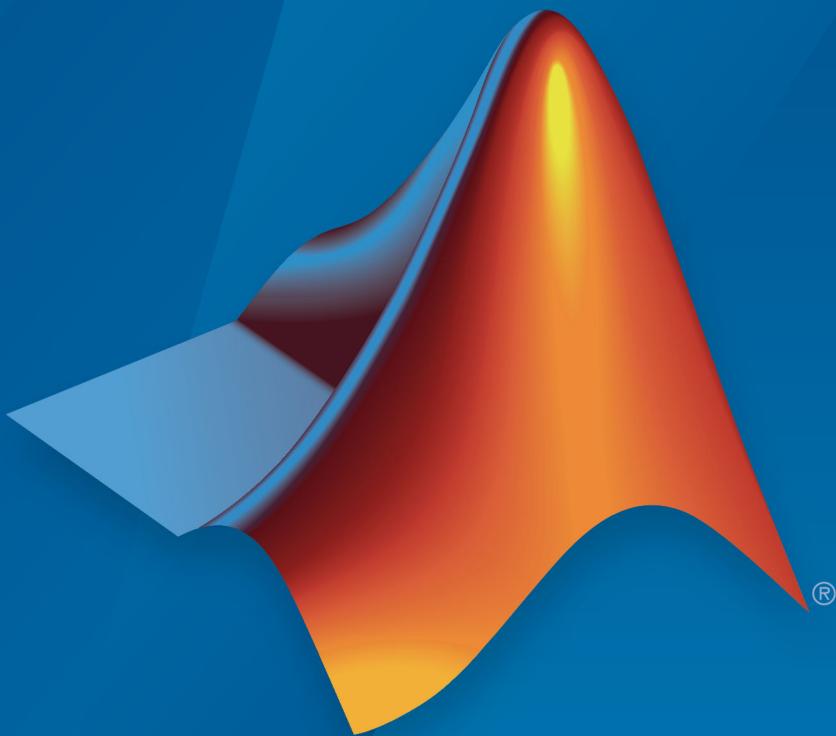


Vehicle Dynamics Blockset™

Reference



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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)

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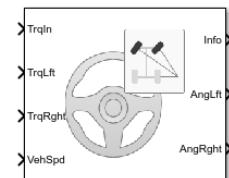
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Chassis Blocks – Alphabetical List

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.

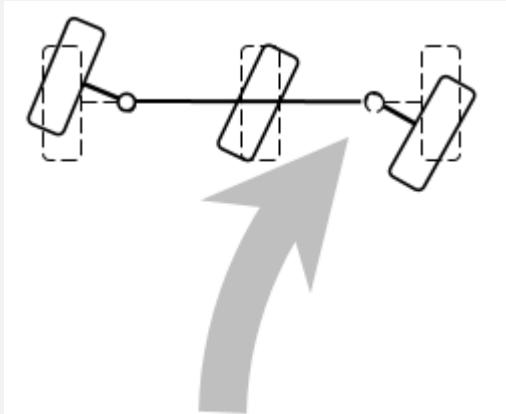
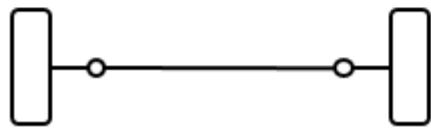
Setting	Block Implementation
Ackerman	Ideal Ackerman steering. Wheel angles have a common turning circle center.
Rack and pinion	Ideal rack-and-pinion steering. Gears convert the steering rotation into linear motion.
Parallel	Parallel steering. Wheel angles are equal.

