Rear left wheel, $Pitch_{RL}$	Rotation(4,1)
Rear left wheel, $Roll_{RL}$	Rotation(4,2)
Rear left wheel, $Yaw_{RL}$	Rotation(4,3)
Rear right wheel, $Pitch_{RR}$	Rotation(5,1)

Rotation	Array Element
Rear right wheel, $Roll_{RR}$	Rotation(5,2)
Rear right wheel, $Yaw_{RR}$	Rotation(5,3)

**Scale – Actor scale**

array

Actor scale. Array dimensions are number of number of parts per actor-by-3.

- Scale(1,1), Scale(1,2), and Scale(1,3) – Vehicle scale along world X-, Y-, and Z- axes, respectively.
- Scale(...,1), Scale(...,2), and Scale(...,3) – Actor scale along world X-, Y-, and Z- axes, respectively.

For example, consider a vehicle actor with a vehicle body and four wheels. The Scale signal:

- Dimensions are [5x3].
- Contains scale information according to the axle and wheel locations.

$$Scale = \begin{bmatrix} X_{V_{scale}} & Y_{V_{scale}} & Z_{V_{scale}} \\ X_{FL_{scale}} & Y_{FL_{scale}} & Z_{FL_{scale}} \\ X_{FR_{scale}} & Y_{FR_{scale}} & Z_{FR_{scale}} \\ X_{RL_{scale}} & Y_{RL_{scale}} & Z_{RL_{scale}} \\ X_{RR_{scale}} & Y_{RR_{scale}} & Z_{RR_{scale}} \end{bmatrix}$$

Scale	Array Element
Vehicle, $X_{V_{scale}}$	Scale(1,1)
Vehicle, $Y_{V_{scale}}$	Scale(1,2)
Vehicle, $Z_{V_{scale}}$	Scale(1,3)
Front left wheel, $X_{FL_{scale}}$	Scale(2,1)
Front left wheel, $Y_{FL_{scale}}$	Scale(2,2)
Front left wheel, $Z_{FL_{scale}}$	Scale(2,3)
Front right wheel, $X_{FR_{scale}}$	Scale(3,1)
Front right wheel, $Y_{FR_{scale}}$	Scale(3,2)
Front right wheel, $Z_{FR_{scale}}$	Scale(3,3)
Rear left wheel, $X_{RL_{scale}}$	Scale(4,1)
Rear left wheel, $Y_{RL_{scale}}$	Scale(4,2)
Rear left wheel, $Z_{RL_{scale}}$	Scale(4,3)
Rear right wheel, $X_{RR_{scale}}$	Scale(5,1)
Rear right wheel, $Y_{RR_{scale}}$	Scale(5,2)
Rear right wheel, $Z_{RR_{scale}}$	Scale(5,3)

## Parameters

### Actor Setup

#### Tag for actor in 3D scene, ActorTag — Name

SimulinkActor1 (default) | character vector

Actor name.

Actors are scene objects that support 3D translation, rotation, and scale. Parts are actor components. Components do not exist by themselves; they are associated with an actor.

The block does not support multiple instances of the same actor tag. To refer to the same scene actor when you use the 3D block pairs (e.g. Simulation 3D Actor Transform Get and Simulation 3D Actor Transform Set), specify the same **Tag for actor in 3D scene, ActorTag** parameter.

#### Number of parts per actor to set, NumberOfParts — Name

1 (default) | scalar

Number of parts per actor. Actors are scene objects that support 3D translation, rotation, and scale. Parts are actor components. Components do not exist by themselves; they are associated with an actor. Typically, a vehicle actor with a body and four wheels has 5 parts.

The block does not support multiple instances of the same actor tag. To refer to the same scene actor when you use the 3D block pairs (e.g. Simulation 3D Actor Transform Get and Simulation 3D Actor Transform Set), specify the same **Tag for actor in 3D scene, ActorTag** parameter.

### Initial Values

#### Initial array values to translate actor per part, Translation — Actor initial position

[0 0 0] (default) | array

Actor initial position, along world X-, Y-, and Z- axes, in m.

Array dimensions are number of parts per actor-by-3.

- Translation(1,1), Translation(1,2), and Translation(1,3) — Vehicle displacement along world X-, Y, and Z- axes, respectively.
- Translation(...,1), Translation(...,2), and Translation(...,3) — Actor displacement relative to vehicle, in vehicle-fixed coordinate system initially aligned with world X-, Y, and Z- axes, respectively.

For example, consider a vehicle actor with a vehicle body and four wheels. The parameter:

- Dimensions are [5x3].
- Contains translation information according to the axle and wheel locations, relative to vehicle.

$$Translation = \begin{bmatrix} X_v & Y_v & Z_v \\ X_{FL} & Y_{FL} & Z_{FL} \\ X_{FR} & Y_{FR} & Z_{FR} \\ X_{RL} & Y_{RL} & Z_{RL} \\ X_{RR} & Y_{RR} & Z_{RR} \end{bmatrix}$$

Translation	Array Element
Vehicle, $X_v$	Translation(1,1)
Vehicle, $Y_v$	Translation(1,2)
Vehicle, $Z_v$	Translation(1,3)
Front left wheel, $X_{FL}$	Translation(2,1)
Front left wheel, $Y_{FL}$	Translation(2,2)
Front left wheel, $Z_{FL}$	Translation(2,3)
Front right wheel, $X_{FR}$	Translation(3,1)
Front right wheel, $Y_{FR}$	Translation(3,2)
Front right wheel, $Z_{FR}$	Translation(3,3)
Rear left wheel, $X_{RL}$	Translation(4,1)
Rear left wheel, $Y_{RL}$	Translation(4,2)
Rear left wheel, $Z_{RL}$	Translation(4,3)
Rear right wheel, $X_{RR}$	Translation(5,1)
Rear right wheel, $Y_{RR}$	Translation(5,2)
Rear right wheel, $Z_{RR}$	Translation(5,3)

**Initial array values to rotate actor per part, Rotation – Actor initial rotation**  
 [0 0 0] (default) | array

Actor initial rotation about world X-, Y-, and Z- axes across a [-pi/2, pi/2] range, in rad.

Array dimensions are number of parts per actor-by-3.

- Rotation(1,1), Rotation(1,2), and Rotation(1,3) – Vehicle rotation about vehicle-fixed pitch, roll, and yaw Y-, Z-, and X- axes, respectively.
- Rotation(...,1), Rotation(...,2), and Rotation(...,3) – Actor rotation about vehicle-fixed pitch, roll, and yaw Y-, Z-, and X- axes, respectively.

For example, consider a vehicle actor with a vehicle body and four wheels. The parameter:

- Dimensions are [5x3].
- Contains rotation information according to the axle and wheel locations.

$$Rotation = \begin{bmatrix} Pitch_v & Roll_v & Yaw_v \\ Pitch_{FL} & Roll_{FL} & Yaw_{FL} \\ Pitch_{FR} & Roll_{FR} & Yaw_{FR} \\ Pitch_{RL} & Roll_{RL} & Yaw_{RL} \\ Pitch_{RR} & Roll_{RR} & Yaw_{RR} \end{bmatrix}$$

Rotation	Array Element
Vehicle, $Pitch_v$	Rotation(1,1)
Vehicle, $Roll_v$	Rotation(1,2)
Vehicle, $Yaw_v$	Rotation(1,3)

Rotation	Array Element
Front left wheel, $Pitch_{FL}$	Rotation(2,1)
Front left wheel, $Roll_{FL}$	Rotation(2,2)
Front left wheel, $Yaw_{FL}$	Rotation(2,3)
Front right wheel, $Pitch_{FR}$	Rotation(3,1)
Front right wheel, $Roll_{FR}$	Rotation(3,2)
Front right wheel, $Yaw_{FR}$	Rotation(3,3)
Rear left wheel, $Pitch_{RL}$	Rotation(4,1)
Rear left wheel, $Roll_{RL}$	Rotation(4,2)
Rear left wheel, $Yaw_{RL}$	Rotation(4,3)
Rear right wheel, $Pitch_{RR}$	Rotation(5,1)
Rear right wheel, $Roll_{RR}$	Rotation(5,2)
Rear right wheel, $Yaw_{RR}$	Rotation(5,3)

### Initial array values to scale actor per part, **Scale** – Actor initial scale

[1 1 1] (default) | array

Actor initial scale.

Array dimensions are number of number of parts per actor-by-3.

- $Scale(1,1)$ ,  $Scale(1,2)$ , and  $Scale(1,3)$  – Vehicle scale along world X-, Y, and Z- axes, respectively.
- $Scale(\dots,1)$ ,  $Scale(\dots,2)$ , and  $Scale(\dots,3)$  – Actor scale along world X-, Y, and Z- axes, respectively.

For example, consider a vehicle actor with a vehicle body and four wheels. The parameter:

- Dimensions are [5x3].
- Contains scale information according to the axle and wheel locations.

$$Scale = \begin{bmatrix} X_{V_{scale}} & Y_{V_{scale}} & Z_{V_{scale}} \\ X_{FL_{scale}} & Y_{FL_{scale}} & Z_{FL_{scale}} \\ X_{FR_{scale}} & Y_{FR_{scale}} & Z_{FR_{scale}} \\ X_{RL_{scale}} & Y_{RL_{scale}} & Z_{RL_{scale}} \\ X_{RR_{scale}} & Y_{RR_{scale}} & Z_{RR_{scale}} \end{bmatrix}$$

Scale	Array Element	Scale Axis
Vehicle, $X_{V_{scale}}$	Scale(1,1)	World X-axis
Vehicle, $Y_{V_{scale}}$	Scale(1,2)	World Y-axis
Vehicle, $Z_{V_{scale}}$	Scale(1,3)	World Z-axis
Front left wheel, $X_{FL_{scale}}$	Scale(2,1)	World X-axis
Front left wheel, $Y_{FL_{scale}}$	Scale(2,2)	World Y-axis

Scale	Array Element	Scale Axis
Front left wheel, $Z_{FL_{scale}}$	Scale(2,3)	World Z-axis
Front right wheel, $X_{FR_{scale}}$	Scale(3,1)	World X-axis
Front right wheel, $Y_{FR_{scale}}$	Scale(3,2)	World Y-axis
Front right wheel, $Z_{FR_{scale}}$	Scale(3,3)	World Z-axis
Rear left wheel, $X_{RL_{scale}}$	Scale(4,1)	World X-axis
Rear left wheel, $Y_{RL_{scale}}$	Scale(4,2)	World Y-axis
Rear left wheel, $Z_{RL_{scale}}$	Scale(4,3)	World Z-axis
Rear right wheel, $X_{RR_{scale}}$	Scale(5,1)	World X-axis
Rear right wheel, $Y_{RR_{scale}}$	Scale(5,2)	World Y-axis
Rear right wheel, $Z_{RR_{scale}}$	Scale(5,3)	World Z-axis

**Sample time – Sample time**

-1 (default) | scalar

Sample time,  $T_s$ . The graphics frame rate is the inverse of the sample time.

**See Also**

Simulation 3D Actor Transform Get | Simulation 3D Camera Get | Simulation 3D Scene Configuration | Vehicle Terrain Sensor

**Topics**

- “Coordinate Systems in Vehicle Dynamics Blockset”
- “How 3D Simulation for Vehicle Dynamics Blockset Works”
- “3D Visualization Engine Requirements and Limitations”

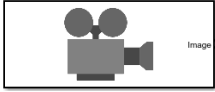
**Introduced in R2018a**



# Simulation 3D Camera Get

Camera image

**Library:** Vehicle Dynamics Blockset / Vehicle Scenarios / Sim3D / Sim3D Core



## Description

The Simulation 3D Camera Get block provides an interface to an ideal camera in the 3D visualization environment. The image output is a red, green, and blue (RGB) array.

If you set the sample time to -1, the block uses the sample time specified in the Simulation 3D Scene Configuration block. To use this sensor, ensure that the Simulation 3D Scene Configuration block is in your model.

---

**Tip** Verify that the Simulation 3D Scene Configuration block executes before the Simulation 3D Camera Get block. That way, the Unreal Engine 3D visualization environment prepares the data before the Simulation 3D Camera Get block receives it. To check the block execution order, right-click the blocks and select **Properties**. On the **General** tab, confirm these **Priority** settings:

- Simulation 3D Scene Configuration — 0
- Simulation 3D Camera Get — 1

For more information about execution order, see “Control and Display Execution Order”.

---

## Ports

### Output

#### Image — 3D output camera image

*m*-by-*n*-by-3 array of RGB triplet values

3D output camera image, returned as an *m*-by-*n*-by-3 array of RGB triplet values. *m* is the vertical resolution of the image, and *n* is the horizontal resolution of the image.

Data Types: int8 | uint8

## Parameters

### Mounting

#### Sensor identifier — Number to identify unique sensor

0 (default) | positive integer

Unique sensor identifier, specified as a positive integer. This number is used to identify a specific sensor. The sensor identifier distinguishes between sensors in a multi-sensor system.

Example: 2

### Vehicle name — Name of a vehicle

Scene Origin (default) | character vector

Vehicle name. Block provides a list of vehicles in the model. If you select Scene Origin, the block places a sensor at the scene origin.

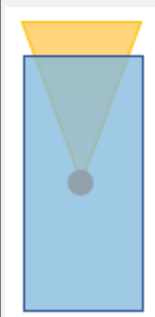
Example: SimulinkVehicle1

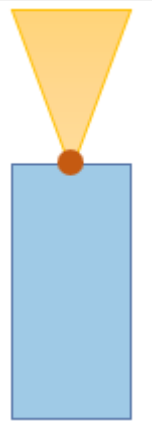
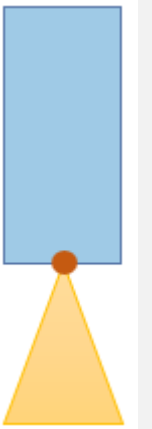
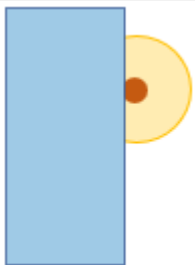
### Vehicle mounting location — Sensor mounting location

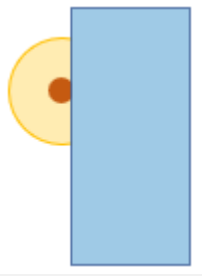

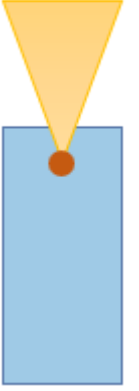
Origin (default) | Front bumper | Rear bumper | Right mirror | Left mirror | Rearview mirror | Hood center | Roof center


Sensor mounting location.

- When **Vehicle name** is Scene Origin, the block mounts the sensor to the origin of the scene, and **Mounting location** can be set to Origin only. During simulation, the sensor remains stationary.
- When **Vehicle name** is the name of a vehicle (for example, SimulinkVehicle1) the block mounts the sensor to one of the predefined mounting locations described in the table. During simulation, the sensor travels with the vehicle.

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Origin	<p>Forward-facing sensor mounted to the vehicle origin, which is on the ground, at the geometric center of the vehicle</p> 	[0, 0, 0]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Front bumper	Forward-facing sensor mounted to the front bumper 	[0, 0, 0]
Rear bumper	Backward-facing sensor mounted to the rear bumper 	[0, 0, 180]
Right mirror	Downward-facing sensor mounted to the right side-view mirror 	[0, -90, 0]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Left mirror	<p>Downward-facing sensor mounted to the left side-view mirror</p>  <p>The diagram shows a blue vertical rectangle representing a side-view mirror. A yellow semi-circle is attached to the left side of the rectangle. A brown dot is located at the center of the semi-circle, representing the sensor. A yellow cone extends downwards from the dot, indicating the sensor's field of view.</p>	[0, -90, 0]
Rearview mirror	<p>Forward-facing sensor mounted to the rearview mirror, inside the vehicle</p>  <p>The diagram shows a blue vertical rectangle representing a rearview mirror. A grey dot is located at the top center of the rectangle, representing the sensor. A yellow cone extends upwards from the dot, indicating the sensor's field of view.</p>	[0, 0, 0]
Hood center	<p>Forward-facing sensor mounted to the center of the hood</p>  <p>The diagram shows a blue vertical rectangle representing the hood. A brown dot is located at the top center of the rectangle, representing the sensor. A yellow cone extends upwards from the dot, indicating the sensor's field of view.</p>	[0, 0, 0]

Vehicle Mounting Location	Description	Orientation Relative to Vehicle Origin [Roll, Pitch, Yaw] (deg)
Roof center	Forward-facing sensor mounted to the center of the roof 	[0, 0, 0]

The  $(X, Y, Z)$  location of the sensor relative to the vehicle depends on the vehicle type. To specify the vehicle type, use the **Type** parameter of the Simulation 3D Scene Configuration block to which you are mounting. The tables show the  $X$ ,  $Y$ , and  $Z$  locations of sensors in the vehicle coordinate system. In this coordinate system:

- The  $X$ -axis points forward from the vehicle.
- The  $Y$ -axis points to the left of the vehicle, as viewed when facing forward.
- The  $Z$ -axis points up from the ground.
- Roll, pitch, and yaw are clockwise-positive when looking in the positive direction of the  $X$ -axis,  $Y$ -axis, and  $Z$ -axis, respectively. When looking at a vehicle from the top down, then the yaw angle (that is, the orientation angle) is counterclockwise-positive, because you are looking in the negative direction of the axis.

#### Box Truck — Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	5.10	0	0.60
Rear bumper	-5	0	0.60
Right mirror	2.90	1.60	2.10
Left mirror	2.90	-1.60	2.10
Rearview mirror	2.60	0.20	2.60
Hood center	3.80	0	2.10
Roof center	1.30	0	4.20

**Hatchback – Sensor Locations Relative to Vehicle Origin**

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	1.93	0	0.51
Rear bumper	-1.93	0	0.51
Right mirror	0.43	-0.84	1.01
Left mirror	0.43	0.84	1.01
Rearview mirror	0.32	0	1.27
Hood center	1.44	0	1.01
Roof center	0	0	1.57

**Muscle Car – Sensor Locations Relative to Vehicle Origin**

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	2.47	0	0.45
Rear bumper	-2.47	0	0.45
Right mirror	0.43	-1.08	1.01
Left mirror	0.43	1.08	1.01
Rearview mirror	0.32	0	1.20
Hood center	1.28	0	1.14
Roof center	-0.25	0	1.58

**Sedan – Sensor Locations Relative to Vehicle Origin**

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	2.42	0	0.51
Rear bumper	-2.42	0	0.51
Right mirror	0.59	-0.94	1.09
Left mirror	0.59	0.94	1.09
Rearview mirror	0.43	0	1.31
Hood center	1.46	0	1.11
Roof center	-0.45	0	1.69

**Small Pickup Truck – Sensor Locations Relative to Vehicle Origin**

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	3.07	0	0.51
Rear bumper	-3.07	0	0.51
Right mirror	1.10	-1.13	1.52
Left mirror	1.10	1.13	1.52
Rearview mirror	0.85	0	1.77
Hood center	2.22	0	1.59
Roof center	0	0	2.27

**Sport Utility Vehicle – Sensor Locations Relative to Vehicle Origin**

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	2.42	0	0.51
Rear bumper	-2.42	0	0.51
Right mirror	0.60	-1	1.35
Left mirror	0.60	1	1.35
Rearview mirror	0.39	0	1.55
Hood center	1.58	0	1.39
Roof center	-0.56	0	2

Example: Origin

**Specify offset – Specify offset from mounting location**

off (default) | on

Select this parameter to specify an offset from the mounting location.

**Relative translation [X, Y, Z] – Translation offset from mounting location**

[0, 0, 0] (default) | real-valued 1-by-3 vector

Specify a translation offset from the mount location, about the vehicle coordinate system X, Y, and Z axes. Units are in meters.

- The X-axis points forward from the vehicle.
- The Y-axis points to the left of the vehicle, as viewed when facing forward.
- The Z-axis points up.

Example: [0, 0, 0.01]

**Dependencies**

To enable this parameter, select **Specify offset**.

**Relative rotation [Roll, Pitch, Yaw] – Rotational offset from mounting location**

[0, 0, 0] (default) | real-valued 1-by-3 vector

Specify a rotational offset from the mounting location, about the vehicle coordinate system X, Y, and Z axes. Units are in degrees.

- Roll angle is the angle of rotation about the *X*-axis of the vehicle coordinate system. A positive roll angle corresponds to a clockwise rotation when looking in the positive direction of the *X*-axis.
- Pitch angle is the angle of rotation about the *Y*-axis of the vehicle coordinate system. A positive pitch angle corresponds to a clockwise rotation when looking in the positive direction of the *Y*-axis.
- Yaw angle is the angle of rotation about the *Z* of the vehicle coordinate system. A positive yaw angle corresponds to a clockwise rotation when looking in the positive direction of the *Z*-axis.

Example: [0, 0, 10]

### Dependencies

To enable this parameter, select **Specify offset**.

### Sample time – Sample time

-1 (default) | positive scalar

Sample time of the block in seconds. The 3D simulation environment frame rate is the inverse of the sample time.

If you set the sample time to -1, the block uses the sample time specified in the Simulation 3D Scene Configuration block.

### Parameter

#### Horizontal resolution – Pixels

uint32(1280) (default) | scalar

Horizontal image resolution, in pixels.

#### Vertical resolution – Pixels

uint32(720) (default) | scalar

Vertical image resolution, in pixels.

#### Horizontal field of view – Field of view

single(60) (default) | scalar

Horizontal field of view (FOV), in deg.

### See Also

Simulation 3D Actor Transform Get | Simulation 3D Actor Transform Set | Simulation 3D Scene Configuration | Vehicle Terrain Sensor

### Topics

“How 3D Simulation for Vehicle Dynamics Blockset Works”

“Scene Interrogation in 3D Environment”

“3D Visualization Engine Requirements and Limitations”

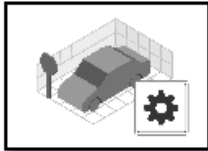
### Introduced in R2018a



# Simulation 3D Scene Configuration

Scene configuration for 3D simulation environment

**Library:** Automated Driving Toolbox / Simulation 3D  
Vehicle Dynamics Blockset / Vehicle Scenarios / Sim3D /  
Sim3D Core



## Description

The Simulation 3D Scene Configuration block implements a 3D simulation environment that is rendered by using the Unreal Engine from Epic Games®. Vehicle Dynamics Blockset integrates the 3D simulation environment with Simulink so that you can query the world around the vehicle and virtually test perception, control, and planning algorithms.

You can simulate from a set of prebuilt scenes or from your own custom scenes. Scene customization requires the Vehicle Dynamics Blockset Interface for Unreal Engine 4 Projects support package. For more details, see “Customize 3D Scenes for Vehicle Dynamics Simulations”.

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**Note** The Simulation 3D Scene Configuration block must execute after blocks that send data to the 3D environment and before blocks that receive data from the 3D environment. To verify the execution order of such blocks, right-click the blocks and select **Properties**. Then, on the **General** tab, confirm these **Priority** settings:

- For blocks that send data to the 3D environment, such as Simulation 3D Vehicle with Ground Following blocks, **Priority** must be set to -1. That way, these blocks prepare their data before the 3D environment receives it.
- For the Simulation 3D Scene Configuration block in your model, **Priority** must be set to 0.
- For blocks that receive data from the 3D environment, such as Simulation 3D Message Get blocks, **Priority** must be set to 1. That way, the 3D environment can prepare the data before these blocks receive it.

For more information about execution order, see “Control and Display Execution Order”.

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## Parameters

### Scene Selection

#### Scene source — Source of scene

Default Scenes (default) | Unreal Executable | Unreal Editor

Source of the scene in which to simulate, specified as one of the options in the table.

Option	Description
Default Scenes	Simulate in one of the default, prebuilt scenes specified in the <b>Scene name</b> parameter.
Unreal Executable	<p>Simulate in a scene that is part of an Unreal Engine executable file. Specify the executable file in the <b>File name</b> parameter. Specify the scene in the <b>Scene</b> parameter.</p> <p>Select this option to simulate in custom scenes that have been packaged into an executable for faster simulation.</p>
Unreal Editor	<p>Simulate in a scene that is part of an Unreal Engine project (.uproject) file and is open in the Unreal® Editor. Specify the project file in the <b>Project</b> parameter.</p> <p>Select this option when developing custom scenes. By clicking <b>Open Unreal Editor</b>, you can co-simulate within Simulink and the Unreal Editor and modify your scenes based on the simulation results.</p>

#### Scene name — Name of prebuilt 3D scene

Straight road (default) | Curved road | Parking lot | Double lane change | Open surface | US city block | US highway | Virtual Mcity | Large parking lot

Name of the prebuilt 3D scene in which to simulate, specified as one of these options. For details about a scene, see its listed corresponding reference page.

- Straight road — **Straight Road**
- Curved road — **Curved Road**
- Parking lot — **Parking Lot**
- Double lane change — **Double Lane Change**
- Open surface — **Open Surface**
- US city block — **US City Block**
- US highway — **US Highway**
- Virtual Mcity — **Virtual Mcity**
- Large parking lot — **Large Parking Lot**

The Vehicle Dynamics Blockset Interface for Unreal Engine 4 Projects contains customizable versions of these scenes. For details about customizing scenes, see “Customize 3D Scenes for Vehicle Dynamics Simulations”.

#### Dependencies

To enable this parameter, set **Scene source** to Default Scenes.

#### File name — Name of Unreal Engine executable file

VehicleSimulation.exe (default) | valid executable file name

Name of the Unreal Engine executable file, specified as a valid executable file name. You can either browse for the file or specify the full path to the file, using backslashes. To specify a scene from this file to simulate in, use the **Scene** parameter.

By default, **File name** is set to `VehicleSimulation.exe`, which is on the MATLAB search path.

Example: `C:\Local\WindowsNoEditor\AutoVrtlEnv.exe`

### Dependencies

To enable this parameter, set **Scene source** to `Unreal Executable`.

### Scene — Name of scene from executable file

`/Game/Maps/HwStrght` (default) | path to valid scene name

Name of a scene from the executable file specified by the **File name** parameter, specified as a path to a valid scene name.

When you package scenes from an Unreal Engine project into an executable file, the Unreal Editor saves the scenes to an internal folder within the executable file. This folder is located at the path `/Game/Maps`. Therefore, you must prepend `/Game/Maps` to the scene name. You must specify this path using forward slashes. For the file name, do not specify the `.umap` extension. For example, if the scene from the executable in which you want to simulate is named `myScene.umap`, specify **Scene** as `/Game/Maps/myScene`.

Alternatively, you can browse for the scene in the corresponding Unreal Engine project. These scenes are typically saved to the `Content/Maps` subfolder of the project. This subfolder contains all the scenes in your project. The scenes have the extension `.umap`. Select one of the scenes that you packaged into the executable file specified by the **File name** parameter. Use backward slashes and specify the `.umap` extension for the scene.

By default, **Scene** is set to `/Game/Maps/HwStrght`, which is a scene from the default `VehicleSimulation.exe` executable file specified by the **File name** parameter. This scene corresponds to the prebuilt **Straight Road** scene.

Example: `/Game/Maps/scene1`

Example: `C:\Local\myProject\Content\Maps\scene1.umap`

### Dependencies

To enable this parameter, set **Scene source** to `Unreal Executable`.

### Project — Name of Unreal Engine project file

valid project file name

Name of the Unreal Engine project file, specified as a valid project file name. You can either browse for the file or specify the full path to the file, using backslashes. The file must contain no spaces. To simulate scenes from this project in the Unreal Editor, click **Open Unreal Editor**. If you have an Unreal Editor session open already, then this button is disabled.

To run the simulation, in Simulink, click **Run**. Before you click **Play** in the Unreal Editor, wait until the Diagnostic Viewer window displays this confirmation message:

In the Simulation 3D Scene Configuration block, you set the scene source to 'Unreal Editor'.  
In Unreal Editor, select 'Play' to view the scene.

This message confirms that Simulink has instantiated the scene actors, including the vehicles and cameras, in the Unreal Engine 3D environment. If you click **Play** before the Diagnostic Viewer

window displays this confirmation message, Simulink might not instantiate the actors in the Unreal Editor.

### Dependencies

To enable this parameter, set **Scene source** to Unreal Editor.

### Scene Parameters

#### Scene view — Configure placement of virtual camera that displays scene

Scene Origin (default) | vehicle name

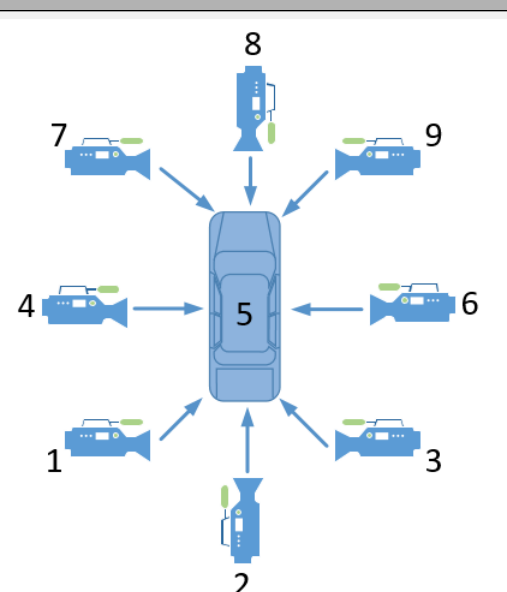
Configure the placement of the virtual camera that displays the scene during simulation.


- If your model contains no Simulation 3D Vehicle or Simulation 3D Vehicle with Ground Following blocks, then during simulation, you view the scene from a camera positioned at the scene origin.
- If your model contains at least one vehicle block, then by default, you view the scene from behind the first vehicle that was placed in your model. To change the view to a different vehicle, set **Scene view** to the name of that vehicle. The **Scene view** parameter list is populated with all the **Name** parameter values of the vehicle blocks contained in your model.

If you add a Simulation 3D Scene Configuration block to your model before adding any vehicle blocks, the virtual camera remains positioned at the scene. To reposition the camera to follow a vehicle, update this parameter.


When **Scene view** is set to a vehicle name, during simulation, you can change the location of the camera around the vehicle.

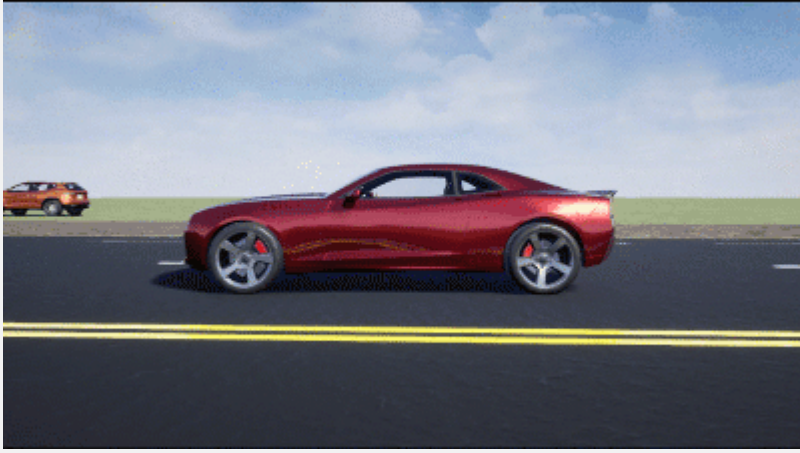
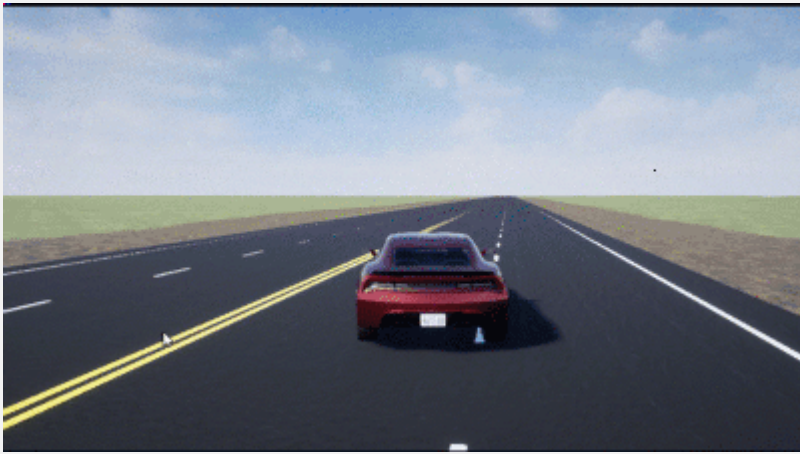
To smoothly change the camera views, use these key commands.

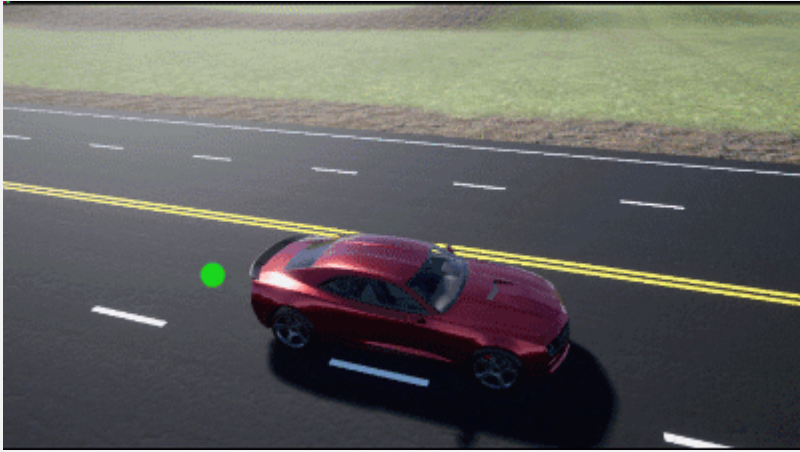
Key	Camera View	
1	Back left	
2	Back	
3	Back right	
4	Left	
5	Internal	
6	Right	
7	Front left	
8	Front	
9	Front right	

Key	Camera View	
0	Overhead	<b>View Animated GIF</b>  A red sports car is shown from a side-rear perspective on a paved road. The car is positioned on the left side of the road, with a white dashed line to its right. The background features a clear blue sky and a flat, green landscape.

For additional camera controls, use these key commands.

Key	Camera Control
Tab	Cycle the view between all vehicles in the scene. <b>View Animated GIF</b>  An orange SUV is shown from a rear-quarter perspective on a grassy field. The car is positioned in the center of the frame, facing towards the right. The background features a clear blue sky and a flat, green landscape.

Key	Camera Control
<p>Mouse scroll wheel</p>	<p>Control the camera distance from the vehicle.</p> <p><b>View Animated GIF</b></p> 
<p><b>L</b></p>	<p>Toggle a camera lag effect on or off. When you enable the lag effect, the camera view includes:</p> <ul style="list-style-type: none"> <li>• Position lag, based on the vehicle translational acceleration</li> <li>• Rotation lag, based on the vehicle rotational velocity</li> </ul> <p>This lag enables improved visualization of overall vehicle acceleration and rotation.</p> <p><b>View Animated GIF</b></p> 

Key	Camera Control
F	<p>Toggle the free camera mode on or off. When you enable the free camera mode, you can use the mouse to change the pitch and yaw of the camera. This mode enables you to orbit the camera around the vehicle.</p> <p><b>View Animated GIF</b></p> 

### Sample time – Sample time of visualization engine

.02 (default) | scalar greater than or equal to 0.01

Sample time,  $T_s$ , of the visualization engine, specified as a scalar greater than or equal to 0.01. Units are in seconds.

The graphics frame rate of the visualization engine is the inverse of the sample time. For example, if **Sample time** is  $1/60$ , then the visualization engine solver tries to achieve a frame rate of 60 frames per second. However, the real-time graphics frame rate is often lower due to factors such as graphics card performance and model complexity.

By default, blocks that receive data from the visualization engine, such as Simulation 3D Message blocks, inherit this sample rate.

### Display 3D simulation window – Unreal Engine visualization

on (default) | off

Select whether to run simulations in the 3D visualization environment without visualizing the results, that is, in headless mode.

Consider running in headless mode in these cases:

- You want to run multiple 3D simulations in parallel to test models in different Unreal Engine scenarios.
- You want to optimize model parameters without visualizing the results. For example, consider using headless mode if you want to tune vehicle suspension parameters over a terrain scenario defined in Unreal Engine.

### Dependencies

To enable this parameter, set **Scene source** to `Default Scenes` or `Unreal Executable`.

## **See Also**

Simulation 3D Vehicle | Simulation 3D Vehicle with Ground Following

## **Topics**

“How 3D Simulation for Vehicle Dynamics Blockset Works”

“Scene Interrogation in 3D Environment”

“3D Visualization Engine Requirements and Limitations”

“Customize 3D Scenes for Vehicle Dynamics Simulations”

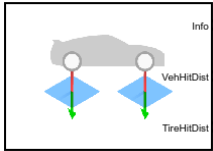
**Introduced in R2018a**



# Vehicle Terrain Sensor

Vehicle and tire distances to objects

**Library:** Vehicle Dynamics Blockset / Vehicle Scenarios / Sim3D /  
Sim3D Vehicle / Components



## Description

The Vehicle Terrain Sensor block implements ray tracing to detect the terrain below the tires and objects in front of the vehicle. Specifically, for these actor components, the block returns the hit location (in the world coordinate system) and the distance to an object.

- Vehicle body
- Left front wheel
- Right front wheel
- Left rear wheel
- Right rear wheel

**Tip** Verify that the Vehicle Terrain Sensor block executes before the Simulation 3D Fisheye Camera block. That way, the Unreal Engine 3D visualization environment prepares the data before the Vehicle Terrain Sensor block receives it. To check the block execution order, right-click the blocks and select **Properties**. On the **General** tab, confirm these **Priority** settings:

- Simulation 3D Scene Configuration — 0
- Vehicle Terrain Sensor — 1

For more information about execution order, see “Control and Display Execution Order”.

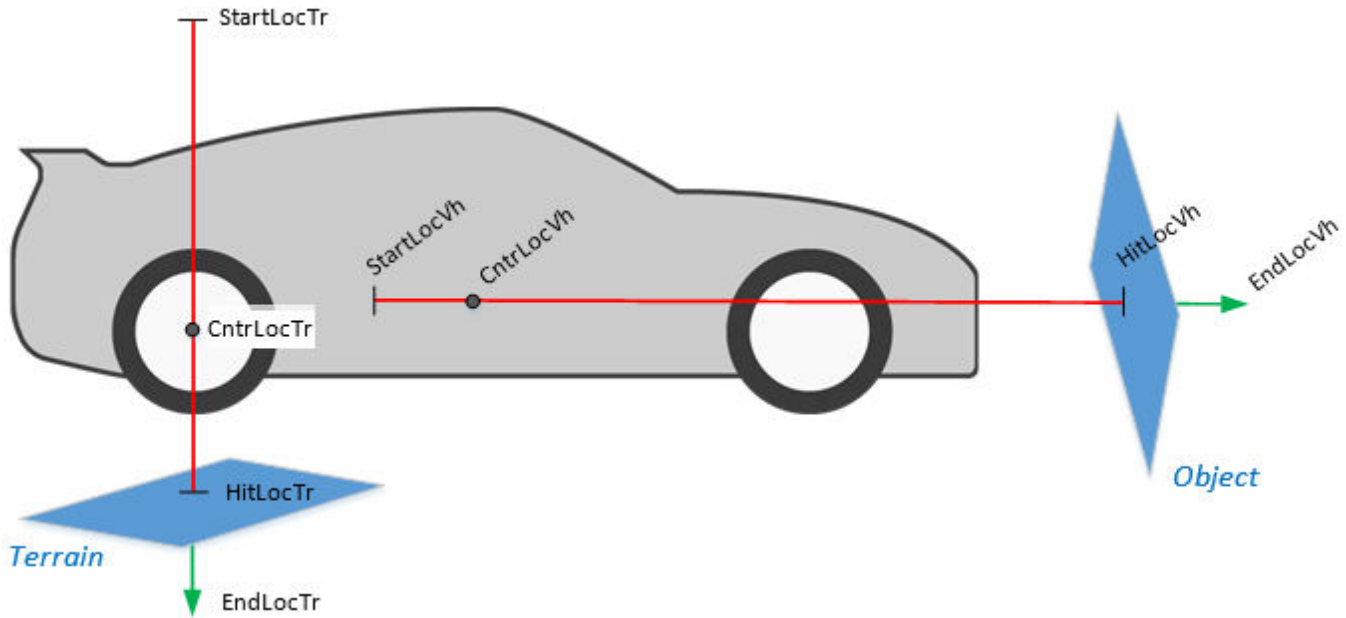
Actors are scene objects that support 3D translation, rotation, and scale. Parts are actor components. Components do not exist by themselves; they are associated with an actor.

## Hit Distance

To calculate the hit distances shown in the illustration, the block implements these equations.

Front of vehicle to object, <i>DistToHitVhAdjust</i>	$\text{DistToHitVh} = \text{GetLength}(\text{CntrLocVh}, \text{HitLocVh})$ $\text{DistToHitVhAdjust} = \text{DistToHitVh} - \text{VehCntrLngthVal}$ $\text{EndLocVh} = \text{CntrLocVh} + \text{VehRayLngth} - \text{VehRayOffset}$ $\text{VehRayOffset} = \text{CntrLocVh} - \text{StartLocVh}$ $\text{VehRayLngth} = \text{StartLocVh} - \text{EndLocVh}$
---	--

Tires to terrain, <i>DistToHitTrAdjust</i>	$\text{DistToHitTr} = \text{GetLength}(\text{CntrLocTr}, \text{HitLocTr})$ $\text{DistToHitTrAdjust} = \text{DistToHitTr} - \text{TireRadiiVal}$
	$\text{EndLocTr} = \text{CntrLocTr} + \text{LengthTr} - \text{OffsetTr}$ $\text{OffsetTr} = \text{CntrLocTr} - \text{StartLocTr}$ $\text{LengthTr} = \text{StartLocTr} - \text{EndLocTr}$



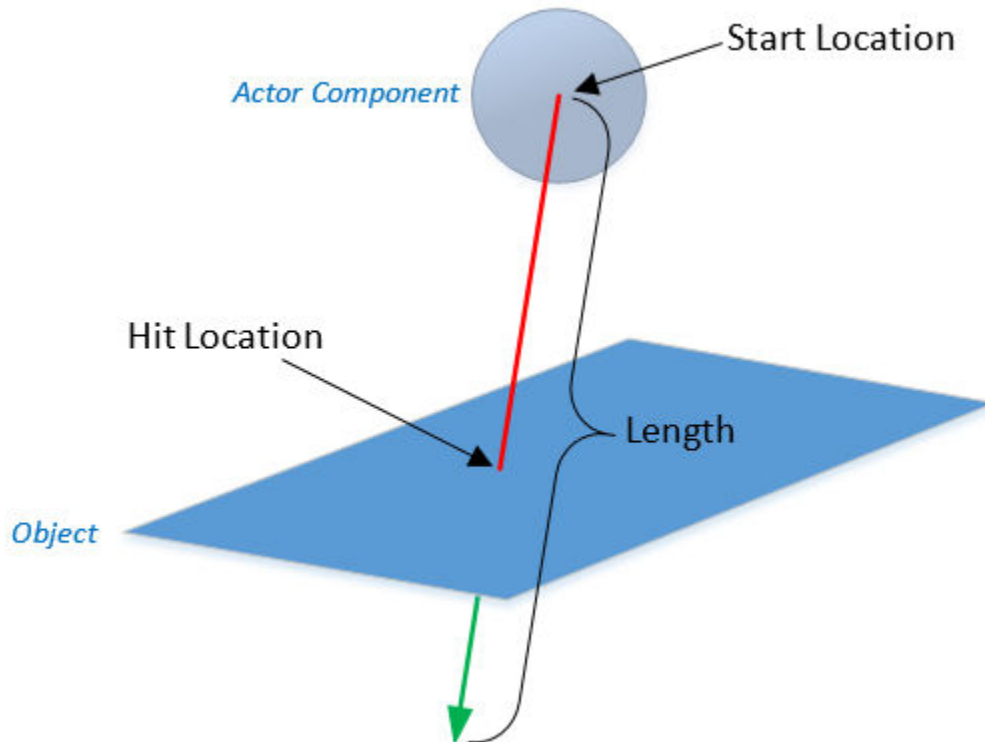
This illustration and equations use these variables.

<i>CntrLocVh</i>	Vehicle center location
<i>DistToHitVh</i>	Distance from vehicle center location to object
<i>DistToHitVhAdjust</i>	Distance from the front of the vehicle to object
<i>EndLocVh</i>	Vehicle ray trace end
<i>HitLocVh</i>	Vehicle hit location
<i>OffsetVh</i>	Vehicle trace offset
<i>StartLocVh</i>	Vehicle ray trace start
<i>VehRayLngth</i>	Vehicle trace length
<i>VehCntrLngthVal</i>	Distance from vehicle center to front
<i>CntrLocTr</i>	Tire center location
<i>DistToHitTr</i>	Distance from tire center location to terrain
<i>DistToHitTrAdjust</i>	Distance from tire to terrain
<i>HitLocTr</i>	Tire hit location
<i>EndLocTr</i>	Tire ray trace end
<i>OffsetTr</i>	Tire trace offset
<i>StartLocTr</i>	Tire ray trace start

*LengthTr*                      Tire trace length  
*TireRadiiVal*                Tire radius

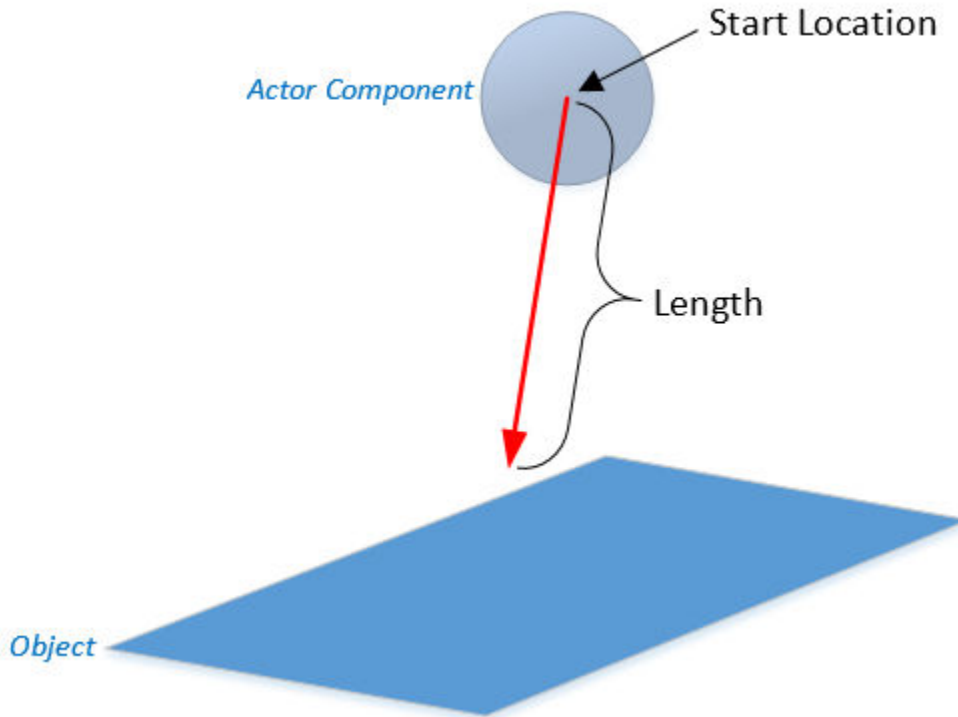
### Hit Event

To determine a hit event, the block uses the ray trace. The block provides the hit location in the world coordinate system.



### Miss Event

To determine a miss event, the block uses the ray trace.



## Ports

### Input

#### **VehCntr – Vehicle distance from center to front**

scalar

Distance from the vehicle center to front, *VehCntrLngthVal*, in m.

### Dependencies

Distance to vehicle center	Creates Port	Creates Parameter
Constant	None	<b>Distance from vehicle center to front, VehCntrLngthVal</b>
External input	VehCntr	<i>None</i>

#### **TireRadii – Tire radii**

array

Tire radii, *TireRadiiVal*, in m.

**Dependencies**

Distance to tire center Setting	Creates Port	Creates Parameter
Constant	None	<b>Distance from tire center to ground, TireRadiiVal</b>
External input	TireRadii	None

**Output**

**Info – Bus signal**

bus

Bus signal containing block values. The signals are arrays that depend on the wheel location.

Signal	Description	Variable	Units
HitFlg	Vehicle and wheel hit flag: <ul style="list-style-type: none"> <li>Hit an object - 1</li> <li>Miss an object - 0</li> </ul>	$\begin{bmatrix} Vehicle \\ FrontLeft \\ FrontRight \\ RearLeft \\ RearRight \end{bmatrix}$	NA
HitLoc	Vehicle, <i>HitLocVh</i> , and tire, <i>HitLocTr</i> , hit locations, in world coordinate system X-, Y, and Z- axes, respectively	$\begin{bmatrix} Vehicle_x & Vehicle_y & Vehicle_z \\ FrontLeft_x & FrontLeft_y & FrontLeft_z \\ FrontRight_x & FrontRight_y & FrontRight_z \\ RearLeft_x & RearLeft_y & RearLeft_z \\ RearRear_x & RearRear_y & RearRear_z \end{bmatrix}$	m
StartLoc	Vehicle, <i>StartLocVh</i> , and tire, <i>StartLocTr</i> , ray trace start locations, in world coordinate system X-, Y, and Z- axes, respectively		m

**VehHitDist – Front of vehicle distance to object**

scalar

Distance from the front of the vehicle to object, *DistToHitVhAdjust*, in m.

**TireHitDist – Tire distance to terrain**

vector

Distance from tire to terrain, *DistToHitTrAdjust*, in m.

*DistToHitTrAdjust* = [*FrontLeft FrontRight RearLeft RearRight*]

**Parameters**

**Actor Setup**

**Tag for actor in 3D scene, ActorTag – Name**

SimulinVehicle1 (default) | character vector

Actor name.

Actors are scene objects that support 3D translation, rotation, and scale. Parts are actor components. Components do not exist by themselves; they are associated with an actor.

The block does not support multiple instances of the same actor tag. To refer to the same scene actor when you use the 3D block pairs (e.g. Simulation 3D Actor Transform Get and Simulation 3D Actor Transform Set), specify the same **Tag for actor in 3D scene, ActorTag** parameter.

### Distance to vehicle center – Selection

Constant (default) | External input

Configure how to provide the distance to the vehicle center.

#### Dependencies

Distance to vehicle center	Creates Port	Creates Parameter
Constant	None	<b>Distance from vehicle center to front, VehCntrLnghVal</b>
External input	VehCntr	None

### Distance to tire center – Selection

Constant (default) | External input

Configure how to provide the distance to the tire center.

#### Dependencies

Distance to tire center Setting	Creates Port	Creates Parameter
Constant	None	<b>Distance from tire center to ground, TireRadiiVal</b>
External input	TireRadii	None

### Distance from vehicle center to front, VehCntrLnghVal – Vehicle center

0 (default) | scalar

Distance from the vehicle center to front, *VehCntrLnghVal*, in m.

#### Dependencies

Distance to vehicle center	Creates Port	Creates Parameter
Constant	None	<b>Distance from vehicle center to front, VehCntrLnghVal</b>
External input	VehCntr	None

### Distance from tire center to ground, TireRadiiVal – Tire radii

0 (default) | scalar

Tire radius, *TireRadiiVal*, in m.

**Dependencies**

<b>Distance to tire center Setting</b>	<b>Creates Port</b>	<b>Creates Parameter</b>
Constant	None	<b>Distance from tire center to ground, TireRadiiVal</b>
External input	TireRadii	None

**Trace Lengths****Vehicle body x-axis trace length, VehRayLngth – Trace length**

5 (default) | scalar

Vehicle body trace length, *VehRayLngth*, in m.**Left front wheel z-axis trace length, LfRayLngth – Trace length**

5 (default) | scalar

Left front wheel trace length, *LfRayLngth* and *LengthTr*, in m.**Right front wheel z-axis trace length, RfRayLngth – Trace length**

5 (default) | scalar

Right front wheel trace length, *RfRayLngth* and *LengthTr*, in m.**Left rear wheel z-axis trace length, LrRayLngth – Trace length**

5 (default) | scalar

Left rear wheel trace length, *LrRayLngth* and *LengthTr*, in m.**Right rear wheel z-axis trace length, RrRayLngth – Trace length**

5 (default) | scalar

Right rear wheel trace length, *RrRayLngth* and *LengthTr*, in m.**Starting Point Offsets****Vehicle body x-axis trace offset, VehRay0ffset – Offset the vehicle ray trace**

0 (default) | scalar

Vehicle body trace offset, *OffsetVh*, in m.**Left front wheel z-axis trace offset, LfRay0ffset – Offset the left front wheel ray trace**

0 (default) | scalar

Left front wheel trace offset, *LfRayOffset* and *OffsetTr*, in m.**Right front wheel z-axis trace offset, RfRay0ffset – Offset the right front wheel ray trace**

0 (default) | scalar

Right front wheel trace offset, *RfRayOffset* and *OffsetTr*, in m.

**Left rear wheel z-axis trace offset, LrRayOffset – Offset the left rear wheel ray trace**

0 (default) | scalar

Left rear wheel trace offset, *LrRayOffset* and *OffsetTr*, in m.

**Right rear wheel z-axis trace offset, RrRayOffset – Offset the right rear wheel ray trace**

0 (default) | scalar

Right rear wheel trace offset, *RrRayOffset* and *OffsetTr*, in m.

**Enable Traces****Vehicle body – Enable vehicle body ray tracing**

on (default) | off

Enable vehicle body ray tracing.

**Left front tire – Enable left front tire ray tracing**

on (default) | off

Enable left front tire ray tracing.

**Right front tire – Enable right front tire ray tracing**

on (default) | off

Enable right front tire ray tracing.

**Left rear tire – Enable left rear tire ray tracing**

on (default) | off

Enable left rear tire ray tracing.

**Right rear tire – Enable right rear tire ray tracing**

on (default) | off

Enable right rear tire ray tracing.

**Trace line visualization – Visualize ray traces**

on (default) | off

Enable trace line visualization.

**Sample time – Sample time**

-1 (default) | scalar

Sample time,  $T_s$ . The graphics frame rate is the inverse of the sample time.

**See Also**

Simulation 3D Vehicle | Simulation 3D Camera Get | Simulation 3D Scene Configuration | Simulation 3D Vehicle with Ground Following

**Topics**

“Scene Interrogation in 3D Environment”



**External Websites**

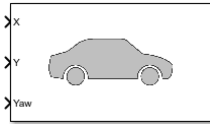
Unreal Engine

**Introduced in R2018a**

## Simulation 3D Vehicle with Ground Following

Implement vehicle that follows ground in 3D environment

**Library:** Automated Driving Toolbox / Simulation 3D  
Vehicle Dynamics Blockset / Vehicle Scenarios / Sim3D /  
Sim3D Vehicle / Components



### Description

The Simulation 3D Vehicle with Ground Following block implements a vehicle with four wheels in a 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The block uses the input ( $X$ ,  $Y$ ) position and yaw angle of the vehicle to adjust the elevation, roll angle, and pitch angle of the vehicle so that it follows the ground terrain. The block determines the vehicle velocity and heading and adjusts the steering angle and rotation for each wheel. Use this block for automated driving applications.