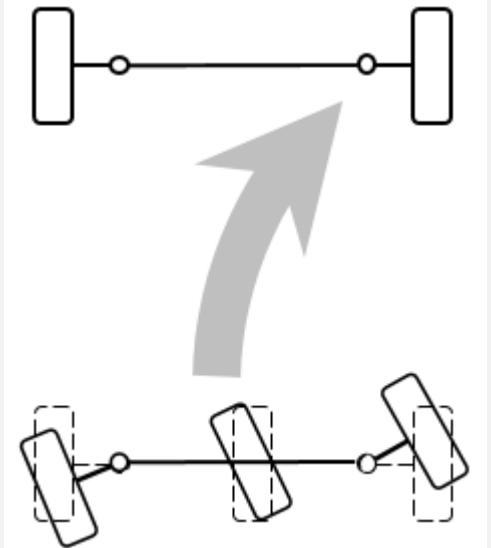
To specify the type of data for the steering mechanism, use the **Parametrized by** parameter.

Setting	Block Implementation
Constant	Steering mechanism uses constant parameter data.

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

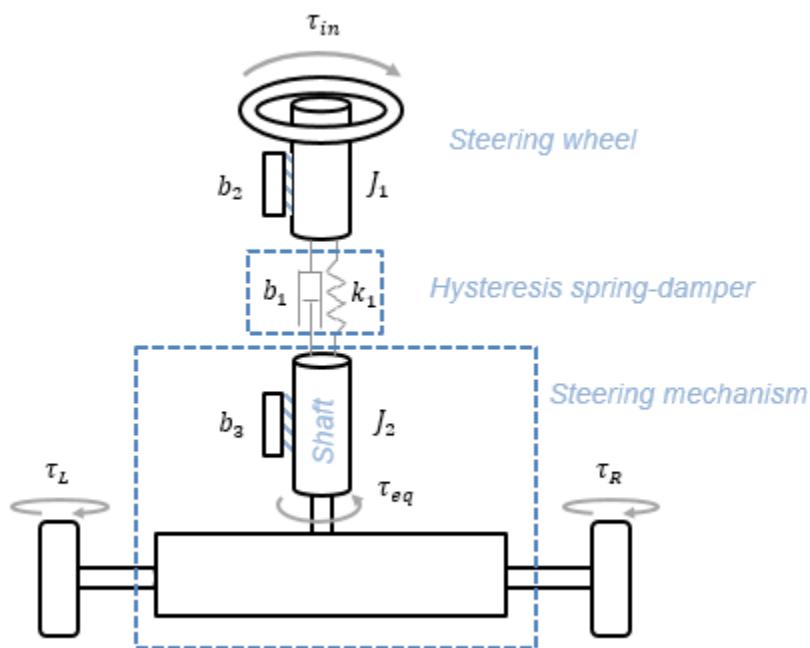
Use the **Location** parameter to specify front or rear steering.

Setting	Implementation
Front	Front steering  

Setting	Implementation
Rear	Rear steering 

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	$\delta = \theta_1 - \theta_2$ $\Delta\delta = \delta_{current} - \delta_{previous}$ $\tau_{hys} = (b_1 \dot{\delta} - k_1 \delta) \left(1 + \exp\left(-\frac{ \Delta\delta }{\beta}\right) \right)$ $\beta = \begin{cases} \beta_u & \text{when } \delta > 0 \\ \beta_l & \text{when } \delta \leq 0 \end{cases}$

Calculation	Equations
Optional power assist	$\tau_{ast} = f_{trq}(v, \tau_{in})$ $J_1 \ddot{\theta}_1 = \tau_{in} + \tau_{ast} - b_2 \dot{\theta}_1 - \tau_{hys}$ $J_2 \ddot{\theta}_2 = \tau_{eq} + \tau_{ast} - b_3 \dot{\theta}_2 + \tau_{hys} - \tau_{fric}$