To use this block, ensure that the Simulation 3D Scene Configuration block is in your model. If you set the **Sample time** parameter of the Simulation 3D Vehicle with Ground Following block to -1, the block inherits the sample time specified in the Simulation 3D Scene Configuration block.

The block input uses the vehicle Z-down *right-handed* (RH) *Cartesian* coordinate system defined in SAE J670<sup>1</sup>. The coordinate system is inertial and initially aligned with the vehicle geometric center:

- X-axis — Along vehicle longitudinal axis, points forward
- Y-axis — Along vehicle lateral axis, points to the right
- Z-axis — Points downward

**Note** The Simulation 3D Vehicle with Ground Following block must execute before the Simulation 3D Scene Configuration block. That way, the Simulation 3D Vehicle with Ground Following block prepares the signal data before the Unreal Engine 3D visualization environment receives it. To check the block execution order, right-click the blocks and select **Properties**. On the **General** tab, confirm these **Priority** settings:

- Simulation 3D Scene Configuration — 0
- Simulation 3D Vehicle with Ground Following — -1

For more information about execution order, see “Control and Display Execution Order”.

### Ports

#### Input

**X — Longitudinal position of vehicle**

scalar

Longitudinal position of the vehicle along the  $X$ -axis of the scene.  $X$  is in the inertial  $Z$ -down coordinate system. Units are in meters.

### **Y — Lateral position of vehicle**

scalar

Lateral position of the vehicle along the  $Y$ -axis of the scene.  $Y$  is in the inertial  $Z$ -down coordinate system. Units are in meters.

### **Yaw — Yaw orientation angle of vehicle**

scalar

Yaw orientation angle of the vehicle along the  $Z$ -axis of the scene.  $Yaw$  is in the  $Z$ -down coordinate system. Units are in radians.

## **Parameters**

### **Vehicle Parameters**

#### **Type — Type of vehicle**

Muscle car (default) | Sedan | Sport utility vehicle | Small pickup truck | Hatchback | Box truck

Select the type of vehicle. To obtain the dimensions of each vehicle type, see these reference pages:

- Muscle car — **Muscle Car**
- Sedan — **Sedan**
- Sport utility vehicle — **Sport Utility Vehicle**
- Small pickup truck — **Small Pickup Truck**
- Hatchback — **Hatchback**
- Box truck — **Box Truck**

#### **Color — Color of vehicle**

Red (default) | Orange | Yellow | Green | Blue | Black | White | Silver

Select the color of the vehicle.

#### **Initial position [X, Y, Z], InitialPos (m) — Initial vehicle position**

[0, 0, 0] (default) | real-valued 1-by-3 vector

Initial vehicle position along the  $X$ -axis,  $Y$ -axis, and  $Z$ -axis in the inertial  $Z$ -down coordinate system, in m.

#### **Initial rotation [Roll, Pitch, Yaw], InitialRot (rad) — Initial angle of vehicle rotation**

[0, 0, 0] (default) | real-valued 1-by-3 vector

Initial angle of vehicle rotation, in rad. The angle of rotation is defined by the roll, pitch, and yaw of the vehicle.

#### **Name, ActorName — Name of vehicle**

SimulinkVehicle1 (default) | vehicle name

Name of vehicle. By default, when you use the block in your model, the block sets the **Name** parameter to `SimulinkVehicleX`. The value of  $X$  depends on the number of Simulation 3D Vehicle with Ground Following blocks that you have in your model.

**Sample time, SampleTime – Sample time**

-1 (default) | positive scalar

Sample time,  $T_s$ . The graphics frame rate is the inverse of the sample time.

If you set the sample time to -1, the block uses the sample time specified in the Simulation 3D Scene Configuration block.

**References**

[1] Vehicle Dynamics Standards Committee. *Vehicle Dynamics Terminology*. SAE J670. Warrendale, PA: Society of Automotive Engineers, 2008.

[2] Technical Committee. *Road vehicles – Vehicle dynamics and road-holding ability – Vocabulary*. ISO 8855:2011. Geneva, Switzerland: International Organization for Standardization, 2011.

**See Also**

Simulation 3D Scene Configuration | Simulation 3D Vehicle

**Topics**

“How 3D Simulation for Vehicle Dynamics Blockset Works”

“Scene Interrogation in 3D Environment”

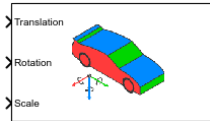
“3D Visualization Engine Requirements and Limitations”

**Introduced in R2019b**

# Simulation 3D Vehicle

Implement vehicle in 3D environment

**Library:** Vehicle Dynamics Blockset / Vehicle Scenarios / Sim3D /  
Sim3D Vehicle / Components



## Description

The Simulation 3D Vehicle block implements a vehicle with four wheels in the 3D simulation environment.

To use this block, ensure that the Simulation 3D Scene Configuration block is in your model. If you set the **Sample time** parameter of this block to -1, the block uses the sample time specified in the Simulation 3D Scene Configuration block.

The block input uses the vehicle Z-down *right-handed* (RH) *Cartesian* coordinate system defined in SAE J670<sup>1</sup>. The coordinate system is inertial and initially aligned with the vehicle geometric center:

- X-axis — Along vehicle longitudinal axis, points forward
- Y-axis — Along vehicle lateral axis, points to the right
- Z-axis — Points downward

---

**Tip** Verify that the Simulation 3D Vehicle block executes before the Simulation 3D Scene Configuration block. That way, Simulation 3D Vehicle prepares the signal data before the Unreal Engine 3D visualization environment receives it. To check the block execution order, right-click the blocks and select **Properties**. On the **General** tab, confirm these **Priority** settings:

- Simulation 3D Scene Configuration — 0
- Simulation 3D Vehicle — -1

For more information about execution order, see “Control and Display Execution Order”.

---

## Ports

### Input

#### Translation — Vehicle translation

5-by-3 array

Vehicle and wheel translation, in m. Array dimensions are 5-by-3.

- Translation(1,1), Translation(1,2), and Translation(1,3) — Vehicle translation along the inertial vehicle Z-down X-, Y-, and Z- axes, respectively.
- Translation(...,1), Translation(...,2), and Translation(...,3) — Wheel translation relative to vehicle, along the vehicle Z-down X-, Y-, and Z- axes, respectively.

The signal contains translation information according to the axle and wheel locations.

$$Translation = \begin{bmatrix} X_v & Y_v & Z_v \\ X_{FL} & Y_{FL} & Z_{FL} \\ X_{FR} & Y_{FR} & Z_{FR} \\ X_{RL} & Y_{RL} & Z_{RL} \\ X_{RR} & Y_{RR} & Z_{RR} \end{bmatrix}$$

Translation	Array Element	Translation Axis
Vehicle, $X_v$	Translation(1,1)	Inertial vehicle Z-down X-axis
Vehicle, $Y_v$	Translation(1,2)	Inertial vehicle Z-down Y-axis
Vehicle, $Z_v$	Translation(1,3)	Inertial vehicle Z-down Z-axis
Front left wheel, $X_{FL}$	Translation(2,1)	Vehicle Z-down X-axis
Front left wheel, $Y_{FL}$	Translation(2,2)	Vehicle Z-down Y-axis
Front left wheel, $Z_{FL}$	Translation(2,3)	Vehicle Z-down Z-axis
Front right wheel, $X_{FR}$	Translation(3,1)	Vehicle Z-down X-axis
Front right wheel, $Y_{FR}$	Translation(3,2)	Vehicle Z-down Y-axis
Front right wheel, $Z_{FR}$	Translation(3,3)	Vehicle Z-down Z-axis
Rear left wheel, $X_{RL}$	Translation(4,1)	Vehicle Z-down X-axis
Rear left wheel, $Y_{RL}$	Translation(4,2)	Vehicle Z-down Y-axis
Rear left wheel, $Z_{RL}$	Translation(4,3)	Vehicle Z-down Z-axis
Rear right wheel, $X_{RR}$	Translation(5,1)	Vehicle Z-down X-axis
Rear right wheel, $Y_{RR}$	Translation(5,2)	Vehicle Z-down Y-axis
Rear right wheel, $Z_{RR}$	Translation(5,3)	Vehicle Z-down Z-axis

### Rotation – Vehicle rotation

5-by-3 array

Vehicle and wheel rotation, in rad. Array dimensions are 5-by-3.

- Rotation(1,1), Rotation(1,2), and Rotation(1,3) – Vehicle rotation about the inertial vehicle Z-down X-, Y-, and Z- axes, respectively.
- Rotation(...,1), Rotation(...,2), and Rotation(...,3) – Wheel rotation relative to vehicle, about the vehicle Z-down X-, Y-, and Z- axes, respectively.

The signal contains rotation information according to the axle and wheel locations.

$$Rotation = \begin{bmatrix} Roll_v & Pitch_v & Yaw_v \\ Roll_{FL} & Pitch_{FL} & Yaw_{FL} \\ Roll_{FR} & Pitch_{FR} & Yaw_{FR} \\ Roll_{RL} & Pitch_{RL} & Yaw_{RL} \\ Roll_{RR} & Pitch_{RR} & Yaw_{RR} \end{bmatrix}$$

Rotation	Array Element	Rotation Axis
Vehicle, $Roll_v$	Rotation(1,1)	Inertial vehicle Z-down X-axis
Vehicle, $Pitch_v$	Rotation(1,2)	Inertial vehicle Z-down Y-axis
Vehicle, $Yaw_v$	Rotation(1,3)	Inertial vehicle Z-down Z-axis
Front left wheel, $Roll_{FL}$	Rotation(2,1)	Vehicle Z-down X-axis
Front left wheel, $Pitch_{FL}$	Rotation(2,2)	Vehicle Z-down Y-axis
Front left wheel, $Yaw_{FL}$	Rotation(2,3)	Vehicle Z-down Z-axis
Front right wheel, $Roll_{FR}$	Rotation(3,1)	Vehicle Z-down X-axis
Front right wheel, $Pitch_{FR}$	Rotation(3,2)	Vehicle Z-down Y-axis
Front right wheel, $Yaw_{FR}$	Rotation(3,3)	Vehicle Z-down Z-axis
Rear left wheel, $Roll_{RL}$	Rotation(4,1)	Vehicle Z-down X-axis
Rear left wheel, $Pitch_{RL}$	Rotation(4,2)	Vehicle Z-down Y-axis
Rear left wheel, $Yaw_{RL}$	Rotation(4,3)	Vehicle Z-down Z-axis
Rear right wheel, $Roll_{RR}$	Rotation(5,1)	Vehicle Z-down X-axis
Rear right wheel, $Pitch_{RR}$	Rotation(5,2)	Vehicle Z-down Y-axis
Rear right wheel, $Yaw_{RR}$	Rotation(5,3)	Vehicle Z-down Z-axis

### Scale – Vehicle scale

5-by-3

Vehicle and wheel scale, dimensionless. Array dimensions are 5-by-3.

- $Scale(1,1)$ ,  $Scale(1,2)$ , and  $Scale(1,3)$  – Vehicle scale along the inertial vehicle Z-down X-, Y-, and Z- axes, respectively.
- $Scale(\dots,1)$ ,  $Scale(\dots,2)$ , and  $Scale(\dots,3)$  – Wheel scale relative to vehicle, along vehicle Z-down X-, Y-, and Z- axes, respectively.

The signal contains scale information according to the axle and wheel locations.

$$Scale = \begin{bmatrix} X_{Vscale} & Y_{Vscale} & Z_{Vscale} \\ X_{FLscale} & Y_{FLscale} & Z_{FLscale} \\ X_{FRscale} & Y_{FRscale} & Z_{FRscale} \\ X_{RLscale} & Y_{RLscale} & Z_{RLscale} \\ X_{RRscale} & Y_{RRscale} & Z_{RRscale} \end{bmatrix}$$

Scale	Array Element	Scale Axis
Vehicle, $X_{Vscale}$	Scale(1,1)	Vehicle Z-down X-axis
Vehicle, $Y_{Vscale}$	Scale(1,2)	Vehicle Z-down Y-axis
Vehicle, $Z_{Vscale}$	Scale(1,3)	Vehicle Z-down Z-axis
Front left wheel, $X_{FLscale}$	Scale(2,1)	Vehicle Z-down X-axis
Front left wheel, $Y_{FLscale}$	Scale(2,2)	Vehicle Z-down Y-axis

Scale	Array Element	Scale Axis
Front left wheel, $Z_{FL_{scale}}$	Scale(2,3)	Vehicle Z-down Z-axis
Front right wheel, $X_{FR_{scale}}$	Scale(3,1)	Vehicle Z-down X-axis
Front right wheel, $Y_{FR_{scale}}$	Scale(3,2)	Vehicle Z-down Y-axis
Front right wheel, $Z_{FR_{scale}}$	Scale(3,3)	Vehicle Z-down Z-axis
Rear left wheel, $X_{RL_{scale}}$	Scale(4,1)	Vehicle Z-down X-axis
Rear left wheel, $Y_{RL_{scale}}$	Scale(4,2)	Vehicle Z-down Y-axis
Rear left wheel, $Z_{RL_{scale}}$	Scale(4,3)	Vehicle Z-down Z-axis
Rear right wheel, $X_{RR_{scale}}$	Scale(5,1)	Vehicle Z-down X-axis
Rear right wheel, $Y_{RR_{scale}}$	Scale(5,2)	Vehicle Z-down Y-axis
Rear right wheel, $Z_{RR_{scale}}$	Scale(5,3)	Vehicle Z-down Z-axis

## Parameters

### Vehicle Parameters

#### Type — Type

Muscle car (default) | Sedan | Sport utility vehicle | Small pickup truck | Hatchback | Box truck

If you set **Actor type** to **Passenger vehicle**, use the **Vehicle type** parameter to specify the vehicle. This table provides links to the vehicle dimensions.

Vehicle type Setting	Vehicle Dimensions
Muscle car	<b>Muscle Car</b>
Sedan	<b>Sedan</b>
Sport utility vehicle	<b>Sport Utility Vehicle</b>
Small pickup truck	<b>Small Pickup Truck</b>
Hatchback	<b>Hatchback</b>
Box truck	<b>Box Truck</b>

#### Color — Vehicle

Red (default) | Orange | Yellow | Green | Blue | Black | White | Silver

Specify the vehicle color.

#### Name — Name of vehicle

SimulinkVehicle1 (default) | character vector

Name of vehicle. By default, when you use the block in your model, the block sets the **Name** parameter to SimulinkVehicleX. The value of X depends on the number of Simulation 3D Vehicle with Ground Following and Simulation 3D Vehicle blocks that you have in your model.



## Initial Values

### Initial array values to translate vehicle per part, Translation – Vehicle initial translation

zeros( 5, 3 ) (default) | 5-by-3 array

Initial vehicle and wheel translation, in m. Array dimensions are 5-by-3.

- Translation(1,1), Translation(1,2), and Translation(1,3) – Initial vehicle translation along the inertial vehicle Z-down coordinate system X-, Y-, and Z- axes, respectively.
- Translation(...,1), Translation(...,2), and Translation(...,3) – Initial wheel translation relative to vehicle, along the vehicle Z-down X-, Y-, and Z- axes, respectively.

The parameter contains translation information according to the axle and wheel locations.

$$Translation = \begin{bmatrix} X_v & Y_v & Z_v \\ X_{FL} & Y_{FL} & Z_{FL} \\ X_{FR} & Y_{FR} & Z_{FR} \\ X_{RL} & Y_{RL} & Z_{RL} \\ X_{RR} & Y_{RR} & Z_{RR} \end{bmatrix}$$

Translation	Array Element	Translation Axis
Vehicle, $X_v$	Translation(1,1)	Inertial vehicle Z-down X-axis
Vehicle, $Y_v$	Translation(1,2)	Inertial vehicle Z-down Y-axis
Vehicle, $Z_v$	Translation(1,3)	Inertial vehicle Z-down Z-axis
Front left wheel, $X_{FL}$	Translation(2,1)	Vehicle Z-down X-axis
Front left wheel, $Y_{FL}$	Translation(2,2)	Vehicle Z-down Y-axis
Front left wheel, $Z_{FL}$	Translation(2,3)	Vehicle Z-down Z-axis
Front right wheel, $X_{FR}$	Translation(3,1)	Vehicle Z-down X-axis
Front right wheel, $Y_{FR}$	Translation(3,2)	Vehicle Z-down Y-axis
Front right wheel, $Z_{FR}$	Translation(3,3)	Vehicle Z-down Z-axis
Rear left wheel, $X_{RL}$	Translation(4,1)	Vehicle Z-down X-axis
Rear left wheel, $Y_{RL}$	Translation(4,2)	Vehicle Z-down Y-axis
Rear left wheel, $Z_{RL}$	Translation(4,3)	Vehicle Z-down Z-axis
Rear right wheel, $X_{RR}$	Translation(5,1)	Vehicle Z-down X-axis
Rear right wheel, $Y_{RR}$	Translation(5,2)	Vehicle Z-down Y-axis
Rear right wheel, $Z_{RR}$	Translation(5,3)	Vehicle Z-down Z-axis

### Initial array values to rotate vehicle per part, Rotation – Vehicle initial rotation

zeros( 5, 3 ) (default) | 5-by-3 array

Initial vehicle and wheel rotation, about the vehicle Z-down X-, Y-, and Z- axes.

Array dimensions are 5-by-3.

- $Rotation(1,1)$ ,  $Rotation(1,2)$ , and  $Rotation(1,3)$  — Initial vehicle rotation about the inertial vehicle Z-down coordinate system X-, Y-, and Z- axes, respectively.
- $Rotation(\dots,1)$ ,  $Rotation(\dots,2)$ , and  $Rotation(\dots,3)$  — Initial wheel rotation relative to vehicle, about the vehicle Z-down X-, Y-, and Z- axes, respectively.

The parameter contains rotation information according to the axle and wheel locations.

$$Rotation = \begin{bmatrix} Roll_v & Pitch_v & Yaw_v \\ Roll_{FL} & Pitch_{FL} & Yaw_{FL} \\ Roll_{FR} & Pitch_{FR} & Yaw_{FR} \\ Roll_{RL} & Pitch_{RL} & Yaw_{RL} \\ Roll_{RR} & Pitch_{RR} & Yaw_{RR} \end{bmatrix}$$

Rotation	Array Element	Rotation Axis
Vehicle, $Roll_v$	$Rotation(1,1)$	Inertial vehicle Z-down X-axis
Vehicle, $Pitch_v$	$Rotation(1,2)$	Inertial vehicle Z-down Y-axis
Vehicle, $Yaw_v$	$Rotation(1,3)$	Inertial vehicle Z-down Z-axis
Front left wheel, $Roll_{FL}$	$Rotation(2,1)$	Vehicle Z-down X-axis
Front left wheel, $Pitch_{FL}$	$Rotation(2,2)$	Vehicle Z-down Y-axis
Front left wheel, $Yaw_{FL}$	$Rotation(2,3)$	Vehicle Z-down Z-axis
Front right wheel, $Roll_{FR}$	$Rotation(3,1)$	Vehicle Z-down X-axis
Front right wheel, $Pitch_{FR}$	$Rotation(3,2)$	Vehicle Z-down Y-axis
Front right wheel, $Yaw_{FR}$	$Rotation(3,3)$	Vehicle Z-down Z-axis
Rear left wheel, $Roll_{RL}$	$Rotation(4,1)$	Vehicle Z-down X-axis
Rear left wheel, $Pitch_{RL}$	$Rotation(4,2)$	Vehicle Z-down Y-axis
Rear left wheel, $Yaw_{RL}$	$Rotation(4,3)$	Vehicle Z-down Z-axis
Rear right wheel, $Roll_{RR}$	$Rotation(5,1)$	Vehicle Z-down X-axis
Rear right wheel, $Pitch_{RR}$	$Rotation(5,2)$	Vehicle Z-down Y-axis
Rear right wheel, $Yaw_{RR}$	$Rotation(5,3)$	Vehicle Z-down Z-axis

**Initial array values to scale vehicle per part, Scale — Vehicle initial scale**

$ones(5,3)$  (default) | 5-by-3 array

Initial vehicle and wheel scale, dimensionless. Array dimensions are 5-by-3.

- $Scale(1,1)$ ,  $Scale(1,2)$ , and  $Scale(1,3)$  — Initial vehicle scale along the inertial vehicle Z-down X-, Y-, and Z- axes, respectively.
- $Scale(\dots,1)$ ,  $Scale(\dots,2)$ , and  $Scale(\dots,3)$  — Initial wheel scale relative to vehicle, along vehicle Z-down X-, Y-, and Z- axes, respectively.

The parameter contains scale information according to the axle and wheel locations.

$$Scale = \begin{bmatrix} X_{V_{scale}} & Y_{V_{scale}} & Z_{V_{scale}} \\ X_{FL_{scale}} & Y_{FL_{scale}} & Z_{FL_{scale}} \\ X_{FR_{scale}} & Y_{FR_{scale}} & Z_{FR_{scale}} \\ X_{RL_{scale}} & Y_{RL_{scale}} & Z_{RL_{scale}} \\ X_{RR_{scale}} & Y_{RR_{scale}} & Z_{RR_{scale}} \end{bmatrix}$$

Scale	Array Element	Scale Axis
Vehicle, $X_{V_{scale}}$	Scale(1,1)	Vehicle Z-down X-axis
Vehicle, $Y_{V_{scale}}$	Scale(1,2)	Vehicle Z-down Y-axis
Vehicle, $Z_{V_{scale}}$	Scale(1,3)	Vehicle Z-down Z-axis
Front left wheel, $X_{FL_{scale}}$	Scale(2,1)	Vehicle Z-down X-axis
Front left wheel, $Y_{FL_{scale}}$	Scale(2,2)	Vehicle Z-down Y-axis
Front left wheel, $Z_{FL_{scale}}$	Scale(2,3)	Vehicle Z-down Z-axis
Front right wheel, $X_{FR_{scale}}$	Scale(3,1)	Vehicle Z-down X-axis
Front right wheel, $Y_{FR_{scale}}$	Scale(3,2)	Vehicle Z-down Y-axis
Front right wheel, $Z_{FR_{scale}}$	Scale(3,3)	Vehicle Z-down Z-axis
Rear left wheel, $X_{RL_{scale}}$	Scale(4,1)	Vehicle Z-down X-axis
Rear left wheel, $Y_{RL_{scale}}$	Scale(4,2)	Vehicle Z-down Y-axis
Rear left wheel, $Z_{RL_{scale}}$	Scale(4,3)	Vehicle Z-down Z-axis
Rear right wheel, $X_{RR_{scale}}$	Scale(5,1)	Vehicle Z-down X-axis
Rear right wheel, $Y_{RR_{scale}}$	Scale(5,2)	Vehicle Z-down Y-axis
Rear right wheel, $Z_{RR_{scale}}$	Scale(5,3)	Vehicle Z-down Z-axis

### Sample time – Sample time

-1 (default) | scalar

Sample time,  $T_s$ . The graphics frame rate is the inverse of the sample time.

## References

- [1] Vehicle Dynamics Standards Committee. *Vehicle Dynamics Terminology*. SAE J670. Warrendale, PA: Society of Automotive Engineers, 2008.
- [2] Technical Committee. *Road vehicles – Vehicle dynamics and road-holding ability – Vocabulary*. ISO 8855:2011. Geneva, Switzerland: International Organization for Standardization, 2011.

## See Also

Simulation 3D Scene Configuration | Simulation 3D Vehicle with Ground Following

## Topics

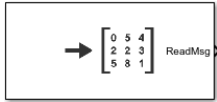
“Coordinate Systems in Vehicle Dynamics Blockset”  
 “How 3D Simulation for Vehicle Dynamics Blockset Works”  
 “3D Visualization Engine Requirements and Limitations”

**Introduced in R2019b**

# Simulation 3D Message Get

Retrieve data from Unreal Engine visualization environment

**Library:** Vehicle Dynamics Blockset / Vehicle Scenarios / Sim3D /  
Sim3D Core



## Description

The Simulation 3D Message Get block retrieves data from the Unreal Engine 3D visualization environment. In your model, ensure that the Simulation 3D Scene Configuration block is at the same level as the Simulation 3D Message Get block.

---

**Tip** Verify that the Simulation 3D Scene Configuration block executes before the Simulation 3D Message Get block. That way, the Unreal Engine 3D visualization environment prepares the data before the Simulation 3D Message Get block receives it. To check the block execution order, right-click the blocks and select **Properties**. On the **General** tab, confirm these **Priority** settings:

- Simulation 3D Scene Configuration — 0
- Simulation 3D Message Get — 1

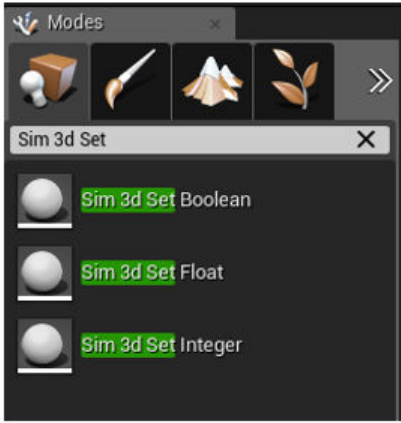
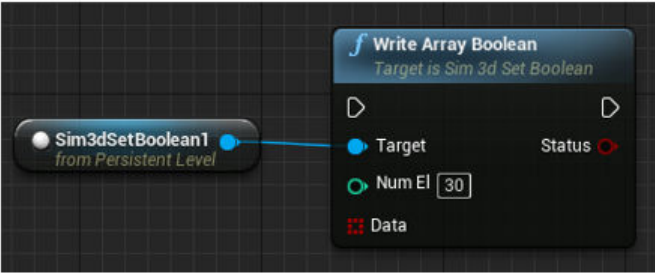
For more information about execution order, see “Control and Display Execution Order”.

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## Configure Scenes to Send Data

To use the block, you must configure scenes in the Unreal Engine environment to send data to the Simulink model:

- 1 Install the “Customize 3D Scenes for Vehicle Dynamics Simulations”.
- 2 In the Unreal Editor, follow these general workflows to send data to Simulink. For detailed information, see “Get Started Communicating with the Unreal Engine Visualization Environment”.

Unreal Engine User	Workflow
Blueprint	<p><b>a</b> Instantiate the Sim3DSet actor that corresponds to the data type you want to send to the Simulink model. This example shows the Unreal Editor Sim3DSet data types.</p>  <p><b>b</b> Specify an actor tag name that matches the Simulation 3D Message Get block <b>Signal name</b> parameter.</p> <p><b>c</b> Navigate to the Level Blueprint.</p> <p><b>d</b> Find the blueprint method for the Sim3DSet actor class based on the data type and size specified by the Simulation 3D Message Get block <b>Data type</b> and <b>Message size</b> parameters.</p> <p>For example, in Unreal Editor, this diagram shows that Write Array Boolean is the method for the Sim3DSetBoolean actor class that sends Boolean data type of array size 30.</p>  <p><b>e</b> Compile and save the scene.</p> <p><b>Note</b> By default, the Double Lane Change scene has a Sim3DSetBoolean actor with tag name NumOfConesHit.</p>

Unreal Engine User	Workflow
C++ class	<p><b>a</b> Create a new actor class for the mesh or asset that you want the Simulink model to interact with. Derive it from <code>ASim3dActor</code>.</p> <p><b>b</b> In the new actor class:</p> <ul style="list-style-type: none"> <li>• Declare a pointer to the signal name as a class field.</li> <li>• Get the class tag.</li> <li>• Create a signal writer and assign the pointer in the method <code>Sim3dSetup</code>.</li> <li>• In the method <code>Sim3dStep</code>, invoke the <code>WriteSimulation3DMessage</code> function to write the data to the Simulink model.</li> <li>• Delete the signal writer in the method <code>Sim3dRelease</code> of the actor.</li> </ul>

For more information about the Unreal Editor, see the Unreal Engine 4 Documentation.

## Ports

### Output

#### ReadMsg – Data retrieved from scene

scalar | array

Data retrieved from the 3D visualization environment scene data. In the Unreal Engine environment, you can use the `Sim3DSet` class to configure scene actors to send data to the Simulink model.

For example, in the Unreal Editor, the Double Lane Change scene has a `Sim3DSetBoolean` actor with tag name `NumOfConesHit`. Use it to retrieve the number of cones the vehicle hits during a double-lane change maneuver.

This table provides the Double Lane Change scene cone name that corresponds to the `ReadMsg` array element.

Simulation 3D Message Get Block ReadMsg Value	Unreal Editor Cone Name	Simulation 3D Message Get Block Array Element	Unreal Editor Cone Name
<code>ReadMsg(1,1)</code>	<code>SM_Cone5</code>	<code>ReadMsg(2,1)</code>	<code>SM_Cone10</code>
<code>ReadMsg(1,2)</code>	<code>SM_Cone4</code>	<code>ReadMsg(2,2)</code>	<code>SM_Cone09</code>
<code>ReadMsg(1,3)</code>	<code>SM_Cone3</code>	<code>ReadMsg(2,3)</code>	<code>SM_Cone08</code>
<code>ReadMsg(1,4)</code>	<code>SM_Cone2</code>	<code>ReadMsg(2,4)</code>	<code>SM_Cone07</code>
<code>ReadMsg(1,5)</code>	<code>SM_Cone01</code>	<code>ReadMsg(2,5)</code>	<code>SM_Cone06</code>
<code>ReadMsg(1,6)</code>	<code>SM_Cone15</code>	<code>ReadMsg(2,6)</code>	<code>SM_Cone20</code>
<code>ReadMsg(1,7)</code>	<code>SM_Cone14</code>	<code>ReadMsg(2,7)</code>	<code>SM_Cone19</code>
<code>ReadMsg(1,8)</code>	<code>SM_Cone13</code>	<code>ReadMsg(2,8)</code>	<code>SM_Cone18</code>

Simulation 3D Message Get Block ReadMsg Value	Unreal Editor Cone Name	Simulation 3D Message Get Block Array Element	Unreal Editor Cone Name
ReadMsg (1, 9)	SM_Cone12	ReadMsg (2, 9)	SM_Cone17
ReadMsg (1, 10)	SM_Cone11	ReadMsg (2, 10)	SM_Cone16
ReadMsg (1, 11)	SM_Cone25	ReadMsg (2, 11)	SM_Cone30
ReadMsg (1, 12)	SM_Cone24	ReadMsg (2, 12)	SM_Cone29
ReadMsg (1, 13)	SM_Cone23	ReadMsg (2, 13)	SM_Cone28
ReadMsg (1, 14)	SM_Cone22	ReadMsg (2, 14)	SM_Cone27
ReadMsg (1, 15)	SM_Cone21	ReadMsg (2, 15)	SM_Cone26

## Parameters

### Signal name, SigName — Message signal name

mySignal (default)

Specifies the signal name in the 3D visualization environment. In the Unreal Engine environment, use the Sim3DSet actor class 'Tags' property located in the 'Details' pane.

For example, you can retrieve data from the double-lane change scene that indicates if cones are hit during a double-lane change maneuver. To retrieve cone hit data from the double-lane change scene, set this parameter to NumOfConesHit. In the double-lane change scene, the Sim3DSet actor class 'Tags' property is set to NumOfConesHit.

### Data type, DataType — Message data type

uint8 (default) | double | single | int8 | int16 | uint16 | int32 | uint32 | boolean

3D visualization environment signal data type. In the Unreal Engine environment, instantiate the Sim3DSet actor class for the data type that you want to send to the Simulink model.

For example, you can retrieve data from the double-lane change scene that indicates if cones are hit during a double-lane change maneuver. To retrieve cone hit data from the double-lane change scene, set this parameter to boolean. In the double-lane change scene, the Sim3DSetBoolean actor class is instantiated to send the cone hit or miss boolean data.

### Message size, MsgSize — Message dimension

[1 1] (default) | scalar | array

3D visualization environment signal dimension. In the Unreal Engine environment blueprint, set the input to the node of the Sim3DSet actor class to specify the dimensions of data that you want to send to the Simulink model.

For example, you can retrieve data from the double-lane change scene that indicates if cones are hit during a double-lane change maneuver. To retrieve cone hit data from the double-lane change scene, set this parameter to [2 15]. In the double-lane change scene, the input to the blueprint node for the Sim3DSetBoolean actor class is set to 30, the number of cones in the scene.

### Sample time — Sample time

0.02 (default) | -1 | scalar



Sample time, in s. The graphics frame rate is the inverse of the sample time. If you set the sample time to -1, the block uses the sample time specified in the Simulation 3D Scene Configuration block.

## **See Also**

**Double Lane Change** | Simulation 3D Message Set | Simulation 3D Scene Configuration

### **Topics**

“Get Started Communicating with the Unreal Engine Visualization Environment”

“Send and Receive Double-Lane Change Scene Data”

“Customize 3D Scenes for Vehicle Dynamics Simulations”

### **External Websites**

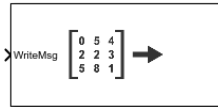
Unreal Engine

**Introduced in R2019b**

## Simulation 3D Message Set

Send data to Unreal Engine visualization environment

**Library:** Vehicle Dynamics Blockset / Vehicle Scenarios / Sim3D /  
Sim3D Core



### Description

The Simulation 3D Message Set block sends data to the Unreal Engine 3D visualization environment. In your model, ensure that the Simulation 3D Scene Configuration block is at the same level as the Simulation 3D Message Set block.

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**Tip** Verify that the Simulation 3D Message Set block executes before the Simulation 3D Scene Configuration block. That way, Simulation 3D Message Set prepares the signal data before the Unreal Engine 3D visualization environment receives it. To check the block execution order, right-click the blocks and select **Properties**. On the **General** tab, confirm these **Priority** settings:

- Simulation 3D Scene Configuration — 0
- Simulation 3D Message Set — -1

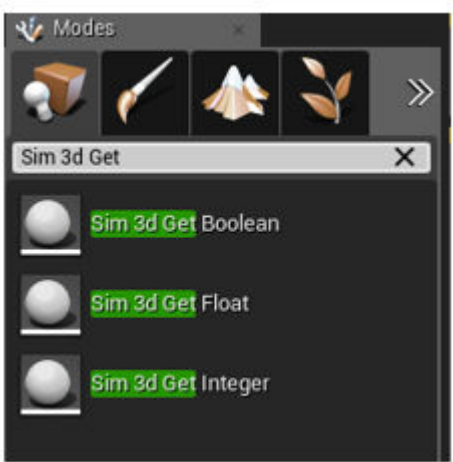
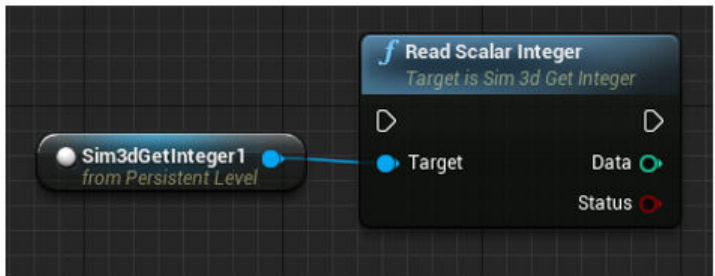
For more information about execution order, see “Control and Display Execution Order”.

---

### Configure Scenes to Receive Data

To use the block, you must configure scenes in the Unreal Engine environment to receive data from the Simulink model:

- 1 Install the “Customize 3D Scenes for Vehicle Dynamics Simulations”.
- 2 In the Unreal Editor, follow these general workflows to receive data from Simulink. For detailed information, see “Get Started Communicating with the Unreal Engine Visualization Environment”.

Unreal Engine User	Workflow
Blueprint	<p><b>a</b> Instantiate the Sim3DGet actor that corresponds to the data type you want to receive from the Simulink model. This example shows the Unreal Editor Sim3DGet data types.</p>  <p><b>b</b> Specify an actor tag name that matches the Simulation 3D Message Set block <b>Signal name</b> parameter.</p> <p><b>c</b> Navigate to the Level Blueprint.</p> <p><b>d</b> Find the blueprint method for the Sim3DGet actor class based on the data type and size that you want to receive from the Simulink model.</p> <p>For example, in Unreal Editor, this diagram shows that <code>Read Scalar Integer</code> is the method for <code>Sim3DGetInteger</code> actor class to receive <code>int32</code> data type of size scalar.</p>  <p><b>e</b> Compile and save the scene.</p> <p><b>Note</b> By default, the Double Lane Change scene has a <code>Sim3DGetInteger</code> actor with tag name <code>TrafficLight1</code>.</p>

Unreal Engine User	Workflow
C++ class	<p><b>a</b> Create a new actor class for the mesh or asset that you want the Simulink model to interact with. Derive it from <code>ASim3dActor</code>.</p> <p><b>b</b> In the new actor class:</p> <ul style="list-style-type: none"> <li>• Declare a pointer to the signal name as a class field.</li> <li>• Get the class tag.</li> <li>• Create a signal reader and assign the pointer in the method <code>Sim3dSetup</code>.</li> <li>• In the method <code>Sim3dStep</code>, invoke the <code>ReadSimulation3DMessage</code> function to read the data from a Simulink model.</li> <li>• Delete the signal reader in the method <code>Sim3dRelease</code> of the actor.</li> </ul>

For more information about the Unreal Editor, see the Unreal Engine 4 Documentation.

## Ports

### Input

#### WriteMsg — Data sent to scene

scalar | array

Data sent to the 3D visualization environment scene. In the Unreal Engine environment, you can configure the `Sim3DGet` class to receive the data from the Simulink model.

For example, in the Unreal Editor, the Double Lane Change scene has a `Sim3DGetInteger` integer actor with tag name `TrafficLight1`. The integer actor reads `int32` data type from the Simulink model. You can use it to control the traffic signal light color.

This table provides the scene traffic signal light color that corresponds to the `WriteMsg` value in the Double Lane Change scene.

Simulation 3D Message Set Block WriteMsg Value	TrafficLight1 Color
0	Red
1	Yellow
2	Green

## Parameters

#### Signal name, SigName — Message signal name

`mySignal` (default)

Specifies the signal name in the 3D visualization environment. In the Unreal Engine environment, use the `Sim3Get` actor class 'Tags' property located in the 'Details' pane.

For example, you can send data to the double lane change scene that changes the traffic signal light color to red, yellow, or green. To send data to the traffic signal light, set this parameter to `TrafficLight1`. In the double lane change scene, the 'Tags' property value for `Sim3dGetInteger` actor class is set to `TrafficLight1`.

**Sample time – Sample time**

0.02 (default) | -1 | scalar

Sample time, in s. The graphics frame rate is the inverse of the sample time. If you set the sample time to -1, the block uses the sample time specified in the Simulation 3D Scene Configuration block.

**See Also**

**Double Lane Change** | [Simulation 3D Message Get](#) | [Simulation 3D Scene Configuration](#)

**Topics**

[“Get Started Communicating with the Unreal Engine Visualization Environment”](#)

[“Send and Receive Double-Lane Change Scene Data”](#)

[“Customize 3D Scenes for Vehicle Dynamics Simulations”](#)

**External Websites**

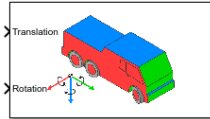
[Unreal Engine](#)

**Introduced in R2019b**

## Simulation 3D Tractor

Implement tractor in 3D environment

**Library:** Vehicle Dynamics Blockset / Vehicle Scenarios / Sim3D /  
Sim3D Vehicle / Components



### Description

The Simulation 3D Tractor block implements a tree-axle tractor in the 3D simulation environment.

To use the Simulation 3D Tractor block, ensure that the Simulation 3D Scene Configuration block is in your model. If you set the **Sample time** parameter of the Simulation 3D Tractor block to -1, the block uses the sample time specified in the Simulation 3D Scene Configuration block.

The block input uses the vehicle Z-down *right-handed* (RH) *Cartesian* coordinate system defined in SAE J670<sup>1</sup>. The coordinate system is inertial and initially aligned with the vehicle geometric center:

- X-axis — Points forward along vehicle longitudinal axis
- Y-axis — Points to the right along vehicle lateral axis
- Z-axis — Points downward

---

**Tip** Verify that the Simulation 3D Tractor block executes before the Simulation 3D Scene Configuration block. That way, Simulation 3D Vehicle prepares the signal data before the Unreal Engine 3D visualization environment receives it. To check the block execution order, right-click the blocks and select **Properties**. On the **General** tab, confirm these **Priority** settings:

- Simulation 3D Scene Configuration — 0
- Simulation 3D Tractor — -1

For more information about execution order, see “Control and Display Execution Order”.

---

### Ports

#### Input

##### Translation — Vehicle translation

7-by-3 array

Vehicle and wheel translation, in m. The array dimensions are 7-by-3, where:

- Translation(1,1), Translation(1,2), and Translation(1,3) — Vehicle translation along the inertial vehicle Z-down X-, Y-, and Z-axes, respectively.
- Translation(...,1), Translation(...,2), and Translation(...,3) — Wheel translation relative to vehicle, along the vehicle Z-down X-, Y-, and Z-axes, respectively.

The signal contains translation information according to the axle and wheel locations.

$$Translation = \begin{bmatrix} X_v & Y_v & Z_v \\ X_{FL} & Y_{FL} & Z_{FL} \\ X_{FR} & Y_{FR} & Z_{FR} \\ X_{ML} & Y_{ML} & Z_{ML} \\ X_{MR} & Y_{MR} & Z_{MR} \\ X_{RL} & Y_{RL} & Z_{RL} \\ X_{RR} & Y_{RR} & Z_{RR} \end{bmatrix}$$

Translation	Array Element	Translation Axis
Vehicle, $X_v$	Translation(1,1)	Inertial vehicle Z-down X-axis
Vehicle, $Y_v$	Translation(1,2)	Inertial vehicle Z-down Y-axis
Vehicle, $Z_v$	Translation(1,3)	Inertial vehicle Z-down Z-axis
Front left wheel, $X_{FL}$	Translation(2,1)	Vehicle Z-down X-axis
Front left wheel, $Y_{FL}$	Translation(2,2)	Vehicle Z-down Y-axis
Front left wheel, $Z_{FL}$	Translation(2,3)	Vehicle Z-down Z-axis
Front right wheel, $X_{FR}$	Translation(3,1)	Vehicle Z-down X-axis
Front right wheel, $Y_{FR}$	Translation(3,2)	Vehicle Z-down Y-axis
Front right wheel, $Z_{FR}$	Translation(3,3)	Vehicle Z-down Z-axis
Middle left wheel, $X_{ML}$	Translation(4,1)	Vehicle Z-down X-axis
Middle left wheel, $Y_{ML}$	Translation(4,2)	Vehicle Z-down Y-axis
Middle left wheel, $Z_{ML}$	Translation(4,3)	Vehicle Z-down Z-axis
Middle right wheel, $X_{MR}$	Translation(5,1)	Vehicle Z-down X-axis
Middle right wheel, $Y_{MR}$	Translation(5,2)	Vehicle Z-down Y-axis
Middle right wheel, $Z_{MR}$	Translation(5,3)	Vehicle Z-down Z-axis
Rear left wheel, $X_{RL}$	Translation(6,1)	Vehicle Z-down X-axis
Rear left wheel, $Y_{RL}$	Translation(6,2)	Vehicle Z-down Y-axis
Rear left wheel, $Z_{RL}$	Translation(6,3)	Vehicle Z-down Z-axis
Rear right wheel, $X_{RR}$	Translation(7,1)	Vehicle Z-down X-axis
Rear right wheel, $Y_{RR}$	Translation(7,2)	Vehicle Z-down Y-axis
Rear right wheel, $Z_{RR}$	Translation(7,3)	Vehicle Z-down Z-axis

### Rotation – Vehicle rotation

7-by-3 array

Vehicle and wheel rotation, in rad. The array dimensions are 7-by-3, where:

- Rotation(1,1), Rotation(1,2), and Rotation(1,3) – Vehicle rotation about the inertial vehicle Z-down X-, Y-, and Z-axes, respectively.
- Rotation(...,1), Rotation(...,2), and Rotation(...,3) – Wheel rotation relative to vehicle, about the vehicle Z-down X-, Y-, and Z-axes, respectively.

The signal contains rotation information according to the axle and wheel locations.

$$Rotation = \begin{bmatrix} Roll_v & Pitch_v & Yaw_v \\ Roll_{FL} & Pitch_{FL} & Yaw_{FL} \\ Roll_{FR} & Pitch_{FR} & Yaw_{FR} \\ Roll_{ML} & Pitch_{ML} & Yaw_{ML} \\ Roll_{MR} & Pitch_{MR} & Yaw_{MR} \\ Roll_{RL} & Pitch_{RL} & Yaw_{RL} \\ Roll_{RR} & Pitch_{RR} & Yaw_{RR} \end{bmatrix}$$

Rotation	Array Element	Rotation Axis
Vehicle, $Roll_v$	Rotation(1,1)	Inertial vehicle Z-down X-axis
Vehicle, $Pitch_v$	Rotation(1,2)	Inertial vehicle Z-down Y-axis
Vehicle, $Yaw_v$	Rotation(1,3)	Inertial vehicle Z-down Z-axis
Front left wheel, $Roll_{FL}$	Rotation(2,1)	Vehicle Z-down X-axis
Front left wheel, $Pitch_{FL}$	Rotation(2,2)	Vehicle Z-down Y-axis
Front left wheel, $Yaw_{FL}$	Rotation(2,3)	Vehicle Z-down Z-axis
Front right wheel, $Roll_{FR}$	Rotation(3,1)	Vehicle Z-down X-axis
Front right wheel, $Pitch_{FR}$	Rotation(3,2)	Vehicle Z-down Y-axis
Front right wheel, $Yaw_{FR}$	Rotation(3,3)	Vehicle Z-down Z-axis
Middle left wheel, $Roll_{ML}$	Rotation(4,1)	Vehicle Z-down X-axis
Middle left wheel, $Pitch_{ML}$	Rotation(4,2)	Vehicle Z-down Y-axis
Middle left wheel, $Yaw_{ML}$	Rotation(4,3)	Vehicle Z-down Z-axis
Middle right wheel, $Roll_{MR}$	Rotation(5,1)	Vehicle Z-down X-axis
Middle right wheel, $Pitch_{MR}$	Rotation(5,2)	Vehicle Z-down Y-axis
Middle right wheel, $Yaw_{MR}$	Rotation(5,3)	Vehicle Z-down Z-axis
Rear left wheel, $Roll_{RL}$	Rotation(6,1)	Vehicle Z-down X-axis
Rear left wheel, $Pitch_{RL}$	Rotation(6,2)	Vehicle Z-down Y-axis
Rear left wheel, $Yaw_{RL}$	Rotation(6,3)	Vehicle Z-down Z-axis
Rear right wheel, $Roll_{RR}$	Rotation(7,1)	Vehicle Z-down X-axis
Rear right wheel, $Pitch_{RR}$	Rotation(7,2)	Vehicle Z-down Y-axis
Rear right wheel, $Yaw_{RR}$	Rotation(7,3)	Vehicle Z-down Z-axis

## Parameters

### Vehicle Parameters

#### Type – Tractor type

Conventional tractor (default) | Cab-over tractor

Type of tractor. For the dimensions, see:



- **Cab-Over Tractor**
- **Conventional Tractor**

### Color — Vehicle color

Red (default) | Orange | Yellow | Green | Blue | Black | White | Silver

Specify the vehicle color.

### Name — Name of vehicle

SimulinkVehicle1 (default) | character vector

Name of the vehicle. By default, when you use the block in your model, the block sets the **Name** parameter to SimulinkVehicleX. The value of X depends on the number of Simulation 3D Vehicle with Ground Following and Simulation 3D Vehicle blocks that you have in your model.

### Initial Values

#### Initial array values to translate vehicle per part, Translation — Vehicle initial translation

zeros( 7, 3 ) (default) | 7-by-3 array

Initial vehicle and wheel translation, in m. The array dimensions are 7-by-3, where:

- Translation(1,1), Translation(1,2), and Translation(1,3) — Initial vehicle translation along the inertial vehicle Z-down coordinate system X-, Y-, and Z-axes, respectively.
- Translation(...,1), Translation(...,2), and Translation(...,3) — Initial wheel translation relative to the vehicle, along the vehicle Z-down X-, Y-, and Z-axes, respectively.

The parameter contains translation information according to the axle and wheel locations.

$$Translation = \begin{bmatrix} X_v & Y_v & Z_v \\ X_{FL} & Y_{FL} & Z_{FL} \\ X_{FR} & Y_{FR} & Z_{FR} \\ X_{ML} & Y_{ML} & Z_{ML} \\ X_{MR} & Y_{MR} & Z_{MR} \\ X_{RL} & Y_{RL} & Z_{RL} \\ X_{RR} & Y_{RR} & Z_{RR} \end{bmatrix}$$

Translation	Array Element	Translation Axis
Vehicle, $X_v$	Translation(1,1)	Inertial vehicle Z-down X-axis
Vehicle, $Y_v$	Translation(1,2)	Inertial vehicle Z-down Y-axis
Vehicle, $Z_v$	Translation(1,3)	Inertial vehicle Z-down Z-axis
Front left wheel, $X_{FL}$	Translation(2,1)	Vehicle Z-down X-axis
Front left wheel, $Y_{FL}$	Translation(2,2)	Vehicle Z-down Y-axis
Front left wheel, $Z_{FL}$	Translation(2,3)	Vehicle Z-down Z-axis
Front right wheel, $X_{FR}$	Translation(3,1)	Vehicle Z-down X-axis
Front right wheel, $Y_{FR}$	Translation(3,2)	Vehicle Z-down Y-axis

Translation	Array Element	Translation Axis
Front right wheel, $Z_{FR}$	Translation(3,3)	Vehicle Z-down Z-axis
Middle left wheel, $X_{ML}$	Translation(4,1)	Vehicle Z-down X-axis
Middle left wheel, $Y_{ML}$	Translation(4,2)	Vehicle Z-down Y-axis
Middle left wheel, $Z_{ML}$	Translation(4,3)	Vehicle Z-down Z-axis
Middle right wheel, $X_{MR}$	Translation(5,1)	Vehicle Z-down X-axis
Middle right wheel, $Y_{MR}$	Translation(5,2)	Vehicle Z-down Y-axis
Middle right wheel, $Z_{MR}$	Translation(5,3)	Vehicle Z-down Z-axis
Rear left wheel, $X_{RL}$	Translation(6,1)	Vehicle Z-down X-axis
Rear left wheel, $Y_{RL}$	Translation(6,2)	Vehicle Z-down Y-axis
Rear left wheel, $Z_{RL}$	Translation(6,3)	Vehicle Z-down Z-axis
Rear right wheel, $X_{RR}$	Translation(7,1)	Vehicle Z-down X-axis
Rear right wheel, $Y_{RR}$	Translation(7,2)	Vehicle Z-down Y-axis
Rear right wheel, $Z_{RR}$	Translation(7,3)	Vehicle Z-down Z-axis

**Initial array values to rotate vehicle per part, Rotation – Vehicle initial rotation**

zeros( 7, 3 ) (default) | 7-by-3 array

Initial vehicle and wheel rotation, about the vehicle Z-down X-, Y-, and Z-axes, in rad.

The array dimensions are 7-by-3.

- Rotation(1,1), Rotation(1,2), and Rotation(1,3) — Initial vehicle rotation about the inertial vehicle Z-down coordinate system X-, Y-, and Z-axes, respectively.
- Rotation(...,1), Rotation(...,2), and Rotation(...,3) — Initial wheel rotation relative to the vehicle, about the vehicle Z-down X-, Y-, and Z-axes, respectively.

The parameter contains rotation information according to the axle and wheel locations.

$$\text{Rotation} = \begin{bmatrix} \text{Roll}_v & \text{Pitch}_v & \text{Yaw}_v \\ \text{Roll}_{FL} & \text{Pitch}_{FL} & \text{Yaw}_{FL} \\ \text{Roll}_{FR} & \text{Pitch}_{FR} & \text{Yaw}_{FR} \\ \text{Roll}_{ML} & \text{Pitch}_{ML} & \text{Yaw}_{ML} \\ \text{Roll}_{MR} & \text{Pitch}_{MR} & \text{Yaw}_{MR} \\ \text{Roll}_{RL} & \text{Pitch}_{RL} & \text{Yaw}_{RL} \\ \text{Roll}_{RR} & \text{Pitch}_{RR} & \text{Yaw}_{RR} \end{bmatrix}$$

Rotation	Array Element	Rotation Axis
Vehicle, $\text{Roll}_v$	Rotation(1,1)	Inertial vehicle Z-down X-axis
Vehicle, $\text{Pitch}_v$	Rotation(1,2)	Inertial vehicle Z-down Y-axis
Vehicle, $\text{Yaw}_v$	Rotation(1,3)	Inertial vehicle Z-down Z-axis
Front left wheel, $\text{Roll}_{FL}$	Rotation(2,1)	Vehicle Z-down X-axis

Rotation	Array Element	Rotation Axis
Front left wheel, $Pitch_{FL}$	Rotation(2,2)	Vehicle Z-down Y-axis
Front left wheel, $Yaw_{FL}$	Rotation(2,3)	Vehicle Z-down Z-axis
Front right wheel, $Roll_{FR}$	Rotation(3,1)	Vehicle Z-down X-axis
Front right wheel, $Pitch_{FR}$	Rotation(3,2)	Vehicle Z-down Y-axis
Front right wheel, $Yaw_{FR}$	Rotation(3,3)	Vehicle Z-down Z-axis
Middle left wheel, $Roll_{ML}$	Rotation(4,1)	Vehicle Z-down X-axis
Middle left wheel, $Pitch_{ML}$	Rotation(4,2)	Vehicle Z-down Y-axis
Middle left wheel, $Yaw_{ML}$	Rotation(4,3)	Vehicle Z-down Z-axis
Middle right wheel, $Roll_{MR}$	Rotation(5,1)	Vehicle Z-down X-axis
Middle right wheel, $Pitch_{MR}$	Rotation(5,2)	Vehicle Z-down Y-axis
Middle right wheel, $Yaw_{MR}$	Rotation(5,3)	Vehicle Z-down Z-axis
Rear left wheel, $Roll_{RL}$	Rotation(6,1)	Vehicle Z-down X-axis
Rear left wheel, $Pitch_{RL}$	Rotation(6,2)	Vehicle Z-down Y-axis
Rear left wheel, $Yaw_{RL}$	Rotation(6,3)	Vehicle Z-down Z-axis
Rear right wheel, $Roll_{RR}$	Rotation(7,1)	Vehicle Z-down X-axis
Rear right wheel, $Pitch_{RR}$	Rotation(7,2)	Vehicle Z-down Y-axis
Rear right wheel, $Yaw_{RR}$	Rotation(7,3)	Vehicle Z-down Z-axis

### Sample time – Sample time

-1 (default) | scalar

Sample time,  $T_s$ . The graphics frame rate is the inverse of the sample time.

## References

- [1] Vehicle Dynamics Standards Committee. *Vehicle Dynamics Terminology*. SAE J670. Warrendale, PA: Society of Automotive Engineers, 2008.
- [2] Technical Committee. *Road vehicles – Vehicle dynamics and road-holding ability – Vocabulary*. ISO 8855:2011. Geneva, Switzerland: International Organization for Standardization, 2011.

## See Also

Simulation 3D Trailer | Vehicle Body 3DOF | Vehicle Body 3DOF Three Axles | Vehicle Body 6DOF | Vehicle Body 6DOF Three Axles

## Topics

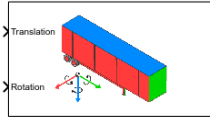
“Coordinate Systems in Vehicle Dynamics Blockset”  
 “How 3D Simulation for Vehicle Dynamics Blockset Works”

## Introduced in R2020b

## Simulation 3D Trailer

Implement trailer in 3D environment

**Library:** Vehicle Dynamics Blockset / Vehicle Scenarios / Sim3D /  
Sim3D Vehicle / Components



### Description

The Simulation 3D Trailer block implements a trailer with two or three axles in the 3D simulation environment.

To use the Simulation 3D Trailer block, ensure that the Simulation 3D Scene Configuration block is in your model. If you set the **Sample time** parameter of the Simulation 3D Trailer block to -1, the block uses the sample time specified in the Simulation 3D Scene Configuration block.

The block input uses the vehicle Z-down *right-handed* (RH) *Cartesian* coordinate system defined in SAE J670<sup>1</sup>. The coordinate system is inertial and initially aligned with the vehicle geometric center:

- X-axis — Points forward along vehicle longitudinal axis
- Y-axis — Points to the right along vehicle lateral axis
- Z-axis — Points downward

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**Tip** Verify that the Simulation 3D Trailer block executes before the Simulation 3D Scene Configuration block. That way, Simulation 3D Vehicle prepares the signal data before the Unreal Engine 3D visualization environment receives it. To check the block execution order, right-click the blocks and select **Properties**. On the **General** tab, confirm these **Priority** settings:

- Simulation 3D Scene Configuration — 0
- Simulation 3D Trailer — -1

For more information about execution order, see “Control and Display Execution Order”.

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### Ports

#### Input

##### Translation — Vehicle translation

5-by-3 array (default) | 7-by-3 array

Vehicle and wheel translation, in m. The array dimensions are 5-by-3 for a two-axle trailer and 7-by-3 for a three-axle trailer, where:

- Translation(1,1), Translation(1,2), and Translation(1,3) — Vehicle translation along the inertial vehicle Z-down X-, Y-, and Z-axes, respectively.

- Translation(...,1), Translation(...,2), and Translation(...,3) — Wheel translation relative to vehicle, along the vehicle Z-down X-, Y-, and Z-axes, respectively.

The signal contains translation information according to the axle and wheel locations.

For a two-axle trailer:

$$Translation = \begin{bmatrix} X_v & Y_v & Z_v \\ X_{FL} & Y_{FL} & Z_{FL} \\ X_{FR} & Y_{FR} & Z_{FR} \\ X_{RL} & Y_{RL} & Z_{RL} \\ X_{RR} & Y_{RR} & Z_{RR} \end{bmatrix}$$

Translation	Array Element	Translation Axis
Vehicle, $X_v$	Translation(1,1)	Inertial vehicle Z-down X-axis
Vehicle, $Y_v$	Translation(1,2)	Inertial vehicle Z-down Y-axis
Vehicle, $Z_v$	Translation(1,3)	Inertial vehicle Z-down Z-axis
Front left wheel, $X_{FL}$	Translation(2,1)	Vehicle Z-down X-axis
Front left wheel, $Y_{FL}$	Translation(2,2)	Vehicle Z-down Y-axis
Front left wheel, $Z_{FL}$	Translation(2,3)	Vehicle Z-down Z-axis
Front right wheel, $X_{FR}$	Translation(3,1)	Vehicle Z-down X-axis
Front right wheel, $Y_{FR}$	Translation(3,2)	Vehicle Z-down Y-axis
Front right wheel, $Z_{FR}$	Translation(3,3)	Vehicle Z-down Z-axis
Rear left wheel, $X_{RL}$	Translation(4,1)	Vehicle Z-down X-axis
Rear left wheel, $Y_{RL}$	Translation(4,2)	Vehicle Z-down Y-axis
Rear left wheel, $Z_{RL}$	Translation(4,3)	Vehicle Z-down Z-axis
Rear right wheel, $X_{RR}$	Translation(5,1)	Vehicle Z-down X-axis
Rear right wheel, $Y_{RR}$	Translation(5,2)	Vehicle Z-down Y-axis
Rear right wheel, $Z_{RR}$	Translation(5,3)	Vehicle Z-down Z-axis

For a three-axle trailer:

$$Translation = \begin{bmatrix} X_v & Y_v & Z_v \\ X_{FL} & Y_{FL} & Z_{FL} \\ X_{FR} & Y_{FR} & Z_{FR} \\ X_{ML} & Y_{ML} & Z_{ML} \\ X_{MR} & Y_{MR} & Z_{MR} \\ X_{RL} & Y_{RL} & Z_{RL} \\ X_{RR} & Y_{RR} & Z_{RR} \end{bmatrix}$$

Translation	Array Element	Translation Axis
Vehicle, $X_v$	Translation(1,1)	Inertial vehicle Z-down X-axis

Translation	Array Element	Translation Axis
Vehicle, $Y_v$	Translation(1,2)	Inertial vehicle Z-down Y-axis
Vehicle, $Z_v$	Translation(1,3)	Inertial vehicle Z-down Z-axis
Front left wheel, $X_{FL}$	Translation(2,1)	Vehicle Z-down X-axis
Front left wheel, $Y_{FL}$	Translation(2,2)	Vehicle Z-down Y-axis
Front left wheel, $Z_{FL}$	Translation(2,3)	Vehicle Z-down Z-axis
Front right wheel, $X_{FR}$	Translation(3,1)	Vehicle Z-down X-axis
Front right wheel, $Y_{FR}$	Translation(3,2)	Vehicle Z-down Y-axis
Front right wheel, $Z_{FR}$	Translation(3,3)	Vehicle Z-down Z-axis
Middle left wheel, $X_{ML}$ (for three-axle trailer)	Translation(4,1)	Vehicle Z-down X-axis
Middle left wheel, $Y_{ML}$	Translation(4,2)	Vehicle Z-down Y-axis
Middle left wheel, $Z_{ML}$	Translation(4,3)	Vehicle Z-down Z-axis
Middle right wheel, $X_{MR}$	Translation(5,1)	Vehicle Z-down X-axis
Middle right wheel, $Y_{MR}$	Translation(5,2)	Vehicle Z-down Y-axis
Middle right wheel, $Z_{MR}$	Translation(5,3)	Vehicle Z-down Z-axis
Rear left wheel, $X_{RL}$	Translation(6,1)	Vehicle Z-down X-axis
Rear left wheel, $Y_{RL}$	Translation(6,2)	Vehicle Z-down Y-axis
Rear left wheel, $Z_{RL}$	Translation(6,3)	Vehicle Z-down Z-axis
Rear right wheel, $X_{RR}$	Translation(7,1)	Vehicle Z-down X-axis
Rear right wheel, $Y_{RR}$	Translation(7,2)	Vehicle Z-down Y-axis
Rear right wheel, $Z_{RR}$	Translation(7,3)	Vehicle Z-down Z-axis

**Rotation – Vehicle rotation**

5-by-3 array (default) | 7-by-3 array

Vehicle and wheel rotation, in rad. The array dimensions are 5-by-3 for a two-axle trailer and 7-by-3 for a three-axle trailer, where:

- Rotation(1,1), Rotation(1,2), and Rotation(1,3) – Vehicle rotation about the inertial vehicle Z-down X-, Y-, and Z-axes, respectively.
- Rotation(...,1), Rotation(...,2), and Rotation(...,3) – Wheel rotation relative to vehicle, about the vehicle Z-down X-, Y-, and Z-axes, respectively.

The signal contains rotation information according to the axle and wheel locations.

For a two-axle trailer:

$$\text{Rotation} = \begin{bmatrix} \text{Roll}_v & \text{Pitch}_v & \text{Yaw}_v \\ \text{Roll}_{FL} & \text{Pitch}_{FL} & \text{Yaw}_{FL} \\ \text{Roll}_{FR} & \text{Pitch}_{FR} & \text{Yaw}_{FR} \\ \text{Roll}_{RL} & \text{Pitch}_{RL} & \text{Yaw}_{RL} \\ \text{Roll}_{RR} & \text{Pitch}_{RR} & \text{Yaw}_{RR} \end{bmatrix}$$

Rotation	Array Element	Rotation Axis
Vehicle, $Roll_v$	Rotation(1,1)	Inertial vehicle Z-down X-axis
Vehicle, $Pitch_v$	Rotation(1,2)	Inertial vehicle Z-down Y-axis
Vehicle, $Yaw_v$	Rotation(1,3)	Inertial vehicle Z-down Z-axis
Front left wheel, $Roll_{FL}$	Rotation(2,1)	Vehicle Z-down X-axis
Front left wheel, $Pitch_{FL}$	Rotation(2,2)	Vehicle Z-down Y-axis
Front left wheel, $Yaw_{FL}$	Rotation(2,3)	Vehicle Z-down Z-axis
Front right wheel, $Roll_{FR}$	Rotation(3,1)	Vehicle Z-down X-axis
Front right wheel, $Pitch_{FR}$	Rotation(3,2)	Vehicle Z-down Y-axis
Front right wheel, $Yaw_{FR}$	Rotation(3,3)	Vehicle Z-down Z-axis
Rear left wheel, $Roll_{RL}$	Rotation(4,1)	Vehicle Z-down X-axis
Rear left wheel, $Pitch_{RL}$	Rotation(4,2)	Vehicle Z-down Y-axis
Rear left wheel, $Yaw_{RL}$	Rotation(4,3)	Vehicle Z-down Z-axis
Rear right wheel, $Roll_{RR}$	Rotation(5,1)	Vehicle Z-down X-axis
Rear right wheel, $Pitch_{RR}$	Rotation(5,2)	Vehicle Z-down Y-axis
Rear right wheel, $Yaw_{RR}$	Rotation(5,3)	Vehicle Z-down Z-axis

For a three-axle trailer:

$$Rotation = \begin{bmatrix} Roll_v & Pitch_v & Yaw_v \\ Roll_{FL} & Pitch_{FL} & Yaw_{FL} \\ Roll_{FR} & Pitch_{FR} & Yaw_{FR} \\ Roll_{ML} & Pitch_{ML} & Yaw_{ML} \\ Roll_{MR} & Pitch_{MR} & Yaw_{MR} \\ Roll_{RL} & Pitch_{RL} & Yaw_{RL} \\ Roll_{RR} & Pitch_{RR} & Yaw_{RR} \end{bmatrix}$$

Rotation	Array Element	Rotation Axis
Vehicle, $Roll_v$	Rotation(1,1)	Inertial vehicle Z-down X-axis
Vehicle, $Pitch_v$	Rotation(1,2)	Inertial vehicle Z-down Y-axis
Vehicle, $Yaw_v$	Rotation(1,3)	Inertial vehicle Z-down Z-axis
Front left wheel, $Roll_{FL}$	Rotation(2,1)	Vehicle Z-down X-axis
Front left wheel, $Pitch_{FL}$	Rotation(2,2)	Vehicle Z-down Y-axis
Front left wheel, $Yaw_{FL}$	Rotation(2,3)	Vehicle Z-down Z-axis
Front right wheel, $Roll_{FR}$	Rotation(3,1)	Vehicle Z-down X-axis
Front right wheel, $Pitch_{FR}$	Rotation(3,2)	Vehicle Z-down Y-axis
Front right wheel, $Yaw_{FR}$	Rotation(3,3)	Vehicle Z-down Z-axis
Middle left wheel, $Roll_{ML}$	Rotation(4,1)	Vehicle Z-down X-axis
Middle left wheel, $Pitch_{ML}$	Rotation(4,2)	Vehicle Z-down Y-axis

Rotation	Array Element	Rotation Axis
Middle left wheel, $Yaw_{ML}$	Rotation(4,3)	Vehicle Z-down Z-axis
Middle right wheel, $Roll_{MR}$	Rotation(5,1)	Vehicle Z-down X-axis
Middle right wheel, $Pitch_{MR}$	Rotation(5,2)	Vehicle Z-down Y-axis
Middle right wheel, $Yaw_{MR}$	Rotation(5,3)	Vehicle Z-down Z-axis
Rear left wheel, $Roll_{RL}$	Rotation(6,1)	Vehicle Z-down X-axis
Rear left wheel, $Pitch_{RL}$	Rotation(6,2)	Vehicle Z-down Y-axis
Rear left wheel, $Yaw_{RL}$	Rotation(6,3)	Vehicle Z-down Z-axis
Rear right wheel, $Roll_{RR}$	Rotation(7,1)	Vehicle Z-down X-axis
Rear right wheel, $Pitch_{RR}$	Rotation(7,2)	Vehicle Z-down Y-axis
Rear right wheel, $Yaw_{RR}$	Rotation(7,3)	Vehicle Z-down Z-axis

## Parameters

### Vehicle Parameters

#### Type — Trailer type

Two-axle trailer (default) | Three-axle trailer

Trailer type. For the trailer dimensions, see:

- **Two-Axle Trailer**
- **Three-Axle Trailer**

#### Name — Name of vehicle

SimulinkVehicle1 (default) | character vector

Name of vehicle. By default, when you use the block in your model, the block sets the **Name** parameter to SimulinkVehicleX. The value of X depends on the number of Simulation 3D Vehicle with Ground Following and Simulation 3D Vehicle blocks that you have in your model.

### Initial Values

#### Initial array values to translate vehicle per part, Translation — Vehicle initial translation

zeros( 5, 3 ) (default) | zeros( 7, 3 )

Initial vehicle and wheel translation, in m. The array dimensions are 5-by-3 for a two-axle trailer and 7-by-3 for a three-axle trailer, where:

- Translation(1,1), Translation(1,2), and Translation(1,3) — Initial vehicle translation along the inertial vehicle Z-down coordinate system X-, Y-, and Z-axes, respectively.
- Translation(...,1), Translation(...,2), and Translation(...,3) — Initial wheel translation relative to vehicle, along the vehicle Z-down X-, Y-, and Z-axes, respectively.

The signal contains translation information according to the axle and wheel locations.

For a two-axle trailer:



$$Translation = \begin{bmatrix} X_v & Y_v & Z_v \\ X_{FL} & Y_{FL} & Z_{FL} \\ X_{FR} & Y_{FR} & Z_{FR} \\ X_{RL} & Y_{RL} & Z_{RL} \\ X_{RR} & Y_{RR} & Z_{RR} \end{bmatrix}$$

Translation	Array Element	Translation Axis
Vehicle, $X_v$	Translation(1,1)	Inertial vehicle Z-down X-axis
Vehicle, $Y_v$	Translation(1,2)	Inertial vehicle Z-down Y-axis
Vehicle, $Z_v$	Translation(1,3)	Inertial vehicle Z-down Z-axis
Front left wheel, $X_{FL}$	Translation(2,1)	Vehicle Z-down X-axis
Front left wheel, $Y_{FL}$	Translation(2,2)	Vehicle Z-down Y-axis
Front left wheel, $Z_{FL}$	Translation(2,3)	Vehicle Z-down Z-axis
Front right wheel, $X_{FR}$	Translation(3,1)	Vehicle Z-down X-axis
Front right wheel, $Y_{FR}$	Translation(3,2)	Vehicle Z-down Y-axis
Front right wheel, $Z_{FR}$	Translation(3,3)	Vehicle Z-down Z-axis
Rear left wheel, $X_{RL}$	Translation(4,1)	Vehicle Z-down X-axis
Rear left wheel, $Y_{RL}$	Translation(4,2)	Vehicle Z-down Y-axis
Rear left wheel, $Z_{RL}$	Translation(4,3)	Vehicle Z-down Z-axis
Rear right wheel, $X_{RR}$	Translation(5,1)	Vehicle Z-down X-axis
Rear right wheel, $Y_{RR}$	Translation(5,2)	Vehicle Z-down Y-axis
Rear right wheel, $Z_{RR}$	Translation(5,3)	Vehicle Z-down Z-axis

For a three-axle trailer:

$$Translation = \begin{bmatrix} X_v & Y_v & Z_v \\ X_{FL} & Y_{FL} & Z_{FL} \\ X_{FR} & Y_{FR} & Z_{FR} \\ X_{ML} & Y_{ML} & Z_{ML} \\ X_{MR} & Y_{MR} & Z_{MR} \\ X_{RL} & Y_{RL} & Z_{RL} \\ X_{RR} & Y_{RR} & Z_{RR} \end{bmatrix}$$

Translation	Array Element	Translation Axis
Vehicle, $X_v$	Translation(1,1)	Inertial vehicle Z-down X-axis
Vehicle, $Y_v$	Translation(1,2)	Inertial vehicle Z-down Y-axis
Vehicle, $Z_v$	Translation(1,3)	Inertial vehicle Z-down Z-axis
Front left wheel, $X_{FL}$	Translation(2,1)	Vehicle Z-down X-axis
Front left wheel, $Y_{FL}$	Translation(2,2)	Vehicle Z-down Y-axis
Front left wheel, $Z_{FL}$	Translation(2,3)	Vehicle Z-down Z-axis

Translation	Array Element	Translation Axis
Front right wheel, $X_{FR}$	Translation(3,1)	Vehicle Z-down X-axis
Front right wheel, $Y_{FR}$	Translation(3,2)	Vehicle Z-down Y-axis
Front right wheel, $Z_{FR}$	Translation(3,3)	Vehicle Z-down Z-axis
Middle left wheel, $X_{ML}$ (for three-axle trailer)	Translation(4,1)	Vehicle Z-down X-axis
Middle left wheel, $Y_{ML}$	Translation(4,2)	Vehicle Z-down Y-axis
Middle left wheel, $Z_{ML}$	Translation(4,3)	Vehicle Z-down Z-axis
Middle right wheel, $X_{MR}$	Translation(5,1)	Vehicle Z-down X-axis
Middle right wheel, $Y_{MR}$	Translation(5,2)	Vehicle Z-down Y-axis
Middle right wheel, $Z_{MR}$	Translation(5,3)	Vehicle Z-down Z-axis
Rear left wheel, $X_{RL}$	Translation(6,1)	Vehicle Z-down X-axis
Rear left wheel, $Y_{RL}$	Translation(6,2)	Vehicle Z-down Y-axis
Rear left wheel, $Z_{RL}$	Translation(6,3)	Vehicle Z-down Z-axis
Rear right wheel, $X_{RR}$	Translation(7,1)	Vehicle Z-down X-axis
Rear right wheel, $Y_{RR}$	Translation(7,2)	Vehicle Z-down Y-axis
Rear right wheel, $Z_{RR}$	Translation(7,3)	Vehicle Z-down Z-axis

**Initial array values to rotate vehicle per part, Rotation – Vehicle initial rotation**

zeros( 5, 3 ) (default) | zeros( 7, 3 )

Initial vehicle and wheel rotation, about the vehicle Z-down X-, Y-, and Z-axes, in rad.

The array dimensions are 5-by-3 for a two-axle trailer and 7-by-3 for a three-axle trailer, where:

- Rotation(1,1), Rotation(1,2), and Rotation(1,3) – Initial vehicle rotation about the inertial vehicle Z-down coordinate system X-, Y-, and Z-axes, respectively.
- Rotation(...,1), Rotation(...,2), and Rotation(...,3) – Initial wheel rotation relative to the vehicle, about the vehicle Z-down X-, Y-, and Z-axes, respectively.

The signal contains translation information according to the axle and wheel locations.

For a two-axle trailer:

$$Rotation = \begin{bmatrix} Roll_v & Pitch_v & Yaw_v \\ Roll_{FL} & Pitch_{FL} & Yaw_{FL} \\ Roll_{FR} & Pitch_{FR} & Yaw_{FR} \\ Roll_{RL} & Pitch_{RL} & Yaw_{RL} \\ Roll_{RR} & Pitch_{RR} & Yaw_{RR} \end{bmatrix}$$

Rotation	Array Element	Rotation Axis
Vehicle, $Roll_v$	Rotation(1,1)	Inertial vehicle Z-down X-axis
Vehicle, $Pitch_v$	Rotation(1,2)	Inertial vehicle Z-down Y-axis

Rotation	Array Element	Rotation Axis
Vehicle, $Yaw_v$	Rotation(1,3)	Inertial vehicle Z-down Z-axis
Front left wheel, $Roll_{FL}$	Rotation(2,1)	Vehicle Z-down X-axis
Front left wheel, $Pitch_{FL}$	Rotation(2,2)	Vehicle Z-down Y-axis
Front left wheel, $Yaw_{FL}$	Rotation(2,3)	Vehicle Z-down Z-axis
Front right wheel, $Roll_{FR}$	Rotation(3,1)	Vehicle Z-down X-axis
Front right wheel, $Pitch_{FR}$	Rotation(3,2)	Vehicle Z-down Y-axis
Front right wheel, $Yaw_{FR}$	Rotation(3,3)	Vehicle Z-down Z-axis
Rear left wheel, $Roll_{RL}$	Rotation(4,1)	Vehicle Z-down X-axis
Rear left wheel, $Pitch_{RL}$	Rotation(4,2)	Vehicle Z-down Y-axis
Rear left wheel, $Yaw_{RL}$	Rotation(4,3)	Vehicle Z-down Z-axis
Rear right wheel, $Roll_{RR}$	Rotation(5,1)	Vehicle Z-down X-axis
Rear right wheel, $Pitch_{RR}$	Rotation(5,2)	Vehicle Z-down Y-axis
Rear right wheel, $Yaw_{RR}$	Rotation(5,3)	Vehicle Z-down Z-axis

For a three-axle trailer:

$$Rotation = \begin{bmatrix} Roll_v & Pitch_v & Yaw_v \\ Roll_{FL} & Pitch_{FL} & Yaw_{FL} \\ Roll_{FR} & Pitch_{FR} & Yaw_{FR} \\ Roll_{ML} & Pitch_{ML} & Yaw_{ML} \\ Roll_{MR} & Pitch_{MR} & Yaw_{MR} \\ Roll_{RL} & Pitch_{RL} & Yaw_{RL} \\ Roll_{RR} & Pitch_{RR} & Yaw_{RR} \end{bmatrix}$$

Rotation	Array Element	Rotation Axis
Vehicle, $Roll_v$	Rotation(1,1)	Inertial vehicle Z-down X-axis
Vehicle, $Pitch_v$	Rotation(1,2)	Inertial vehicle Z-down Y-axis
Vehicle, $Yaw_v$	Rotation(1,3)	Inertial vehicle Z-down Z-axis
Front left wheel, $Roll_{FL}$	Rotation(2,1)	Vehicle Z-down X-axis
Front left wheel, $Pitch_{FL}$	Rotation(2,2)	Vehicle Z-down Y-axis
Front left wheel, $Yaw_{FL}$	Rotation(2,3)	Vehicle Z-down Z-axis
Front right wheel, $Roll_{FR}$	Rotation(3,1)	Vehicle Z-down X-axis
Front right wheel, $Pitch_{FR}$	Rotation(3,2)	Vehicle Z-down Y-axis
Front right wheel, $Yaw_{FR}$	Rotation(3,3)	Vehicle Z-down Z-axis
Middle left wheel, $Roll_{ML}$	Rotation(4,1)	Vehicle Z-down X-axis
Middle left wheel, $Pitch_{ML}$	Rotation(4,2)	Vehicle Z-down Y-axis
Middle left wheel, $Yaw_{ML}$	Rotation(4,3)	Vehicle Z-down Z-axis
Middle right wheel, $Roll_{MR}$	Rotation(5,1)	Vehicle Z-down X-axis

Rotation	Array Element	Rotation Axis
Middle right wheel, $Pitch_{MR}$	Rotation(5,2)	Vehicle Z-down Y-axis
Middle right wheel, $Yaw_{MR}$	Rotation(5,3)	Vehicle Z-down Z-axis
Rear left wheel, $Roll_{RL}$	Rotation(6,1)	Vehicle Z-down X-axis
Rear left wheel, $Pitch_{RL}$	Rotation(6,2)	Vehicle Z-down Y-axis
Rear left wheel, $Yaw_{RL}$	Rotation(6,3)	Vehicle Z-down Z-axis
Rear right wheel, $Roll_{RR}$	Rotation(7,1)	Vehicle Z-down X-axis
Rear right wheel, $Pitch_{RR}$	Rotation(7,2)	Vehicle Z-down Y-axis
Rear right wheel, $Yaw_{RR}$	Rotation(7,3)	Vehicle Z-down Z-axis

**Sample time – Sample time**

-1 (default) | scalar

Sample time,  $T_s$ . The graphics frame rate is the inverse of the sample time.

**References**

- [1] Vehicle Dynamics Standards Committee. *Vehicle Dynamics Terminology*. SAE J670. Warrendale, PA: Society of Automotive Engineers, 2008.
- [2] Technical Committee. *Road vehicles – Vehicle dynamics and road-holding ability – Vocabulary*. ISO 8855:2011. Geneva, Switzerland: International Organization for Standardization, 2011.

**See Also**

Simulation 3D Tractor | Trailer Body 3DOF | Trailer Body 6DOF | Vehicle Body 3DOF Three Axles

**Topics**

“Coordinate Systems in Vehicle Dynamics Blockset”

“How 3D Simulation for Vehicle Dynamics Blockset Works”

**Introduced in R2020b**

# Scenes

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## Straight Road

Straight road 3D environment

### Description

The **Straight Road** scene is a 3D environment of a straight four-lane divided highway. The scene is rendered using the Unreal Engine from Epic Games.

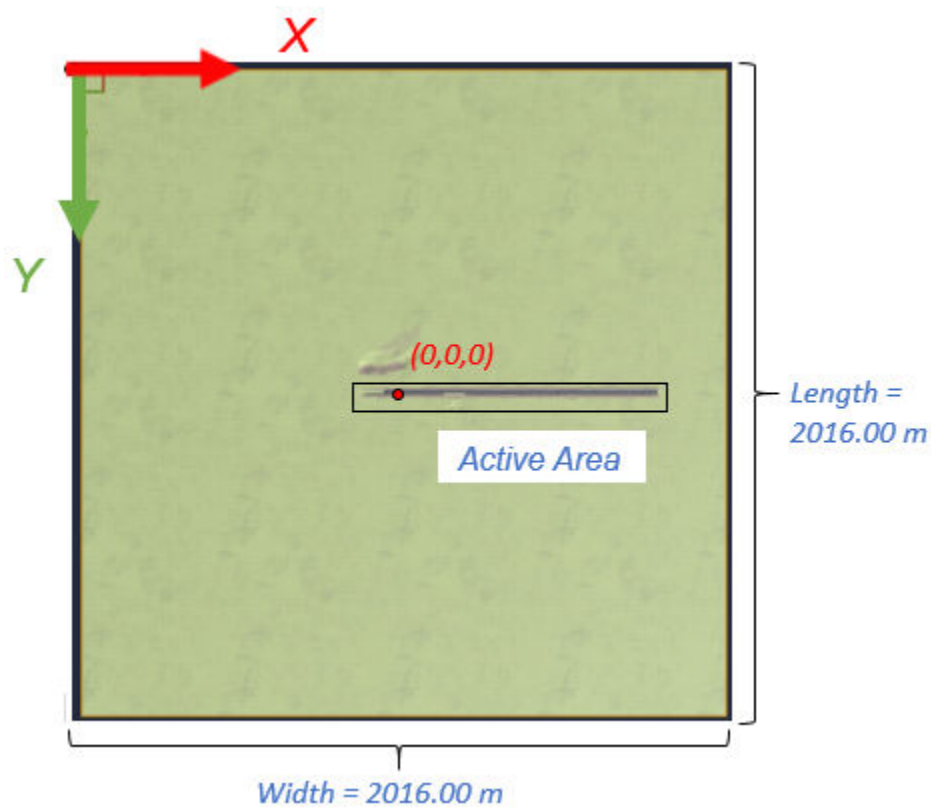


To simulate a driving maneuver in this scene:

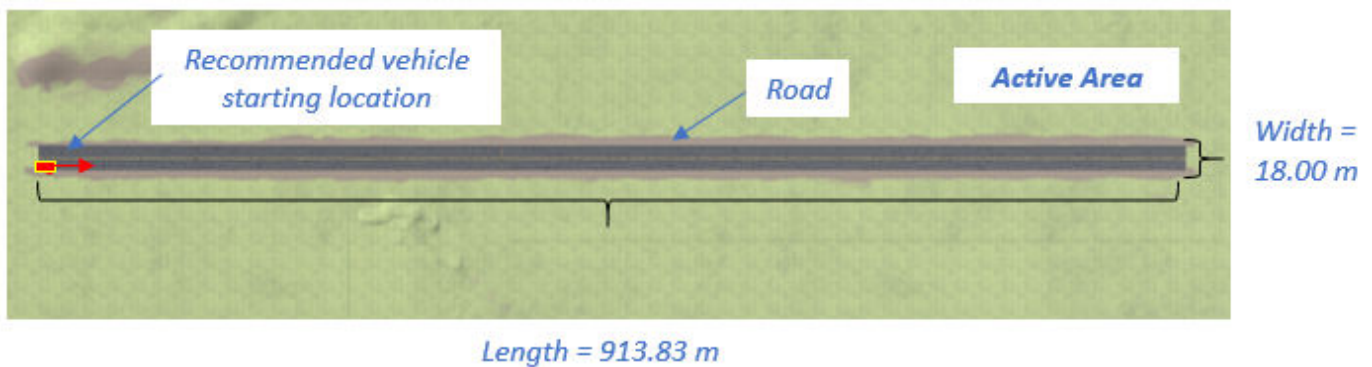
- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene source** parameter to Default Scenes.
- 3 Set the enabled **Scene name** parameter to Straight road.

### Scene Layout

The scene uses the world coordinate system to locate objects.



The active area of the scene contains the road.



This table provides the scene area corner locations in the world coordinate system. Dimensions are in m.

Locations	X (m)	Y (m)	Z (m)
Scene — Top left	- 1080	- 1080	0
Scene — Bottom right	1080	1080	0
Active area — Bottom left	-122.19	6.00	0

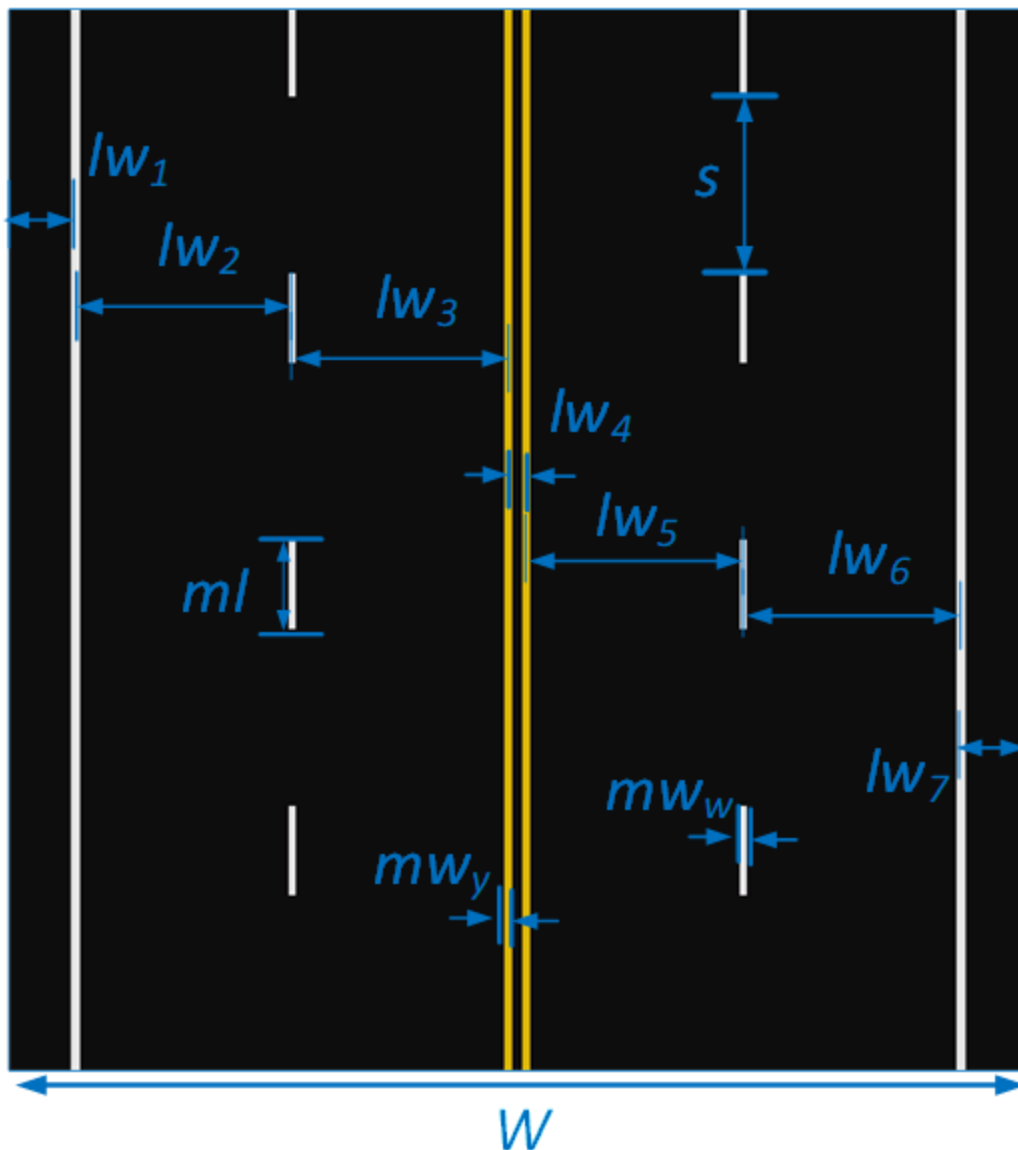
### Recommended Starting Location

This table provides the recommended starting location for the vehicle in the world coordinate system. Dimensions are in m and deg.

Recommended Starting Location					
X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
-118	3.125	0	0	0	0

### Lane Dimensions

This figure and table provides the lane dimensions, in m.

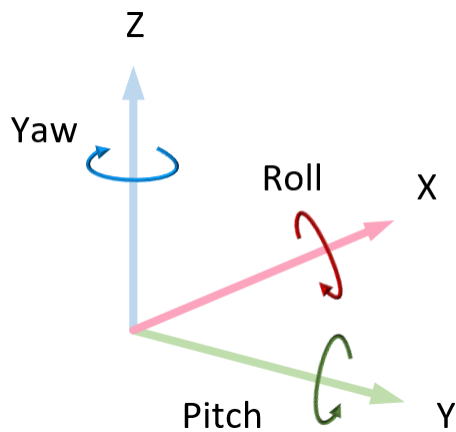




Variable	Dimension (m)
$lw_1$	1.2
$lw_2$	3.84
$lw_3$	3.8
$lw_4$	0.36
$lw_5$	3.8
$lw_6$	3.8
$lw_7$	1.2
$ml$	1.5
$s$	3.0
$mw_w$	0.13
$mw_y$	0.14
$W$	18.0

### World Coordinate System

The 3D visualization environment uses a world coordinate system with axes that are fixed in the inertial reference frame.



Axis	Description
X	Forward direction of the vehicle Roll — Right-handed rotation about X-axis
Y	Extends to the right of the vehicle, parallel to the ground plane Pitch — Right-handed rotation about Y-axis
Z	Extends upwards Yaw — Left-handed rotation about Z-axis

## Tips

- If you have the Vehicle Dynamics Blockset Interface for Unreal Engine 4 Projects support package, then you can modify this scene. In the Unreal Engine project file that comes with the support package, this scene is named HwStright.

For more details on customizing scenes, see “Customize 3D Scenes for Vehicle Dynamics Simulations”.

## See Also

**Curved Road | Double Lane Change | Large Parking Lot | Open Surface | Parking Lot | Simulation 3D Scene Configuration | US City Block | US Highway | Virtual Mcity**

## Topics

“3D Visualization Engine Requirements and Limitations”

“How 3D Simulation for Vehicle Dynamics Blockset Works”

“Customize 3D Scenes for Vehicle Dynamics Simulations”

# Curved Road

Curved road 3D environment

## Description

The **Curved Road** scene is a 3D environment of a curved highway loop. The scene is rendered using the Unreal Engine from Epic Games.

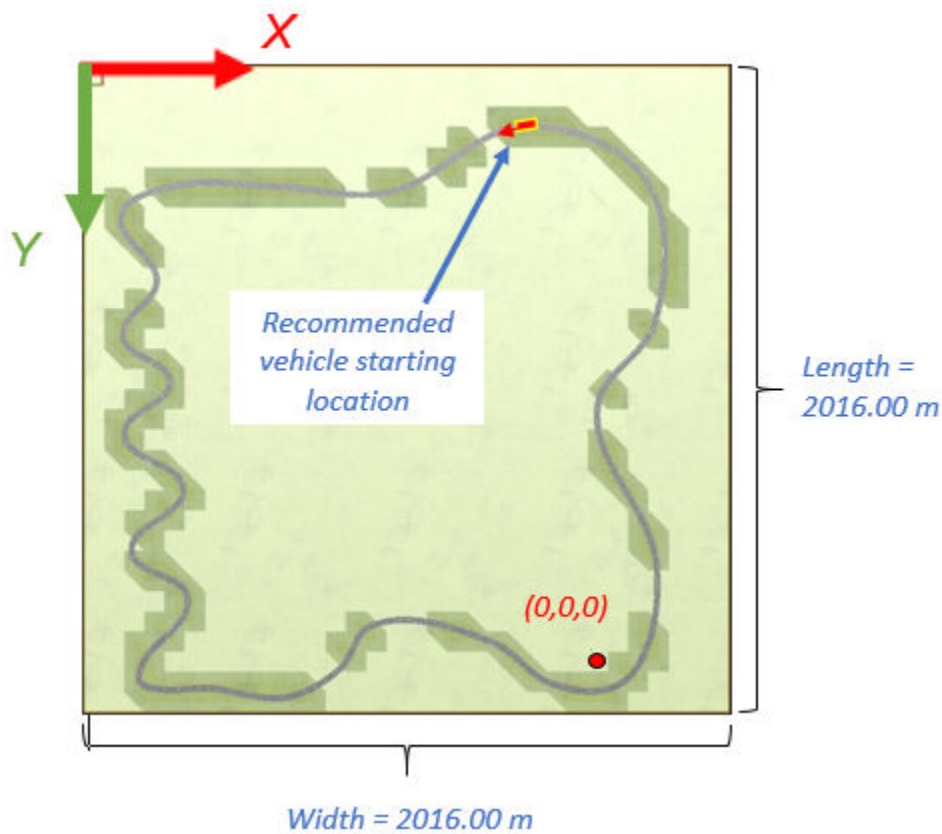


To simulate a driving maneuver in this scene:

- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene source** parameter to `Default Scenes`.
- 3 Set the enabled **Scene name** parameter to `Curved road`.

## Scene Layout

The scene uses the world coordinate system to locate objects.



This table provides the scene corner locations in the world coordinate system. Dimensions are in m.

Location	X (m)	Y (m)	Z (m)
Scene — Bottom left	-1587.75	195.39	0
Scene — Top right	428.26	-1820.60	0

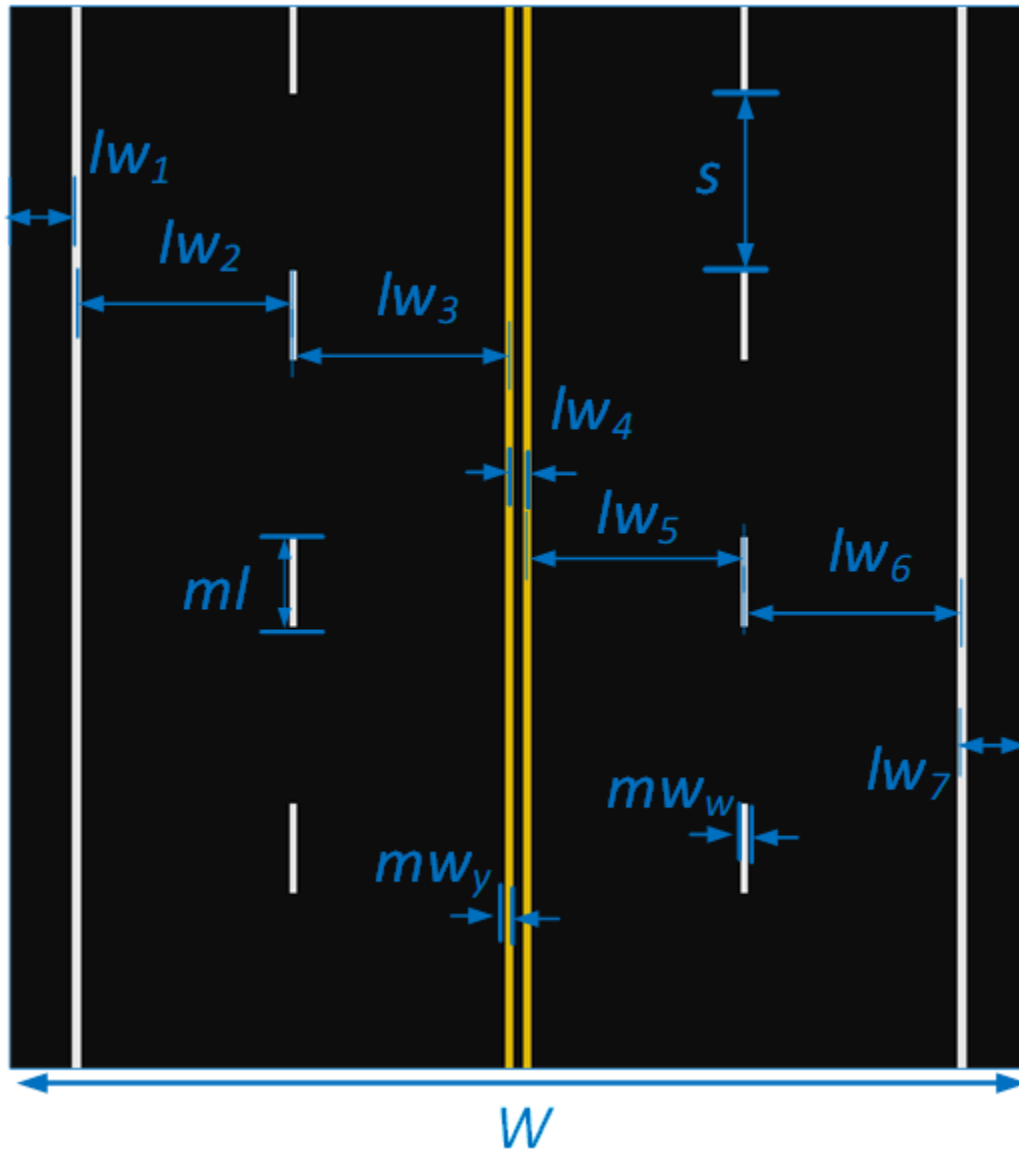
### Recommended Starting Location

This table provides the recommended starting location for the vehicle in the world coordinate system. Dimensions are in m and deg.

Recommended Starting Location					
X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
0.2	-1605.00	0	0	0	-156°

### Lane Dimensions

This figure and table provides the lane dimensions, in m.

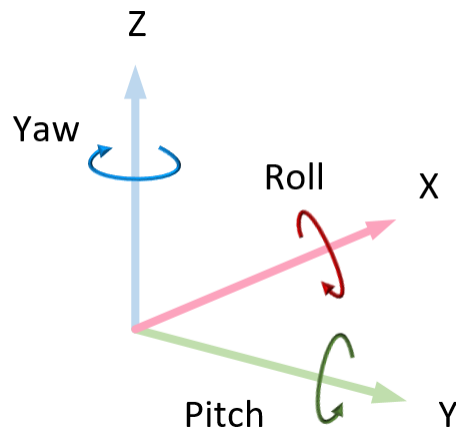


Variable	Dimension (m)
$lw_1$	1.2
$lw_2$	3.82
$lw_3$	3.82
$lw_4$	0.3
$lw_5$	3.83
$lw_6$	3.83
$lw_7$	1.2
$ml$	1.5
$s$	3.0

Variable	Dimension (m)
$mw_w$	0.13
$mw_y$	0.15
$W$	18.0

### World Coordinate System

The 3D visualization environment uses a world coordinate system with axes that are fixed in the inertial reference frame.



Axis	Description
X	Forward direction of the vehicle Roll — Right-handed rotation about X-axis
Y	Extends to the right of the vehicle, parallel to the ground plane Pitch — Right-handed rotation about Y-axis
Z	Extends upwards Yaw — Left-handed rotation about Z-axis

### Tips

- If you have the Vehicle Dynamics Blockset Interface for Unreal Engine 4 Projects support package, then you can modify this scene. In the Unreal Engine project file that comes with the support package, this scene is named HwCurve.

For more details on customizing scenes, see “Customize 3D Scenes for Vehicle Dynamics Simulations”.

### See Also

**Double Lane Change** | **Large Parking Lot** | **Open Surface** | **Parking Lot** | Simulation 3D Scene Configuration | **Straight Road** | **US City Block** | **US Highway** | **Virtual Mcity**

**Topics**

- "3D Visualization Engine Requirements and Limitations"
- "How 3D Simulation for Vehicle Dynamics Blockset Works"
- "Customize 3D Scenes for Vehicle Dynamics Simulations"

## Parking Lot

Parking lot 3D environment

### Description

The **Parking Lot** scene is a 3D environment of a parking lot. The scene is rendered using the Unreal Engine from Epic Games.



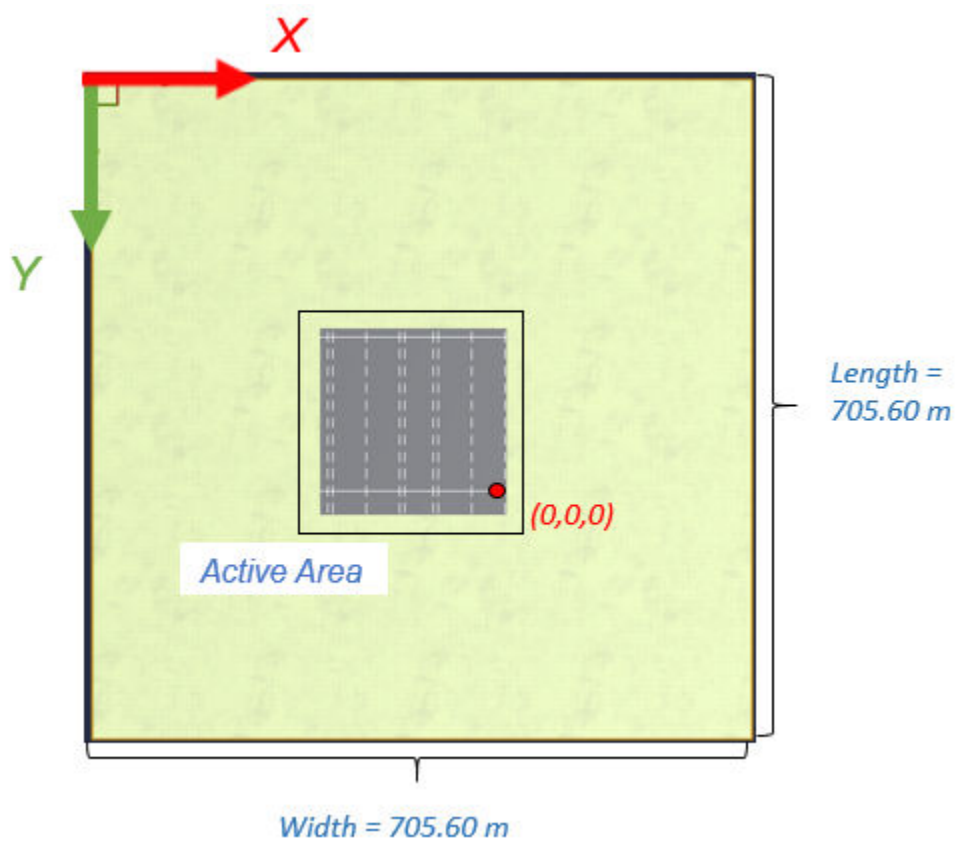
To simulate a driving maneuver in this scene:

- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene source** parameter to Default Scenes.
- 3 Set the enabled **Scene name** parameter to Parking lot.

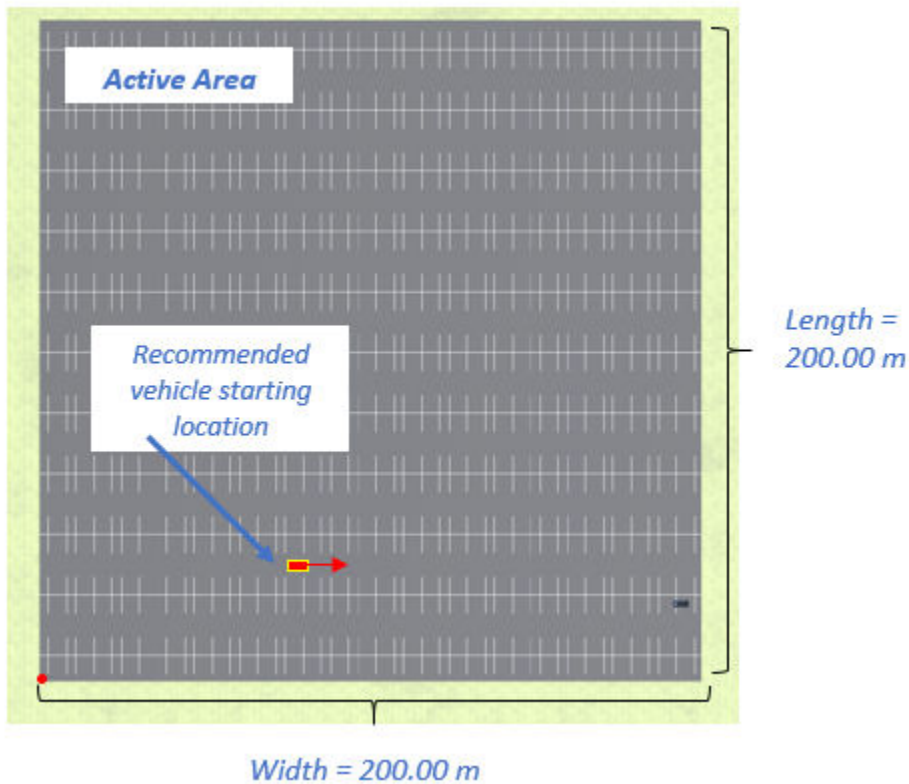
### Scene Layout

The scene uses the world coordinate system to locate objects.





The active area of the scene contains the parking lot.



This table provides the scene and active area corner locations in the world coordinate system. Dimensions are in m.

Locations	X (m)	Y (m)	Z (m)
Scene — Bottom left	-437.32	262.79	0
Scene — Top right	268.28	-442.81	0
Active area — Bottom left	-193.86	23.43	0

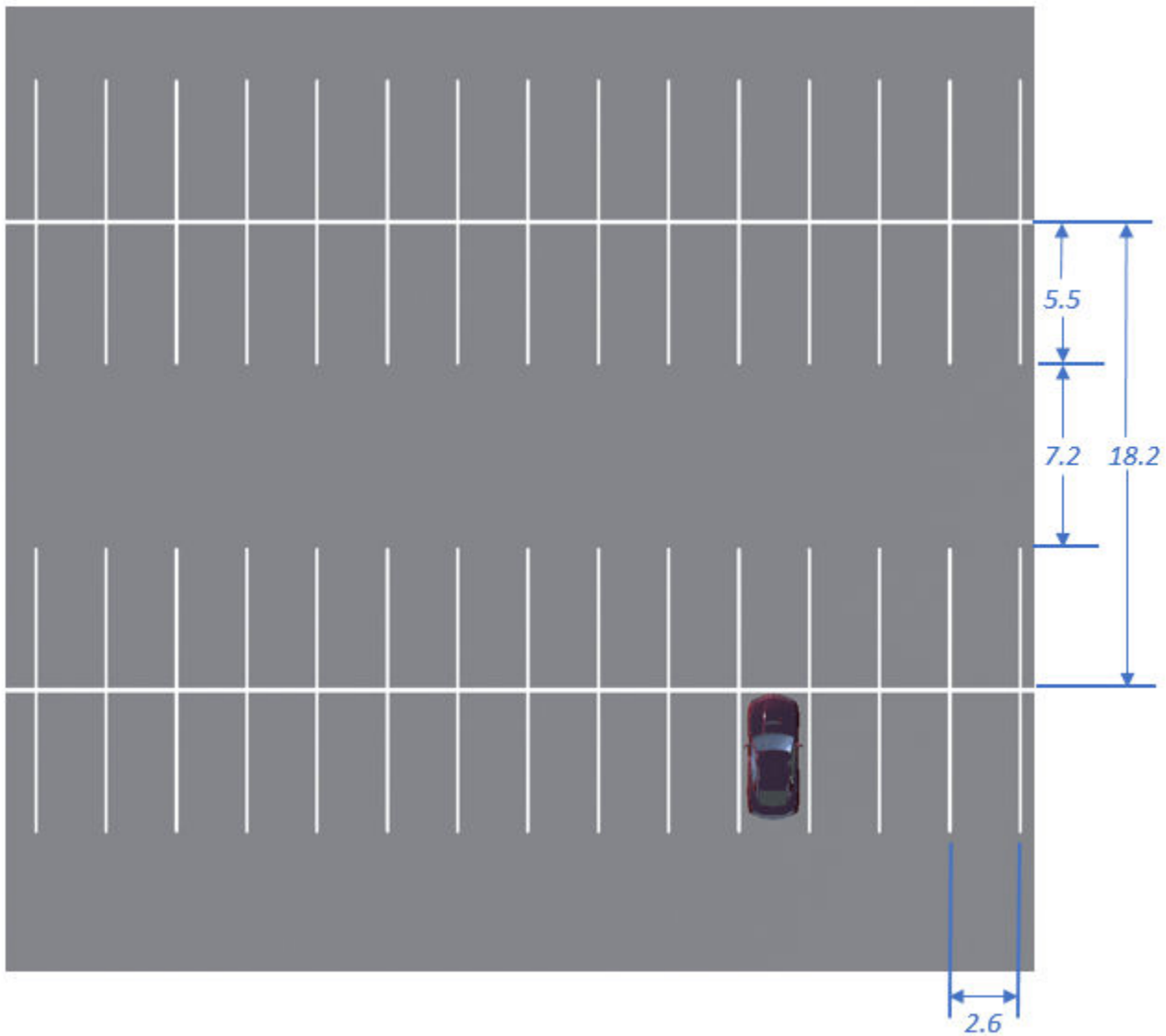
### Recommended Starting Location

This table provides the recommended starting location for the vehicle in the world coordinate system. Dimensions are in m and deg.

Recommended Starting Location					
X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
-104.0	-9.7	0	0	0	0

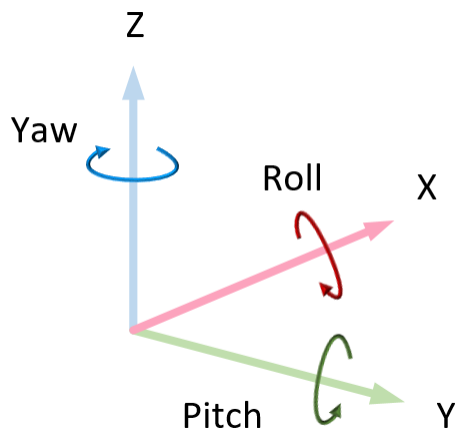
### Parking Space Dimensions

This figure shows the parking space dimensions, in m.



### World Coordinate System

The 3D visualization environment uses a world coordinate system with axes that are fixed in the inertial reference frame.



Axis	Description
X	Forward direction of the vehicle Roll — Right-handed rotation about X-axis
Y	Extends to the right of the vehicle, parallel to the ground plane Pitch — Right-handed rotation about Y-axis
Z	Extends upwards Yaw — Left-handed rotation about Z-axis

## Tips

- If you have the Vehicle Dynamics Blockset Interface for Unreal Engine 4 Projects support package, then you can modify this scene. In the Unreal Engine project file that comes with the support package, this scene is named `SimpleLot`.

For more details on customizing scenes, see “Customize 3D Scenes for Vehicle Dynamics Simulations”.

## See Also

**Curved Road** | **Double Lane Change** | **Large Parking Lot** | **Open Surface** | Simulation 3D Scene Configuration | **Straight Road** | **US City Block** | **US Highway** | **Virtual Mcity**

## Topics

“3D Visualization Engine Requirements and Limitations”  
 “How 3D Simulation for Vehicle Dynamics Blockset Works”  
 “Customize 3D Scenes for Vehicle Dynamics Simulations”

# Large Parking Lot

Large parking lot 3D environment

## Description

The **Large Parking Lot** scene is a 3D environment of a large parking lot that contains cones, curbs, traffic signs, and parked vehicles. The scene is rendered using the Unreal Engine from Epic Games.



To simulate a driving maneuver in this scene:

- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene source** parameter to Default Scenes.
- 3 Set the enabled **Scene name** parameter to Large parking lot.

## Scene Layout

The scene uses the world coordinate system to locate objects.



This table provides the scene area corner locations in the world coordinate system. Dimensions are in m and deg.

Locations	X (m)	Y (m)	Z (m)
Scene — Top left	-78.6	-73.5	0
Scene — Bottom right	72.6	77.7	0

### Recommended Vehicle Starting Location

This table provides the recommended starting location for the vehicle in the world coordinate system. Dimensions are in m and deg.

Recommended Starting Location					
X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
45.0	54.7	0	0	0	-90

### Parking Space Dimensions

This figure shows the parking space dimensions, in m.





**Other Vehicles**

This table provides the vehicle tag names and initial locations for other vehicles in the scene, in the world coordinate system. Dimensions are in m and deg.



Object	Unreal Engine Editor Name	Locations					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
Vehicle	SM_Hatchback	5.68	-14.25	0.05	0	0	-90
	SM_PickupTruck2	5.59	-40.40	0.05	0	0	90
	SM_PickupTruck	-5.35	-34.87	0.05	0	0	-90
	SM_MuscleCar	29.70	-13.80	0.05	0	0	-90
	SM_PickupTruck3	11.10	-0.9	0.05	0	0	90
	SM_SUVCar	11.10	4.80	0.05	0	0	-90
	SM_SedanCar4	5.60	4.80	0.05	0	0	-90
	SM_Hatchback2	-16.10	4.40	0.05	0	0	-90
	SM_SedanCar	-21.50	18.40	0.05	0	0	90
	SM_SUVCar2	-24.20	18.40	0.05	0	0	90
	SM_SedanCar2	-26.90	18.40	0.05	0	0	90
	SM_SedanCar3	-40.40	18.40	0.05	0	0	90
	SM_MuscleCar2	11.10	25.90	0.05	0	0	-90
	SM_Hatchback3	-21.50	38.90	0.05	0	0	90
SM_PickupTruck4	-27.00	46.40	0.05	0	0	-90	

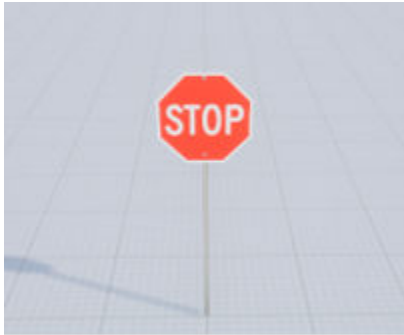
### Cones



This table provides the object names and locations in the world coordinate system. Dimensions are in m and deg.

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
Cone	SM_Cone1	-21.43	-23.41	0.05	0	0	0
	SM_Cone2	-24.20	36.19	0.05	0	0	0
	SM_Cone3	-37.74	48.02	0.05	0	0	0
	SM_Cone4	-26.97	-2.68	0.05	0	0	0
	SM_Cone5	13.95	28.21	0.05	0	0	0

### Traffic Signs



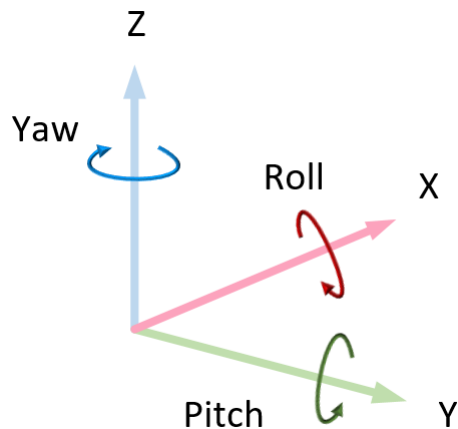
This table provides the object names and locations in the world coordinate system. Dimensions are in m and deg.

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
Traffic signs	SM_StopSign1	34.77	57.38	0.11	0	0	0
	SM_StopSign2	35.29	36.38	0.11	0	0	0
	SM_StopSign3	35.28	15.955	0.11	0	0	180
	SM_StopSign4	35.35	-2.92	0.11	0	0	180
	SM_StopSign5	35.69	-23.64	0.11	0	0	0
	SM_DisabilitySign 1	23.81	42.71	0.11	0	0	0
	SM_DisabilitySign 2	29.21	42.71	0.11	0	0	0
	SM_DisabilitySign 3	23.81	41.71	0.11	0	0	180

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
	SM_DisabilitySign 4	29.21	41.71	0.11	0	0	180
	SM_DisabilitySign 5	24.25	-17.01	0.11	0	0	0
	SM_DisabilitySign 6	29.69	-17.01	0.11	0	0	0
	SM_DisabilitySign 7	25.25	-18.31	0.11	0	0	180
	SM_DisabilitySign 8	29.69	-18.31	0.11	0	0	180

### World Coordinate System

The 3D visualization environment uses a world coordinate system with axes that are fixed in the inertial reference frame.



Axis	Description
X	Forward direction of the vehicle Roll — Right-handed rotation about X-axis
Y	Extends to the right of the vehicle, parallel to the ground plane Pitch — Right-handed rotation about Y-axis
Z	Extends upwards Yaw — Left-handed rotation about Z-axis

## Tips

- If you have the Vehicle Dynamics Blockset Interface for Unreal Engine 4 Projects support package, then you can modify this scene. In the Unreal Engine project file that comes with the support package, this scene is named LargeParkingLot.

For more details on customizing scenes, see “Customize 3D Scenes for Vehicle Dynamics Simulations”.

## See Also

**Curved Road** | **Double Lane Change** | **Open Surface** | **Parking Lot** | Simulation 3D Scene Configuration | **Straight Road** | **US City Block** | **US Highway** | **Virtual Mcity**

## Topics

“3D Visualization Engine Requirements and Limitations”

“How 3D Simulation for Vehicle Dynamics Blockset Works”

“Customize 3D Scenes for Vehicle Dynamics Simulations”

# Open Surface

Open surface 3D environment

## Description

The **Open Surface** scene contains a 3D environment of an open, black road surface. The scene is rendered using the Unreal Engine from Epic Games.

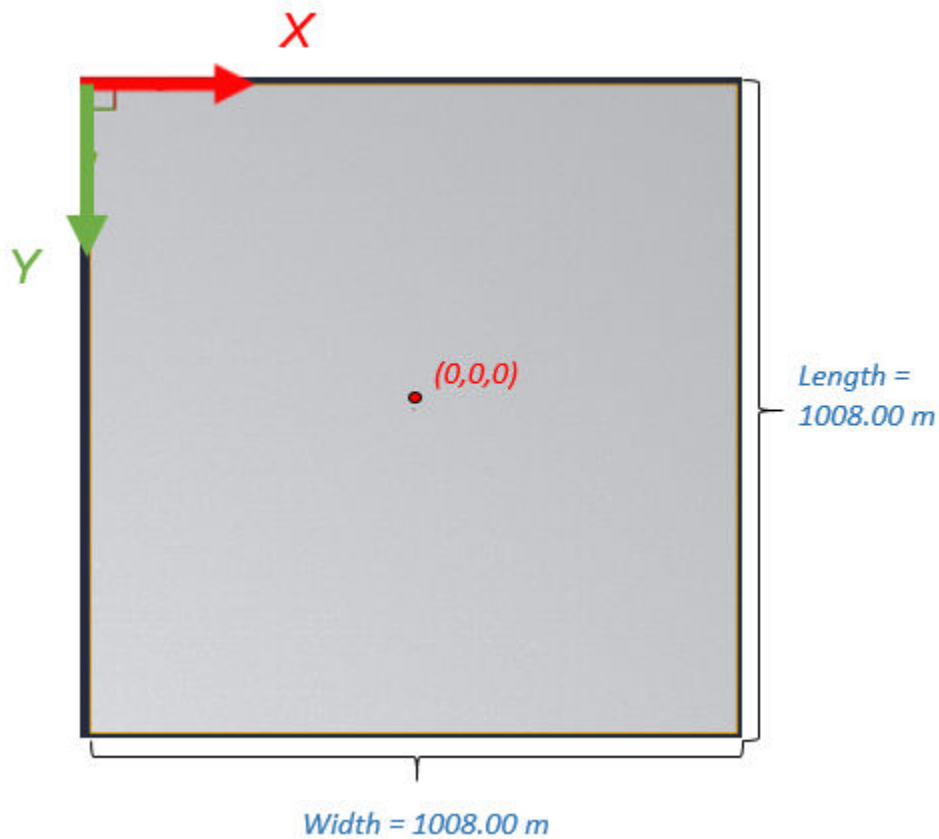


To simulate a driving maneuver in this scene:

- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene source** parameter to Default Scenes.
- 3 Set the enabled **Scene name** parameter to Open surface.

## Scene Layout

The scene uses the world coordinate system to locate objects.



This table provides the scene corner locations in the world coordinate system. Dimensions are in m.

Location	X	Y	Z
Scene — Bottom left	-504.00	504.00	0
Scene — Top right	504.00	-504.00	0

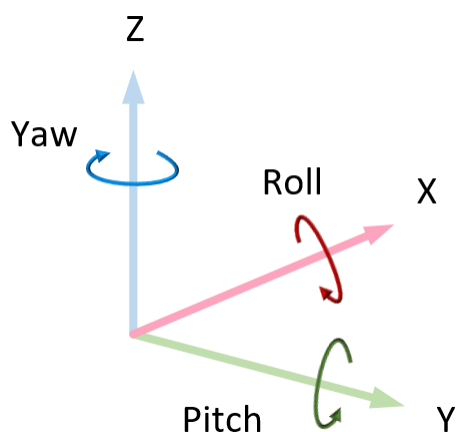
### Recommended Starting Location

This table provides the recommended starting location for the vehicle in the world coordinate system. Dimensions are in m and deg.

Recommended Starting Location					
X	Y	Z	Roll	Pitch	Yaw
(m)	(m)	(m)	(deg)	(deg)	(deg)
0	0	0	0	0	0

### World Coordinate System

The 3D visualization environment uses a world coordinate system with axes that are fixed in the inertial reference frame.



Axis	Description
X	Forward direction of the vehicle Roll — Right-handed rotation about X-axis
Y	Extends to the right of the vehicle, parallel to the ground plane Pitch — Right-handed rotation about Y-axis
Z	Extends upwards Yaw — Left-handed rotation about Z-axis

## Tips

- If you have the Vehicle Dynamics Blockset Interface for Unreal Engine 4 Projects support package, then you can modify this scene. In the Unreal Engine project file that comes with the support package, this scene is named `BlackLake`.

For more details on customizing scenes, see “Customize 3D Scenes for Vehicle Dynamics Simulations”.

## See Also

**Curved Road** | **Double Lane Change** | **Large Parking Lot** | **Parking Lot** | Simulation 3D Scene Configuration | **Straight Road** | **US City Block** | **US Highway** | **Virtual Mcity**

## Topics

“3D Visualization Engine Requirements and Limitations”

“How 3D Simulation for Vehicle Dynamics Blockset Works”

“Customize 3D Scenes for Vehicle Dynamics Simulations”

## Double Lane Change

Double lane change 3D environment

### Description

The **Double Lane Change** scene is a 3D environment of a straight road containing cones, traffic signs, and barrels. The cones are set up for a vehicle to perform a double lane change maneuver. The scene is rendered using the Unreal Engine from Epic Games.



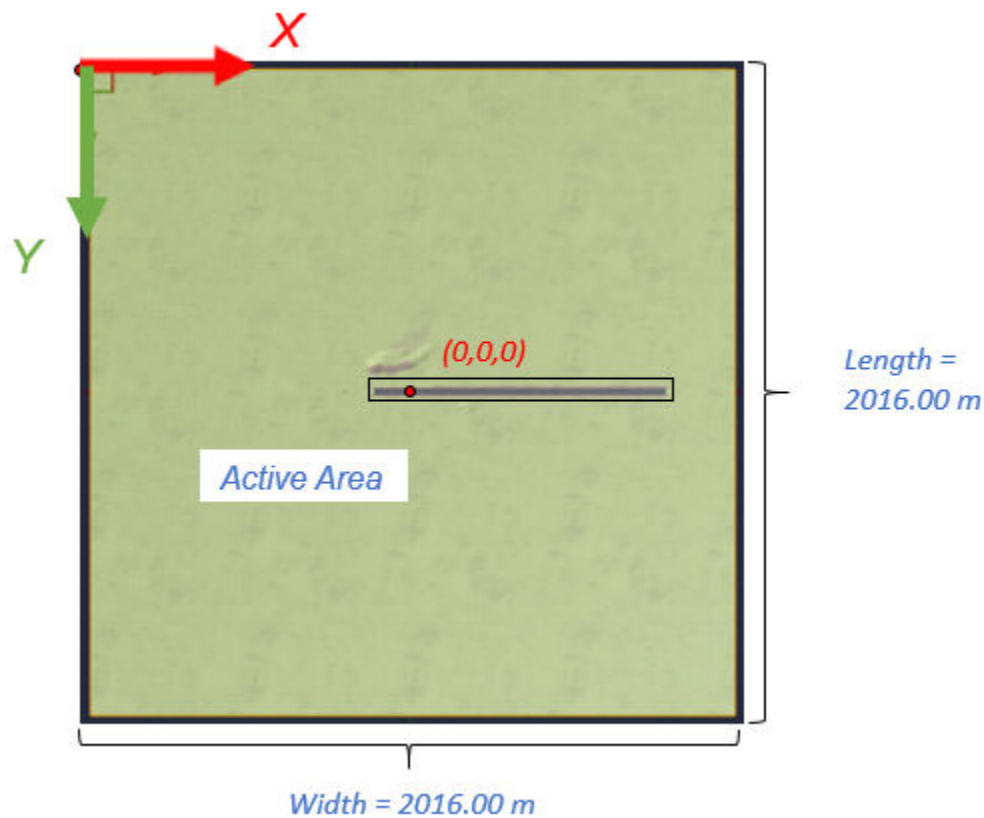
To simulate a driving maneuver in this scene:

- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene source** parameter to Default Scenes.
- 3 Set the enabled **Scene name** parameter to Double lane change.

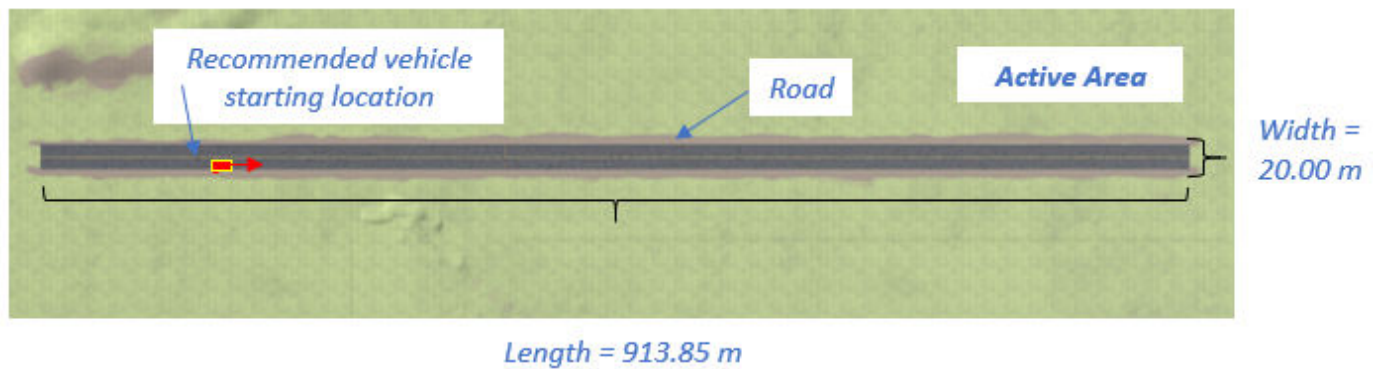
### Scene Layout

The scene uses the world coordinate system to locate objects.





The active area of the scene contains the road.



This table provides the scene area corner locations in the world coordinate system. Dimensions are in m.

Locations	X	Y	Z
Scene — Top left	-1008	-1008	0
Scene — Bottom right	1008	1008	0
Active area — Bottom left	-122.19	6.99	0

### Recommended Starting Location

This table provides the recommended starting location for the vehicle in the world coordinate system. Dimensions are in m and deg.

Recommended Starting Location					
X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
0	3.125	0	0	0	0

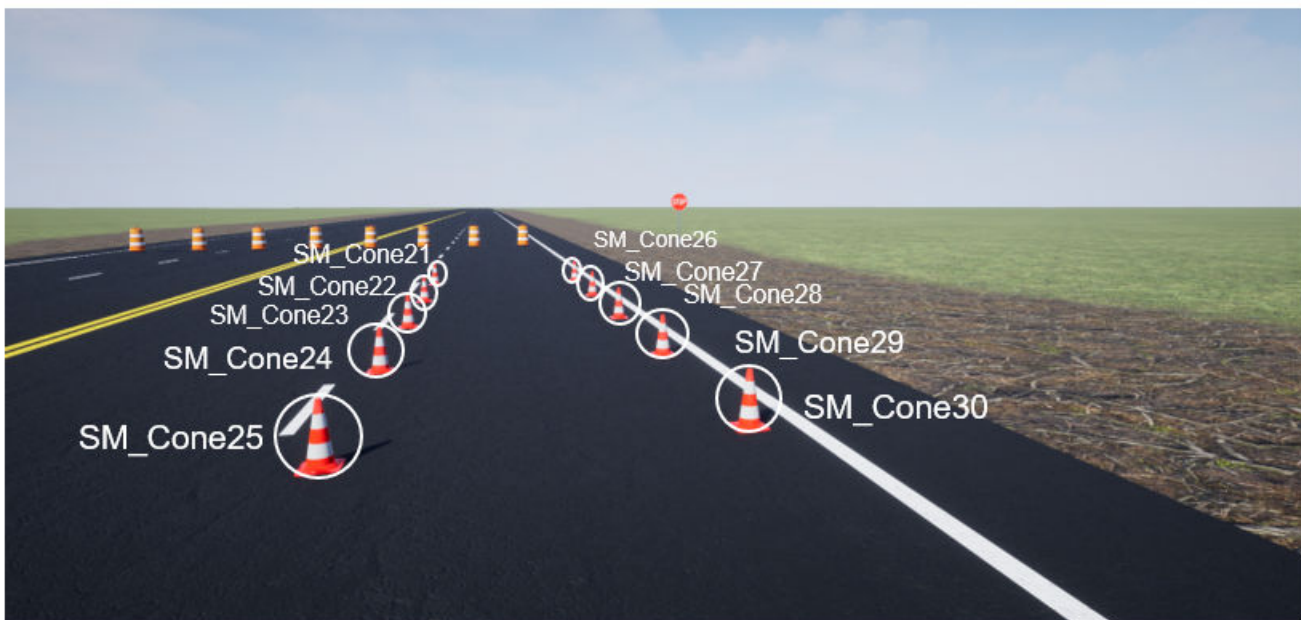
### Cones

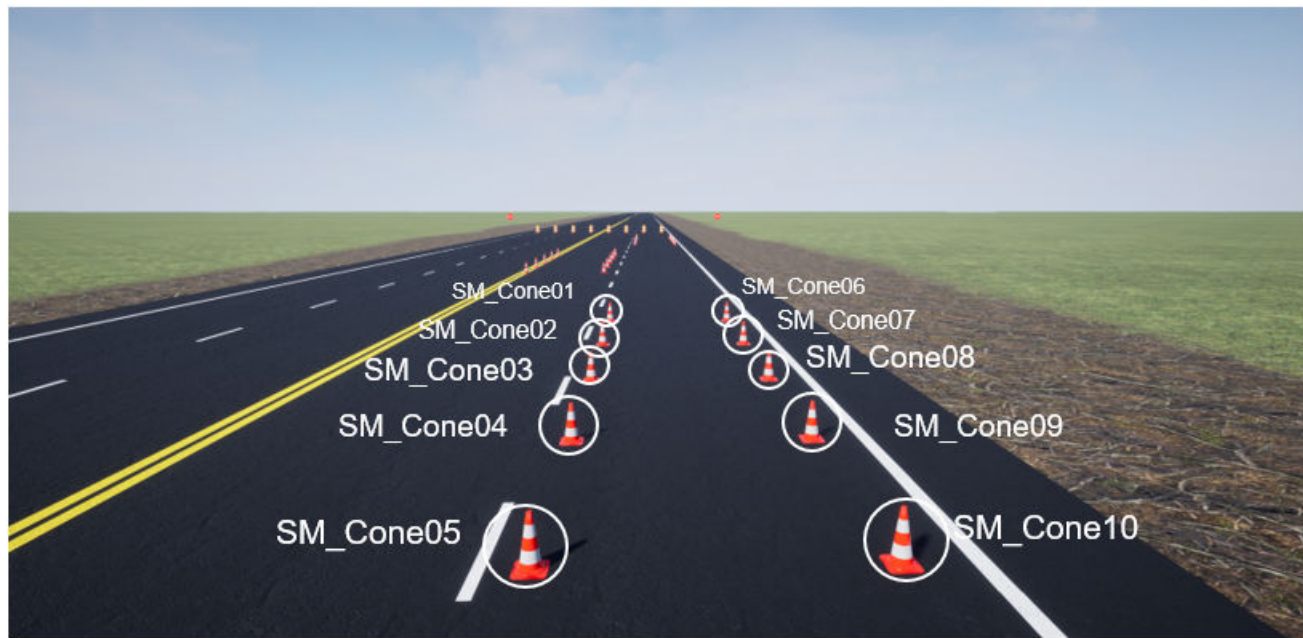
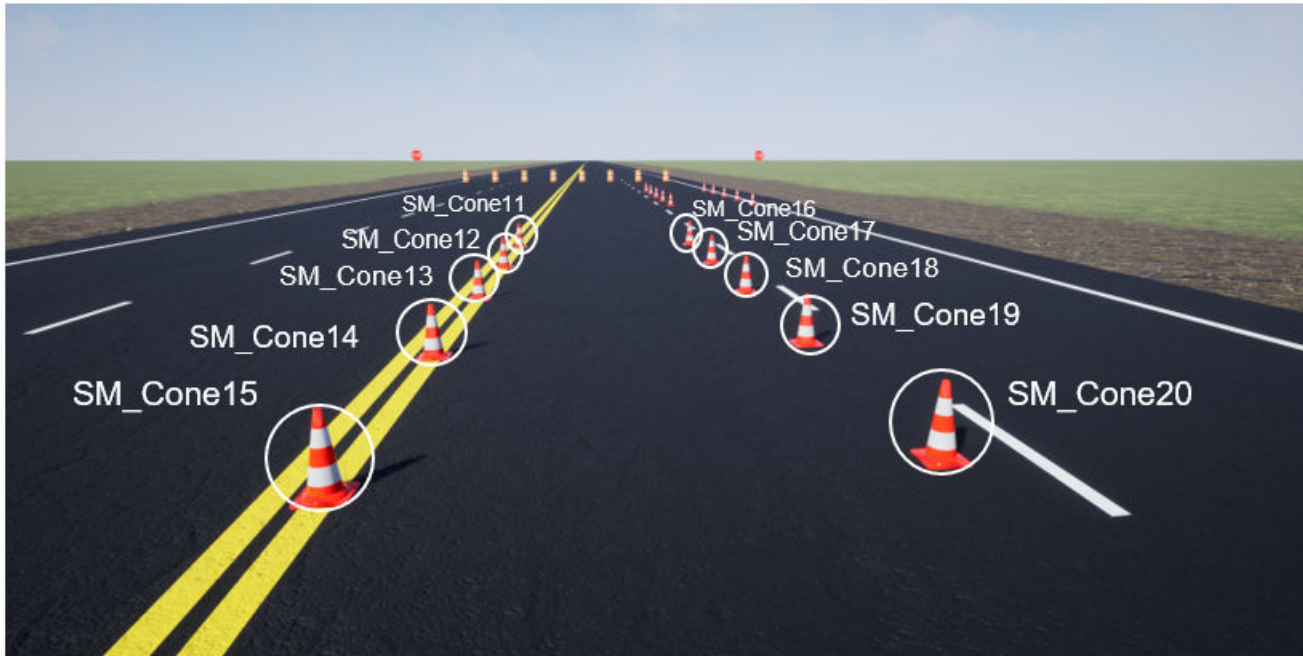


This table provides the object names and locations in the world coordinate system. Dimensions are in m.

Object	Unreal Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
Cone	SM_Cone01	187.90	1.70	.009	0	0	0
	SM_Cone02	184.90	1.70	.009			
	SM_Cone03	181.90	1.70	.009			
	SM_Cone04	178.90	1.70	.009			
	SM_Cone05	175.90	1.70	.009			
	SM_Cone06	187.90	4.73	.009			
	SM_Cone07	184.90	4.73	.009			
	SM_Cone08	181.90	4.73	.009			
	SM_Cone09	178.90	4.73	.009			
	SM_Cone10	175.90	4.73	.009			
	SM_Cone11	212.40	-2.86	.009			
	SM_Cone12	209.65	-2.86	.009			
	SM_Cone13	206.90	-2.86	.009			
	SM_Cone14	204.15	-2.86	.009			

Object	Unreal Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
	SM_Cone15	201.40	-2.86	.009			
	SM_Cone16	212.40	0.69	.009			
	SM_Cone17	209.65	0.69	.009			
	SM_Cone18	206.90	0.69	.009			
	SM_Cone19	204.15	0.69	.009			
	SM_Cone20	201.40	0.69	.009			
	SM_Cone21	236.90	1.70	.009			
	SM_Cone22	236.90	1.70	.009			
	SM_Cone23	230.90	1.70	.009			
	SM_Cone24	227.90	1.70	.009			
	SM_Cone25	224.90	1.70	.009			
	SM_Cone26	236.90	4.95	.009			
	SM_Cone27	233.90	4.95	.009			
	SM_Cone28	230.90	4.95	.009			
	SM_Cone29	227.90	4.95	.009			
	SM_Cone30	224.90	4.95	.009			





In the Unreal Editor, the scene has a `Sim3DSetBoolean` actor with signal name `NumOfConesHit`. You can use it with the `Simulation 3D Message Get` block to retrieve how many cones the vehicle hits during a double-lane change maneuver.

## Traffic Signs



This table provides the object names and locations in the world coordinate system. Dimensions are in m.

Object	Unreal Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
Traffic sign	SM_StopSign	248.80	-13.10	0	0	0	0
	SM_StopSign2	248.80	10.90	0			

## Traffic Signal Light



This table provides the object name and location in the world coordinate system. Dimensions are in m.

Object	Unreal Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
Traffic signal light	SM_Traffic LightsSide Only	5.43	6.00	0	0	0	180.00°

In the Unreal Editor, the Double Lane Change scene has a `Sim3DGetInteger` actor with signal name `TrafficLight1`. You can use it with the Simulation 3D Message Set block to control the traffic signal light color.

### Barrels

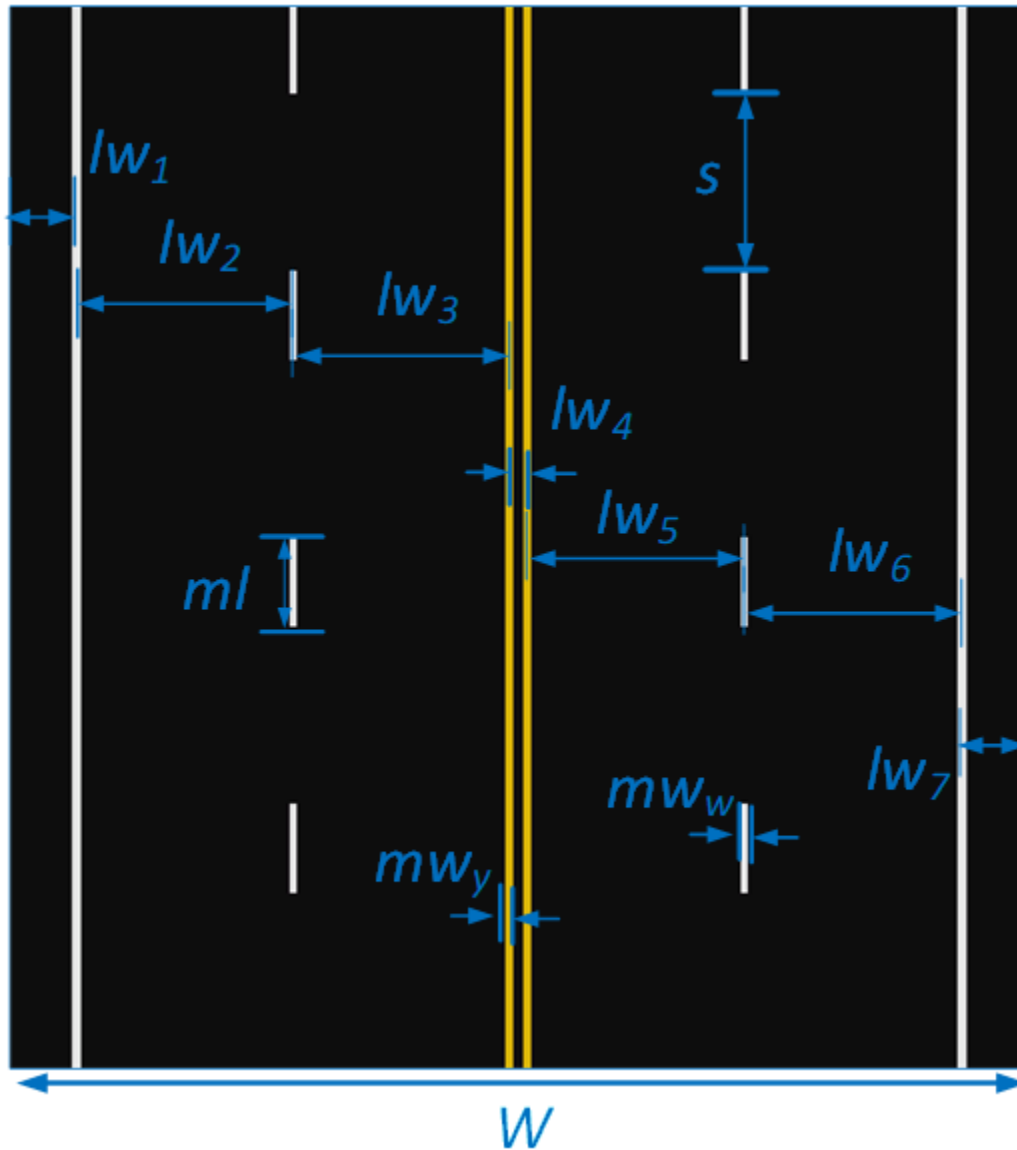


This table provides the object names and locations in the world coordinate system. Dimensions are in m.

Object	Unreal Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
Barrels	SM_Traffic Barrel1	252.70	4.50	0	0	0	180.00°
	SM_Traffic Barrel2	252.70	2.35	0	0	0	0
	SM_Traffic Barrel3	252.70	.20	0	0	0	0
	SM_Traffic Barrel4	252.70	-1.95	0	0	0	0
	SM_Traffic Barrel5	252.70	-4.10	0	0	0	0
	SM_Traffic Barrel6	252.70	-6.25	0	0	0	0
	SM_Traffic Barrel7	252.70	-8.40	0	0	0	0
	SM_Traffic Barrel8	252.70	-10.55	0	0	0	0

### Lane Dimensions

This figure and table provides the lane dimensions, in m.

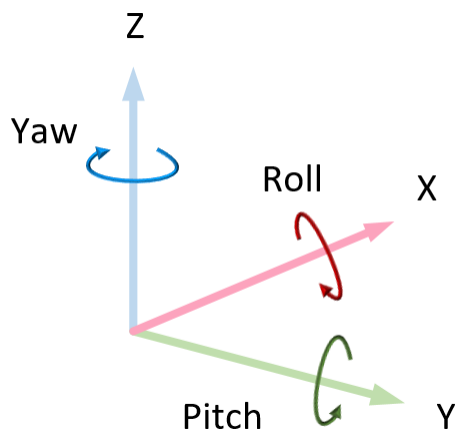


Variable	Dimension (m)
$lw_1$	1.33
$lw_2$	4.25
$lw_3$	4.25
$lw_4$	0.34
$lw_5$	4.25
$lw_6$	4.25
$lw_7$	1.33

Variable	Dimension (m)
$ml$	1.5
$s$	2.0
$mw_w$	0.13
$mw_y$	0.17
$W$	20.0

### World Coordinate System

The 3D visualization environment uses a world coordinate system with axes that are fixed in the inertial reference frame.



Axis	Description
X	Forward direction of the vehicle Roll — Right-handed rotation about X-axis
Y	Extends to the right of the vehicle, parallel to the ground plane Pitch — Right-handed rotation about Y-axis
Z	Extends upwards Yaw — Left-handed rotation about Z-axis

### Tips

- If you have the Vehicle Dynamics Blockset Interface for Unreal Engine 4 Projects support package, then you can modify this scene. In the Unreal Engine project file that comes with the support package, this scene is named DbLLnChng.

For more details on customizing scenes, see “Customize 3D Scenes for Vehicle Dynamics Simulations”.



## **See Also**

**Curved Road** | **Large Parking Lot** | **Open Surface** | **Parking Lot** | Simulation 3D Scene Configuration | **Straight Road** | **US City Block** | **US Highway** | **Virtual Mcity**

## **Topics**

“Send and Receive Double-Lane Change Scene Data”  
“3D Visualization Engine Requirements and Limitations”  
“How 3D Simulation for Vehicle Dynamics Blockset Works”  
“Customize 3D Scenes for Vehicle Dynamics Simulations”

## US City Block

US city block 3D environment

### Description

The **US City Block** scene is a 3D environment of a US city block that contains 15 intersections and 30 traffic lights. The scene is rendered using the Unreal Engine from Epic Games.

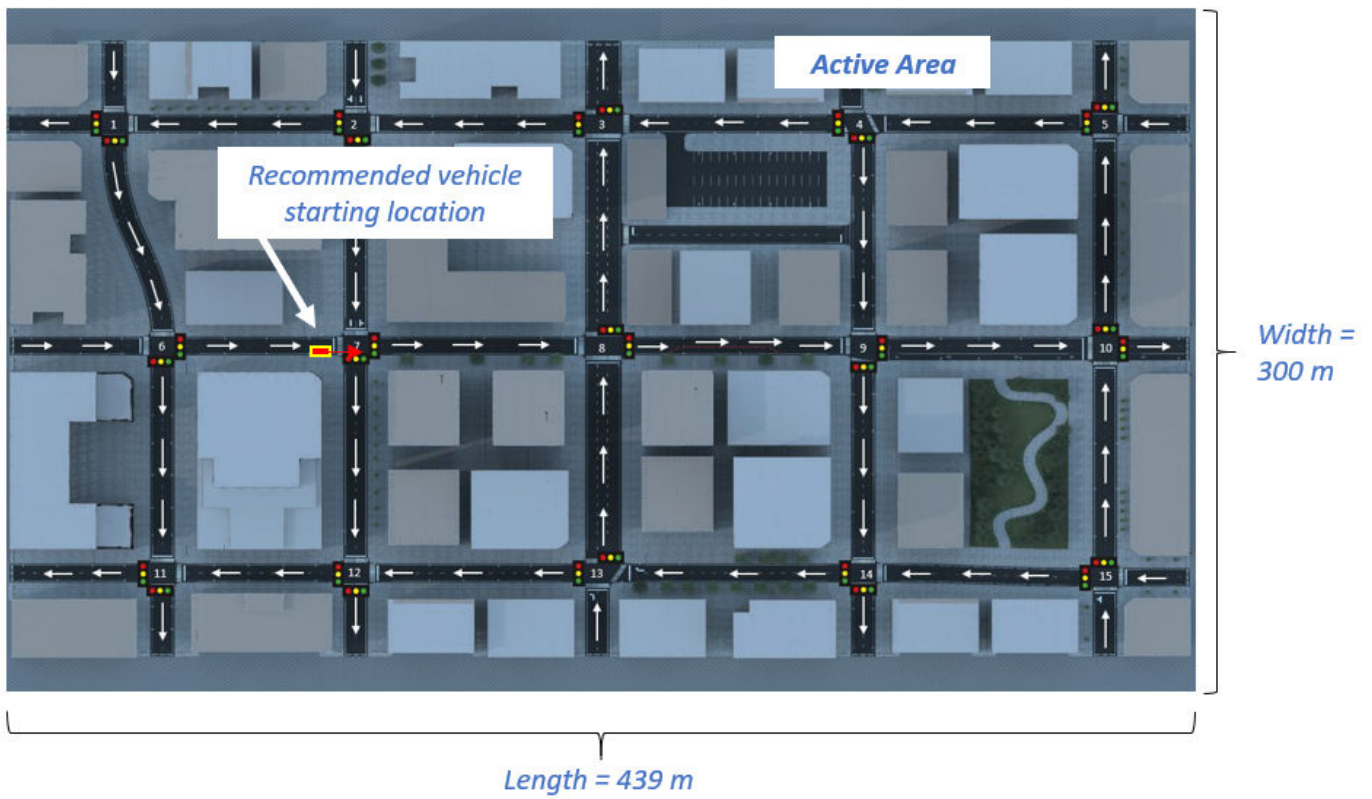
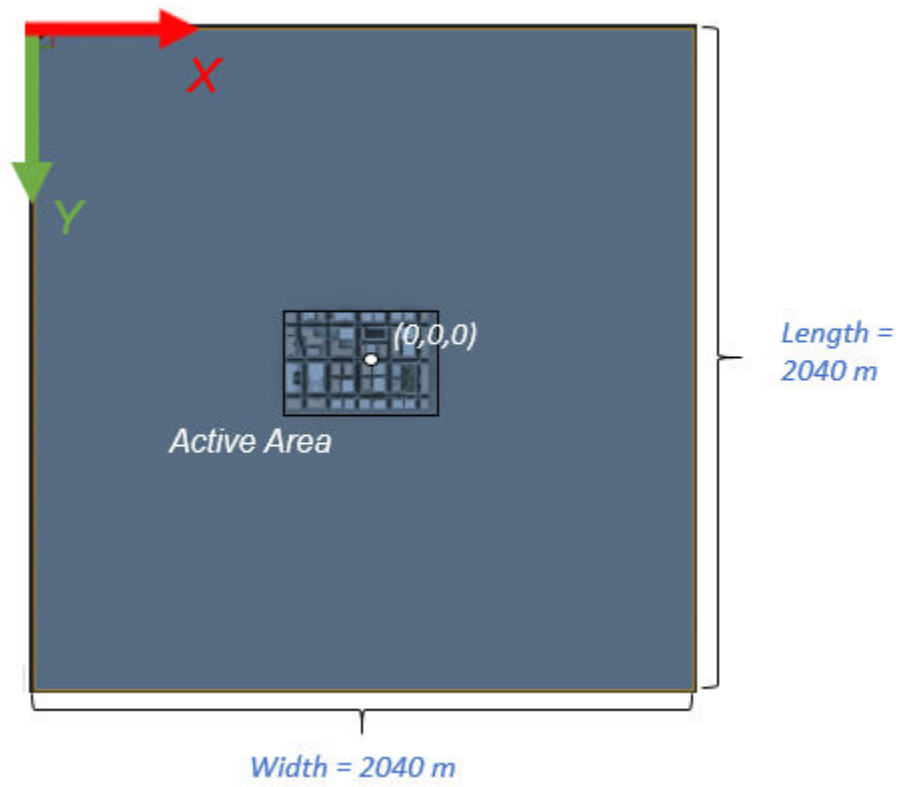


To simulate a driving maneuver in this scene:

- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene source** parameter to Default Scenes.
- 3 Set the enabled **Scene name** parameter to US city block.

### Scene Layout

The scene uses the world coordinate system to locate objects.



This table provides the scene area corner locations in the world coordinate system. Dimensions are in m.

<b>Locations</b>	<b>X (m)</b>	<b>Y (m)</b>	<b>Z (m)</b>
Scene — Top left	-1020	-1020	0
Scene — Bottom right	1020	1020	0
Active area — Bottom left	-240.77	151.67	0

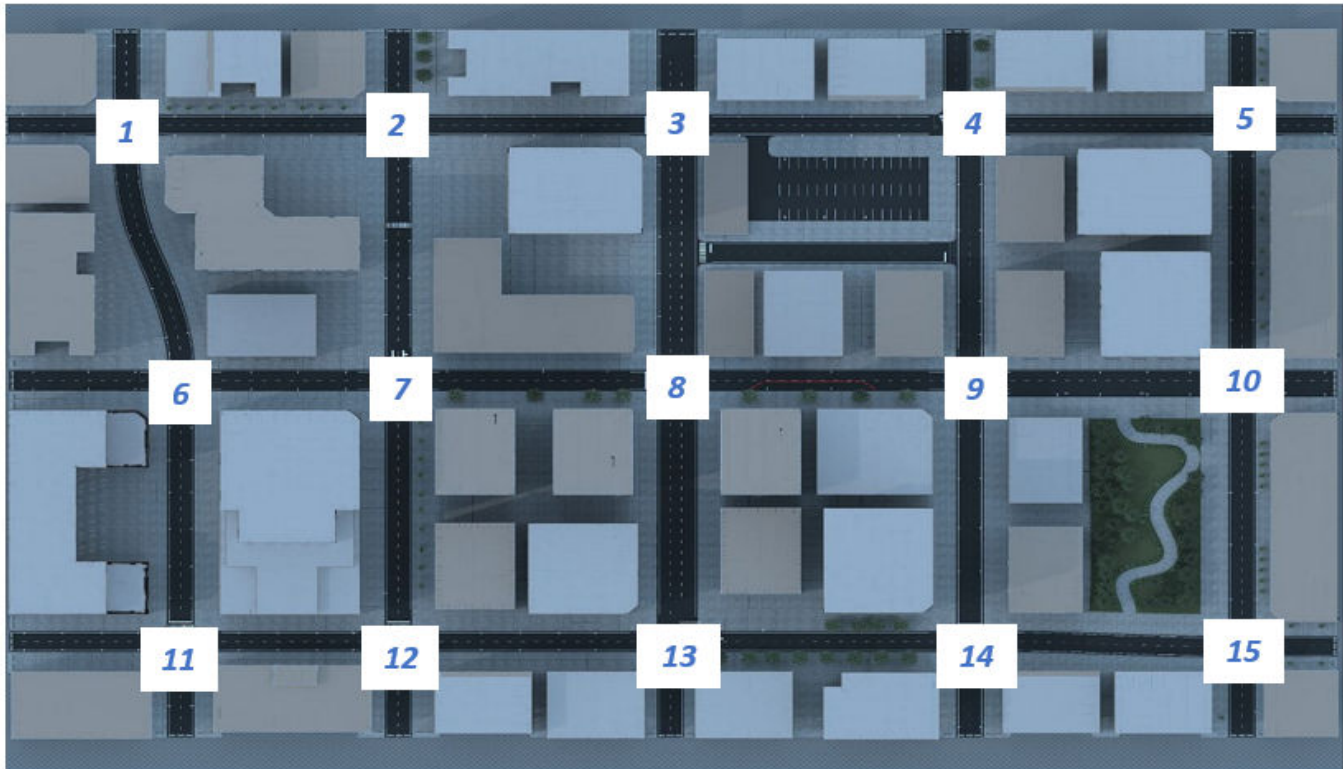
### Recommended Starting Location

This table provides the recommended starting location for the vehicle in the world coordinate system. Dimensions are in m and deg.

<b>Recommended Starting Location</b>					
<b>X (m)</b>	<b>Y (m)</b>	<b>Z (m)</b>	<b>Roll (deg)</b>	<b>Pitch (deg)</b>	<b>Yaw (deg)</b>
-125.19	1.65	0.04 <i>-0.04 in vehicle Z-down coordinate system</i>	0	0	0

### Intersections

The US city block scene has 15 intersections, as indicated in this diagram.

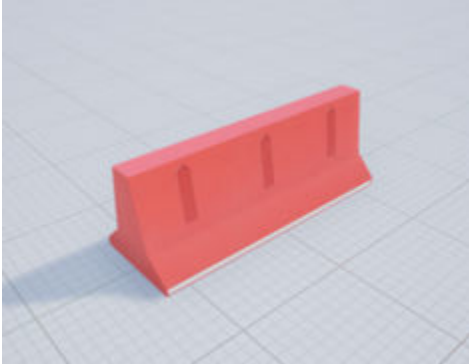


This table provides the intersection locations in the world coordinate system. Dimensions are in m.

Intersection	Center Location		
	X (m)	Y (m)	Z (m)
1	-202.60	-108	.01
2	-112.60	-108	.01
3	-20.38	-108	.01
4	74.58	-108	.01
5	166.40	-108	.01
6	-184.60	0	.01
7	-112.60	0	.01
8	-20.34	0	.01
9	76.40	0	.01
10	166.46	0	.01
11	-184.60	110.50	.01
12	-112.60	110.50	.01
13	-22.60	110.50	.01
14	76.40	110.50	.01

Intersection	Center Location		
	X (m)	Y (m)	Z (m)
15	166.40	112.50	.01

### Barrier



This table provides the object names and locations in the world coordinate system. Dimensions are in m.

Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
Barrier	SM_Barrier	163.5	-146.95	0	0	0	90°
	SM_Barrier 2	166.35	-146.95	0	0	0	90°
	SM_Barrier 3	169.2	-146.95	0	0	0	90°
	SM_Barrier 7	163.5	150.15	0	0	0	90°
	SM_Barrier 8	166.35	150.15	0	0	0	90°
	SM_Barrier 9	169.2	150.15	0	0	0	90°
	SM_Barrier 11	197.05	109.65	0	0	0	-180°
	SM_Barrier 13	197.05	112.5	0	0	0	-180°
	SM_Barrier 14	197.05	115.34	0	0	0	-180°
	SM_Barrier 18	197.05	-2.9	0	0	0	-180°

Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
	SM_Barrier 19	197.05	-0.05	0	0	0	-180°
	SM_Barrier 20	197.05	2.8	0	0	0	-180°
	SM_Barrier 21	-240.5	107.65	0	0	0	-180°
	SM_Barrier 22	197.05	-110.9	0	0	0	-180°
	SM_Barrier 24	197.05	5.6	0	0	0	-180°
	SM_Barrier 27	197.05	-108.05	0	0	0	-180°
	SM_Barrier 28	197.05	-105.25	0	0	0	-180°
	SM_Barrier 31	-240.5	110.5	0	0	0	-180°
	SM_Barrier 32	-240.5	113.35	0	0	0	-180°
	SM_Barrier 36	-240.1	-2.9	0	0	0	-180°
	SM_Barrier 37	-240.1	-0.05	0	0	0	-180°
	SM_Barrier 38	-240.1	2.8	0	0	0	-180°
	SM_Barrier 43	-242.15	110.9	0	0	0	-180°
	SM_Barrier 44	-242.15	-108.05	0	0	0	-180°
	SM_Barrier 45	-242.15	-105.25	0	0	0	-180°
	SM_Barrier 48	73.4	150.15	0	0	0	90°
	SM_Barrier 49	76.25	150.15	0	0	0	90°
	SM_Barrier 50	79.1	150.15	0	0	0	90°
	SM_Barrier 54	-25.55	150.15	0	0	0	90°
	SM_Barrier 55	-22.7	150.15	0	0	0	90°

Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
	SM_Barrier 56	-19.85	150.15	0	0	0	90°
	SM_Barrier 59	-115.3	150.15	0	0	0	90°
	SM_Barrier 60	-112.45	150.15	0	0	0	90°
	SM_Barrier 61	-109.6	150.15	0	0	0	90°
	SM_Barrier 66	69.25	-147.35	0	0	0	90°
	SM_Barrier 68	75.45	-147.5	0.15	0	0	90°
	SM_Barrier 69	72.45	-147.5	0.15	0	0	90°
	SM_Barrier 70	-25.55	-146.45	0	0	0	90°
	SM_Barrier 71	-22.15	-146.45	0	0	0	90°
	SM_Barrier 72	-18.65	-146.45	0	0	0	90°
	SM_Barrier 75	-115.3	-147.6	0	0	0	90°
	SM_Barrier 76	-112.45	-147.6	0	0	0	90°
	SM_Barrier 77	-109.6	-147.6	0	0	0	90°
	SM_Barrier 84	-15.45	-146.45	0	0	0	90°
	SM_Barrier 88	-187.5	150.15	0	0	0	90°
	SM_Barrier 89	-184.65	150.15	0	0	0	90°
	SM_Barrier 90	-181.8	150.15	0	0	0	90°
	SM_Barrier 94	-205.6	-147.4	0	0	0	90°
	SM_Barrier 95	-202.75	-147.4	0	0	0	90°
	SM_Barrier 96	-199.9	-147.4	0	0	0	90°



Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
	SM_Barrier 101	44.15	3.05	0	0	0	-50°
	SM_Barrier 102	39.15	0.55	0	0	0	-90°
	SM_Barrier 103	41.95	1.3	0	0	0	-50°
	SM_Barrier 104	36.5	.55	0	0	0	-90°
	SM_Barrier 105	33.85	.55	0	0	0	-90°
	SM_Barrier 106	31.2	.55	0	0	0	-90°
	SM_Barrier 107	28.45	.55	0	0	0	-90°
	SM_Barrier 108	25.8	.55	0	0	0	-90°
	SM_Barrier 109	23.15	.55	0	0	0	-90°
	SM_Barrier 110	20.5	.55	0	0	0	-90°
	SM_Barrier 111	17.95	.55	0	0	0	-90°
	SM_Barrier 112	15.3	.55	0	0	0	-90°
	SM_Barrier 113	12.65	.55	0	0	0	-90°
	SM_Barrier 114	10.0	.55	0	0	0	-90°
	SM_Barrier 115	7.01	1.38	0	0	0	-125°
	SM_Barrier 116	4.75	3.05	0	0	0	-125°

## Traffic Lights



The US City Scene contains 30 traffic lights, two at each of the 15 intersections. Each intersection has a traffic light group. If you have the “Customize 3D Scenes for Vehicle Dynamics Simulations” for customizing scenes, you can control the timing of the traffic lights.

This table provides the traffic light names and locations in the world coordinate system. Dimensions are in m. Only one of the traffic lights in the group can be green at a time. The traffic lights are green for 10 s and yellow for 3 s. At the start of the simulation, the first traffic lights in the group are green (for example, SM\_TrafficLights1\_3 and SM\_TrafficLights2\_3). The second lights in the group are red (for example, SM\_TrafficLights1\_4 and SM\_TrafficLights2\_4).

Intersect ion	Unreal Engine Editor Name		Location					
	Traffic Light Group	Traffic Light	X	Y	Z	Roll	Pitch	Yaw
1	TrafficLig htGroup	SM_Tr affic Light s1_3	-196.55	-100.65	0	0	0	90°
		SM_Tr affic Light s1_4	-210.20	-113.40	0	0	0	0
2	TrafficLig htGroup2	SM_Tr affic Light s2_3	-106.35	98.35	0	0	0	-90°
		SM_Tr affic Light s2_4	-120.40	-113.50	0	0	0	0
3	TrafficLig htGroup3	SM_Tr affic Light s3_1	-13.10	-116.20	0.2	0	0	90°

Intersection	Unreal Engine Editor Name		Location					
	Traffic Light Group	Traffic Light	X	Y	Z	Roll	Pitch	Yaw
		SM_TrafficLight_s3_4	-30.60	-113.80	0	0	0	0
4	TrafficLightGroup4	SM_TrafficLight_s4_3	71.40	-100.30	0	0	0	-100°
		SM_TrafficLight_s4_4	64.80	-113.0	0	0	0	0
5	TrafficLightGroup5	SM_TrafficLight_s5_1	171.50	-115.70	0	0	0	90°
		SM_TrafficLight_s5_4	157.40	-113.50	0	0	0	0
6	TrafficLightGroup6	SM_TrafficLight_s6_2	-177.30	5.70	0	0	0	180°
		SM_TrafficLight_s6_3	-189.60	7.40	0	0	0	-90°
7	TrafficLightGroup7	SM_TrafficLight_s7_2	-105.20	5.50	0	0	0	180°
		SM_TrafficLight_s7_3	-117.80	7.70	0.2	0	0	-90°
8	TrafficLightGroup8	SM_TrafficLight_s8_1	-13.10	-7.60	0.1	0	0	90°

Intersection	Unreal Engine Editor Name		Location					
	Traffic Light Group	Traffic Light	X	Y	Z	Roll	Pitch	Yaw
		SM_Traffic Lights8_2	-10.90	5.60	0	0	0	180°
9	TrafficLightGroup9	SM_Traffic Lights9_2	85.90	7.60	0.2	0	0	180°
		SM_Traffic Lights9_3	70.90	9.20	0	0	0	-90°
10	TrafficLightGroup10	SM_Traffic Lights10_1	172.10	-7.70	0	0	0	90°
		SM_Traffic Lights10_2	173.70	7.50	0	0	0	180°
11	TrafficLightGroup11	SM_Traffic Lights11_3	-189.80	118.45	0	0	0	-90°
		SM_Traffic Lights11_4	-191.05	104.55	0	0	0	0
12	TrafficLightGroup12	SM_Traffic Lights12_3	-117.60	117.60	0	0	0	-90°
		SM_Traffic Lights12_4	-120.50	105.40	0	0	0	0
13	TrafficLightGroup13	SM_Traffic Lights13_1	-12.80	102.50	0	0	0	90°

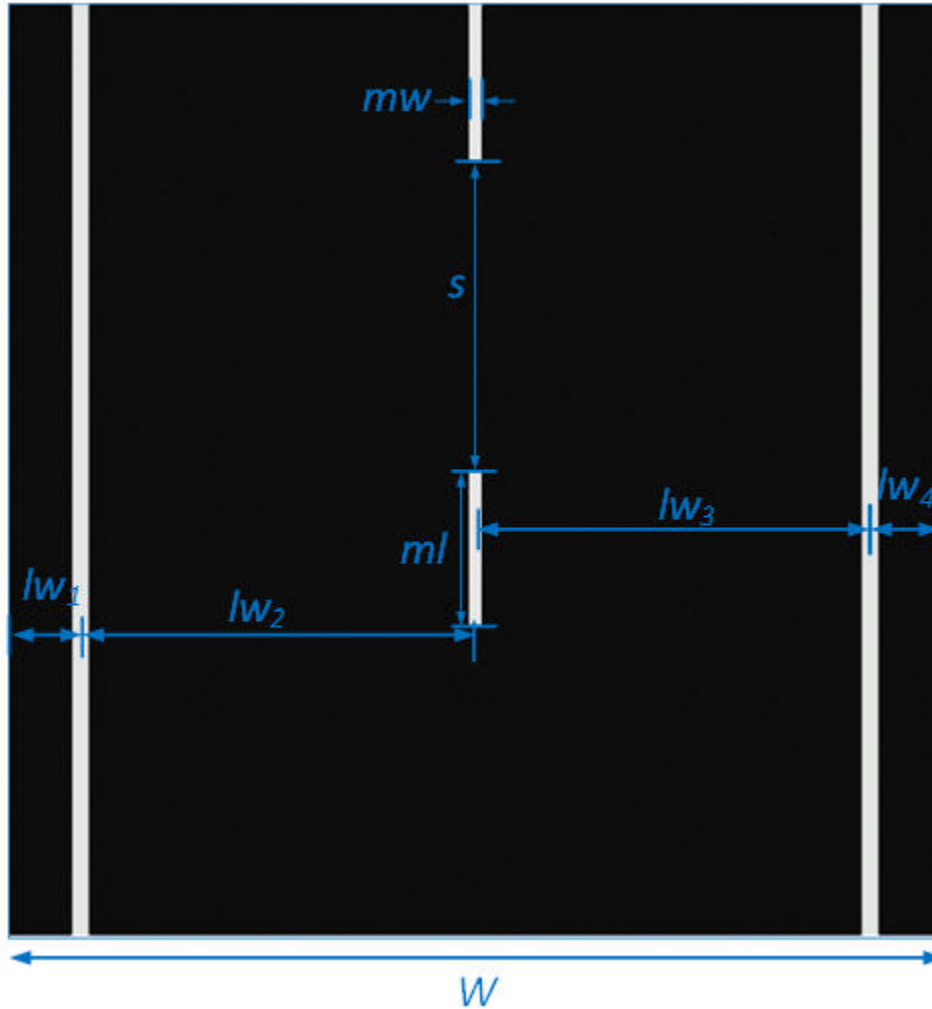
Intersection	Unreal Engine Editor Name		Location					
	Traffic Light Group	Traffic Light	X	Y	Z	Roll	Pitch	Yaw
		SM_TrafficLight_s13_4	-30.50	105.30	0	0	0	0
14	TrafficLightGroup14	SM_TrafficLight_s14_3	70.90	118.70	0	0	0	-90°
		SM_TrafficLight_s14_4	69.30	105.30	0	0	0	0
15	TrafficLightGroup15	SM_TrafficLight_s15_1	171.40	105.20	0	0	0	90°
		SM_TrafficLight_s15_4	158.40	107.20	0	0	0	0

### Lane Dimensions

The scene contains three types of roads.

#### Road Type 1

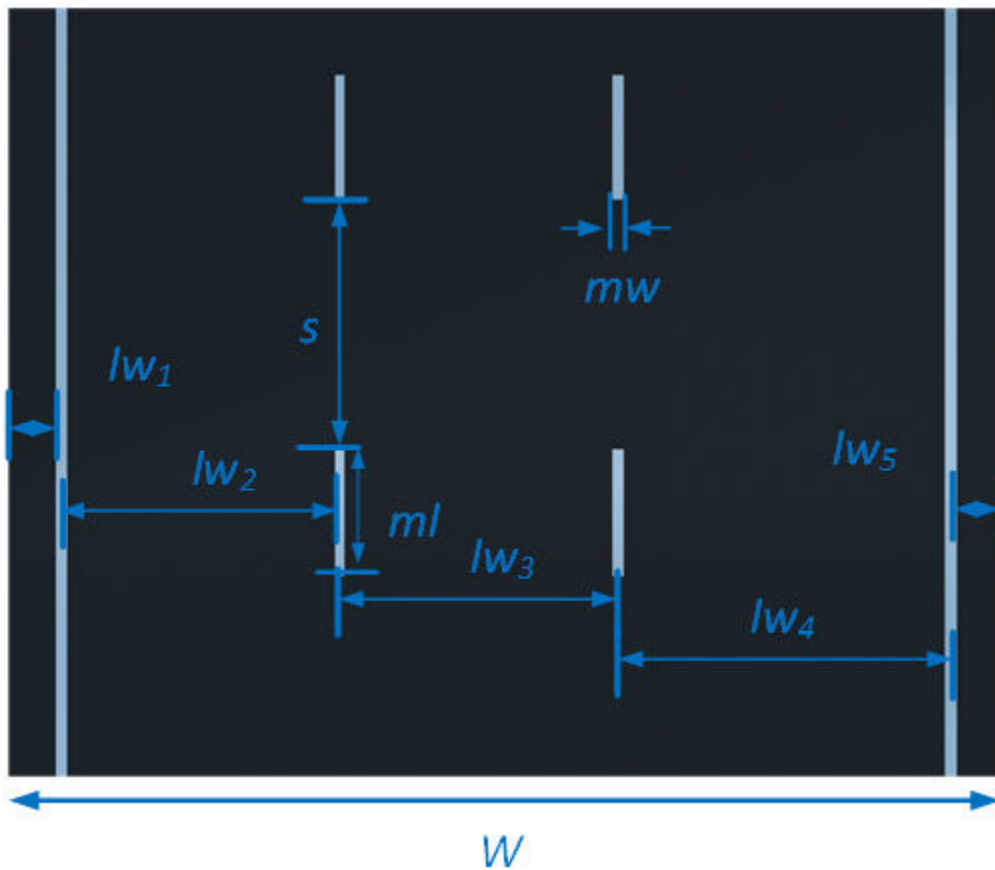
This figure and table provides the road type 1 lane dimensions, in m.



Variable	Dimension (m)
$lw_1$	0.65
$lw_2$	3.85
$lw_3$	3.85
$lw_4$	0.65
$ml$	1.5
$s$	3.0
$mw$	0.13
$W$	9

### Road Type 2

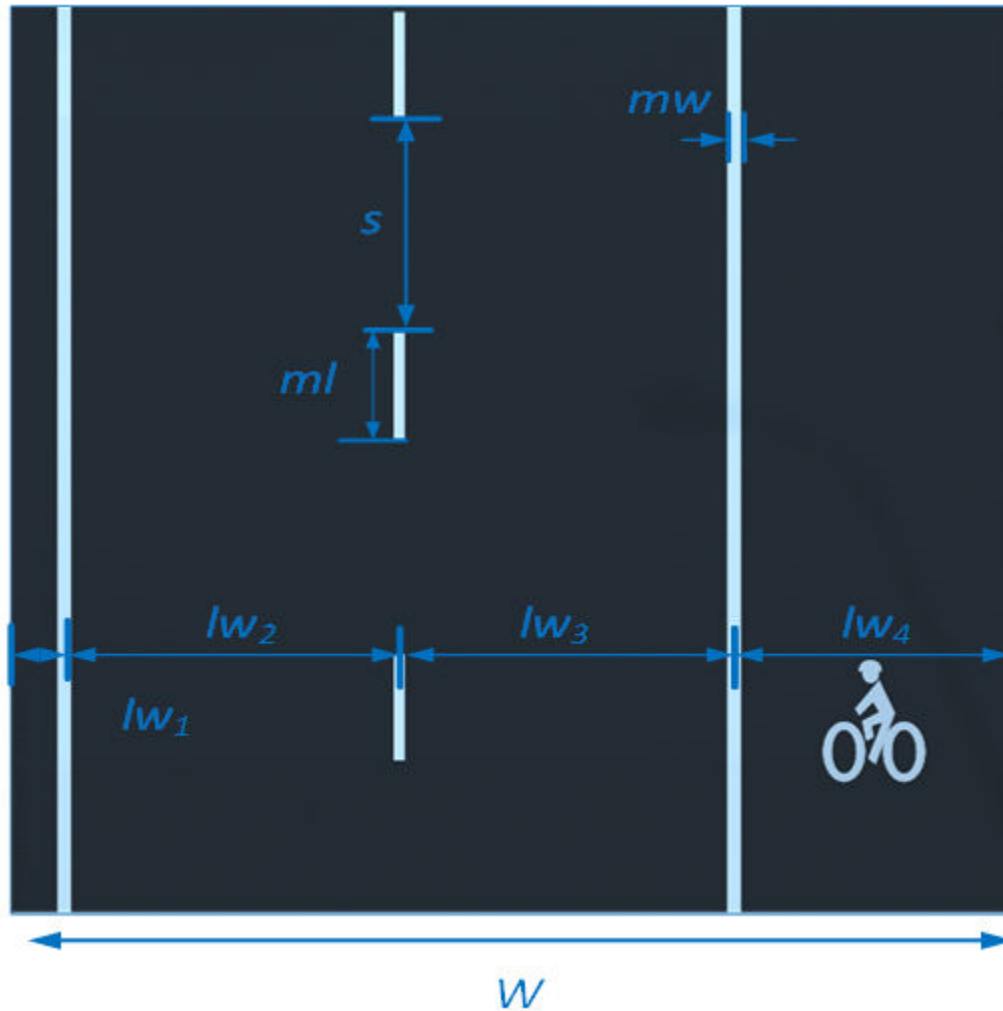
This figure and table provides the road type 2 lane dimensions, in m.



Variable	Dimension (m)
$lw_1$	0.73
$lw_2$	3.77
$lw_3$	3.77
$lw_4$	4.5
$lw_5$	0.73
$ml$	1.5
$s$	3.0
$mw$	0.13
$W$	13.5

### Road Type 3

This figure and table provides the road type 3 lane dimensions, in m.

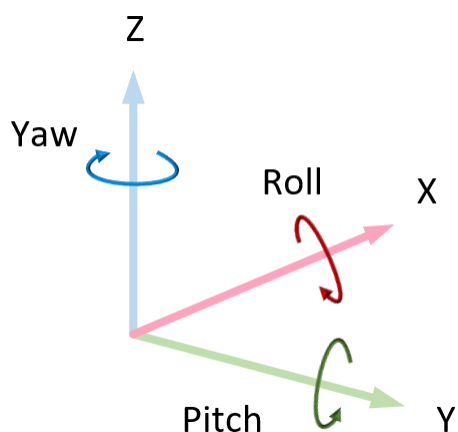


Variable	Dimension (m)
$lw_1$	0.65
$lw_2$	3.85
$lw_3$	3.85
$lw_4$	3.15
$ml$	1.5
$s$	3.0
$mw$	0.13
$W$	11.5

### World Coordinate System

The 3D visualization environment uses a world coordinate system with axes that are fixed in the inertial reference frame.





Axis	Description
X	Forward direction of the vehicle Roll — Right-handed rotation about X-axis
Y	Extends to the right of the vehicle, parallel to the ground plane Pitch — Right-handed rotation about Y-axis
Z	Extends upwards Yaw — Left-handed rotation about Z-axis

## Tips

- If you have the Vehicle Dynamics Blockset Interface for Unreal Engine 4 Projects support package, then you can modify this scene. In the Unreal Engine project file that comes with the support package, this scene is named `USCityBlock`.

For more details on customizing scenes, see “Customize 3D Scenes for Vehicle Dynamics Simulations”.

## See Also

**Curved Road** | **Double Lane Change** | **Large Parking Lot** | **Open Surface** | **Parking Lot** | Simulation 3D Scene Configuration | **Straight Road** | **US Highway** | **Virtual Mcity**

## Topics

“3D Visualization Engine Requirements and Limitations”  
 “How 3D Simulation for Vehicle Dynamics Blockset Works”  
 “Customize 3D Scenes for Vehicle Dynamics Simulations”

## US Highway

US highway 3D environment

### Description

The **US Highway** scene is a 3D environment of a US highway that contains barriers, cones, and traffic signs. The scene is rendered using the Unreal Engine from Epic Games.

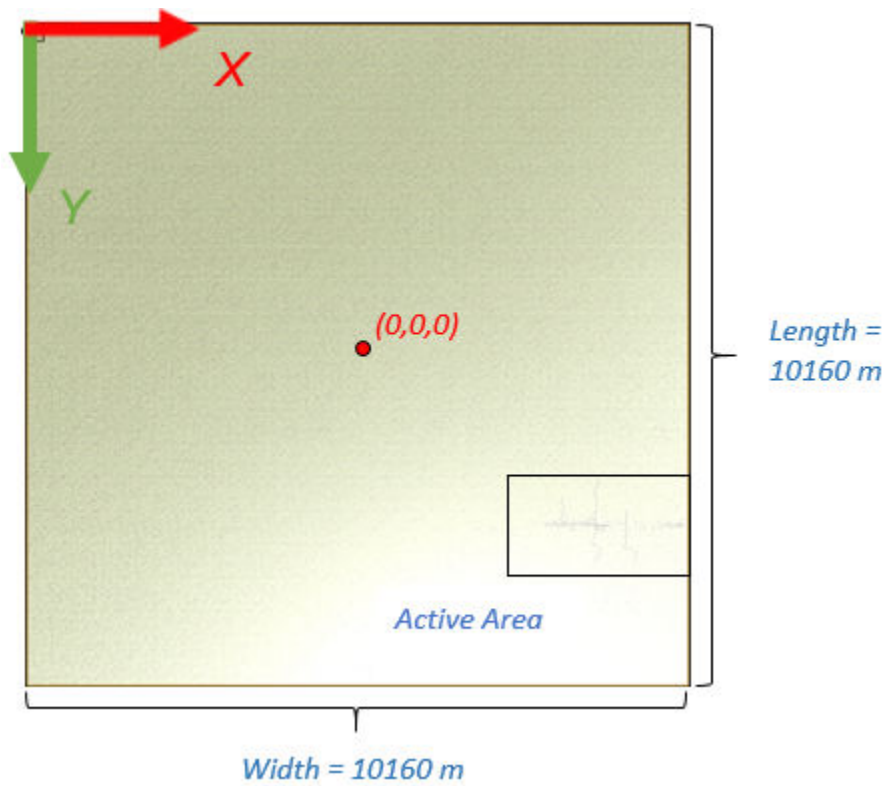


To simulate a driving maneuver in this scene:

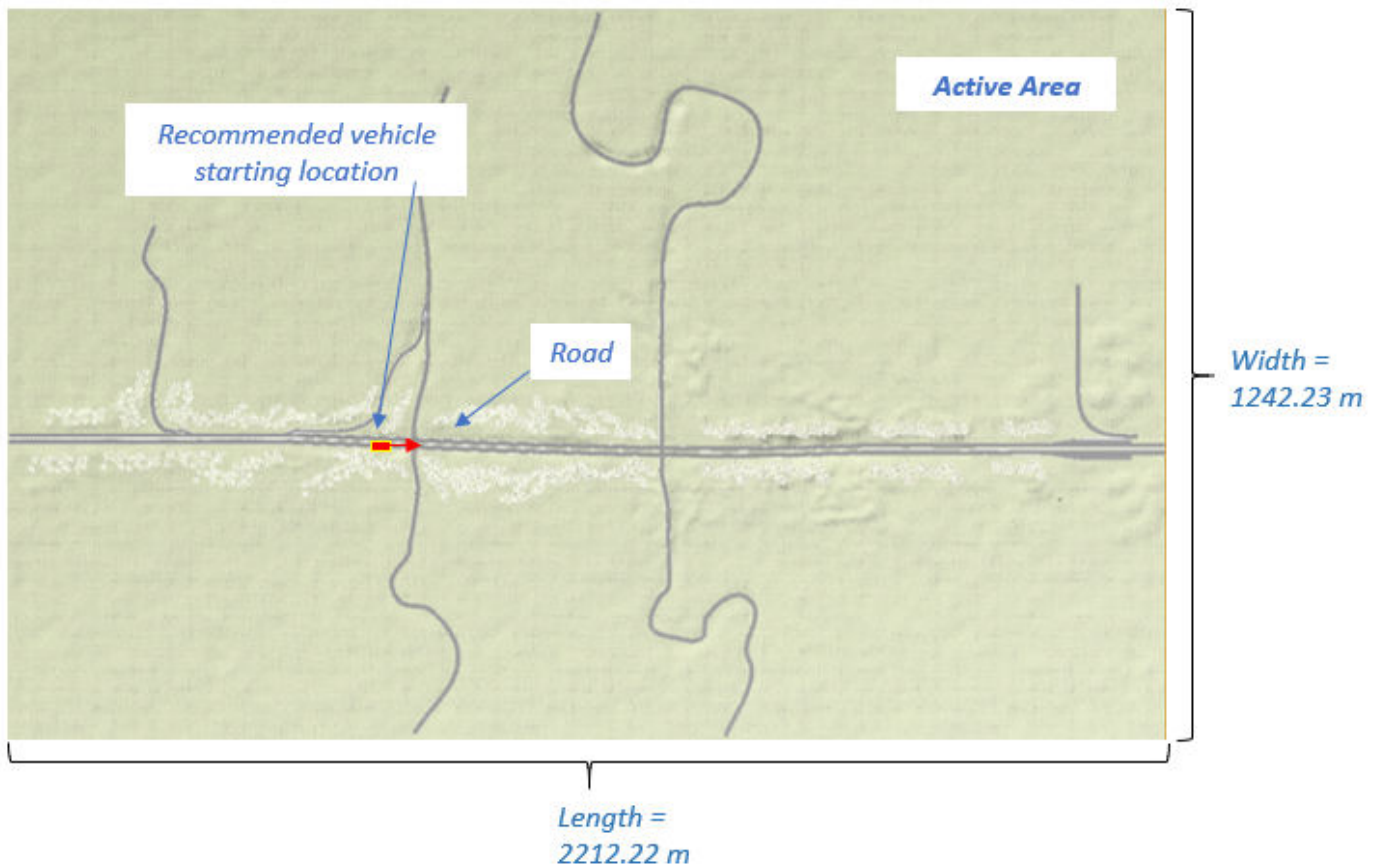
- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene source** parameter to Default Scenes.
- 3 Set the enabled **Scene name** parameter to US highway.

### Scene Layout

The scene uses the world coordinate system to locate objects.



The active area of the scene contains the road.



This table provides the scene area corner locations in the world coordinate system. Dimensions are in m.

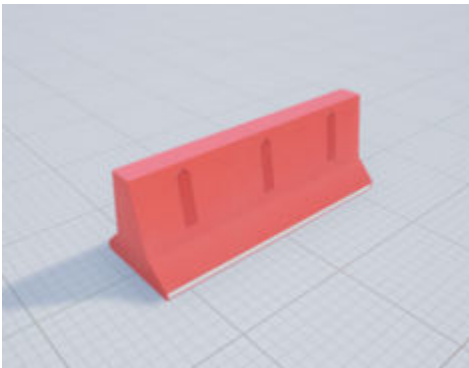
Locations	X (m)	Y (m)	Z (m)
Scene — Top left	-5080	-5080	1
Scene — Bottom right	5080	5080	1
Active area — Bottom left	2867.41	3169.93	1

### Recommended Starting Location

This table provides the recommended starting location for the vehicle in the world coordinate system. Dimensions are in m and deg.

Recommended Starting Location					
X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
3592.00	2617.00	1.00 <i>- 1.00 in vehicle Z-down coordinate system</i>	0	0	0

### Barrier



This table provides the object names and locations in the world coordinate system. Dimensions are in m.

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
Barrier	SM_Barrier 26	2866.45	2612.1	1	0	0	0
	SM_Barrier 27	2866.45	2609.35	1			
	SM_Barrier 28	2866.45	2606.6	1			
	SM_Barrier 29	2866.45	2603.95	1			
	SM_Barrier 30	2866.45	2599.7	1			
	SM_Barrier 31	2866.45	2596.95	1			
	SM_Barrier 32	2866.45	2594.2	1			

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
	SM_Barrier33	2866.45	2591.55	1			

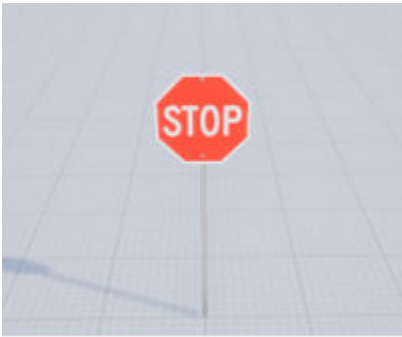
### Cones



This table provides the cone tag names and locations in the world coordinate system. Dimensions are in m.

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
Cone	SM_Cone	3022.85	2599.90	1	0	0	0
	SM_Cone2	3022.85	2599.10	1			
	SM_Cone3	3022.85	2598.25	1			
	SM_Cone4	3022.85	2597.30	1			
	SM_Cone5	3022.85	2596.50	1			
	SM_Cone6	3022.85	2595.65	1			
	SM_Cone7	3022.85	2594.70	1			
	SM_Cone8	3022.85	2593.90	1			
	SM_Cone9	3022.85	2593.05	1			
	SM_Cone10	3022.85	2592.20	1			
	SM_Cone11	3022.85	2591.40	1			

## Traffic Signs

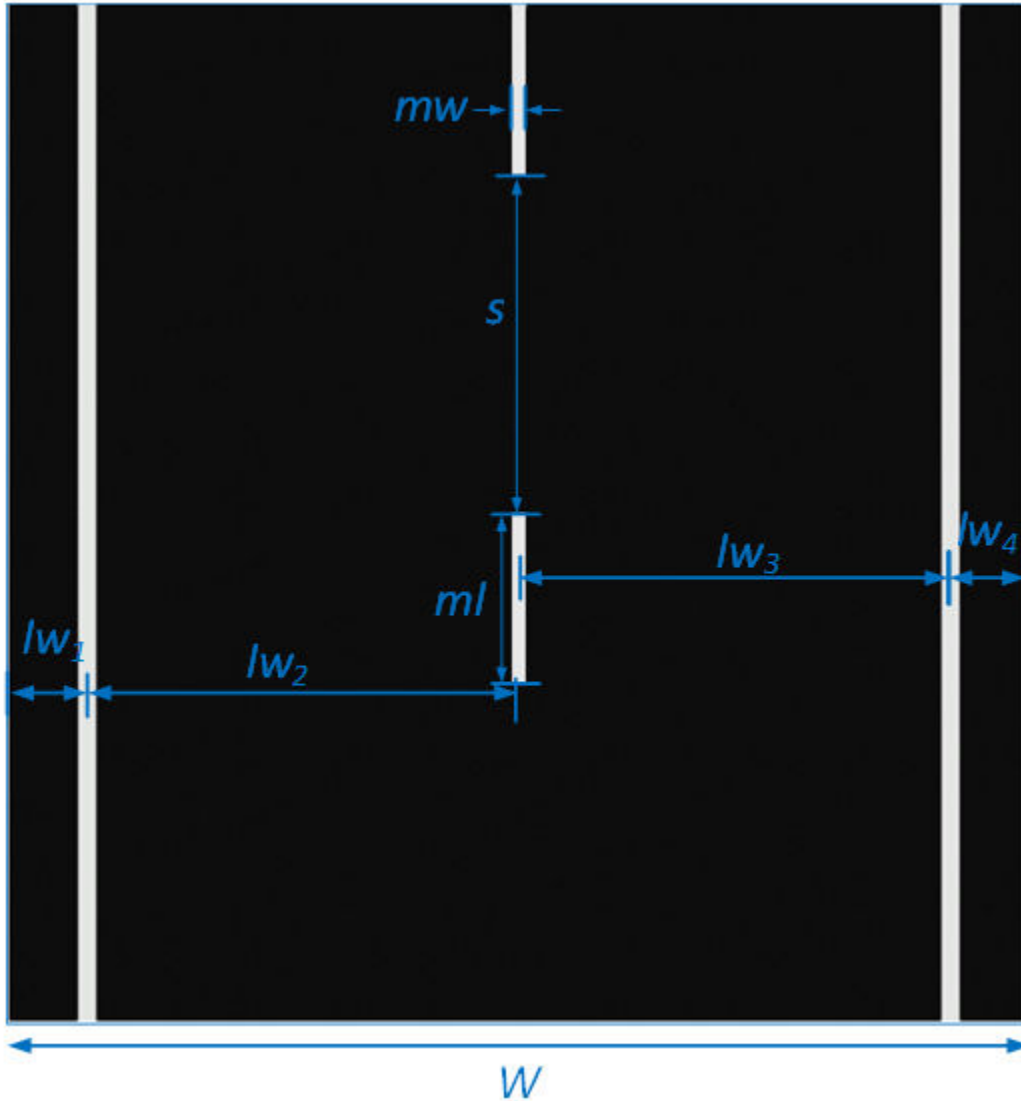


This table provides the traffic sign tag names and locations in the world coordinate system. Dimensions are in m.

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
Traffic Sign	SM_Large_Exit_Sign	3368.15	2588.20	1	0	0	-90°
	SM_Small_Exit_Sign	3232.70	2588.40	1	0	0	-90°
	ChevronAlignmentSign	3154.80	2584.50	1	0	0	-85°
	ChevronAlignmentSign2	3149.10	2579.45	1	0	0	-85°
	ChevronAlignmentSign3	3144.15	2571.95	1	0	0	-85°
	ChevronAlignmentSign4	3139.45	2562.60	1	0	0	-85°

## Lane Dimensions

This figure and table provides the lane dimensions, in m.

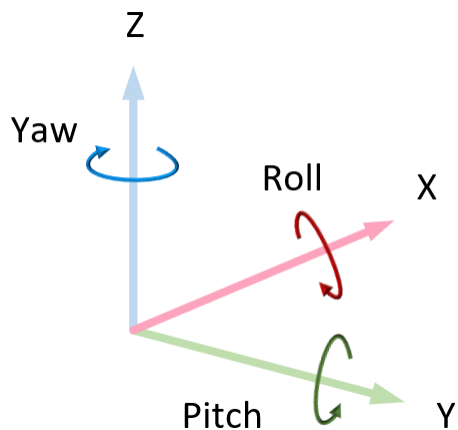


Variable	Dimension (m)
$lw_1$	0.65
$lw_2$	3.85
$lw_3$	3.85
$lw_4$	0.65
$ml$	1.5
$s$	3.0
$mw$	0.13
$W$	9.0



## World Coordinate System

The 3D visualization environment uses a world coordinate system with axes that are fixed in the inertial reference frame.



Axis	Description
X	Forward direction of the vehicle Roll — Right-handed rotation about X-axis
Y	Extends to the right of the vehicle, parallel to the ground plane Pitch — Right-handed rotation about Y-axis
Z	Extends upwards Yaw — Left-handed rotation about Z-axis

## Tips

- If you have the Vehicle Dynamics Blockset Interface for Unreal Engine 4 Projects support package, then you can modify this scene. In the Unreal Engine project file that comes with the support package, this scene is named USHighway.

For more details on customizing scenes, see “Customize 3D Scenes for Vehicle Dynamics Simulations”.

## See Also

**Curved Road | Double Lane Change | Large Parking Lot | Open Surface | Parking Lot | Simulation 3D Scene Configuration | Straight Road | US City Block | Virtual Mcity**

## Topics

“3D Visualization Engine Requirements and Limitations”  
 “How 3D Simulation for Vehicle Dynamics Blockset Works”  
 “Customize 3D Scenes for Vehicle Dynamics Simulations”

## Virtual Mcity

Virtual Mcity 3D environment

### Description

The **Virtual Mcity** scene is a 3D environment containing a virtual representation of Mcity®, which is a testing ground belonging to the University of Michigan. For more details, see Mcity Test Facility.

The scene is rendered using the Unreal Engine from Epic Games.

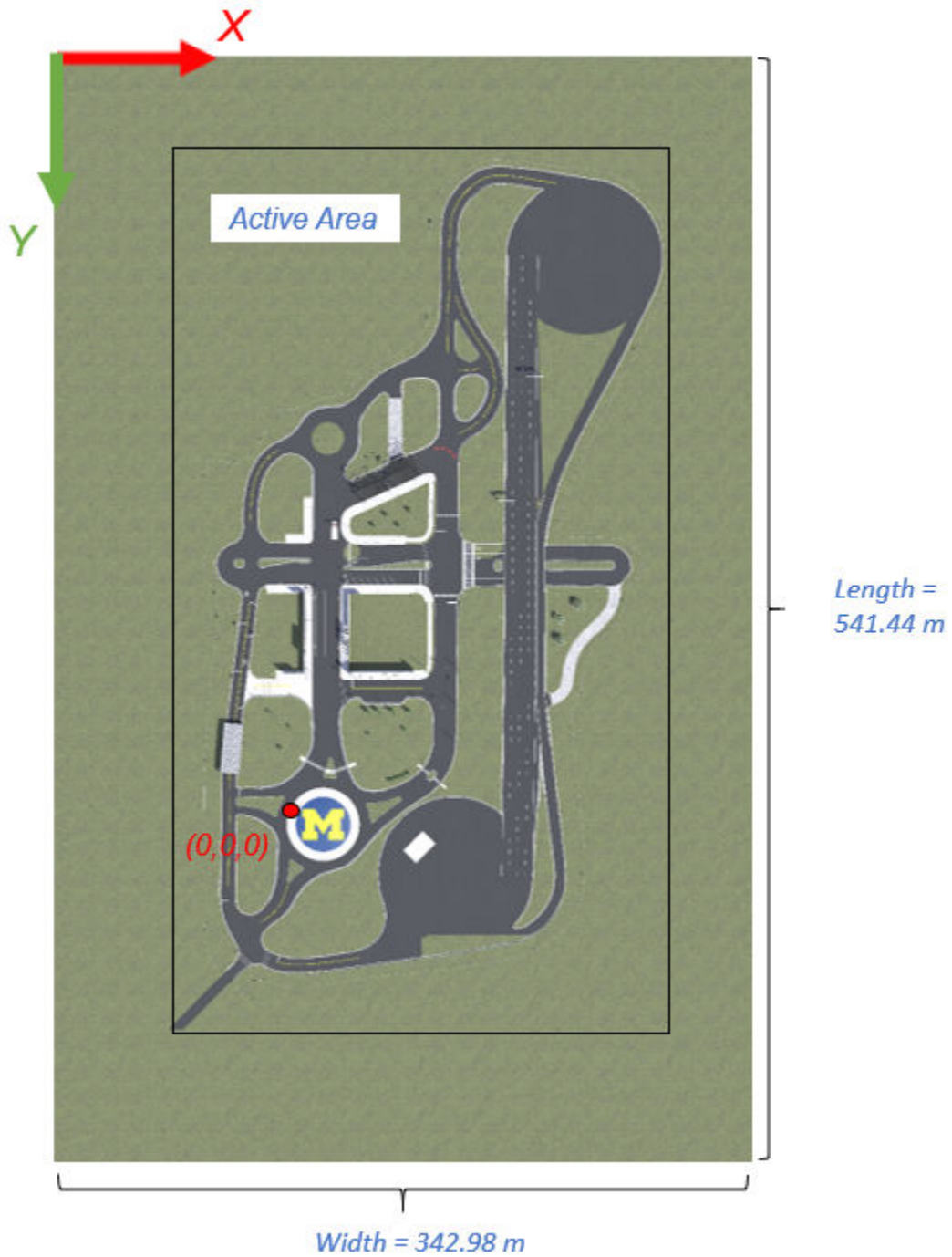


To simulate a driving maneuver in this scene:

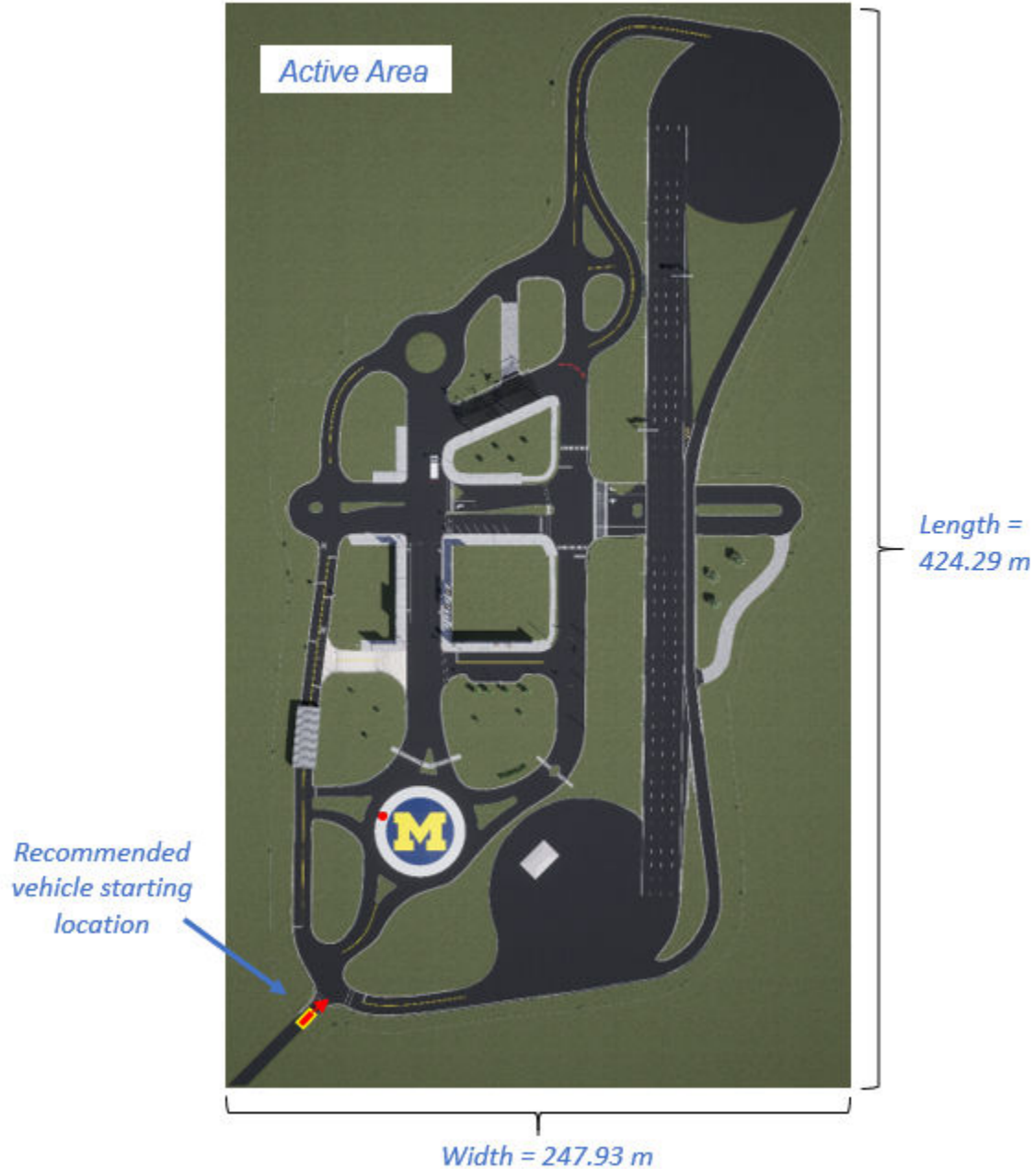
- 1 Add a Simulation 3D Scene Configuration block to your Simulink model.
- 2 In this block, set the **Scene source** parameter to Default Scenes.
- 3 Set the enabled **Scene name** parameter to Virtual Mcity.

### Scene Layout

The scene uses the world coordinate system to locate objects.



The active area of the scene contains the road.



This table provides the scene area corner locations in the world coordinate system. Dimensions are in m.

Locations	X (m)	Y (m)	Z (m)
Scene — Top left	-116.85	-369.18	-.02
Scene — Bottom right	226.13	172.26	-.02
Active area — Bottom left	-60.61	106.75	-.02

### Recommended Vehicle Starting Location

This table provides the recommended starting location for the vehicle in the world coordinate system. Dimensions are in m and deg.

Recommended Starting Location					
X	Y	Z	Roll	Pitch	Yaw
(m)	(m)	(m)	(deg)	(deg)	(deg)
-26.00	76.0	0	0	0	-40

### Other Vehicles

This table provides the vehicle tag names and initial locations for other vehicles in the scene, in the world coordinate system. Dimensions are in m and deg.

Object	Unreal Engine Editor Name	Locations					
		X	Y	Z	Roll	Pitch	Yaw
		(m)	(m)	(m)	(deg)	(deg)	(deg)
Vehicle	SK_BoxTruck	20.96	-136.90	0	0	0	-90
	SM_Motorcycle	42.50	-157.60	0	0	0	-20
	SK_SedanCar	5.83	-117.91	0	0	0	0
	SM_Bicycle	10.88	-84.42	0	0	0	90

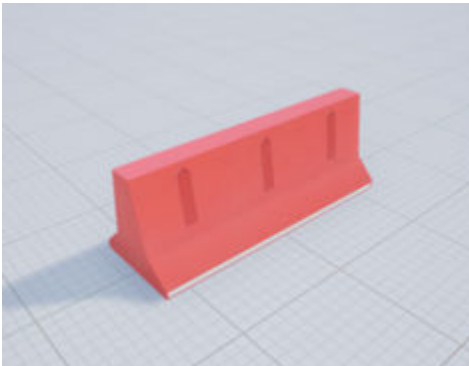
### Cones



This table provides the object names and locations in the world coordinate system. Dimensions are in m and deg.

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
Cone	SM_Cone	22.33	-131.51	0	0	0	0
	SM_Cone2	21.23	-131.51	0	0	0	0
	SM_Cone3	20.03	-131.51	0	0	0	0
	SM_Cone4	18.93	-131.51	0	0	0	0

### Barrier



This table provides the object names and locations in the world coordinate system. Dimensions are in m and deg.

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
Barrier	SM_Barrier13	79.65	-173.39	0	0	0	-35
	SM_Barrier14	77.31	-175.94	0	0	0	-55
	SM_Barrier15	74.42	-177.49	0	0	0	-80
	SM_Barrier16	71.18	-177.64	0	0	0	-95

## Animals



This table provides the object name and location in the world coordinate system. Dimensions are in m and deg.

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
Animals	Deer	36.84	-122.15	0	0	0	0

## Traffic Signs



This table provides the object names and locations in the world coordinate system. Dimensions are in m and deg.

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
Traffic signs	SM_StopSign	-35.21	44.19	0	0	0	95
	SM_YellowRoadSign	-38.75	18.14	-.02	0	0	-170

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
	LargeDoubleArrowSign4	-35.19	-4.39	0	0	0	-90
	LargeDoubleArrowSign	-31.01	-60.55	0	0	0	-80
	RailroadSign2	-27.06	-88.67	0	0	0	5
	RailroadSign	-17.79	-89.77	0	0	0	-170
	SM_YieldSign	26.80	-165.14	0	0	0	0
	SM_StopSign7	54.84	-200.43	0	0	0	-90
	LargeDoubleArrowSign3	47.54	-218.00	0	0	0	-15
	SM_StopSign9	70.32	-195.66	0	0	0	0
	SM_YellowRoadSign3	82.66	-285.75	-.02	0	0	15
	SM_SpeedLimitSign2	80.89	-226.85	-.06	0	0	0
	LargeDoubleArrowSign5	104.10	-212.80	0	0	0	80
	ChevronAlignmentSign	98.45	-191.22	0	0	0	101
	ChevronAlignmentSign2	102.05	-197.62	0	0	0	76.5
	ChevronAlignmentSign3	103.98	-206.06	0	0	0	85
	SM_Large_Exit_Sign	122.45	-212.50	0	0	0	0
	SM_Large_Exit_Sign2	101.79	-151.66	0	0	0	180



Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
	SM_StopSign3	32.01	-163.68	0	0	0	160
	SM_StopSign2	54.98	-177.12	0	0	0	90
	LargeSingleArrowSign	121.01	-148.56	0	0	0	0
	SM_YieldSign2	162.22	-109.64	0	0	0	25
	SM_WindingRoadSign	127.11	-50.21	.01	0	0	50
	SchoolBusOnlySign	44.03	-51.11	0	0	0	90
	SM_YellowRoadSign5	68.05	-47.03	.01	0	0	-175
	SM_CrossSignal8	74.37	-14.11	0	0	0	-165
	SM_CrossSignal7	64.69	-22.69	0	0	0	-150
	SM_CrossSignal6	62.51	-20.34	0	0	0	40
	SM_CrossSignal5	72.42	-12.06	0	0	0	40
	SM_YellowRoadSign2	60.01	-2.69	-.01	0	0	50
	SM_CrossSignal2	28.53	-20.58	0	0	0	-20
	SM_CrossSignal	21.19	-17.95	0	0	0	-20
	SM_CrossSignal3	17.55	-21.53	0	0	0	-170
	SM_CrossSignal4	6.59	-27.66	0	0	0	-145
	SM_YieldSign4	4.89	-23.42	0	0	0	-140
	SM_YellowRoadSign4	9.23	-45.63	0	0	0	-175
	SM_BikeLaneSign	24.13	-92.03	.15	0	0	0

## Traffic Lights



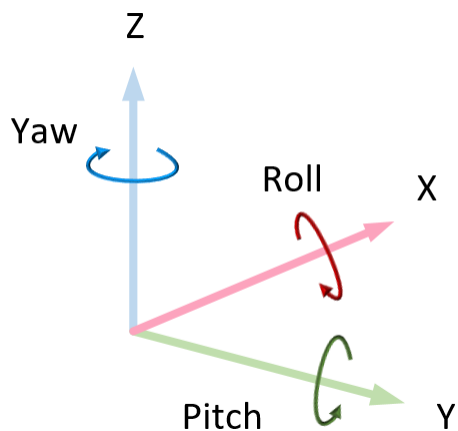
This table provides the object names and locations in the world coordinate system. Dimensions are in m and deg.

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
Traffic lights	SM_TrafficLights	27.40	-138.55	.16	0	0	90
	SM_TrafficLights2	9.38	-106.90	.16	0	0	-90
	SM_TrafficLightsSideOnly3	8.44	-47.95	-.03	0	0	-92.2
	SM_TrafficLightsSideOnly4	1.64	-55.10	.16	0	0	-5
	SM_TrafficLightsSideOnly5	9.24	-67.70	.16	0	0	85
	SM_TrafficLightsSideOnly6	24.50	-67.82	.16	0	0	85
	SM_TrafficLights3	27.89	-109.86	.16	0	0	180
	SM_HangingTrafficLightSingle	74.43	-69.25	7.37	0	0	0
	SM_HangingTrafficLightSingle2	76.13	-69.10	7.34	0	0	0

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
	SM_HangingTrafficLightSingle3	82.58	-60.10	7.57	0	0	-90
	SM_HangingTrafficLightSingle4	82.65	-61.48	7.54	0	0	-90
	SM_HangingTrafficLightSingle6	73.67	-51.25	7.97	0	0	-180
	SM_HangingTrafficLightSingle7	75.07	-51.25	7.95	0	0	-180
	SM_HangingTrafficLight	-24.78	-61.49	6.71	0	0	100
	SM_RoadCrossing4	-18.21	-86.63	.01	0	0	8
	SM_RoadCrossing5	-26.73	-90.78	.01	0	0	-172

### World Coordinate System

The 3D visualization environment uses a world coordinate system with axes that are fixed in the inertial reference frame.



Axis	Description
X	Forward direction of the vehicle Roll — Right-handed rotation about X-axis
Y	Extends to the right of the vehicle, parallel to the ground plane Pitch — Right-handed rotation about Y-axis
Z	Extends upwards Yaw — Left-handed rotation about Z-axis

## Limitations

- In the Vehicle Dynamics Blockset Interface for Unreal Engine 4 Projects support package, this scene is not available for customization.

For details on which scenes you can customize, see “Customize 3D Scenes for Vehicle Dynamics Simulations”.

## See Also

**Curved Road** | **Double Lane Change** | **Large Parking Lot** | **Open Surface** | **Parking Lot** | Simulation 3D Scene Configuration | **Straight Road** | **US City Block** | **US Highway**

## Topics

“3D Visualization Engine Requirements and Limitations”  
 “How 3D Simulation for Vehicle Dynamics Blockset Works”  
 “Customize 3D Scenes for Vehicle Dynamics Simulations”

## External Websites

Mcity Test Facility

# Vehicle Dimensions

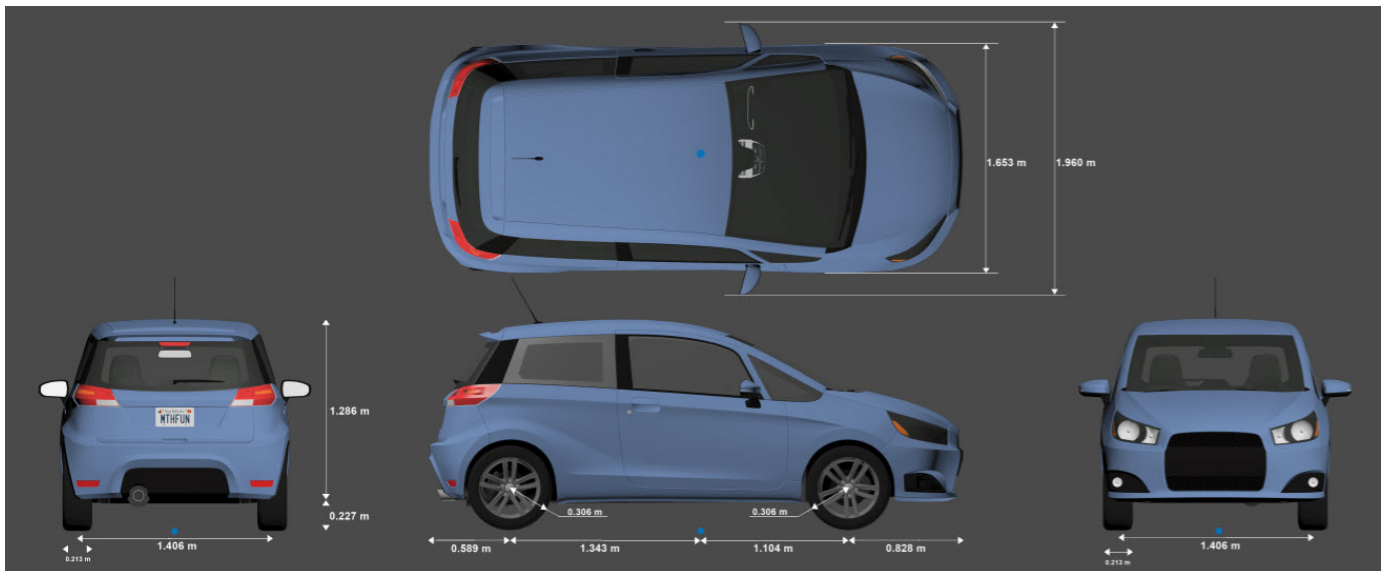
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# Hatchback

Hatchback vehicle dimensions

## Description

**Hatchback** is one of the vehicles that you can use within the 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The diagram provides the dimensions of this vehicle. The height dimensions are with respect to the vertical ground plane. The length and width dimensions are with respect to the origin of the vehicle in the vehicle coordinate system. The origin is on the ground, at the geometric center of the vehicle. For more detailed views of these diagrams, see the **Dimensions** section.

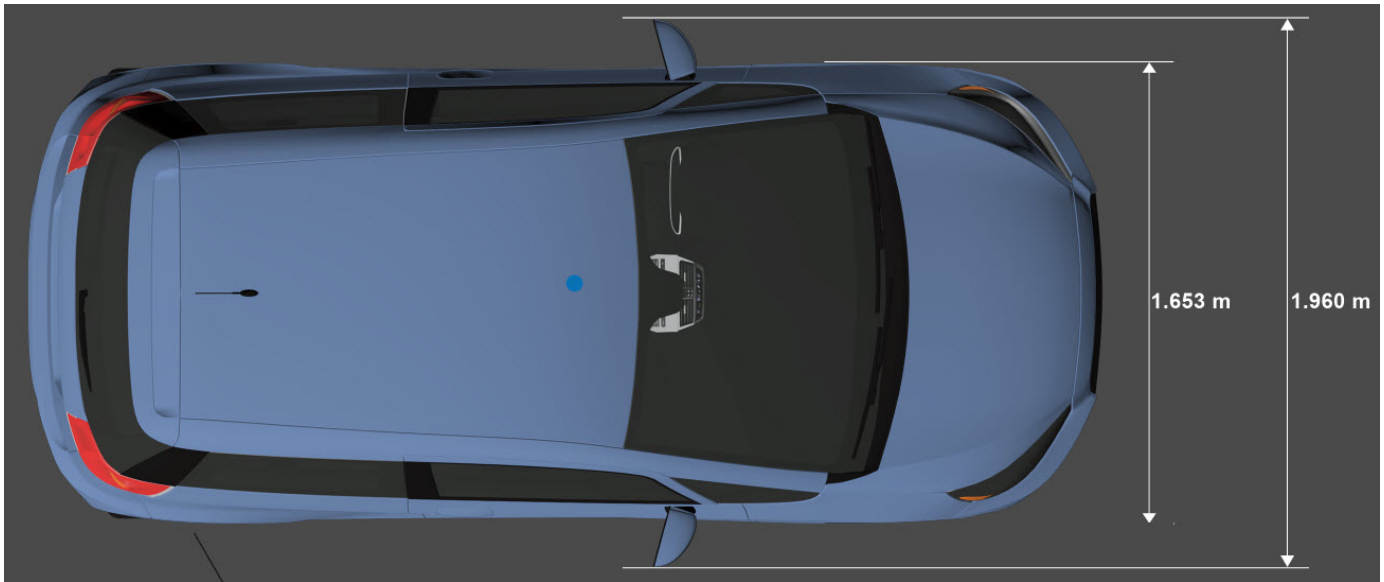


To add this type of vehicle to the 3D simulation environment:

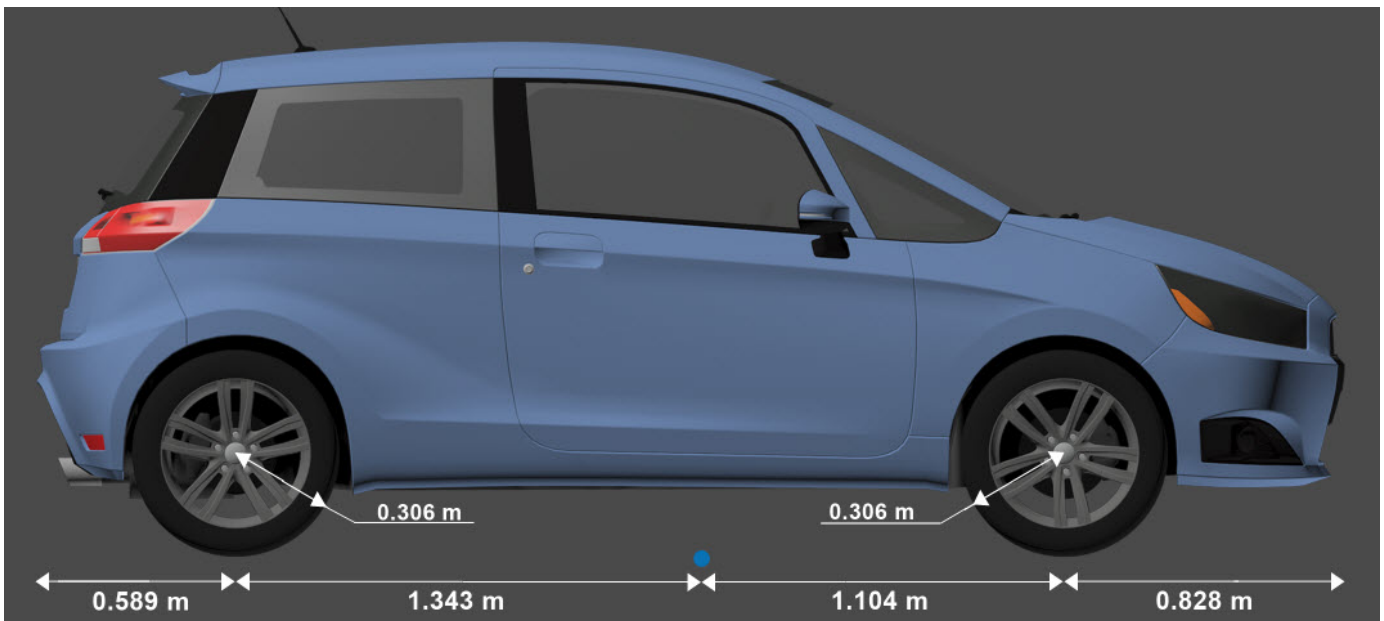
- 1 Add a Simulation 3D Vehicle or Simulation 3D Vehicle with Ground Following block to your Simulink model.
- 2 In the block, set the **Type** parameter to Hatchback.

## Dimensions

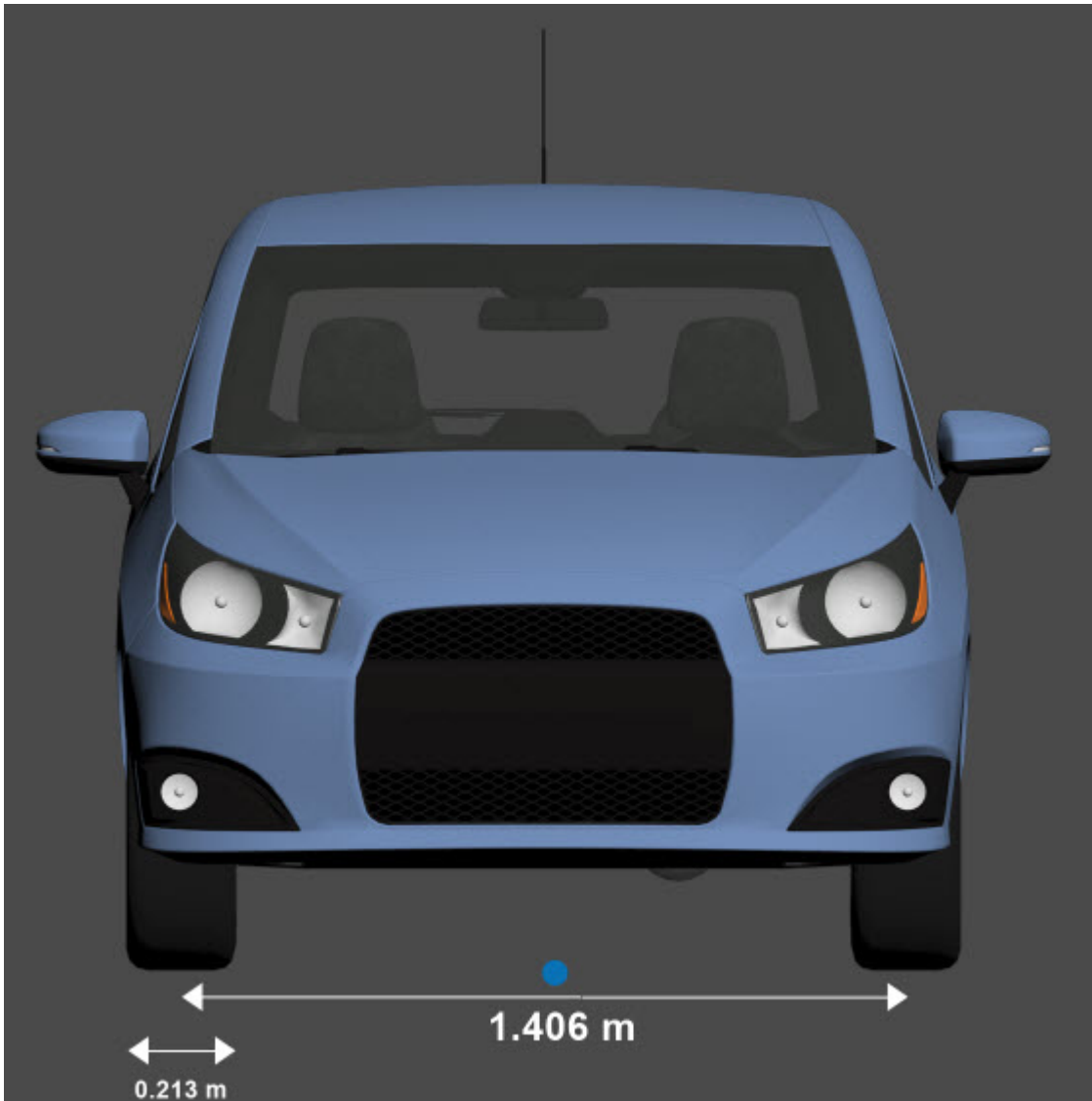
**Top-down view — Vehicle width dimensions**  
diagram



**Side view – Vehicle length, front overhang, and rear overhang dimensions**  
diagram

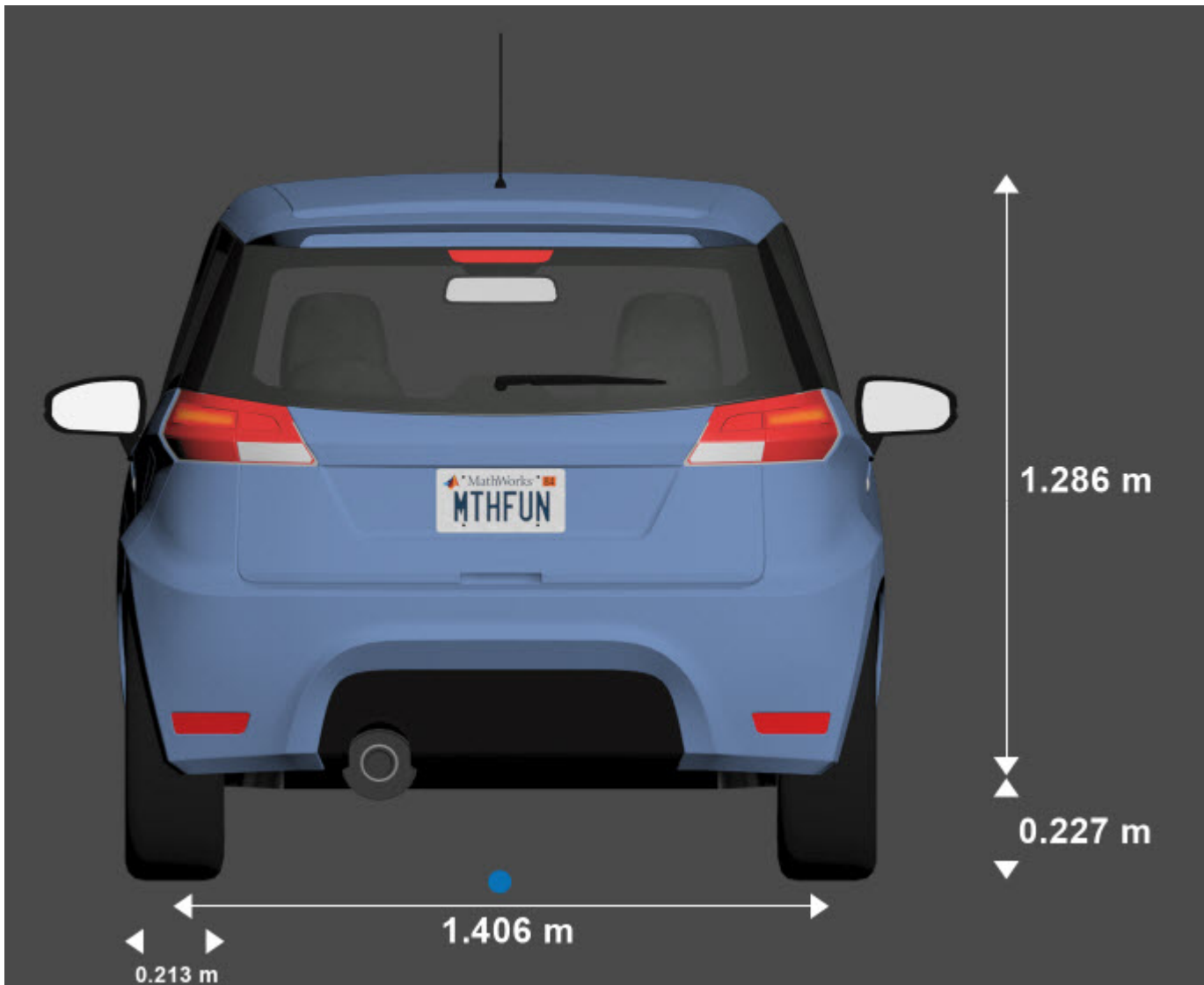


**Front view – Tire width and front axle dimensions**  
diagram



**Rear view – Vehicle height and rear axle dimensions**  
diagram





## Sensor Mounting Locations

In the 3D simulation sensor blocks, use the **Mounting location** parameter to mount sensors at predefined locations on the vehicle. The table shows the *X*, *Y*, and *Z* positions of the mounting locations relative to the vehicle origin. These locations are in the vehicle coordinate system, where:

- The *X*-axis points forward from the vehicle.
- The *Y*-axis points to the left of the vehicle, as viewed when facing forward.
- The *Z*-axis points up from the ground.

**Hatchback – Sensor Locations Relative to Vehicle Origin**

<b>Mounting Location</b>	<b>X (m)</b>	<b>Y (m)</b>	<b>Z (m)</b>
Front bumper	1.93	0	0.51
Rear bumper	-1.93	0	0.51
Right mirror	0.43	-0.84	1.01
Left mirror	0.43	0.84	1.01
Rearview mirror	0.32	0	1.27
Hood center	1.44	0	1.01
Roof center	0	0	1.57

**See Also**

Simulation 3D Scene Configuration | Simulation 3D Vehicle | Simulation 3D Vehicle with Ground Following

**Topics**

“Coordinate Systems in Vehicle Dynamics Blockset”

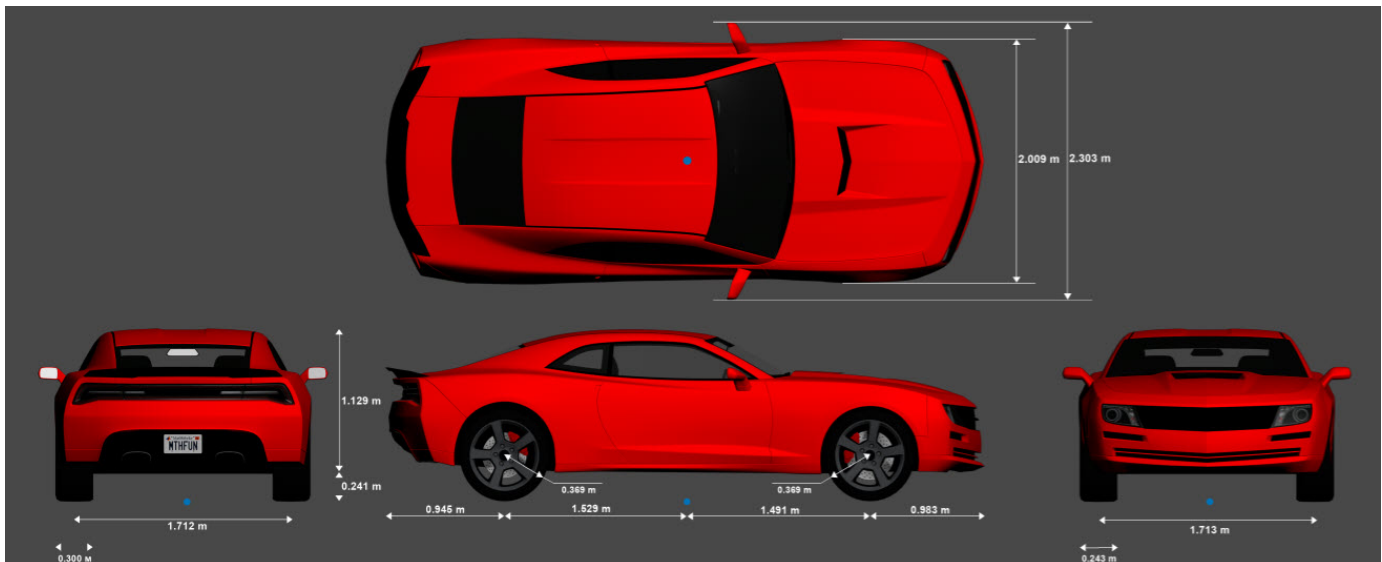
“How 3D Simulation for Vehicle Dynamics Blockset Works”

# Muscle Car

Muscle car vehicle dimensions

## Description

**Muscle Car** is one of the vehicles that you can use within the 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The following diagram provides the dimensions of this vehicle. The height dimensions are with respect to the vertical ground plane. The length and width dimensions are with respect to the origin of the vehicle in the vehicle coordinate system. The origin is on the ground, at the geometric center of the vehicle. For more detailed views of these diagrams, see the **Dimensions** section.

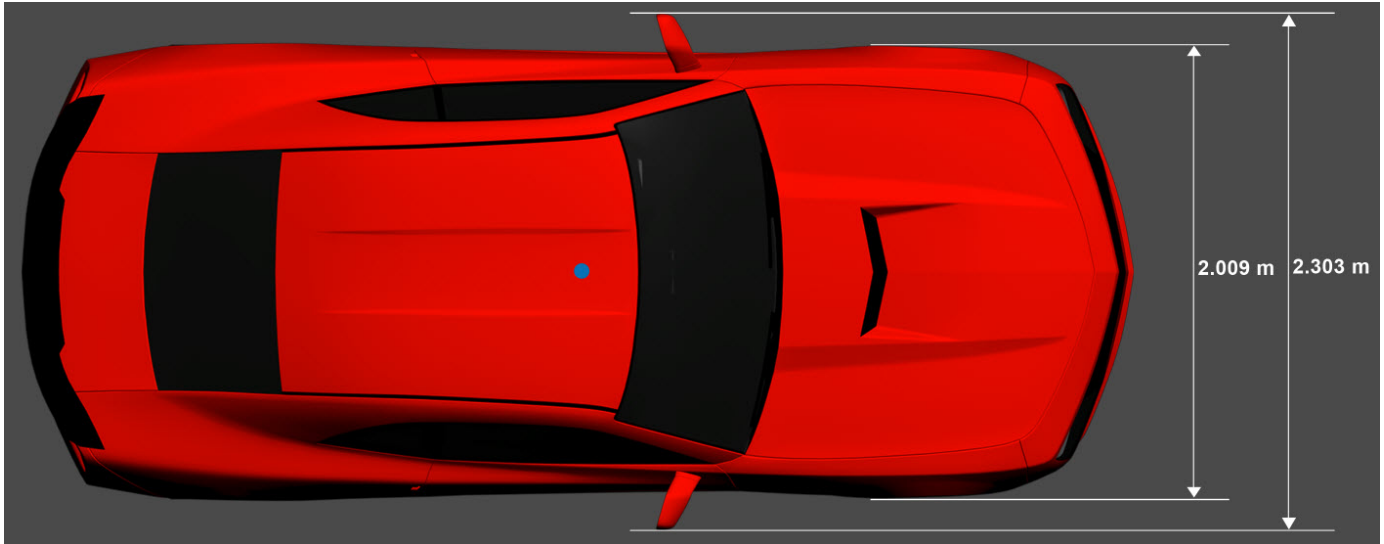


To add this type of vehicle to the 3D simulation environment:

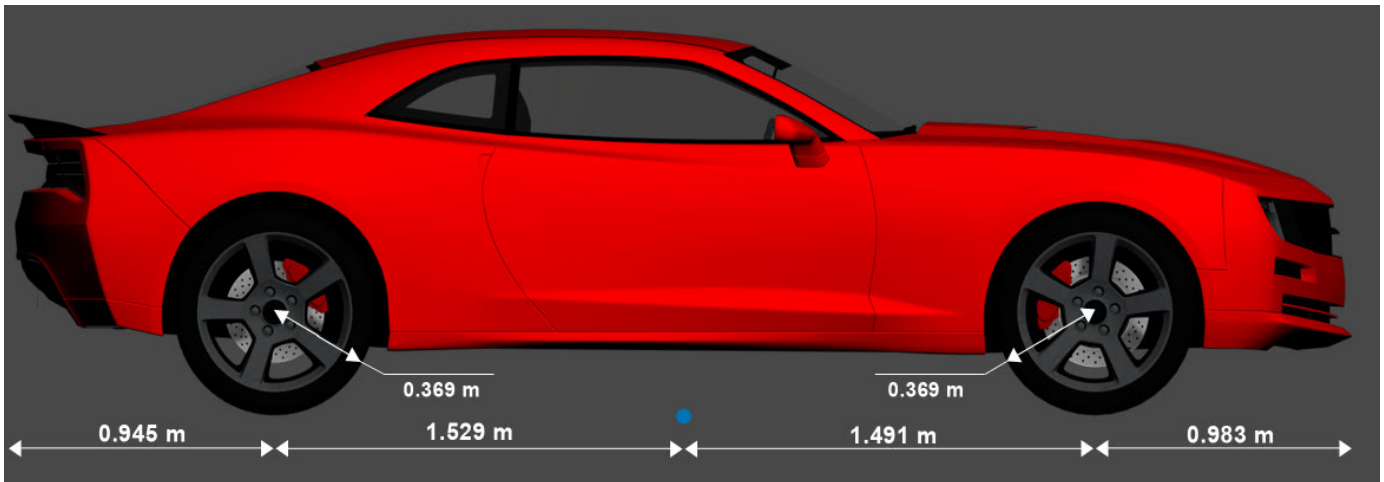
- 1 Add a Simulation 3D Vehicle or Simulation 3D Vehicle with Ground Following block to your Simulink model.
- 2 In the block, set the **Type** parameter to **Muscle car**.

## Dimensions

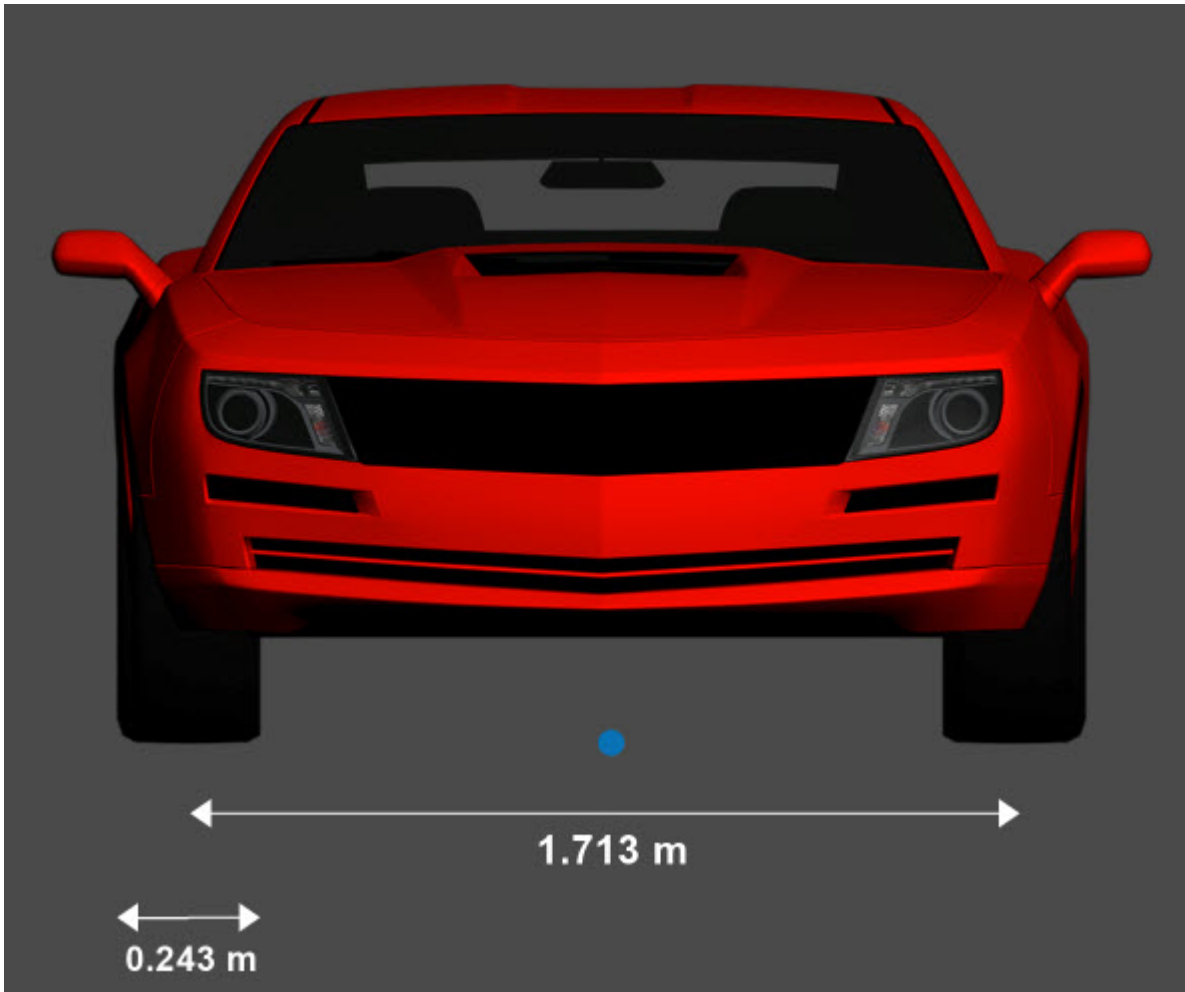
**Top-down view — Vehicle width dimensions**  
diagram



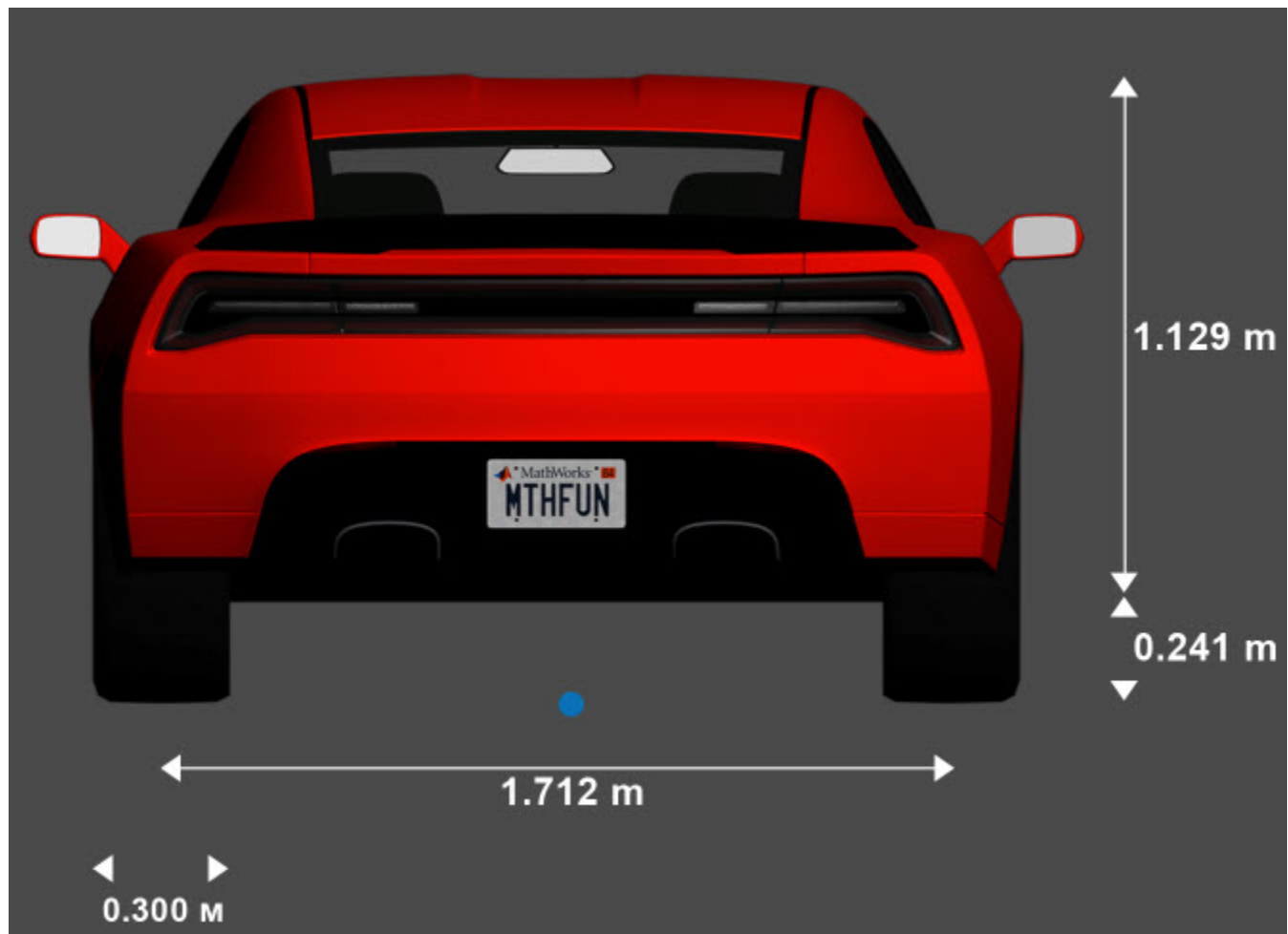
Side view – Vehicle length, front overhang, and rear overhang dimensions diagram



Front view – Tire width and front axle dimensions diagram



**Rear view – Vehicle height and rear axle dimensions**  
diagram



### Sensor Mounting Locations

In the 3D simulation sensor blocks, use the **Mounting location** parameter to mount sensors at predefined locations on the vehicle. The table shows the *X*, *Y*, and *Z* positions of the mounting locations relative to the vehicle origin. These locations are in the vehicle coordinate system, where:

- The *X*-axis points forward from the vehicle.
- The *Y*-axis points to the left of the vehicle, as viewed when facing forward.
- The *Z*-axis points up from the ground.

**Muscle Car – Sensor Locations Relative to Vehicle Origin**

<b>Mounting Location</b>	<b>X (m)</b>	<b>Y (m)</b>	<b>Z (m)</b>
Front bumper	2.47	0	0.45
Rear bumper	-2.47	0	0.45
Right mirror	0.43	-1.08	1.01
Left mirror	0.43	1.08	1.01
Rearview mirror	0.32	0	1.20
Hood center	1.28	0	1.14
Roof center	-0.25	0	1.58

**See Also**

Simulation 3D Scene Configuration | Simulation 3D Vehicle | Simulation 3D Vehicle with Ground Following

**Topics**

“Coordinate Systems in Vehicle Dynamics Blockset”

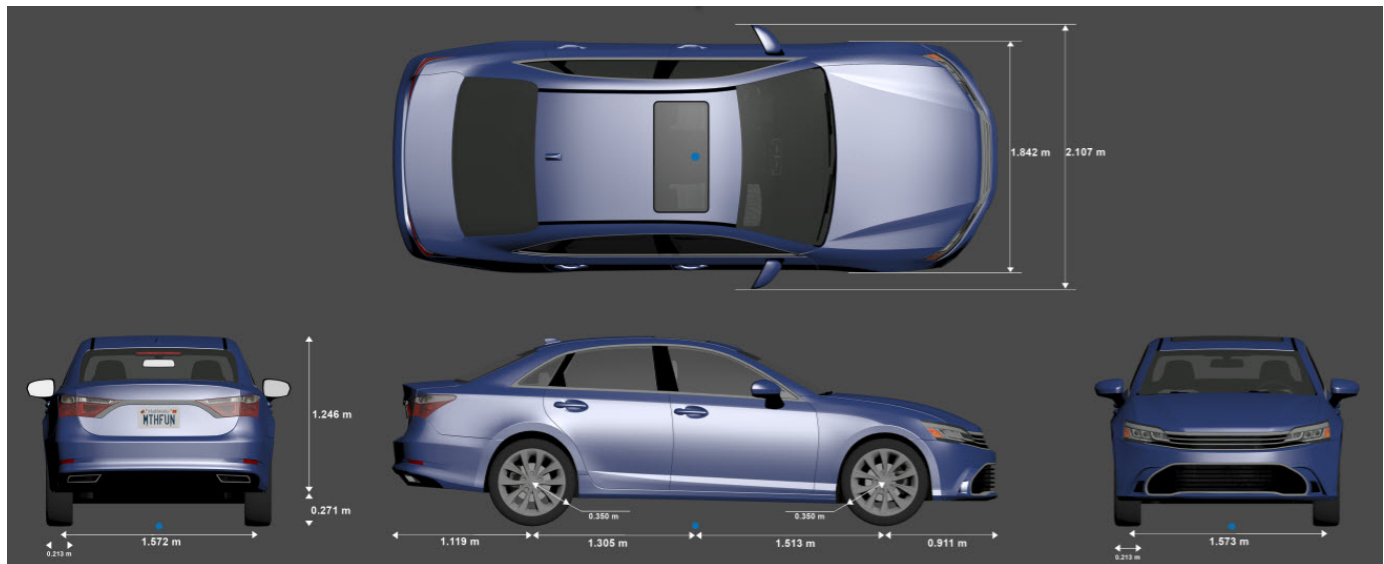
“How 3D Simulation for Vehicle Dynamics Blockset Works”

## Sedan

Sedan vehicle dimensions

### Description

**Sedan** is one of the vehicles that you can use within the 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The diagram provides the dimensions of this vehicle. The height dimensions are with respect to the vertical ground plane. The length and width dimensions are with respect to the origin of the vehicle in the vehicle coordinate system. The origin is on the ground, at the geometric center of the vehicle. For more detailed views of these diagrams, see the **Dimensions** section.



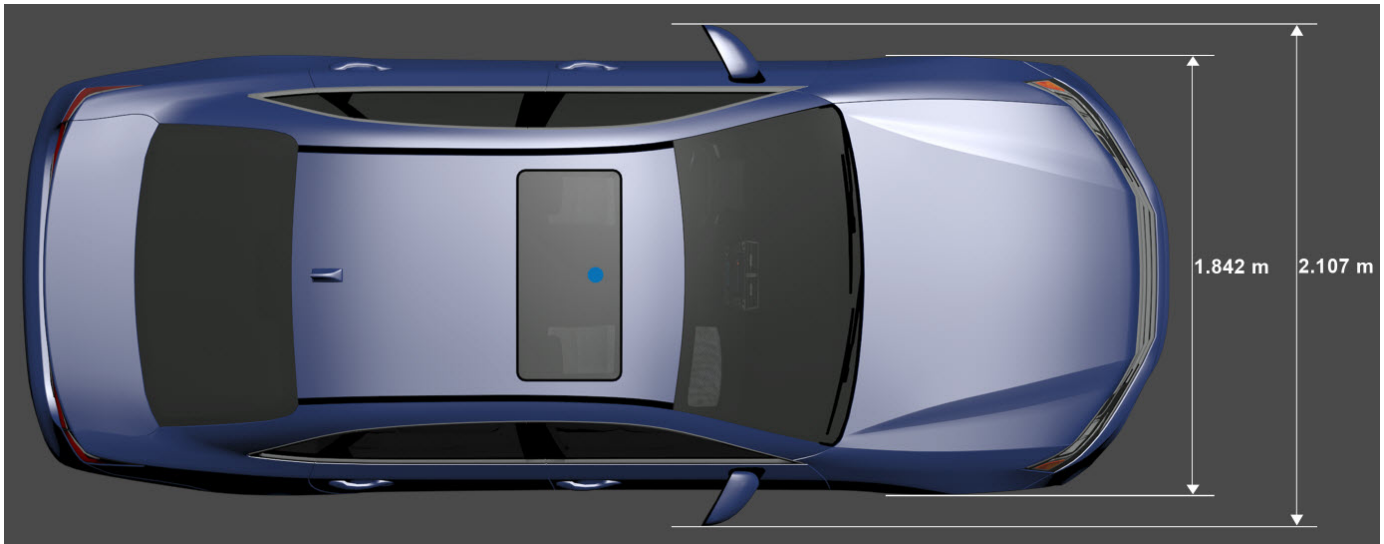
To add this type of vehicle to the 3D simulation environment:

- 1 Add a Simulation 3D Vehicle or Simulation 3D Vehicle with Ground Following block to your Simulink model.
- 2 In the block, set the **Type** parameter to Sedan.

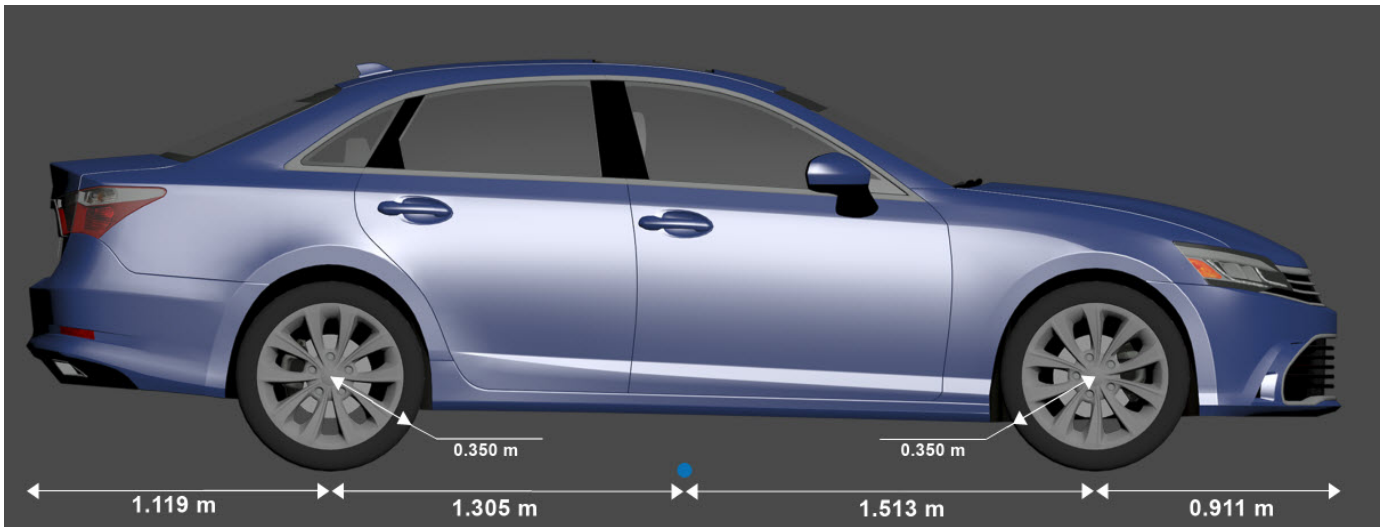
### Dimensions

**Top-down view — Vehicle width dimensions**  
diagram

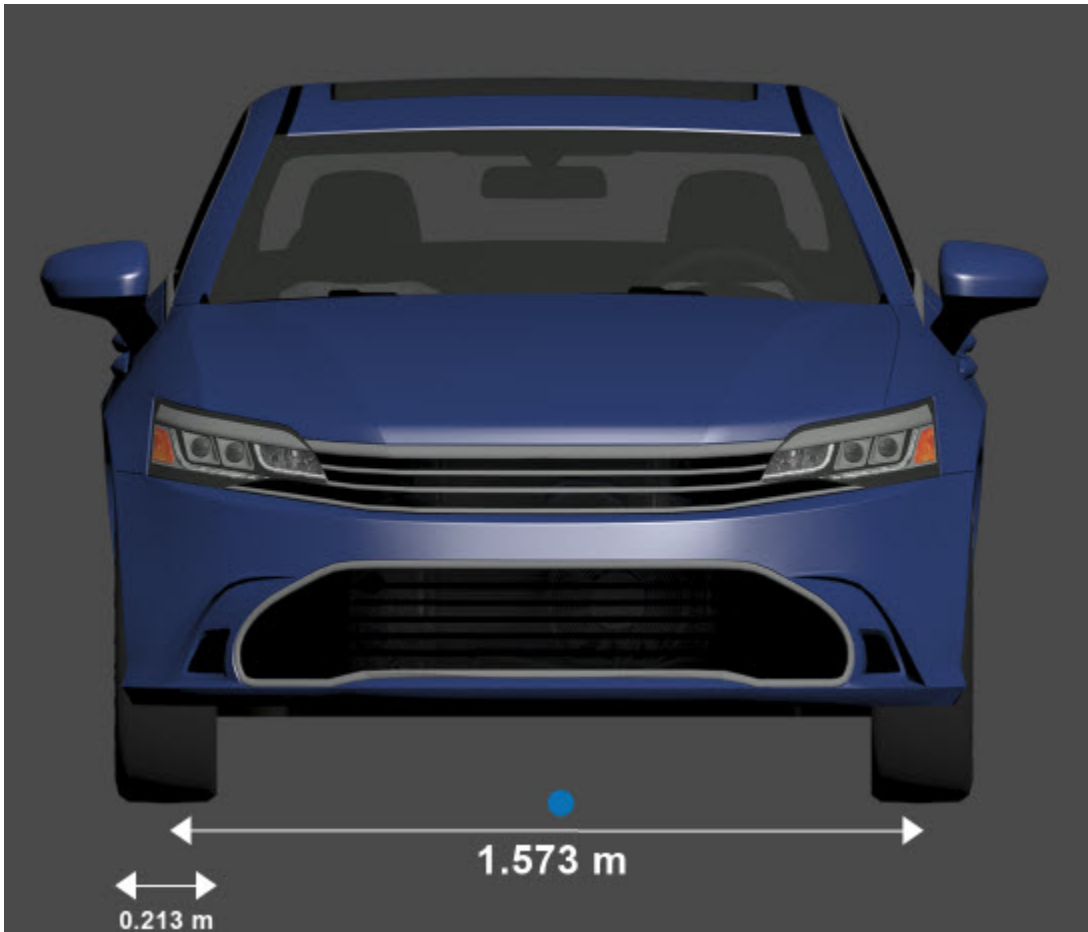




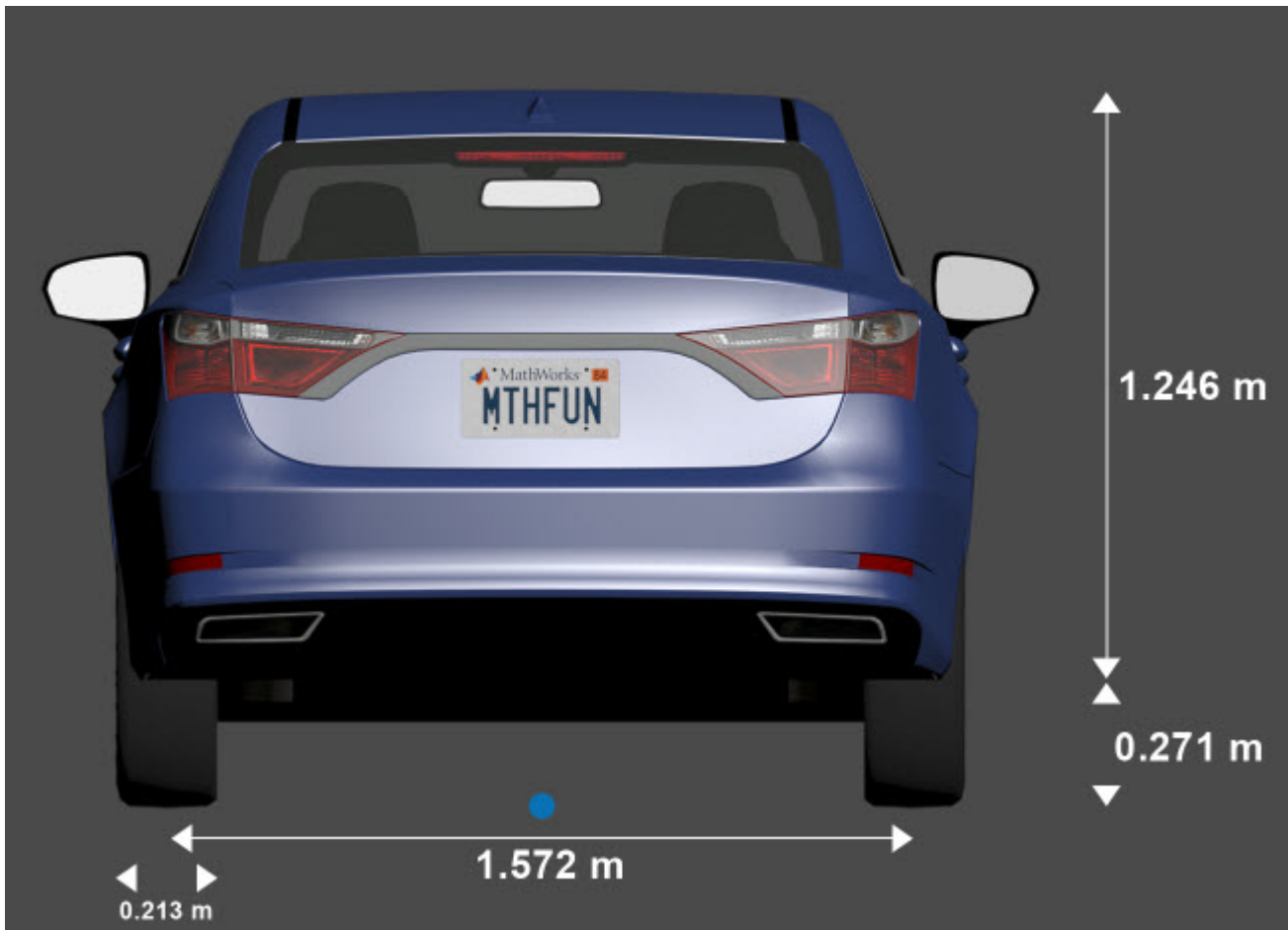
**Side view – Vehicle length, front overhang, and rear overhang dimensions**  
diagram



**Front view – Tire width and front axle dimensions**  
diagram



**Rear view – Vehicle height and rear axle dimensions**  
diagram



## Sensor Mounting Locations

In the 3D simulation sensor blocks, use the **Mounting location** parameter to mount sensors at predefined locations on the vehicle. The table shows the *X*, *Y*, and *Z* positions of the mounting locations relative to the vehicle origin. These locations are in the vehicle coordinate system, where:

- The *X*-axis points forward from the vehicle.
- The *Y*-axis points to the left of the vehicle, as viewed when facing forward.
- The *Z*-axis points up from the ground.

**Sedan – Sensor Locations Relative to Vehicle Origin**

<b>Mounting Location</b>	<b>X (m)</b>	<b>Y (m)</b>	<b>Z (m)</b>
Front bumper	2.42	0	0.51
Rear bumper	-2.42	0	0.51
Right mirror	0.59	-0.94	1.09
Left mirror	0.59	0.94	1.09
Rearview mirror	0.43	0	1.31
Hood center	1.46	0	1.11
Roof center	-0.45	0	1.69

**See Also**

Simulation 3D Scene Configuration | Simulation 3D Vehicle | Simulation 3D Vehicle with Ground Following

**Topics**

“Coordinate Systems in Vehicle Dynamics Blockset”

“How 3D Simulation for Vehicle Dynamics Blockset Works”

# Sport Utility Vehicle

Sport utility vehicle dimensions

## Description

**Sport Utility Vehicle** is one of the vehicles that you can use within the 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The following diagram provides the dimensions of this vehicle. The height dimensions are with respect to the vertical ground plane. The length and width dimensions are with respect to the origin of the vehicle in the vehicle coordinate system. The origin is on the ground, at the geometric center of the vehicle. For more detailed views of these diagrams, see the **Dimensions** section.

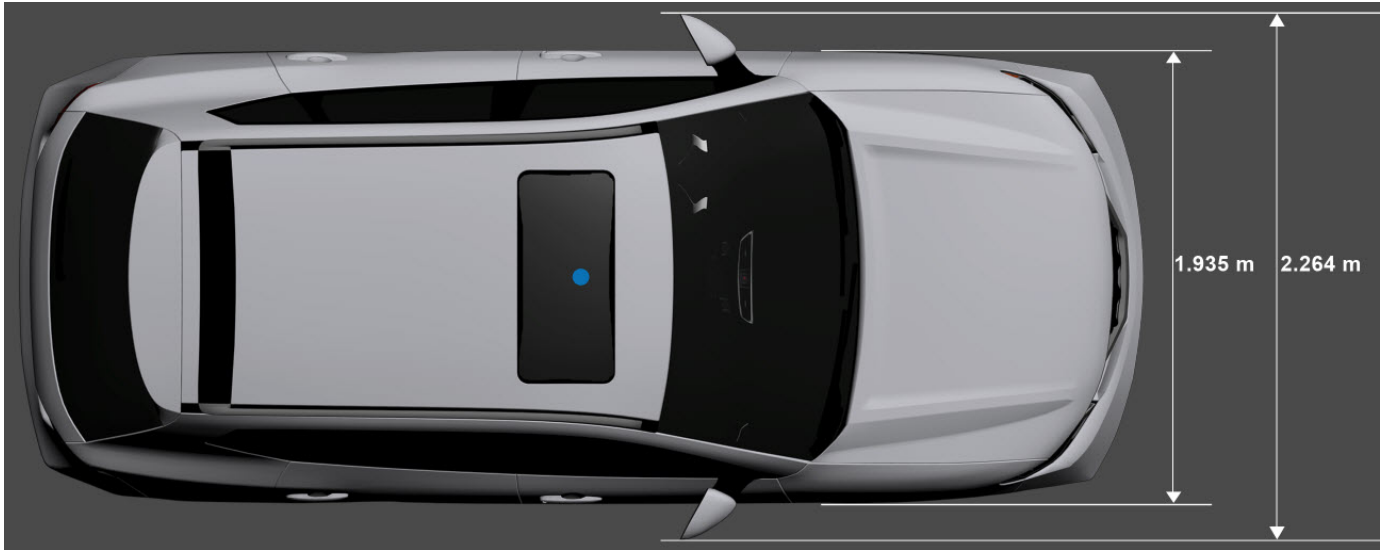


To add this type of vehicle to the 3D simulation environment:

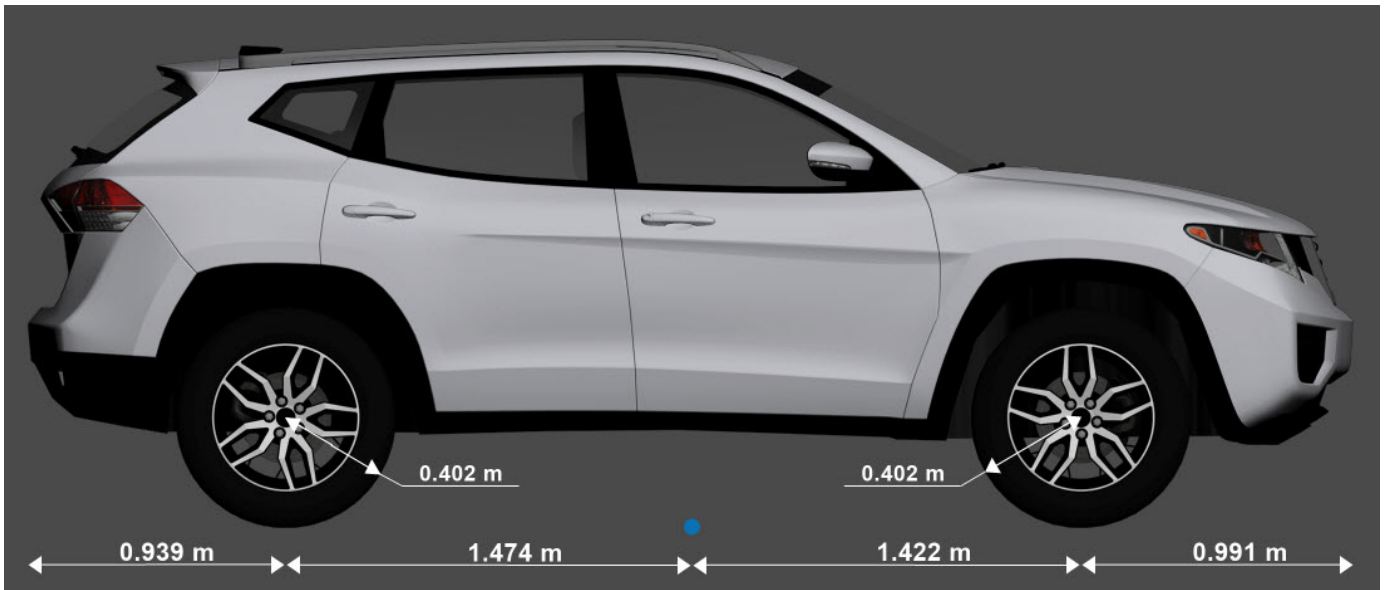
- 1 Add a Simulation 3D Vehicle or Simulation 3D Vehicle with Ground Following block to your Simulink model.
- 2 In the block, set the **Type** parameter to Sport utility vehicle.

## Dimensions

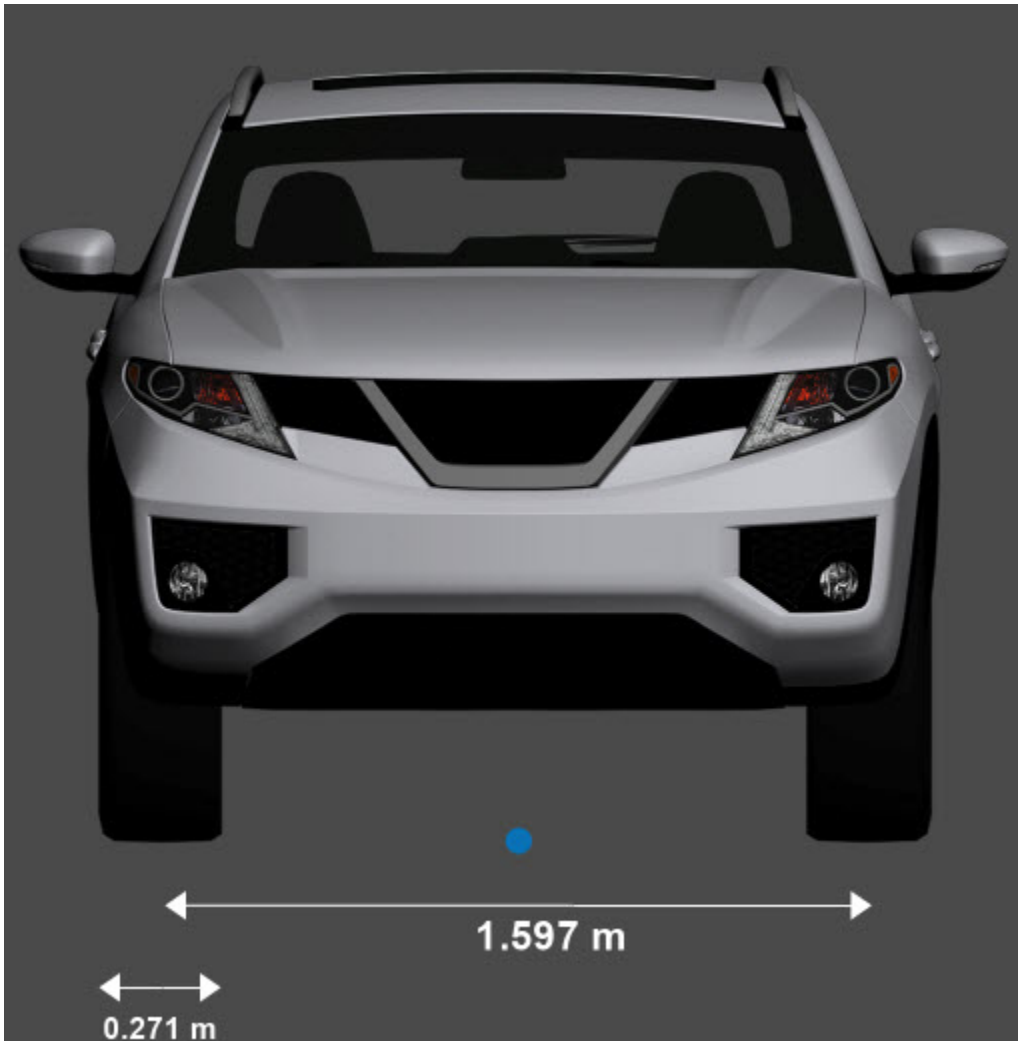
**Top-down view — Vehicle width dimensions**  
diagram



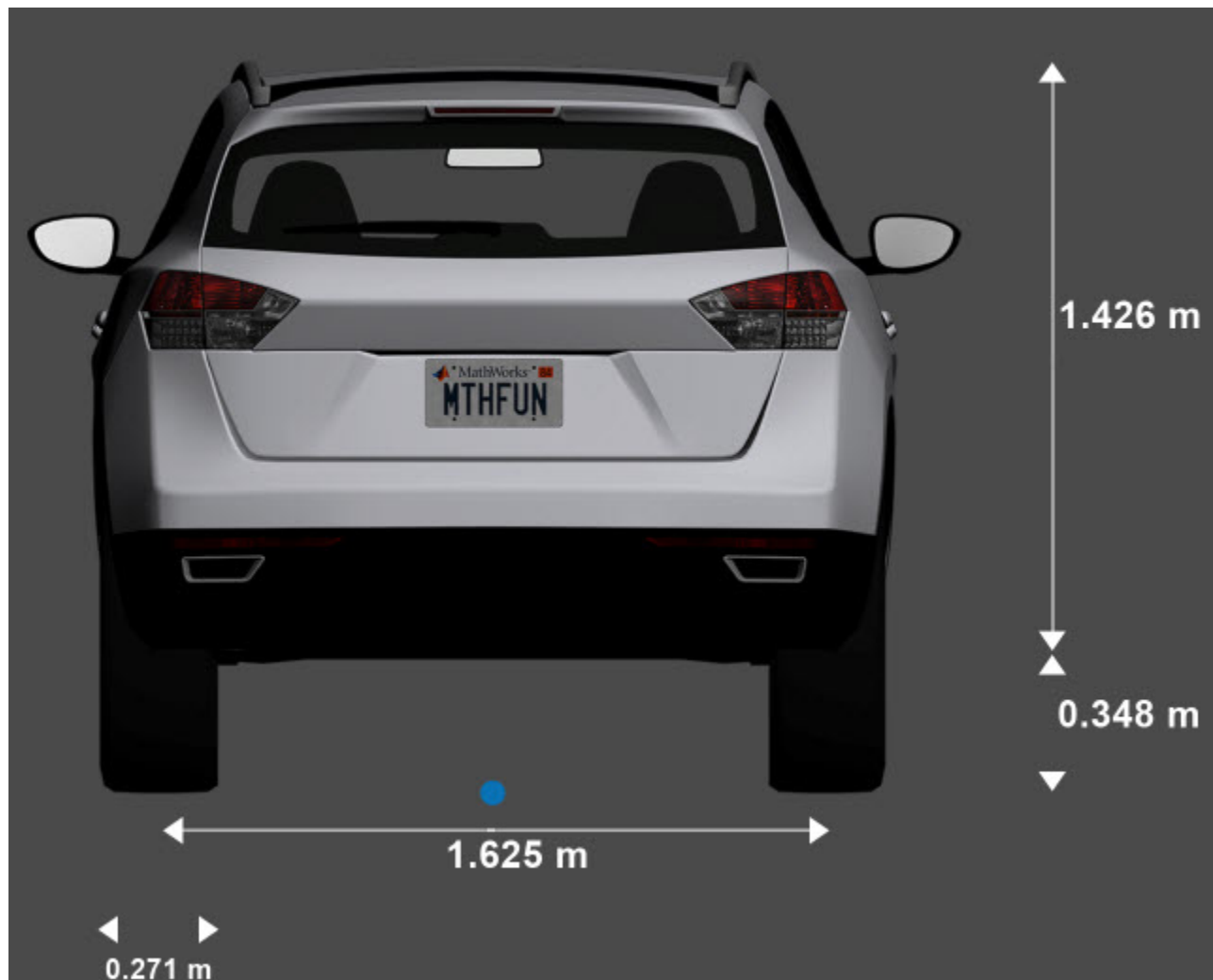
**Side view – Vehicle length, front overhang, and rear overhang dimensions diagram**



**Front view – Tire width and front axle dimensions diagram**



**Rear view – Vehicle height and rear axle dimensions**  
diagram



### Sensor Mounting Locations

In the 3D simulation sensor blocks, use the **Mounting location** parameter to mount sensors at predefined locations on the vehicle. The table shows the *X*, *Y*, and *Z* positions of the mounting locations relative to the vehicle origin. These locations are in the vehicle coordinate system, where:

- The *X*-axis points forward from the vehicle.
- The *Y*-axis points to the left of the vehicle, as viewed when facing forward.
- The *Z*-axis points up from the ground.



**Sport Utility Vehicle – Sensor Locations Relative to Vehicle Origin**

<b>Mounting Location</b>	<b>X (m)</b>	<b>Y (m)</b>	<b>Z (m)</b>
Front bumper	2.42	0	0.51
Rear bumper	-2.42	0	0.51
Right mirror	0.60	-1	1.35
Left mirror	0.60	1	1.35
Rearview mirror	0.39	0	1.55
Hood center	1.58	0	1.39
Roof center	-0.56	0	2

**See Also**

Simulation 3D Scene Configuration | Simulation 3D Vehicle | Simulation 3D Vehicle with Ground Following

**Topics**

“Coordinate Systems in Vehicle Dynamics Blockset”

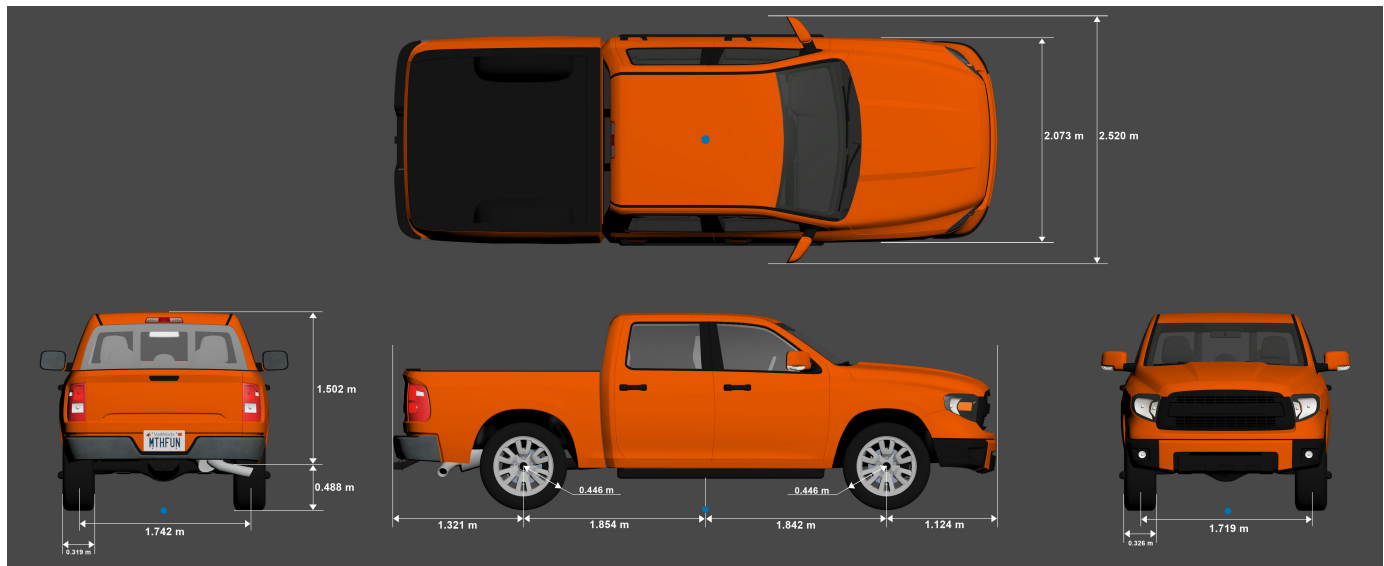
“How 3D Simulation for Vehicle Dynamics Blockset Works”

## Small Pickup Truck

Small pickup truck vehicle dimensions

### Description

**Small Pickup Truck** is one of the vehicles that you can use within the 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The following diagram provides the dimensions of this vehicle. The height dimensions are with respect to the vertical ground plane. The length and width dimensions are with respect to the origin of the vehicle in the vehicle coordinate system. The origin is on the ground, at the geometric center of the vehicle. For more detailed views of these diagrams, see the **Dimensions** section.

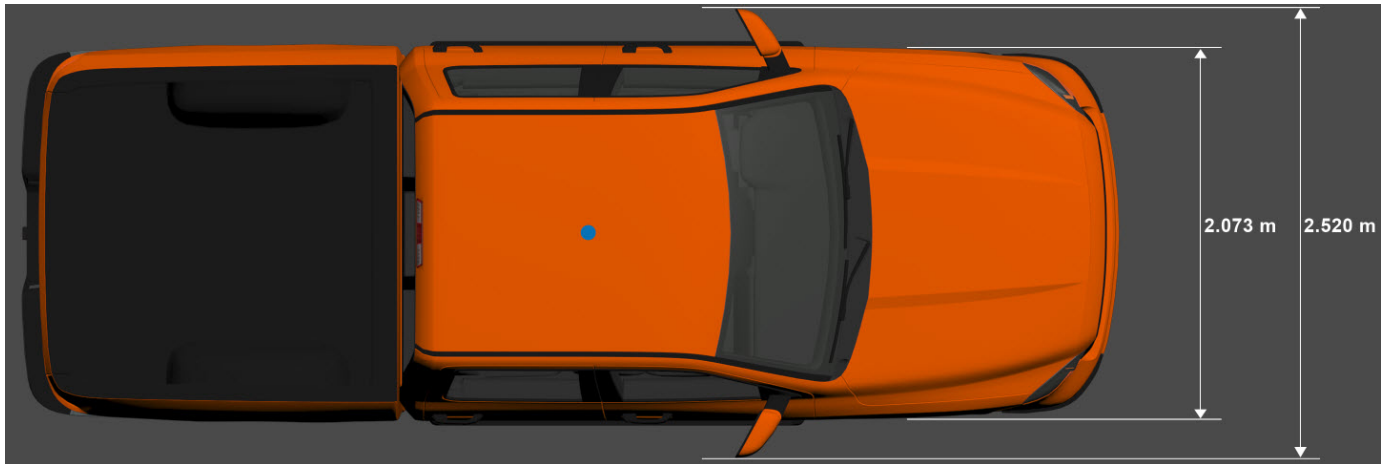


To add this type of vehicle to the 3D simulation environment:

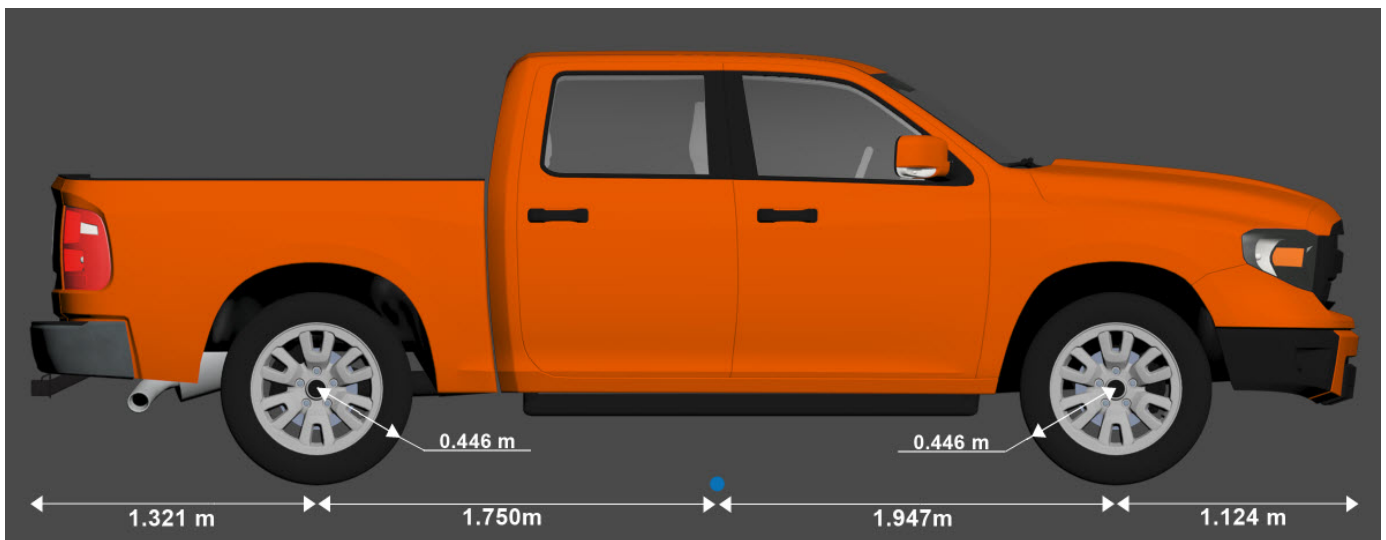
- 1 Add a Simulation 3D Vehicle or Simulation 3D Vehicle with Ground Following block to your Simulink model.
- 2 In the block, set the **Type** parameter to Small pickup truck.

### Dimensions

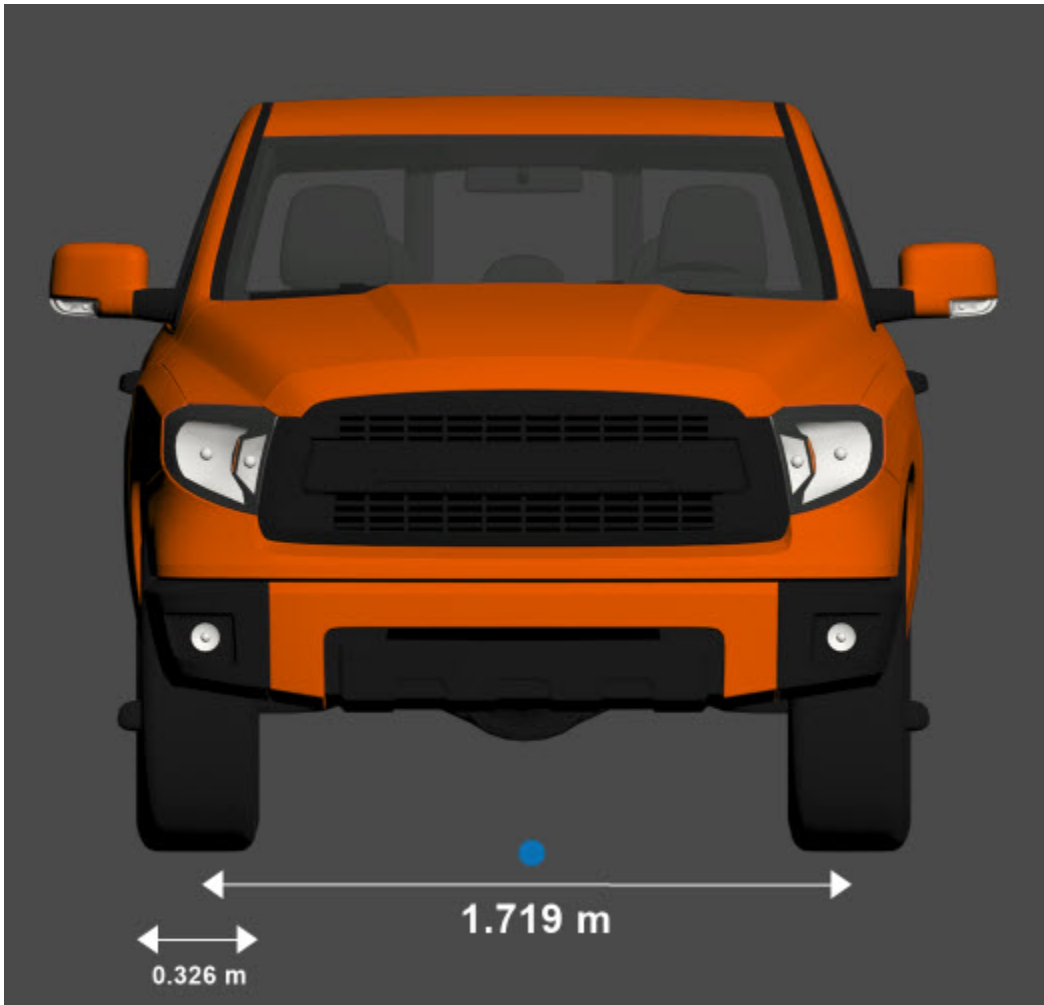
**Top-down view — Vehicle width dimensions**  
diagram



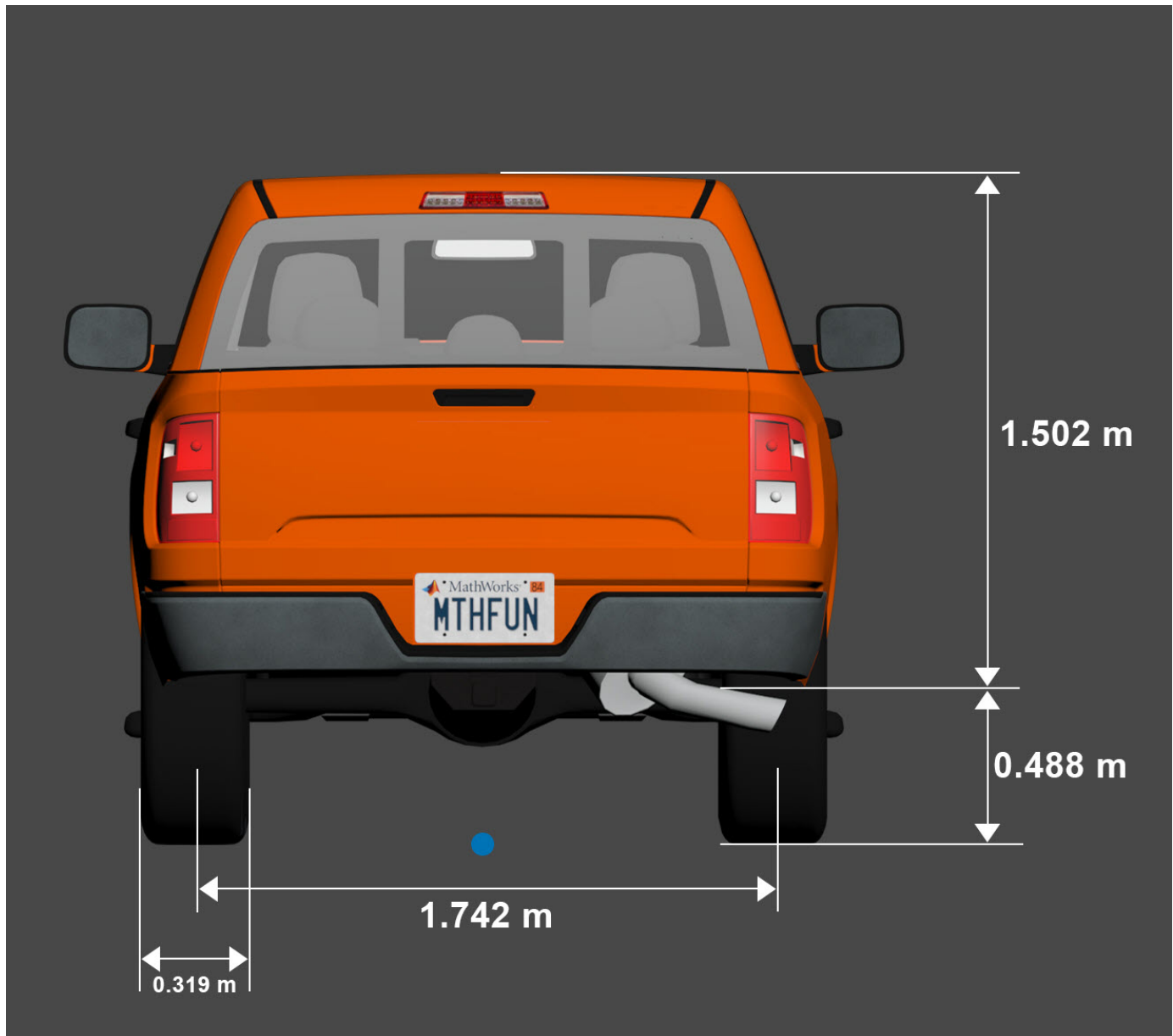
**Side view – Vehicle length, front overhang, and rear overhang dimensions**  
diagram



**Front view – Tire width and front axle dimensions**  
diagram



**Rear view – Vehicle height and rear axle dimensions**  
diagram



## Sensor Mounting Locations

In the 3D simulation sensor blocks, use the **Mounting location** parameter to mount sensors at predefined locations on the vehicle. The table shows the X, Y, and Z positions of the mounting locations relative to the vehicle origin. These locations are in the vehicle coordinate system, where:

- The X-axis points forward from the vehicle.
- The Y-axis points to the left of the vehicle, as viewed when facing forward.
- The Z-axis points up from the ground.

**Small Pickup Truck – Sensor Locations Relative to Vehicle Origin**

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	3.07	0	0.51
Rear bumper	-3.07	0	0.51
Right mirror	1.10	-1.13	1.52
Left mirror	1.10	1.13	1.52
Rearview mirror	0.85	0	1.77
Hood center	2.22	0	1.59
Roof center	0	0	2.27

**See Also**

Simulation 3D Scene Configuration | Simulation 3D Vehicle | Simulation 3D Vehicle with Ground Following

**Topics**

“Coordinate Systems in Vehicle Dynamics Blockset”

“How 3D Simulation for Vehicle Dynamics Blockset Works”

# Box Truck

Box truck vehicle dimensions

## Description

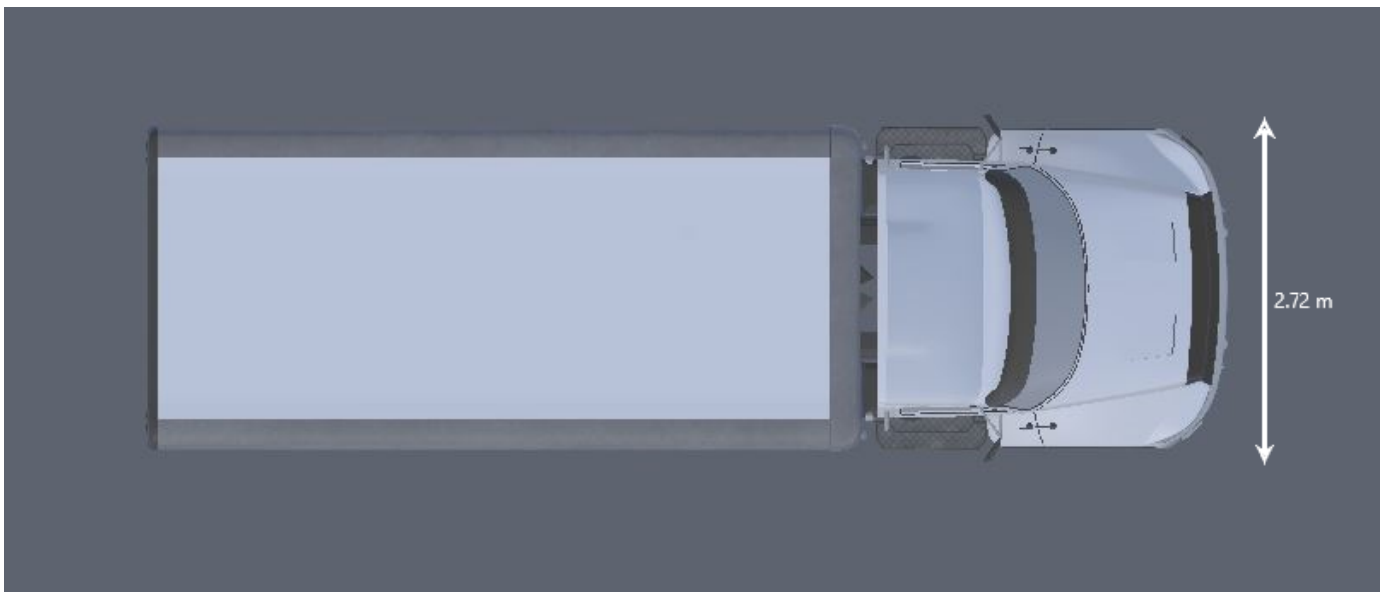
**Box truck** is one of the vehicles that you can use within the 3D simulation environment. This environment is rendered using the Unreal Engine from Epic Games. The following diagram provides the dimensions of this vehicle. The height dimensions are with respect to the vertical ground plane. The length and width dimensions are with respect to the origin of the vehicle in the vehicle coordinate system. The origin is on the ground, at the geometric center of the vehicle. For more detailed views of these diagrams, see the **Dimensions** section.

To add this type of vehicle to the 3D simulation environment:

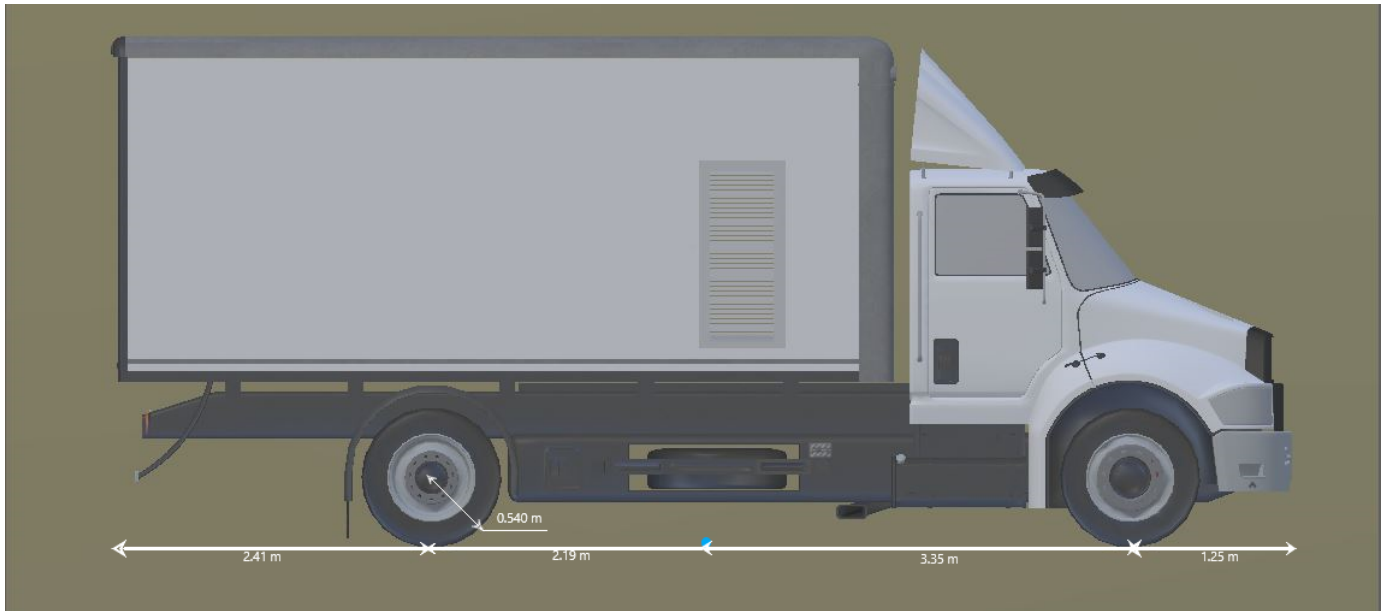
- 1 Add a Simulation 3D Vehicle or Simulation 3D Vehicle with Ground Following block to your Simulink model.
- 2 In the block, set the **Type** parameter to Box truck.

## Dimensions

**Top-down view – Vehicle width dimensions**  
diagram

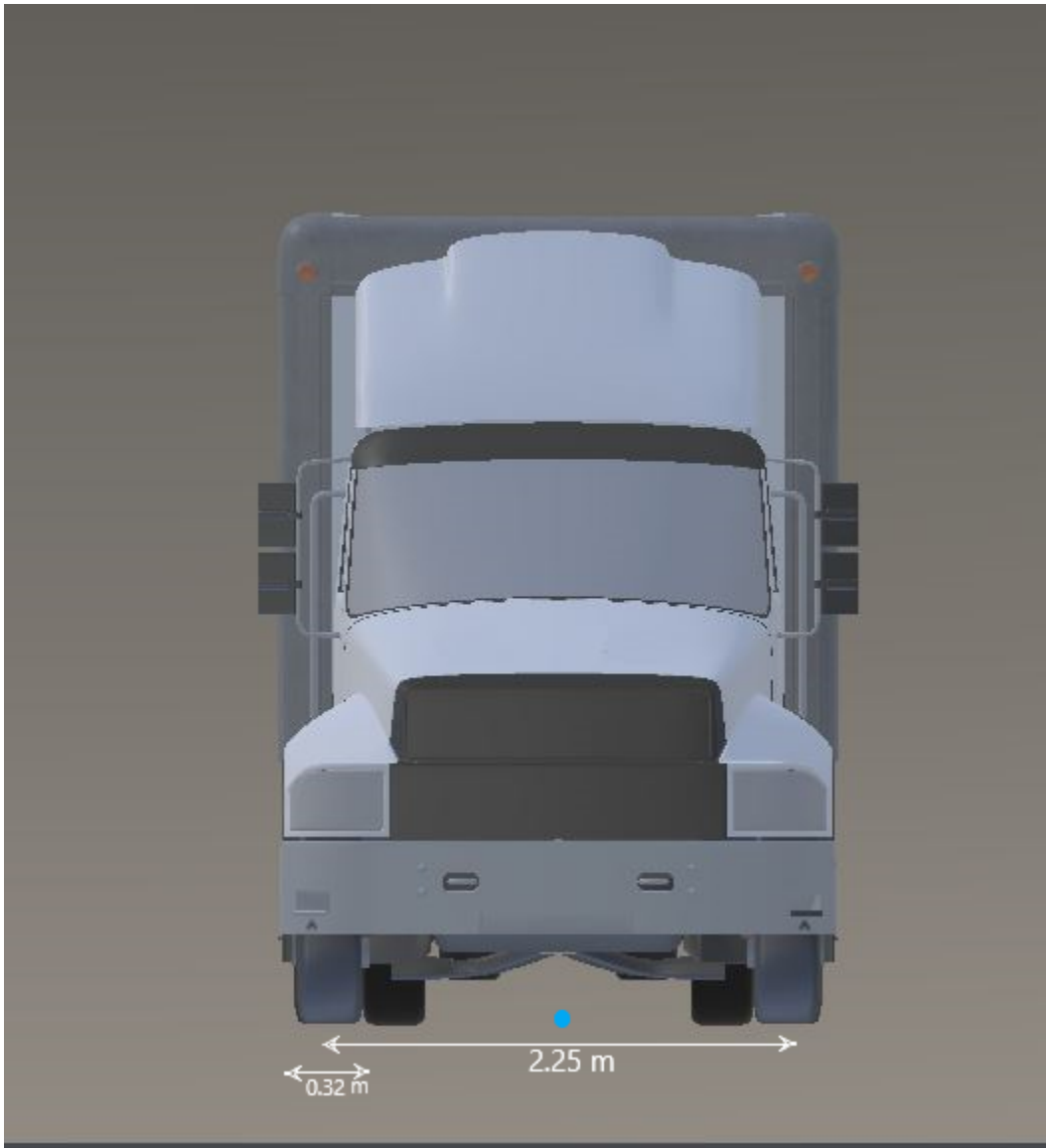


**Side view – Vehicle length, front overhang, and rear overhang dimensions**  
diagram



**Front view – Tire width and front axle dimensions**  
diagram





**Rear view – Vehicle height and rear axle dimensions**  
diagram



### Sensor Mounting Locations

In the 3D simulation sensor blocks, use the **Mounting location** parameter to mount sensors at predefined locations on the vehicle. The table shows the X, Y, and Z positions of the mounting locations relative to the vehicle origin. These locations are in the vehicle coordinate system, where:

- The X-axis points forward from the vehicle.
- The Y-axis points to the left of the vehicle, as viewed when facing forward.
- The Z-axis points up from the ground.

#### Box Truck — Sensor Locations Relative to Vehicle Origin

Mounting Location	X (m)	Y (m)	Z (m)
Front bumper	5.10	0	0.60
Rear bumper	-5	0	0.60
Right mirror	2.90	1.60	2.10
Left mirror	2.90	-1.60	2.10
Rearview mirror	2.60	0.20	2.60
Hood center	3.80	0	2.10
Roof center	1.30	0	4.20

#### See Also

Simulation 3D Scene Configuration | Simulation 3D Vehicle | Simulation 3D Vehicle with Ground Following

#### Topics

“Coordinate Systems in Vehicle Dynamics Blockset”

“How 3D Simulation for Vehicle Dynamics Blockset Works”

## Cab-Over Tractor

Cab-over tractor dimensions

### Description

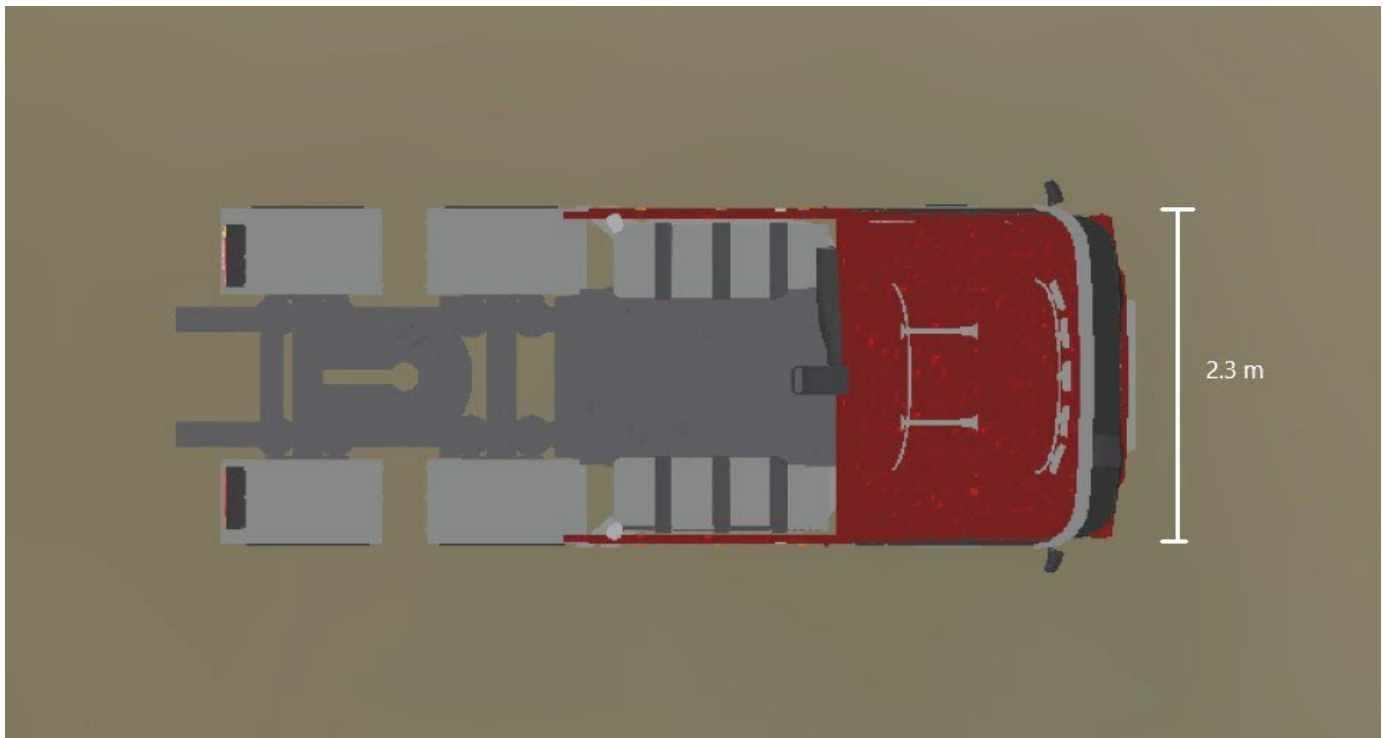
**Cab-Over Tractor** is one of the tractors that you can use in the 3D simulation environment. The environment is rendered using the Unreal Engine from Epic Games. The **Dimensions** section provides the dimensions of this tractor. The height dimensions are with respect to the vertical ground plane. The length and width dimensions are with respect to the origin of the tractor in the vehicle coordinate system. The origin is on the ground, at the geometric center of the tractor.

To add this type of tractor to the 3D simulation environment:

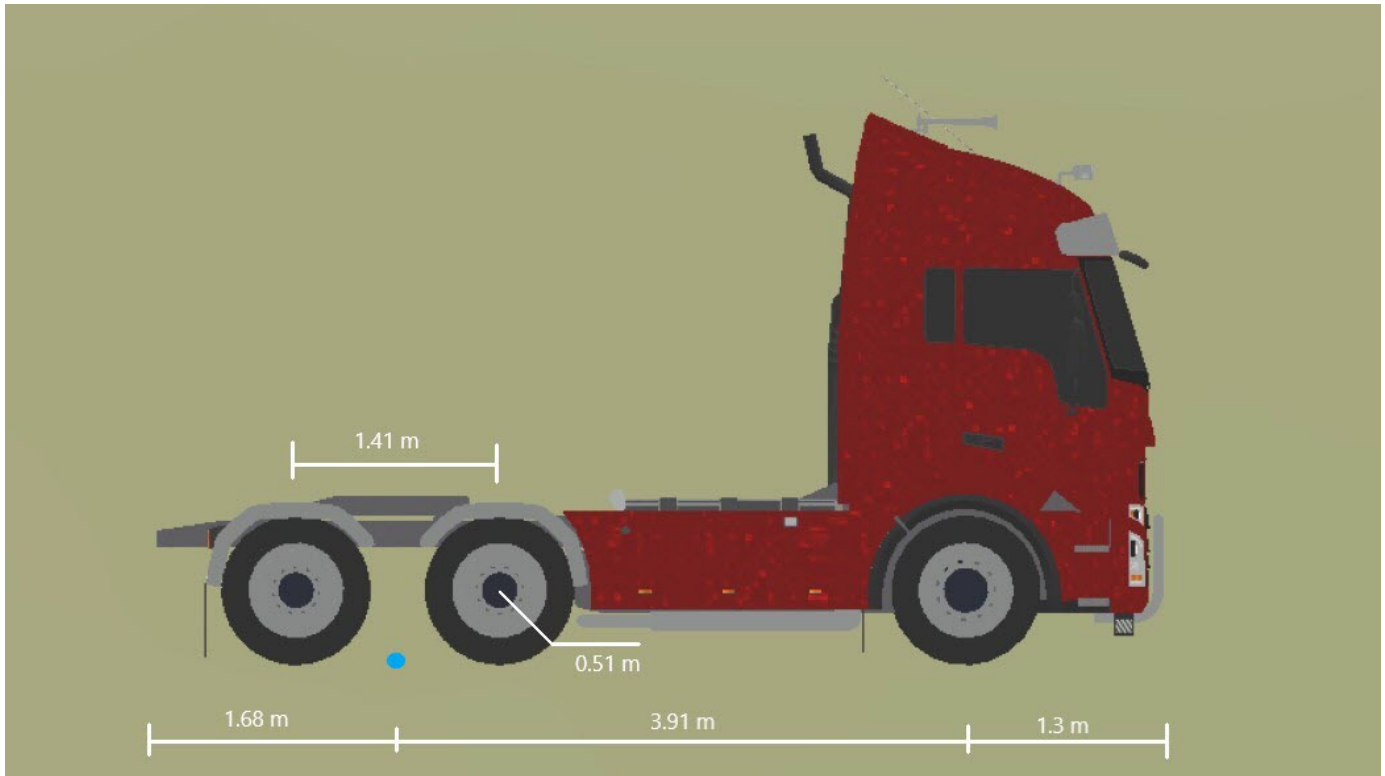
- 1 Add a Simulation 3D Tractor block to your Simulink model.
- 2 In the block, set the **Type** parameter to Cab-over tractor.

### Dimensions

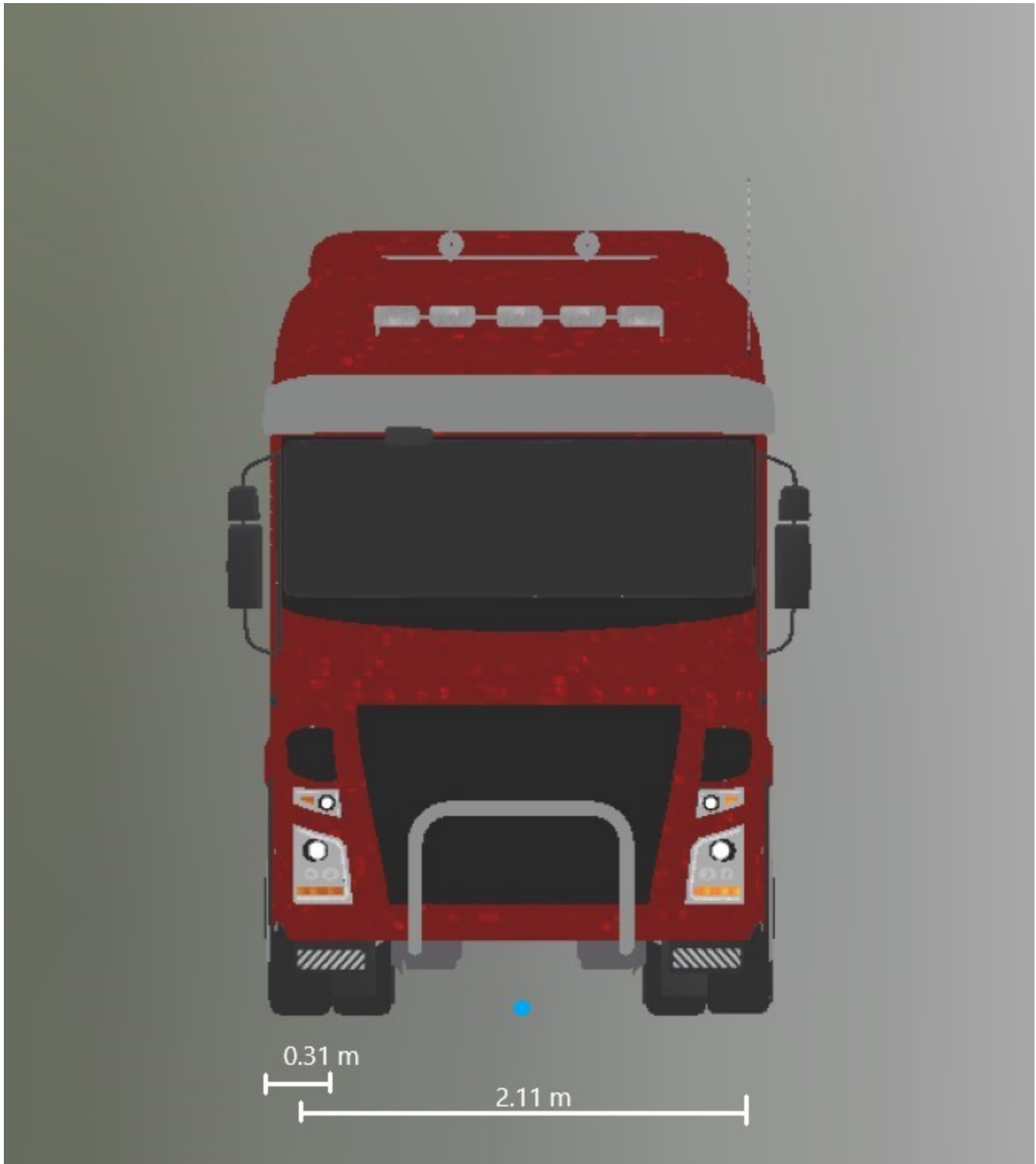
**Top-down view – Tractor width dimensions**  
diagram



**Side view – Tractor length, front overhang, and rear overhang dimensions**  
diagram



**Front view – Tire width and front axle dimensions**  
diagram



**See Also**

Simulation 3D Tractor | Simulation 3D Scene Configuration

**Topics**

“Coordinate Systems in Vehicle Dynamics Blockset”

“How 3D Simulation for Vehicle Dynamics Blockset Works”

## Conventional Tractor

Conventional tractor dimensions

### Description

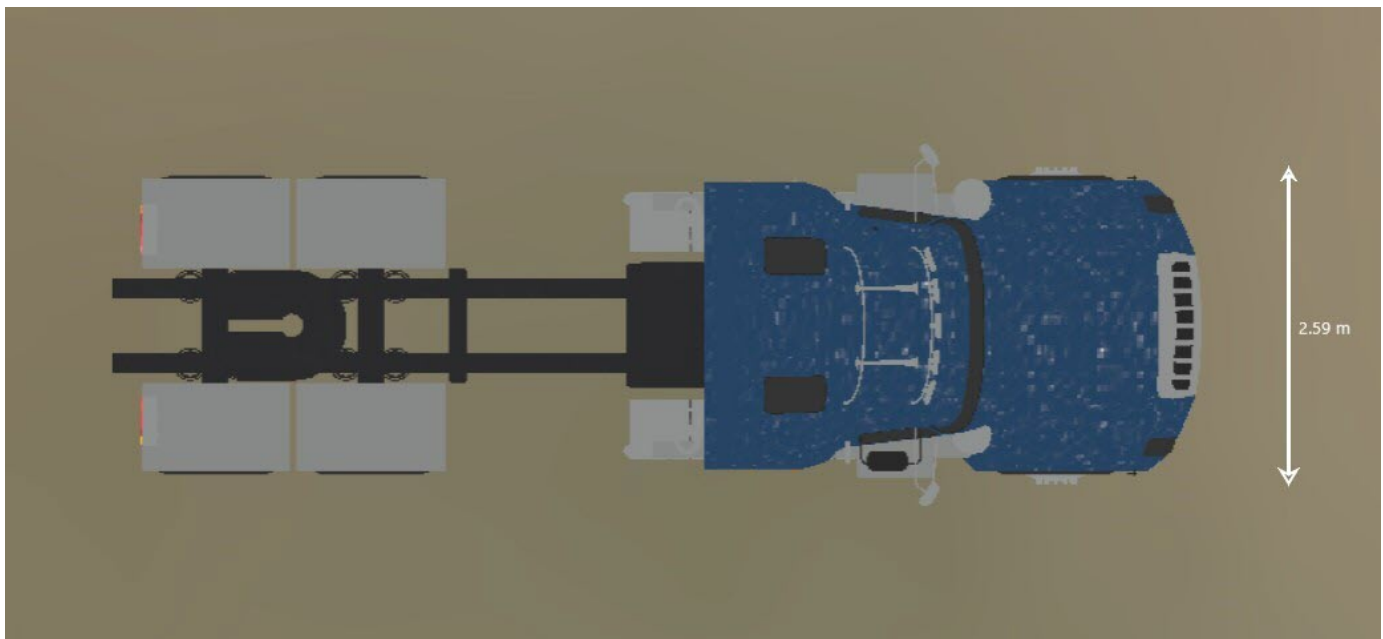
**Conventional Tractor** is one of the tractors that you can use in the 3D simulation environment. The environment is rendered using the Unreal Engine from Epic Games. The **Dimensions** section provides the dimensions of this tractor. The height dimensions are with respect to the vertical ground plane. The length and width dimensions are with respect to the origin of the tractor in the vehicle coordinate system. The origin is on the ground, at the geometric center of the tractor.

To add this type of tractor to the 3D simulation environment:

- 1 Add a Simulation 3D Tractor block to your Simulink model.
- 2 In the block, set the **Type** parameter to Conventional tractor.

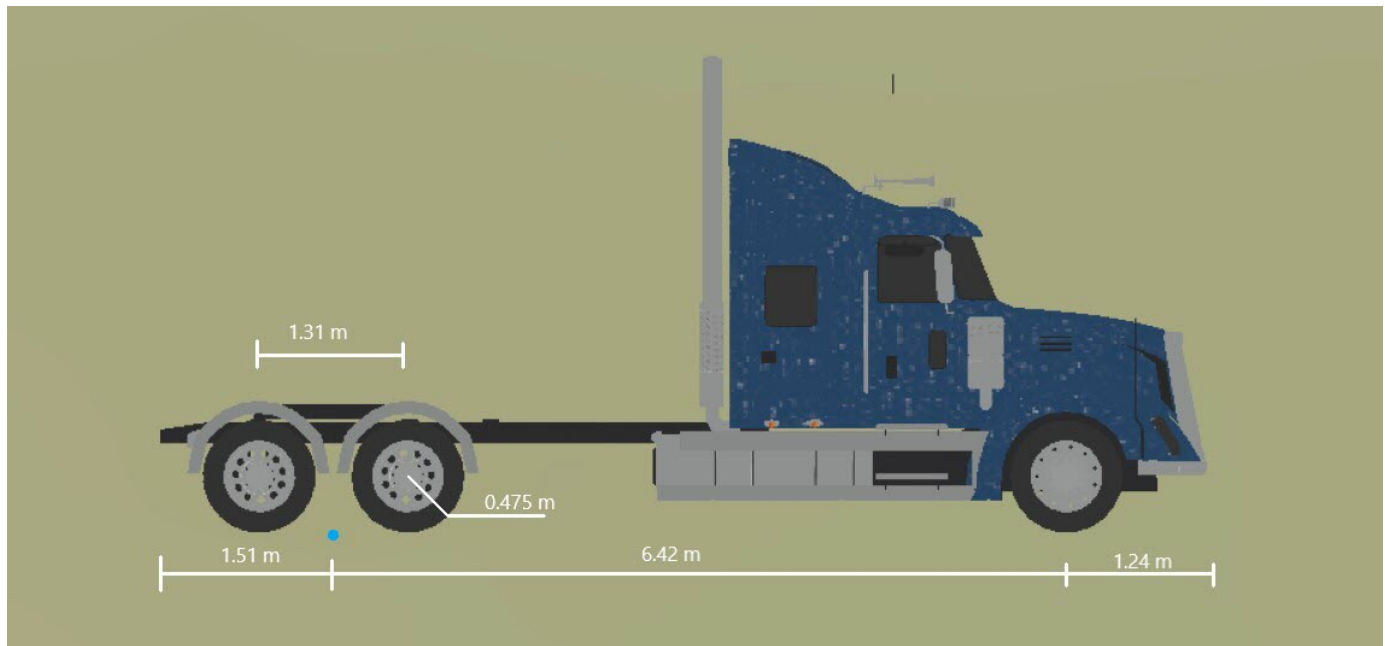
### Dimensions

**Top-down view – Tractor width dimensions**  
diagram



**Side view – Tractor length, front overhang, and rear overhang dimensions**  
diagram





**Front view – Tire width and front axle dimensions**  
diagram



## **See Also**

Simulation 3D Tractor | Simulation 3D Scene Configuration

## **Topics**

“Coordinate Systems in Vehicle Dynamics Blockset”

“How 3D Simulation for Vehicle Dynamics Blockset Works”

## Two-Axle Trailer

Two-axle trailer dimensions

### Description

**Two-Axle Trailer** is one of the trailers that you can use in the 3D simulation environment. The environment is rendered using the Unreal Engine from Epic Games. The **Dimensions** section provides the dimensions of this trailer. The height dimensions are with respect to the vertical ground plane. The length and width dimensions are with respect to the origin of the trailer in the vehicle coordinate system. The origin is on the ground, at the geometric center of the trailer.

To add this type of trailer to the 3D simulation environment:

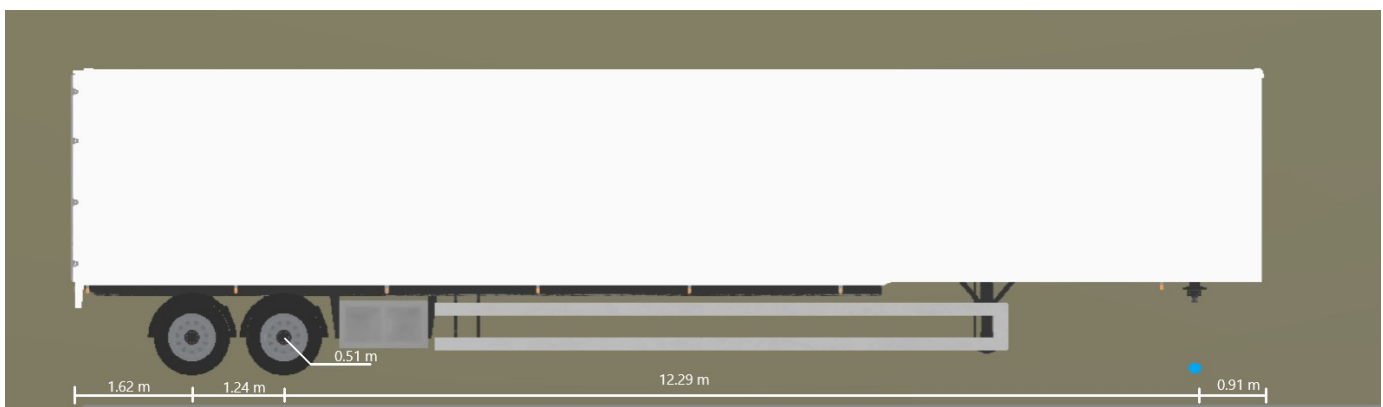
- 1 Add a Simulation 3D Trailer block to your Simulink model.
- 2 In the block, set the **Type** parameter to Two-axle trailer.

### Dimensions

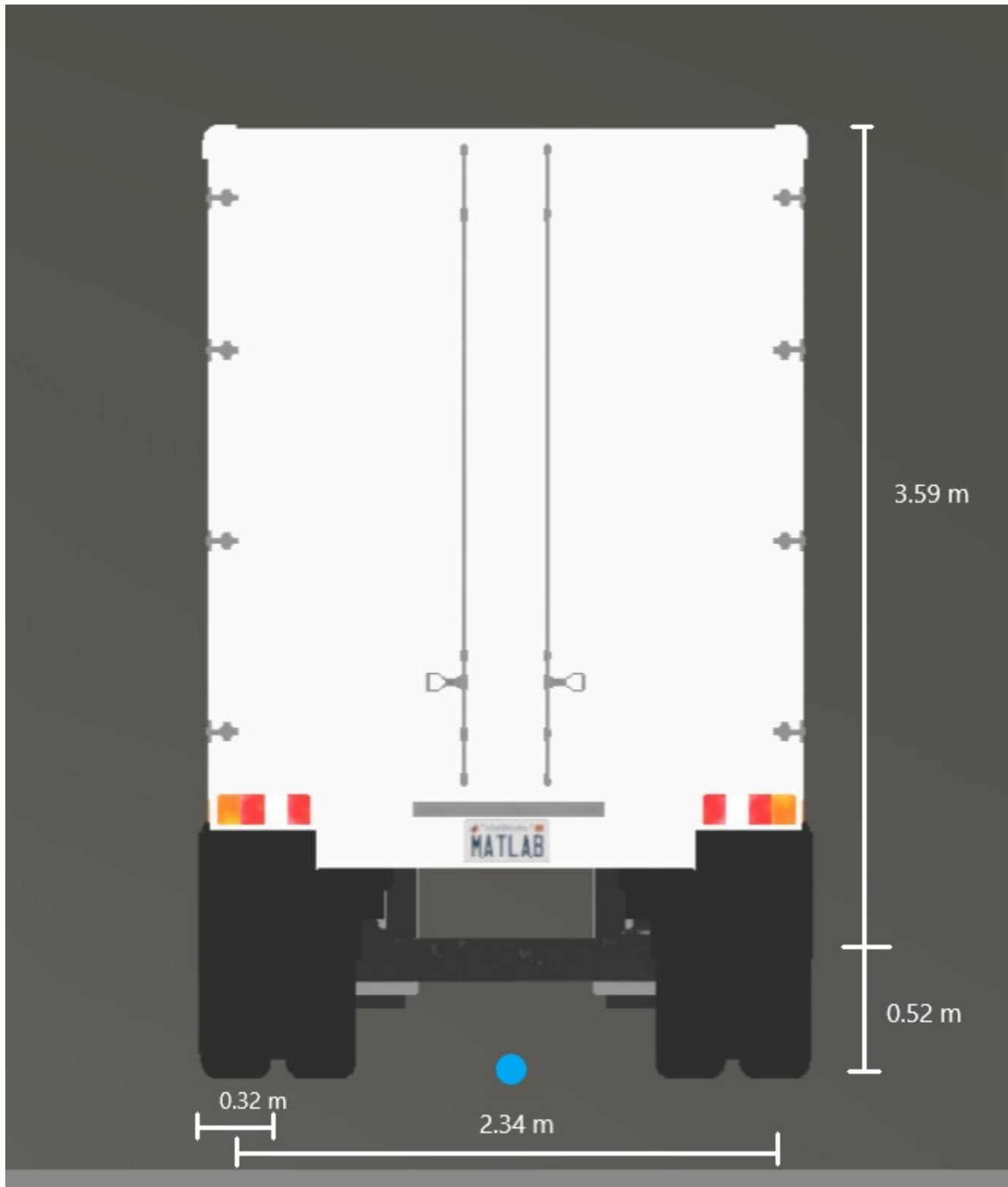
**Top-down view – Trailer width dimensions**  
diagram



**Side view – Trailer length, front overhang, and rear overhang dimensions**  
diagram



**Back view – Tire width and front axle dimensions**  
diagram



**See Also**

Simulation 3D Trailer | Simulation 3D Scene Configuration

**Topics**

“Coordinate Systems in Vehicle Dynamics Blockset”

“How 3D Simulation for Vehicle Dynamics Blockset Works”

# Three-Axle Trailer

Three-axle trailer dimensions

## Description

**Three-Axle Trailer** is one of the trailers that you can use in the 3D simulation environment. The environment is rendered using the Unreal Engine from Epic Games. The **Dimensions** section provides the dimensions of this trailer. The height dimensions are with respect to the vertical ground plane. The length and width dimensions are with respect to the origin of the trailer in the vehicle coordinate system. The origin is on the ground, at the geometric center of the trailer.

To add this type of trailer to the 3D simulation environment:

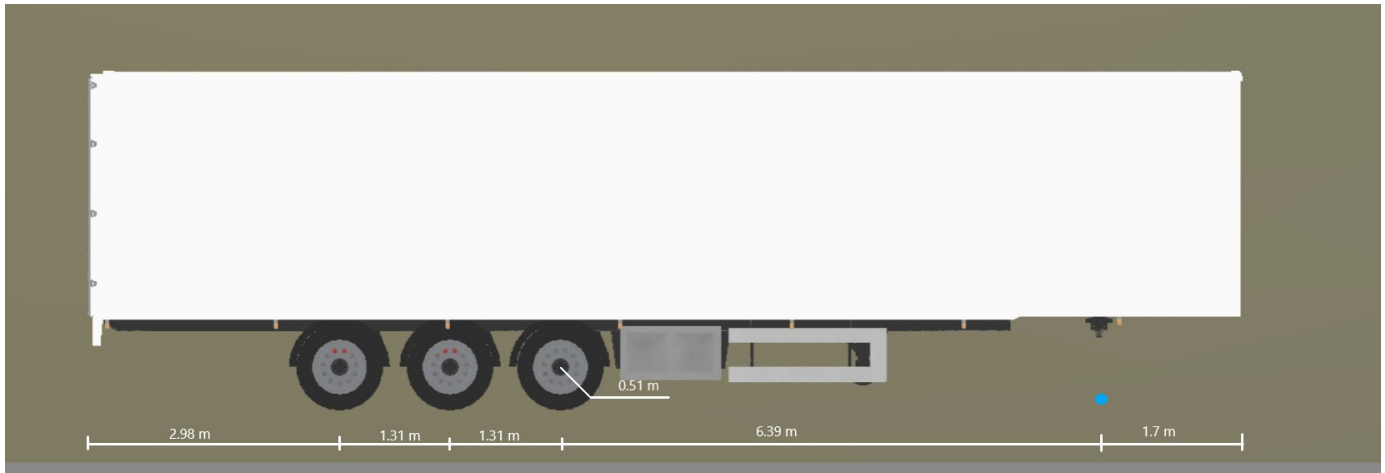
- 1 Add a Simulation 3D Trailer block to your Simulink model.
- 2 In the block, set the **Type** parameter to Three-axle trailer.

## Dimensions

**Top-down view – Trailer width dimensions**  
diagram

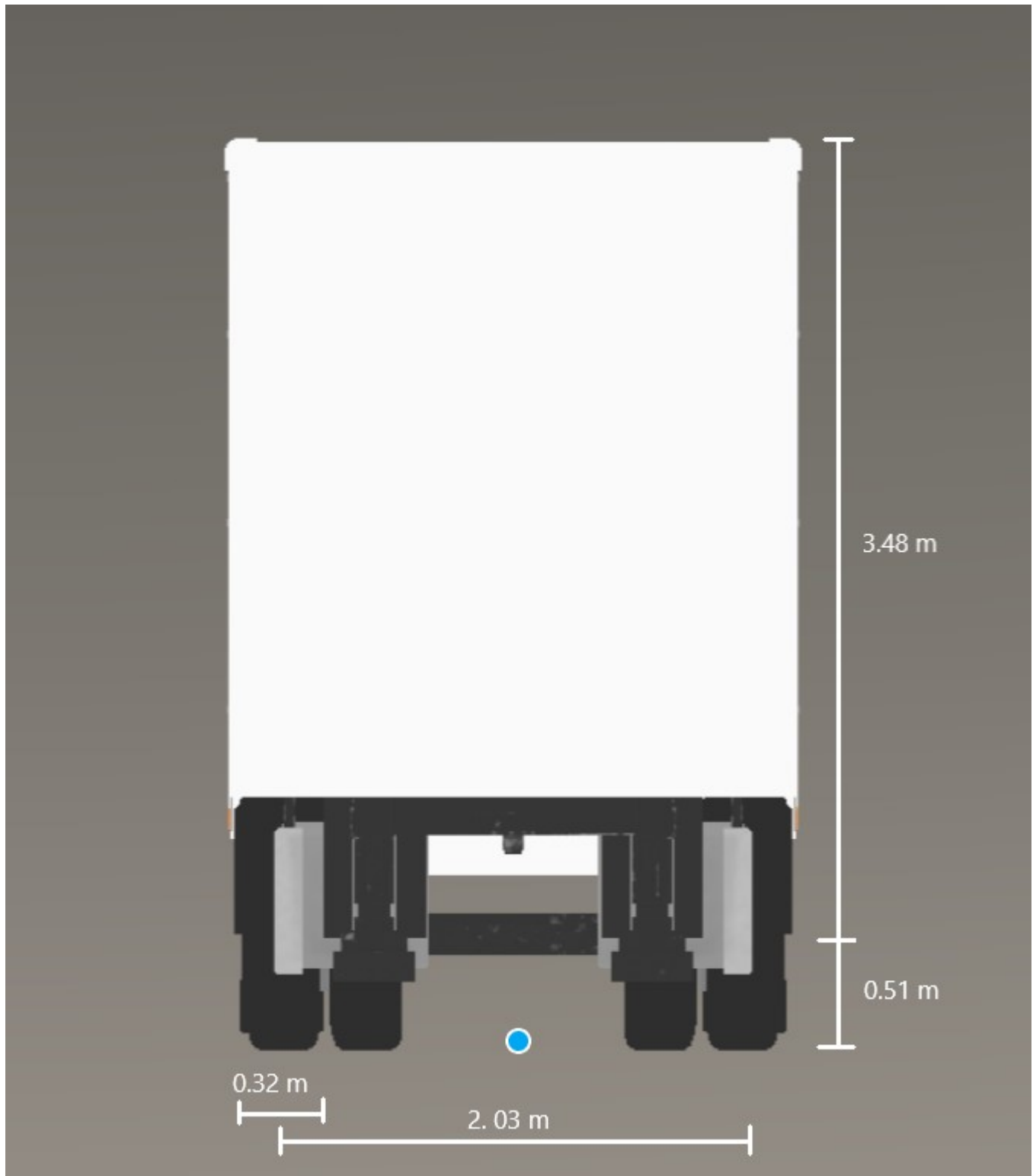


**Side view – Trailer length, front overhang, and rear overhang dimensions**  
diagram



**Front view – Tire width and front axle dimensions**  
diagram





**See Also**

Simulation 3D Trailer | Simulation 3D Scene Configuration

**Topics**

“Coordinate Systems in Vehicle Dynamics Blockset”

“How 3D Simulation for Vehicle Dynamics Blockset Works”

# Blocks in Reference Applications

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## 3D Engine

Configure scenes in reference applications

### Description

The 3D Engine block implements the 3D simulation environment. Vehicle Dynamics Blockset integrates the 3D simulation environment with Simulink so that you can query the world around the vehicle for virtually testing perception, control, and planning algorithms.

To position the vehicle in the scene:

- 1 Select the position initialization method:
  - **Recommended for scene** — Set the initial vehicle position to values recommended for the scene
  - **User-specified** — Set your own initial vehicle position
- 2 Click **Update the model workspaces with the initial values** to overwrite the initial vehicle position in the model workspaces with the applied values.

### Ports

#### Input

##### VehFdbk — Vehicle feedback

Bus

Bus containing vehicle feedback signals, including velocity, acceleration, and steering wheel torque.

### Parameters

#### 3D Engine

##### 3D Engine — Enable 3D visualization

off (default) | on

Enable 3D visualization.

##### Scene — 3D scene

Straight road | Curved road | Parking lot | Double lane change | Open surface | US city block | US highway | Virtual Mcity | Large parking lot

Specify the name of the 3D scene.

##### Engine frame rate, dt3D — Graphics

.03 (default)

Graphics frame rate, in s. The graphics frame rate is the inverse of the sample time.

##### Recommended for scene — Initial vehicle position

on (default) | off

Use vehicle positions that are recommended for the scene.

**User-specified — Initial vehicle position**

off (default) | on

Specify to set your own initial vehicle position values.

**Initial longitudinal position, X\_o — Initial longitudinal position**

off (default) | on

Initial vehicle CG position along the earth-fixed X-axis, in m.

**Initial lateral position, Y\_o — Initial lateral position**

off (default) | on

Initial vehicle CG position along the earth-fixed Y-axis, in m.

**Initial vertical position, Z\_o — Initial vertical position**

off (default) | on

Initial vehicle CG position along the earth-fixed Z-axis, in m.

**Initial roll angle, phi\_o — Roll**

off (default) | on

Rotation of the vehicle-fixed frame about the earth-fixed X-axis (roll), in rad.

**Initial pitch angle, theta\_o — Pitch**

off (default) | on

Rotation of the vehicle-fixed frame about the earth-fixed Y-axis (pitch), in rad.

**Initial yaw angle, psi\_o — Yaw**

off (default) | on

Rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw), in rad.

**See Also**

**Curved Road | Double Lane Change | Large Parking Lot | Open Surface | Parking Lot | Straight Road | US City Block | US Highway | Virtual Mcity**

**Topics**

“Double-Lane Change Maneuver”  
“Slowly Increasing Steering Maneuver”  
“Swept-Sine Steering Maneuver”  
“How 3D Simulation for Vehicle Dynamics Blockset Works”  
“3D Visualization Engine Requirements and Limitations”

**External Websites**

Unreal Engine

**Introduced in R2019a**

## Bicycle Model

Implement a single track 3DOF rigid vehicle body to calculate longitudinal, lateral, and yaw motion

### Description

The Bicycle Model block implements a rigid two-axle single track vehicle body model to calculate longitudinal, lateral, and yaw motion. The block accounts for body mass, aerodynamic drag, and weight distribution between the axles due to acceleration and steering. There are two types of Bicycle Model blocks.

Block	Implementation
<p>Bicycle Model - Velocity Input</p>	<ul style="list-style-type: none"> <li>Block assumes that the external longitudinal velocity is quasi-steady state so the longitudinal acceleration is approximately zero.</li> <li>Since the motion is quasi-steady, the block calculates only lateral forces using the tire slip angles and linear cornering stiffness.</li> </ul>
<p>Bicycle Model - Force Input</p>	<ul style="list-style-type: none"> <li>Block uses the external longitudinal force to accelerate or brake the vehicle.</li> <li>Block calculates lateral forces using the tire slip angles and linear cornering stiffness.</li> </ul>

To calculate the normal forces on the front and rear axles, the block uses rigid-body vehicle motion, suspension system forces, and wind and drag forces. The block resolves the force and moment components on the rigid vehicle body frame.

### Ports

#### Input

##### WhlAngF — Wheel angle

scalar

Front wheel angle, in rad.

##### FxF — Force Input: Total longitudinal force on the front axle

scalar

Longitudinal force on the front axle,  $F_{x_F}$ , along vehicle-fixed x-axis, in N.

Bicycle Model - Force Input block input port.

**FxR – Force Input: Total longitudinal force on the rear axle**

scalar

Longitudinal force on the rear axle,  $F_{xR}$ , along vehicle-fixed x-axis, in N.

Bicycle Model - Force Input block input port.

**xdotin – Velocity Input: Longitudinal velocity**

scalar

Vehicle CG velocity along vehicle-fixed x-axis, in m/s.

Bicycle Model - Velocity Input block input port.

**Output**

**Info – Bus signal**

bus

Bus signal containing these block values.

Signal		Description		Value	Units	
InertFrm	Cg	Disp	X	Vehicle CG displacement along the earth-fixed X-axis	Computed	m
			Y	Vehicle CG displacement along the earth-fixed Y-axis	Computed	m
			Z	Vehicle CG displacement along the earth-fixed Z-axis	0	m
	Vel	Xdot	Vehicle CG velocity along the earth-fixed X-axis	Computed	m/s	
			Ydot	Vehicle CG velocity along the earth-fixed Y-axis	Computed	m/s
			Zdot	Vehicle CG velocity along the earth-fixed Z-axis	0	m/s
	Ang	phi	Rotation of the vehicle-fixed frame about the earth-fixed X-axis (roll)	0	rad	
			theta	Rotation of the vehicle-fixed frame about the earth-fixed Y-axis (pitch)	0	rad
			psi	Rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw)	Computed	rad

Signal				Description	Value	Units
	FrntAxl	Disp	X	Front wheel displacement along the earth-fixed X-axis	Computed	m
			Y	Front wheel displacement along the earth-fixed Y-axis	Computed	m
			Z	Front wheel displacement along the earth-fixed Z-axis	0	m
		Vel	Xdot	Front wheel velocity along the earth-fixed X-axis	Computed	m/s
			Ydot	Front wheel velocity along the earth-fixed Y-axis	Computed	m/s
			Zdot	Front wheel velocity along the earth-fixed Z-axis	0	m/s
	RearAxl	Disp	X	Rear wheel displacement along the earth-fixed X-axis	Computed	m
			Y	Rear wheel displacement along the earth-fixed Y-axis	Computed	m
			Z	Rear wheel displacement along the earth-fixed Z-axis	0	m
		Vel	Xdot	Rear wheel velocity along the earth-fixed X-axis	Computed	m/s
			Ydot	Rear wheel velocity along the earth-fixed Y-axis	Computed	m/s
			Zdot	Rear wheel velocity along the earth-fixed Z-axis	0	m/s
	Hitch	Disp	X	Hitch offset from axle plane along the earth-fixed X-axis	Computed	m
			Y	Hitch offset from center plane along the earth-fixed Y-axis	Computed	m
			Z	Hitch offset from axle plane along the earth-fixed Z-axis	Computed	m
Vel		Xdot	Hitch offset velocity from axle plane along the earth-fixed X-axis	Computed	m	



Signal			Description	Value	Units		
			Ydot	Hitch offset velocity from center plane along the earth-fixed Y-axis	Computed	m	
			Zdot	Hitch offset velocity from axle plane along the earth-fixed Z-axis	Computed	m	
		Geom	Disp	X	Vehicle chassis offset from axle plane along the earth-fixed X-axis	Computed	m
				Y	Vehicle chassis offset from center plane along the earth-fixed Y-axis	Computed	m
				Z	Vehicle chassis offset from axle plane along the earth-fixed Z-axis	Computed	m
		Vel	Xdot	Vehicle chassis offset velocity along the earth-fixed X-axis	Computed	m/s	
			Ydot	Vehicle chassis offset velocity along the earth-fixed Y-axis	Computed	m/s	
			Zdot	Vehicle chassis offset velocity along the earth-fixed Z-axis	Computed	m/s	
		BdyFrm	Cg	Vel	xdot	Vehicle CG velocity along the vehicle-fixed x-axis	Computed
ydot	Vehicle CG velocity along the vehicle-fixed y-axis				Computed	m/s	
zdot	Vehicle CG velocity along the vehicle-fixed z-axis				0	m/s	
Ang	Beta			Body slip angle, $\beta$ $\beta = \frac{V_y}{V_x}$	Computed	rad	
AngVel	p			Vehicle angular velocity about the vehicle-fixed x-axis (roll rate)	0	rad/s	
	q			Vehicle angular velocity about the vehicle-fixed y-axis (pitch rate)	0	rad/s	
	r			Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate)	Computed	rad/s	

Signal				Description	Value	Units
	Acc	ax	ax	Vehicle CG acceleration along the vehicle-fixed x-axis	Computed	gn
			ay	Vehicle CG acceleration along the vehicle-fixed y-axis	Computed	gn
			az	Vehicle CG acceleration along the vehicle-fixed z-axis	0	gn
			xddot	Vehicle CG acceleration along the vehicle-fixed x-axis	Computed	m/s <sup>2</sup>
			yddot	Vehicle CG acceleration along the vehicle-fixed y-axis	Computed	m/s <sup>2</sup>
			zddot	Vehicle CG acceleration along the vehicle-fixed z-axis	0	m/s <sup>2</sup>
		AngAcc	pdot	Vehicle angular acceleration about the vehicle-fixed x-axis	0	rad/s
			qdot	Vehicle angular acceleration about the vehicle-fixed y-axis	0	rad/s
			rdot	Vehicle angular acceleration about the vehicle-fixed z-axis	Computed	rad/s
		DCM	Direction cosine matrix			Computed
	Forces	Body	Fx	Net force on vehicle CG along the vehicle-fixed x-axis	Computed	N
			Fy	Net force on vehicle CG along the vehicle-fixed y-axis	Computed	N
			Fz	Net force on vehicle CG along the vehicle-fixed z-axis	0	N
		Ext	Fx	External force on vehicle CG along the vehicle-fixed x-axis	Computed	N
			Fy	External force on vehicle CG along the vehicle-fixed y-axis	Computed	N

Signal			Description	Value	Units	
		Fz	External force on vehicle CG along the vehicle-fixed z-axis	0	N	
	Hitch	Fx	Hitch force applied to body at the hitch location along the vehicle-fixed x-axis	Input	N	
		Fy	Hitch force applied to body at the hitch location along the vehicle-fixed y-axis	Input	N	
		Fz	Hitch force applied to body at the hitch location along the vehicle-fixed z-axis	Input	N	
	FrntAxl	Fx	Longitudinal force on front wheel, along the vehicle-fixed x-axis	Computed	N	
		Fy	Lateral force on front wheel along the vehicle-fixed y-axis	Computed	N	
		Fz	Normal force on front wheel, along the vehicle-fixed z-axis	Computed	N	
	RearAxl	Fx	Longitudinal force on rear wheel, along the vehicle-fixed x-axis	Computed	N	
		Fy	Lateral force on rear wheel along the vehicle-fixed y-axis	Computed	N	
		Fz	Normal force on rear wheel, along the vehicle-fixed z-axis	Computed	N	
	Tires	FrntTire	Fx	Front tire force, along the vehicle-fixed x-axis	Computed	N
			Fy	Front tire force, along the vehicle-fixed y-axis	Computed	N
			Fz	Front tire force, along the vehicle-fixed z-axis	Computed	N
		RearTire	FxFx	Rear tire force, along the vehicle-fixed x-axis	Computed	N
			Fy	Rear tire force, along the vehicle-fixed y-axis	Computed	N

Signal				Description	Value	Units	
			Fz	Rear tire force, along the vehicle-fixed z-axis	Computed	N	
		Drag	Fx	Drag force on vehicle CG along the vehicle-fixed x-axis	Computed	N	
			Fy	Drag force on vehicle CG along the vehicle-fixed y-axis	Computed	N	
			Fz	Drag force on vehicle CG along the vehicle-fixed z-axis	Computed	N	
		Grvty	Fx	Gravity force on vehicle CG along the vehicle-fixed x-axis	Computed	N	
			Fy	Gravity force on vehicle CG along the vehicle-fixed y-axis	Computed	N	
			Fz	Gravity force on vehicle CG along the vehicle-fixed z-axis	Computed	N	
	Moments	Body	Mx	Body moment on vehicle CG about the vehicle-fixed x-axis	0	N·m	
				My	Body moment on vehicle CG about the vehicle-fixed y-axis	Computed	N·m
				Mz	Body moment on vehicle CG about the vehicle-fixed z-axis	0	N·m
			Drag	Mx	Drag moment on vehicle CG about the vehicle-fixed x-axis	0	N·m
				My	Drag moment on vehicle CG about the vehicle-fixed y-axis	Computed	N·m
				Mz	Drag moment on vehicle CG about the vehicle-fixed z-axis	0	N·m
			Ext	Mx	External moment on vehicle CG about the vehicle-fixed x-axis	0	N·m
				My	External moment on vehicle CG about the vehicle-fixed y-axis	Computed	N·m

Signal			Description	Value	Units	
	Hitch	Mz	External moment on vehicle CG about the vehicle-fixed z-axis	0	N·m	
		Mx	Hitch moment at the hitch location about vehicle-fixed x-axis	0	N·m	
		My	Hitch moment at the hitch location about vehicle-fixed y-axis	Computed	N·m	
		Mz	Hitch moment at the hitch location about vehicle-fixed z-axis	0	N·m	
	FrntAxl	Disp	x	Front wheel displacement along the vehicle-fixed x-axis	Computed	m
			y	Front wheel displacement along the vehicle-fixed y-axis	Computed	m
			z	Front wheel displacement along the vehicle-fixed z-axis	Computed	m
		Vel	x $\dot{}$	Front wheel velocity along the vehicle-fixed x-axis	Computed	m/s
			y $\dot{}$	Front wheel velocity along the vehicle-fixed y-axis	Computed	m/s
			z $\dot{}$	Front wheel velocity along the vehicle-fixed z-axis	0	m/s
		Steer	WhlAngFL	Front left wheel steering angle	Computed	rad
			WhlAngFR	Front right wheel steering angle	Computed	rad
	RearAxl	Disp	x	Rear wheel displacement along the vehicle-fixed x-axis	Computed	m
			y	Rear wheel displacement along the vehicle-fixed y-axis	Computed	m
			z	Rear wheel displacement along the vehicle-fixed z-axis	Computed	m
		Vel	x $\dot{}$	Rear wheel velocity along the vehicle-fixed x-axis	Computed	m/s
			y $\dot{}$	Rear wheel velocity along the vehicle-fixed y-axis	Computed	m/s

Signal				Description	Value	Units	
			zdot	Rear wheel velocity along the vehicle-fixed z-axis	0	m/s	
	Steer	WhlAngRL		Rear left wheel steering angle	Computed	rad	
		WhlAngRR		Rear right wheel steering angle	Computed	rad	
Hitch	Disp	x		Hitch offset from axle plane along the vehicle-fixed x-axis	Input	m	
		y		Hitch offset from center plane along the vehicle-fixed y-axis	Input	m	
		z		Hitch offset from axle plane along the earth-fixed z-axis	Input	m	
	Vel	xdot		Hitch offset velocity along the vehicle-fixed x-axis	Computed	m/s	
		ydot		Hitch offset velocity along the vehicle-fixed y-axis	Computed	m/s	
		zdot		Hitch offset velocity along the vehicle-fixed z-axis	Computed	m/s	
	Pwr	Ext			Applied external power	Computed	W
		Hitch			Power loss due to hitch	Computed	W
		Drag			Power loss due to drag	Computed	W
Geom	Disp	x		Vehicle chassis offset from axle plane along the vehicle-fixed x-axis	Input	m	
		y		Vehicle chassis offset from center plane along the vehicle-fixed y-axis	Input	m	
		z		Vehicle chassis offset from axle plane along the earth-fixed z-axis	Input	m	
	Vel	xdot		Vehicle chassis offset velocity along the vehicle-fixed x-axis	Computed	m/s	
		ydot		Vehicle chassis offset velocity along the vehicle-fixed y-axis	Computed	m/s	
		zdot		Vehicle chassis offset velocity along the vehicle-fixed z-axis	0	m/s	

Signal				Description	Value	Units
		Ang	Beta	Body slip angle, $\beta$ $\beta = \frac{V_y}{V_x}$	Computed	rad

Signal			Description	Value	Units
PwrInfo	PwrTrnsfrd	PwrFxExt	Externally applied longitudinal force power	Computed	W
		PwrFyExt	Externally applied lateral force power	Computed	W
		PwrMzExt	Externally applied roll moment power	Computed	W
		PwrFwFx	Longitudinal force applied at the front axle power	Computed	W
		PwrFwFy	Lateral force applied at the front axle power	Computed	W
		PwrFwRx	Longitudinal force applied at the rear axle power	Computed	W
		PwrFwRy	Lateral force applied at the rear axle power	Computed	W
	PwrNotTrnsfrd	PwrFxDrag	Longitudinal drag force power	Computed	W
		PwrFyDrag	Lateral drag force power	Computed	W
		PwrMzDrag	Drag pitch moment power	Computed	W
	PwrStored	PwrStoredGrvty	Rate change in gravitational potential energy	Computed	W
		PwrStoredxdot	Rate of change of longitudinal kinetic energy	Computed	W
		PwrStoredydot	Rate of change of lateral kinetic energy	Computed	W
		PwrStoredr	Rate of change of rotational yaw kinetic energy	Computed	W

**xdot – Vehicle body longitudinal velocity**

scalar

Vehicle CG velocity along vehicle-fixed x-axis, in m/s.

**ydot – Vehicle body lateral velocity**

scalar

Vehicle CG velocity along vehicle-fixed y-axis, in m/s.

**psi – Yaw**

scalar

Rotation of the vehicle-fixed frame about earth-fixed Z-axis (yaw), in rad..

**r – Yaw rate**

scalar

Vehicle angular velocity,  $r$ , about the vehicle-fixed z-axis (yaw rate), in rad/s.

**Parameters****Longitudinal****Number of wheels on front axle, NF – Front wheel count**

2 (default) | scalar

Number of wheels on front axle,  $N_F$ . The value is dimensionless.

**Number of wheels on rear axle, NR – Rear wheel count**

2 (default) | scalar

Number of wheels on rear axle,  $N_R$ . The value is dimensionless.

**Vehicle mass, m – Vehicle mass**

2000 (default) | scalar

Vehicle mass,  $m$ , in kg.

**Longitudinal distance from center of mass to front axle, a – Front axle distance**

1.4 (default) | scalar

Horizontal distance  $a$  from the vehicle CG to the front wheel axle, in m.

**Longitudinal distance from center of mass to rear axle, b – Rear axle distance**

1.6 (default) | scalar

Horizontal distance  $b$  from the vehicle CG to the rear wheel axle, in m.

**Vertical distance from center of mass to axle plane, h – Height**

0.35 (default) | scalar

Height of vehicle CG above the axles,  $h$ , in m.

**Longitudinal distance from center of mass to hitch, dh – Distance from CM to hitch**

1 (default) | scalar

Longitudinal distance from center of mass to hitch,  $dh$ , in m.

**Dependencies**

To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.

**Vertical distance from hitch to axle plane, hh – Distance from hitch to axle plane**

0.2 (default) | scalar



Vertical distance from hitch to axle plane,  $hh$ , in m.

**Dependencies**

To enable this parameter, on the **Input signals** pane, select **Hitch forces** or **Hitch moments**.

**Initial inertial frame longitudinal position,  $X_o$  – Position**

0 (default) | scalar

Initial vehicle CG displacement along earth-fixed  $X$ -axis, in m.

**Initial longitudinal velocity,  $\dot{x}_o$  – Velocity**

0 (default) | scalar

Initial vehicle CG velocity along vehicle-fixed  $x$ -axis, in m/s.

**Dependencies**

For the Vehicle Body 3DOF Single Track or Vehicle Body 3DOF Dual Track blocks, to enable this parameter, set **Axle forces** to one of these options:

- External longitudinal forces
- External forces

**Lateral**

**Front tire corner stiffness,  $C_{y_f}$  – Stiffness**

12e3 (default) | scalar

Front tire corner stiffness,  $C_{y_f}$ , in N/rad.

**Dependencies**

For the Vehicle Body 3DOF Single Track or Vehicle Body 3DOF Dual Track blocks, to enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Clear **Mapped corner stiffness**.

**Rear tire corner stiffness,  $C_{y_r}$  – Stiffness**

11e3 (default) | scalar

Rear tire corner stiffness,  $C_{y_r}$ , in N/rad.

**Dependencies**

For the Vehicle Body 3DOF Single Track or Vehicle Body 3DOF Dual Track blocks, to enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces

2 Clear **Mapped corner stiffness**.

**Initial inertial frame lateral displacement, Y\_o – Position**

0 (default) | scalar

Initial vehicle CG displacement along earth-fixed Y-axis, in m.

**Initial lateral velocity, ydot\_o – Velocity**

0 (default) | scalar

Initial vehicle CG velocity along vehicle-fixed y-axis, in m/s.

**Yaw**

**Yaw polar inertia, Izz – Inertia**

4000 (default) | scalar

Yaw polar inertia, in kg\*m<sup>2</sup>.

**Initial yaw angle, psi\_o – Psi rotation**

0 (default) | scalar

Rotation of the vehicle-fixed frame about earth-fixed Z-axis (yaw), in rad.

**Initial yaw rate, r\_o – Yaw rate**

0 (default) | scalar

Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate), in rad/s.

**Aerodynamic**

**Longitudinal drag area, Af – Effective vehicle cross-sectional area**

2 (default) | scalar

Effective vehicle cross-sectional area,  $A_f$ , to calculate the aerodynamic drag force on the vehicle, in m<sup>2</sup>.

**Longitudinal drag coefficient, Cd – Air drag coefficient**

.3 (default) | scalar

Air drag coefficient,  $C_d$ . The value is dimensionless.

**Longitudinal lift coefficient, Cl – Air lift coefficient**

.1 (default) | scalar

Air lift coefficient,  $C_l$ . The value is dimensionless.

**Longitudinal drag pitch moment, Cpm – Pitch drag**

.1 (default) | scalar

Longitudinal drag pitch moment coefficient,  $C_{pm}$ . The value is dimensionless.

**Relative wind angle vector, beta\_w – Wind angle**

[0:0.01:0.3] (default) | vector

Relative wind angle vector,  $\beta_w$ , in rad.

**Side force coefficient vector, Cs – Side force coefficient**

[0:0.03:0.9] (default) | vector

Side force coefficient vector coefficient,  $C_s$ . The value is dimensionless.**Yaw moment coefficient vector, Cym – Yaw moment drag**

[0:0.01:0.3] (default) | vector

Yaw moment coefficient vector coefficient,  $C_{ym}$ . The value is dimensionless.**Environment****Absolute air pressure, Pabs – Pressure**

101325 (default) | scalar | scalar

Environmental absolute pressure,  $P_{abs}$ , in Pa.**Air temperature, Tair – Temperature**

273 (default) | scalar

Environmental absolute temperature,  $T$ , in K.**Dependencies**To enable this parameter, clear **Air temperature**.**Gravitational acceleration, g – Gravity**

9.81 (default) | scalar

Gravitational acceleration,  $g$ , in  $m/s^2$ .**Nominal friction scaling factor, mu – Friction scale factor**

1 (default) | scalar

Nominal friction scale factor,  $\mu$ . The value is dimensionless.**Dependencies**

For the Vehicle Body 3DOF Single Track or Vehicle Body 3DOF Dual Track blocks, to enable this parameter:

- 1 Set **Axle forces** to one of these options:
  - External longitudinal velocity
  - External longitudinal forces
- 2 Clear **External Friction**.

**Simulation****Longitudinal velocity tolerance, xdot\_tol – Tolerance**

.01 (default) | scalar

Longitudinal velocity tolerance, in m/s.

**Nominal normal force, Fznom – Normal force**

5000 (default) | scalar

Nominal normal force, in N.

#### Dependencies

For the Vehicle Body 3DOF Single Track or Vehicle Body 3DOF Dual Track blocks, to enable this parameter, set **Axle forces** to one of these options:

- External longitudinal velocity
- External longitudinal forces

#### Geometric longitudinal offset from axle plane, `longOff` — Longitudinal offset

0 (default) | scalar

Vehicle chassis offset from axle plane along body-fixed  $x$ -axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independent of the vehicle CG.

#### Geometric lateral offset from center plane, `latOff` — Lateral offset

0 (default) | scalar

Vehicle chassis offset from center plane along body-fixed  $y$ -axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independent of the vehicle CG.

#### Geometric vertical offset from axle plane, `vertOff` — Vertical offset

0 (default) | scalar

Vehicle chassis offset from axle plane along body-fixed  $z$ -axis, in m. When you use the 3D visualization engine, consider using the offset to locate the chassis independent of the vehicle CG.

#### Wrap Euler angles, `wrapAng` — Selection

off (default) | on

Wrap the Euler angles to the interval  $[-\pi, \pi]$ . For vehicle maneuvers that might undergo vehicle yaw rotations that are outside of the interval, consider deselecting the parameter if you want to:

- Track the total vehicle yaw rotation.
- Avoid discontinuities in the vehicle state estimators.

## References

[1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers (SAE), 1992.

**Introduced in R2018a**

# Driver Commands

Configure driver

## Description

The Driver Commands block implements the driver model that the reference application uses to generate acceleration, braking, gear, and steering commands. By default, if you select the Reference Generator block parameter **Use maneuver-specific driver, initial position, and scene**, the reference application selects the driver for the maneuver that you specified.

Vehicle Command Mode Setting	Implementation
Longitudinal Driver	Longitudinal Driver block — Longitudinal speed-tracking controller. Based on reference and feedback velocities, the block generates normalized acceleration and braking commands that can vary from 0 through 1. Use the block to model the dynamic response of a driver or to generate the commands necessary to track a longitudinal drive cycle.
Predictive Driver	Predictive Driver block — Controller that generates normalized steering, acceleration, and braking commands to track longitudinal velocity and a lateral reference displacement. The normalized commands can vary between -1 to 1. The controller uses a single-track (bicycle) model for optimal single-point preview control.
Open Loop	Implements an open-loop system so that you can configure the reference application for constant or signal-based steering, acceleration, braking, and gear command input.

## Ports

### Input

#### VehRef — Vehicle reference signals

Bus

Bus containing the vehicle reference signals, including longitudinal and lateral displacement, and steering.

#### VehFdbk — Vehicle feedback signals

Bus

Bus containing vehicle displacement feedback signals.

### Output

#### Driver — Command signals

Bus

Bus containing the commands, including steering, acceleration, braking, and gear commands.

## **Parameters**

### **Vehicle command mode — Enable 3D visualization**

Predictive Driver (default) | Longitudinal Driver | Open Loop

Specify driver model.

## **See Also**

Longitudinal Driver | Predictive Driver

**Introduced in R2019a**

# Reference Generator

Generate maneuver reference signals

## Description

The Reference Generator block sets the parameters that configure the maneuver and 3D simulation environment. By default, the block is set for the constant radius maneuver with the 3D simulation engine environment disabled.

## Model

Use the **Maneuver** parameter to specify the type of maneuver. After you select the maneuver, use the parameters to specify the maneuver settings. By default:

- **Use maneuver-specific driver, initial position, and scene** — Set to on
- **Maneuver start time** — Set to 3s
- **Longitudinal velocity reference** — Set to 30s
- **Longitudinal entrance velocity setpoint units** — Set to mph

Maneuver Setting	Implementation
Double Lane Change	“Double-Lane Change Maneuver” <ul style="list-style-type: none"> <li>• <b>Vehicle width</b> — Lane signals for the Visualization subsystem; used for the left and right lane boundaries</li> <li>• <b>Lateral reference data</b> — Lateral reference trajectory as a function of the longitudinal distance</li> <li>• <b>Distance after target speed to begin reference</b> — Start the maneuver at specified distance after the vehicle reaches the target speed</li> </ul>
Increasing Steer	“Slowly Increasing Steering Maneuver” <ul style="list-style-type: none"> <li>• <b>Handwheel rate</b> — Linear rate to increase steering wheel angle</li> <li>• <b>Maximum handwheel angle</b> — Maximum steering wheel angle</li> </ul>
Swept Sine	“Swept-Sine Steering Maneuver” <ul style="list-style-type: none"> <li>• <b>Steering amplitude</b> — Sinusoidal wave amplitude</li> <li>• <b>Final frequency</b> — Cut off frequency to stop the maneuver</li> </ul>

Maneuver Setting	Implementation
Sine with Dwell	In the test, the vehicle: <ul style="list-style-type: none"> <li>• Accelerates until it hits a target velocity.</li> <li>• Maintains the target velocity.</li> <li>• Responds to a sinusoidal with dwell steering command.</li> <li>• <b>Steer frequency</b> — Sinusoidal wave frequency</li> <li>• <b>Steer amplitude</b> — Sinusoidal wave amplitude</li> <li>• <b>Dwell time</b> — Dwell time</li> </ul>
Constant Radius	“Constant Radius Maneuver” <ul style="list-style-type: none"> <li>• <b>Radius value</b> — Turn radius</li> </ul>

### 3D Engine

The 3D engine implements the 3D simulation environment. Vehicle Dynamics Blockset integrates the 3D simulation environment with Simulink so that you can query the world around the vehicle for virtually testing perception, control, and planning algorithms. For 3D engine requirements, see “3D Visualization Engine Requirements and Limitations”. To enable the 3D engine, on the **3D Engine** tab, select **Enabled**.

To position the vehicle in the scene:

- 1 Select the position initialization method:
  - **Recommended for scene** — Set the initial vehicle position to values recommended for the scene
  - **User-specified** — Set your own initial vehicle position
- 2 Click **Update the model workspaces with the initial values** to overwrite the initial vehicle position in the model workspaces with the applied values.

### Ports

#### Input

##### VehFdbk — Vehicle feedback

Bus

Bus containing vehicle feedback signals, including velocity, acceleration, and steering wheel torque.

#### Output

##### Vis — Visualization reference signals

Bus

Bus containing the visualization reference signals, including longitudinal and lateral displacement, and steering.

##### Ref — Vehicle reference signals

Bus



Bus containing the vehicle reference signals, including longitudinal and lateral displacement, and steering.

### **Fdbk — Vehicle location feedback signals**

Bus

Bus containing vehicle location feedback signals, including position.

## **Parameters**

### **Configuration**

#### **Maneuver — Select maneuver**

Constant Radius (default) | Double Lane Change | Increasing Steer | Swept Sine | Sine with Dwell

Specify the scene type.

#### **Maneuver start time — Start time**

on (default) | off

Specify the name of the 3D scene.

#### **Longitudinal velocity reference — Target velocity**

scalar

Target velocity.

#### **Longitudinal entrance velocity setpoint units — Units**

mph (default)

Units for target velocity.

#### **Simulation time — Simulation time**

scalar

Time, in s.

### **Constant Radius**

#### **Radius value — Radius**

scalar

Radius value, in m.

#### **Turn direction — Turn direction**

Right (default) | Left

Turn direction.

#### **Lateral acceleration threshold — Lateral acceleration**

scalar

Lateral acceleration threshold, in g.

**Stop simulation at lateral acceleration threshold – Selection**

off (default) | on

Stop simulation if vehicle exceeds lateral acceleration threshold.

**Double Lane Change****Inertial longitudinal position of gate entrance – Position**

scalar

Inertial longitudinal position of gate entrance, in m.

**Distance after target speed to begin reference – Start distance**

scalar

Distance after target speed to begin reference, in m.

**Vehicle width – Vehicle width**

scalar

Vehicle width, in m.

The left and right lane boundaries are a function of the **Vehicle width** parameter.

**Lateral offset – Lateral offset**

scalar

Lateral offset, in m.

**Lateral reference position breakpoints – Breakpoints**

scalar

Lateral reference position breakpoints, in m.

Use the **Lateral reference position breakpoints** and **Lateral reference data** parameters to specify the lateral reference trajectory as a function of the longitudinal distance.

**Lateral reference data – Lateral data**

scalar

Use the **Lateral reference position breakpoints** and **Lateral reference data** parameters to specify the lateral reference trajectory as a function of the longitudinal distance.

**Increasing Steer****Handwheel rate – Handwheel rate**

scalar

Handwheel rate, in deg/s.

**Maximum handwheel angle – Maximum handwheel**

scalar

Maximum handwheel angle, in deg.

**Steering hold time after max angle reached – Steering hold**

scalar

Steering hold, in s.

**Lateral acceleration threshold – Lateral acceleration**  
scalar

Lateral acceleration threshold, in g.

**Stop simulation at lateral acceleration threshold – Selection**  
off (default) | on

Stop simulation if vehicle exceeds lateral acceleration threshold.

### **Swept Sign**

**Swept time – Sweep time**  
scalar

Sweep time, in s.

**Steering amplitude – Steering amplitude**  
scalar

Sinusoidal steering amplitude, in deg.

**Final frequency – Final frequency**  
scalar

Cut off frequency to stop the maneuver, in Hz.

### **Sign with Dwell**

**Steer frequency – Steer frequency**  
scalar

Steer frequency, in Hz.

**Steer amplitude – Steer amplitude**  
scalar

Sinusoidal steering amplitude, in deg.

**Dwell time – Dwell time**  
scalar

Dwell time, in s.

### **3D Engine**

**3D Engine – Enable 3D visualization**  
off (default) | on

Enable 3D visualization.

### **Scene – 3D scene**

Straight road | Curved road | Parking lot | Double lane change | Open surface | US city block | US highway | Virtual Mcity | Large parking lot

Specify the name of the 3D scene.

**Engine frame rate, dt3D – Graphics**

.03 (default)

Graphics frame rate, in s. The graphics frame rate is the inverse of the sample time.

**Recommended for scene – Initial vehicle position**

on (default) | off

Use vehicle positions that are recommended for the scene.

**User-specified – Initial vehicle position**

off (default) | on

Specify to set your own initial vehicle position values.

**Initial longitudinal position, X\_o – Initial longitudinal position**

off (default) | on

Initial vehicle CG position along the earth-fixed X-axis, in m.

**Initial lateral position, Y\_o – Initial lateral position**

off (default) | on

Initial vehicle CG position along the earth-fixed Y-axis, in m.

**Initial vertical position, Z\_o – Initial vertical position**

off (default) | on

Initial vehicle CG position along the earth-fixed Z-axis, in m.

**Initial roll angle, phi\_o – Roll**

off (default) | on

Rotation of the vehicle-fixed frame about the earth-fixed X-axis (roll), in rad.

**Initial pitch angle, theta\_o – Pitch**

off (default) | on

Rotation of the vehicle-fixed frame about the earth-fixed Y-axis (pitch), in rad.

**Initial yaw angle, psi\_o – Yaw**

off (default) | on

Rotation of the vehicle-fixed frame about the earth-fixed Z-axis (yaw), in rad.

**See Also**

3D Engine | Driver Commands

**Topics**

“Constant Radius Maneuver”

“Double-Lane Change Maneuver”

“Slowly Increasing Steering Maneuver”

“Swept-Sine Steering Maneuver”

“How 3D Simulation for Vehicle Dynamics Blockset Works”  
“3D Visualization Engine Requirements and Limitations”

**External Websites**

Unreal Engine

**Introduced in R2019a**



# Classes

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## sim3d.Editor

Interface to the Unreal Engine project

### Description

Use the `sim3d.Editor` class to interface with the Unreal Editor.

To develop scenes with the Unreal Editor and co-simulate with Simulink, you need the Vehicle Dynamics Blockset Interface for Unreal Engine 4 Projects support package. The support package contains an Unreal Engine project that allows you to customize the Vehicle Dynamics Blockset scenes. For information about the support package, see “Customize 3D Scenes for Vehicle Dynamics Simulations”.

### Creation

#### Syntax

```
sim3d.Editor(project)
```

#### Description

MATLAB creates an `sim3d.Editor` object for the Unreal Editor project specified in `sim3d.Editor(project)`.

#### Input Arguments

##### **project** — Project path and name

string array

Project path and name.

Example: "C:\Local\AutoVrtlEnv\AutoVrtlEnv.uproject"

Data Types: string

### Properties

##### **Uproject** — Project path and name

string array

This property is read-only.

Project path and name with Unreal Engine project file extension.

Example: "C:\Local\AutoVrtlEnv\AutoVrtlEnv.uproject"

Data Types: string



## Object Functions

open Open the Unreal Editor

## Examples

### Open Project in Unreal Editor

Open an Unreal Engine project in the Unreal Editor.

Create an instance of the `sim3d.Editor` class for the Unreal Engine project located in `C:\Local\AutoVrtlEnv\AutoVrtlEnv.uproject`.

```
editor=sim3d.Editor(fullfile("C:\Local\AutoVrtlEnv\AutoVrtlEnv.uproject"))
```

Open the project in the Unreal Editor.

```
editor.open();
```

## See Also

### Topics

["Customize 3D Scenes for Vehicle Dynamics Simulations"](#)

["How 3D Simulation for Vehicle Dynamics Blockset Works"](#)

["3D Visualization Engine Requirements and Limitations"](#)

**Introduced in R2019b**

## open

Open the Unreal Editor

### Syntax

```
[status,result]=open(sim3dEditorObj)
```

### Description

[status,result]=open(sim3dEditorObj) opens the Unreal Engine project in the Unreal Editor.

To develop scenes with the Unreal Editor and co-simulate with Simulink, you need the Vehicle Dynamics Blockset Interface for Unreal Engine 4 Projects support package. The support package contains an Unreal Engine project that allows you to customize the Vehicle Dynamics Blockset scenes. For information about the support package, see “Customize 3D Scenes for Vehicle Dynamics Simulations”.

### Input Arguments

**sim3dEditorObj** — **sim3d.Editor** object

sim3d.Editor object

sim3d.Editor object for the Unreal Engine project.

### Output Arguments

**status** — **Command exit status**

0 | nonzero integer

Command exit status, returned as either 0 or a nonzero integer. When the command is successful, status is 0. Otherwise, status is a nonzero integer.

- If command includes the ampersand character (&), then status is the exit status when command starts
- If command does not include the ampersand character (&), then status is the exit status upon command completion.

**result** — **Output of operating system command**

character vector

Output of the operating system command, returned as a character vector. The system shell might not properly represent non-Unicode® characters.

### See Also

sim3d.Editor

### Topics

“Customize 3D Scenes for Vehicle Dynamics Simulations”

“How 3D Simulation for Vehicle Dynamics Blockset Works”  
“3D Visualization Engine Requirements and Limitations”

**Introduced in R2019b**

# ASim3dActor

Abstract class to use as a base class for user-defined Unreal Engine C++ or blueprint actors

## Description

ASim3dActor is an abstract class that you can use as a base class for user-defined Unreal Engine C++ or blueprint actors.

The base classes are inherently synchronized during co-simulation with a Simulink model. Additionally, the Simulation 3D Actor Transform Set block can control the base class. To extend behavior of ASim3dActor, you can use the message interface functions to override the class methods so they send and receive messages to and from a model.

ASim3dActor is included in the Vehicle Dynamics Blockset Interface for Unreal Engine 4 Projects. For information about the support package, see “Customize 3D Scenes for Vehicle Dynamics Simulations”.

## Properties

### Translation — Actor translation

1-by-3 (default) | number of parts per actor-by-3

This property is protected. It is used in the derived C++ class. Value is set by the Simulation 3D Actor Transform Set block.

Actor translation along world X-, Y, and Z- axes, respectively, in m. Array dimensions are number of parts per actor-by-3.

Data Types: float

### Rotation — Actor rotation

1-by-3 (default) | number of parts per actor-by-3

This property is protected. It is used in the derived C++ class. Value is set by the Simulation 3D Actor Transform Set block.

Actor rotation across a  $[-\pi/2, \pi/2]$  range about world X-, Y, and Z- axes, respectively, in rad. Array dimensions are number of parts per actor-by-3.

Data Types: float

### Scale — Actor scale

1-by-3 (default) | number of parts per actor-by-3

This property is protected. It is used in the derived C++ class. Value is set by the Simulation 3D Actor Transform Set block.

Actor scale. Array dimensions are number of parts per actor-by-3.

Data Types: float

## Object Functions

Sim3dSetup C++ method that sets up actor in Unreal Engine 3D simulation  
Sim3dStep C++ method that steps actor in Unreal Engine 3D simulation  
Sim3dRelease C++ method that releases actor in Unreal Engine 3D simulation

## See Also

ReadSimulation3DMessage | StartSimulation3DMessageReader |  
StartSimulation3DMessageWriter | StopSimulation3DMessageReader |  
StopSimulation3DMessageWriter | WriteSimulation3DMessage

## External Websites

Unreal Engine 4 Documentation

## Introduced in R2020b

## Sim3dSetup

C++ method that sets up actor in Unreal Engine 3D simulation

### Syntax

```
void ASetGetActorLocation::Sim3dSetup()
```

### Description

The C++ method `void ASetGetActorLocation::Sim3dSetup()` sets up an actor in the Unreal Engine 3D simulation environment. The Unreal Engine `AActor::BeginPlay` class calls the `Sim3dSetup` method every frame.

### Example

#### Set Up Actor

```
void ASetGetActorLocation::Sim3dSetup()
{
    Super::Sim3dSetup();
    if (Tags.Num() != 0) {
        FString tagName = Tags.Top().ToString();

        FString MessageReaderTag = tagName;
        MessageReaderTag.Append(TEXT("SimulinkMessage_OUT")); // a message from Simulink model
        MessageReader = StartSimulation3DMessageReader (TCHAR_TO_ANSI(*MessageReaderTag), MAX_MESSAGE_SIZE);

        FString MessageWriterTag = tagName;
        MessageWriterTag.Append(TEXT("SimulinkMessage_IN")); // a message to Simulink model
        MessageWriter = StartSimulation3DMessageWriter (TCHAR_TO_ANSI(*MessageWriterTag), MAX_MESSAGE_SIZE);
    }
}
```

### See Also

`ASim3dActor`

### Topics

“Customize 3D Scenes for Vehicle Dynamics Simulations”

### External Websites

Unreal Engine 4 Documentation

**Introduced in R2020b**

# Sim3dStep

C++ method that steps actor in Unreal Engine 3D simulation

## Syntax

```
void ASetGetActorLocation::Sim3dStep(float DeltaSeconds)
```

## Description

The C++ method `void ASetGetActorLocation::Sim3dStep(float DeltaSeconds)` steps an actor in the Unreal Engine 3D simulation environment. The Unreal Engine `AActor::Tick` class calls the `Sim3dStep` method.

## Example

### Step Actor

```
void ASetGetActorLocation::Sim3dStep(float DeltaSeconds)
{
    Super::Sim3dStep(DeltaSeconds);
    uint32 messageSize = MAX_MESSAGE_SIZE;
    int statusR = ReadSimulation3DMessage (MessageReader, &messageSize, message);
    ...
    int statusW = WriteSimulation3DMessage (MessageWriter, messageSize, message);
}
```

## Input Arguments

### DeltaSeconds — Elapsed time

.01

Time elapsed since Unreal Engine modified the frame.

Data Types: float

## See Also

`ASim3dActor`

## Topics

“Customize 3D Scenes for Vehicle Dynamics Simulations”

## External Websites

Unreal Engine 4 Documentation

**Introduced in R2020b**

## Sim3dRelease

C++ method that releases actor in Unreal Engine 3D simulation

### Syntax

```
void ASetGetActorLocation::Sim3dRelease()
```

### Description

The C++ method `void ASetGetActorLocation::Sim3dRelease()` releases an actor in the Unreal Engine 3D simulation environment. The Unreal Engine `AActor::EndPlay` class calls the `Sim3dRelease` method when the 3D simulation ends.

### Example

#### Release Actor

```
void ASetGetActorLocation::Sim3dRelease()
{
    Super::Sim3dRelease();
    if (MessageReader) {
        StopSimulation3DMessageReader (SignalReader);
    }
    MessageReader = nullptr;

    if (MessageWriter) {
        StopSimulation3DMessageWriter (SignalWriter);
    }
    MessageWriter = nullptr;
}
```

### See Also

`ASim3dActor`

### Topics

“Customize 3D Scenes for Vehicle Dynamics Simulations”

### External Websites

Unreal Engine 4 Documentation

### Introduced in R2020b



# StartSimulation3DMessageReader

Constructs a message reader object in the Unreal Editor

## Syntax

```
MessageReader = StartSimulation3DMessageReader(topicName, maxSize)
```

## Description

MessageReader = StartSimulation3DMessageReader(topicName, maxSize)  
constructs a message reader object in the Unreal Editor.

The C++ syntax is

```
void *StartSimulation3DMessageReader(const char* topicName, uint32 maxSize);
```

## Input Arguments

**topicName** — Simulink signal topic name

mySignal

Name of the Simulink signal with the message topic.

Data Types: char \*

**maxDataSize** — Maximum size of data

number of bytes | scalar

Maximum size of the data, in bytes.

Data Types: uint32

## Output Arguments

**MessageReader** — Pointer to message reader object

object pointer

Pointer to message reader object, ReadSimulation3DMessage.

Data Types: void \*

## See Also

ASim3dActor

## Topics

“Customize 3D Scenes for Vehicle Dynamics Simulations”

## External Websites

Unreal Engine 4 Documentation

**Introduced in R2020b**

# ReadSimulation3DMessage

Receives message from Simulink model using a message reader object

## Syntax

```
status=ReadSimulation3DMessage(MessageReader, dataSize, data)
```

## Description

`status=ReadSimulation3DMessage(MessageReader, dataSize, data)` receives a message from a Simulink model using a message reader object.

The C++ syntax is

```
int ReadSimulation3DMessage(void *MessageReader, uint32 dataSize, void *data);
```

## Input Arguments

### MessageReader — Pointer to message reader object

object pointer

Pointer to message reader object, `ReadSimulation3DMessage`.

Data Types: `void *`

### dataSize — Size of data

number of bytes | scalar

Size of data, that is, `data (sizeof(datatype) *num_of_elements)`. For example, if you want to read a vector of 3 floats, the data size is `sizeof(float)*3`.

Data Types: `uint32`

### data — Pointer to data object

object pointer

Pointer to data object.

Data Types: `void *`

## Output Arguments

### status — Operation exit status

0 | nonzero integer

Status, returned as either 0 or a nonzero integer. When the operation is successful, `status` is 0. Otherwise, `status` is a nonzero integer.

## See Also

`ASim3dActor`

**Topics**

“Customize 3D Scenes for Vehicle Dynamics Simulations”

**External Websites**

Unreal Engine 4 Documentation

**Introduced in R2020b**

# StopSimulation3DMessageReader

Deletes message reader object in the Unreal Editor

## Syntax

```
status=StopSimulation3DMessageReader(MessageReader)
```

## Description

`status=StopSimulation3DMessageReader(MessageReader)` deletes the Unreal Editor 3D message reader object.

The C++ syntax is

```
int StopSimulation3DMessageReader(void * MessageReader);
```

## Input Arguments

### MessageReader — Pointer to message reader object

object pointer

Pointer to message reader object, `ReadSimulation3DMessage`.

Data Types: `void *`

## Output Arguments

### status — Operation exit status

0 | nonzero integer

Status, returned as either 0 or a nonzero integer. When the operation is successful, status is 0. Otherwise, status is a nonzero integer.

## See Also

`ASim3dActor`

## Topics

“Customize 3D Scenes for Vehicle Dynamics Simulations”

## External Websites

Unreal Engine 4 Documentation

**Introduced in R2020b**

## StartSimulation3DMessageWriter

Constructs a message writer object in the Unreal Editor

### Syntax

```
MessageWriter = StartSimulation3DMessageWriter(topicName, maxDataSize)
```

### Description

`MessageWriter = StartSimulation3DMessageWriter(topicName, maxDataSize)` constructs a message writer object in the Unreal Editor.

The C++ syntax is

```
void *StartSimulation3DMessageWriter(const char* topicName, uint32 maxDataSize);
```

### Input Arguments

#### **topicName** — Simulink signal topic name

`mySignal`

Name of the Simulink signal with the message topic.

Data Types: `char *`

#### **maxDataSize** — Maximum size of data

`number of bytes | scalar`

Maximum size of the data, in bytes.

Data Types: `uint32`

### Output Arguments

#### **MessageWriter** — Pointer to message writer object

`object pointer`

Pointer to message writer object, `WriteSimulation3DMessage`.

Data Types: `void *`

### See Also

`ASim3dActor`

### Topics

“Customize 3D Scenes for Vehicle Dynamics Simulations”

### External Websites

Unreal Engine 4 Documentation

**Introduced in R2020b**

## WriteSimulation3DMessage

Sends message to Simulink model using a message writer object

### Syntax

```
status=WriteSimulation3DMessage(MessageWriter, dataSize, data)
```

### Description

`status=WriteSimulation3DMessage(MessageWriter, dataSize, data)` sends a message to a Simulink model using a message writer object.

The C++ syntax is

```
int WriteSimulation3DMessage(void * MessageWriter, uint32 dataSize, void *data);
```

### Input Arguments

#### MessageWriter — Pointer to message writer object

object pointer

Pointer to message writer object, `WriteSimulation3DMessage`.

Data Types: `void *`

#### dataSize — Size of data

number of bytes | scalar

Size of data, that is, `data (sizeof(datatype) *num_of_elements)`. For example, if you want to read a vector of 3 floats, the data size is `sizeof(float)*3`.

Data Types: `uint32`

#### data — Pointer to data object

object pointer

Pointer to data object.

Data Types: `void *`

### Output Arguments

#### status — Operation exit status

0 | nonzero integer

Status, returned as either 0 or a nonzero integer. When the operation is successful, `status` is 0. Otherwise, `status` is a nonzero integer.

### See Also

`ASim3dActor`



**Topics**

“Customize 3D Scenes for Vehicle Dynamics Simulations”

**External Websites**

Unreal Engine 4 Documentation

**Introduced in R2020b**

## StopSimulation3DMessageWriter

Deletes message writer object in the Unreal Editor

### Syntax

```
status=StopSimulation3DMessageWriter(MessageWriter)
```

### Description

`status=StopSimulation3DMessageWriter(MessageWriter)` deletes the Unreal Editor 3D message writer object.

The C++ syntax is

```
int StopSimulation3DMessageWriter(void *MessageWriter);
```

### Input Arguments

#### **MessageWriter** — Pointer to message writer object

object pointer

Pointer to message writer object, `WriteSimulation3DMessage`.

Data Types: `void *`

### Output Arguments

#### **status** — Operation exit status

0 | nonzero integer

Status, returned as either 0 or a nonzero integer. When the operation is successful, status is 0. Otherwise, status is a nonzero integer.

### See Also

`ASim3dActor`

### Topics

“Customize 3D Scenes for Vehicle Dynamics Simulations”

### External Websites

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