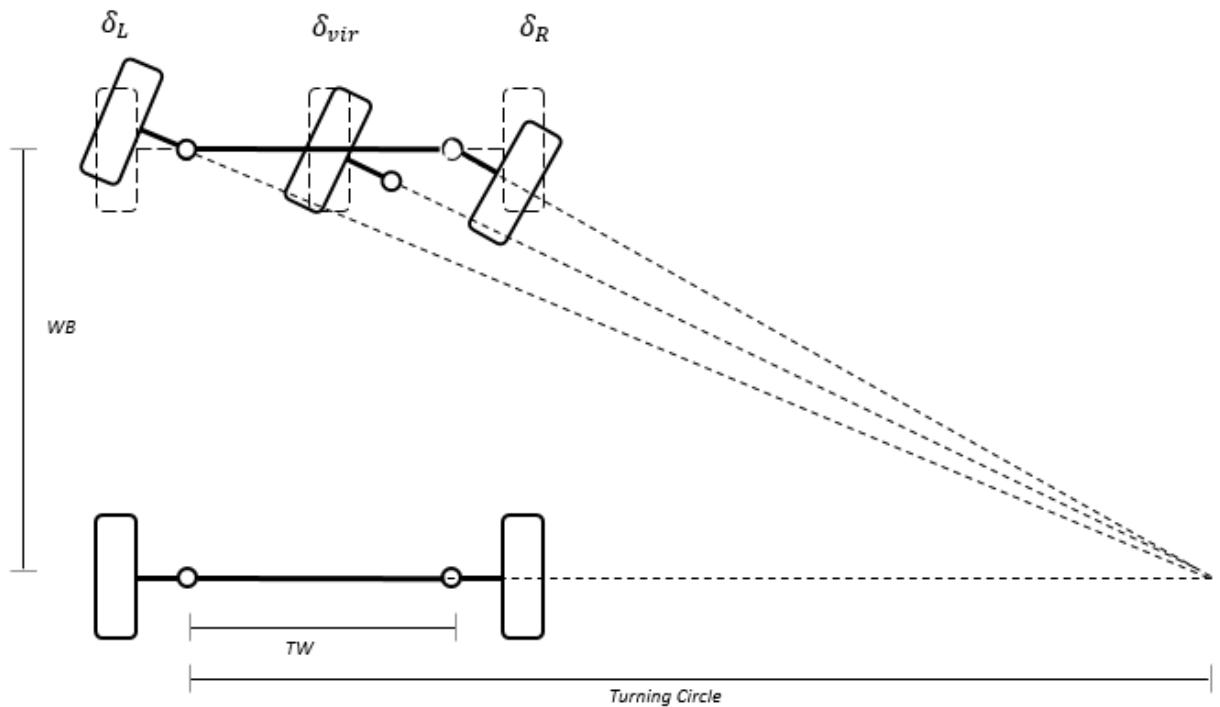
The illustration and equations use these variables.

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
τ_{hys}	Hysteresis spring damping torque
τ_{fric}	Steering mechanism friction torque
τ_{eq}	Wheel equivalent torque
τ_{ast}	Torque assist
β_u, β_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.

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

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

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

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

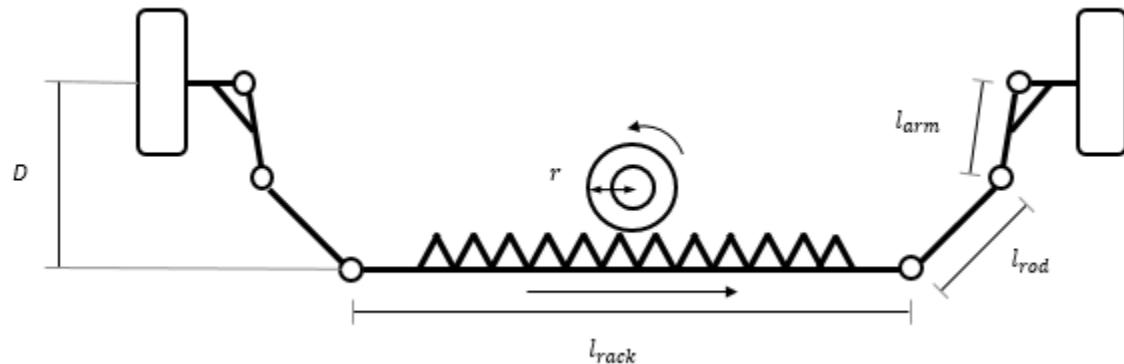
The illustration and equations use these variables.

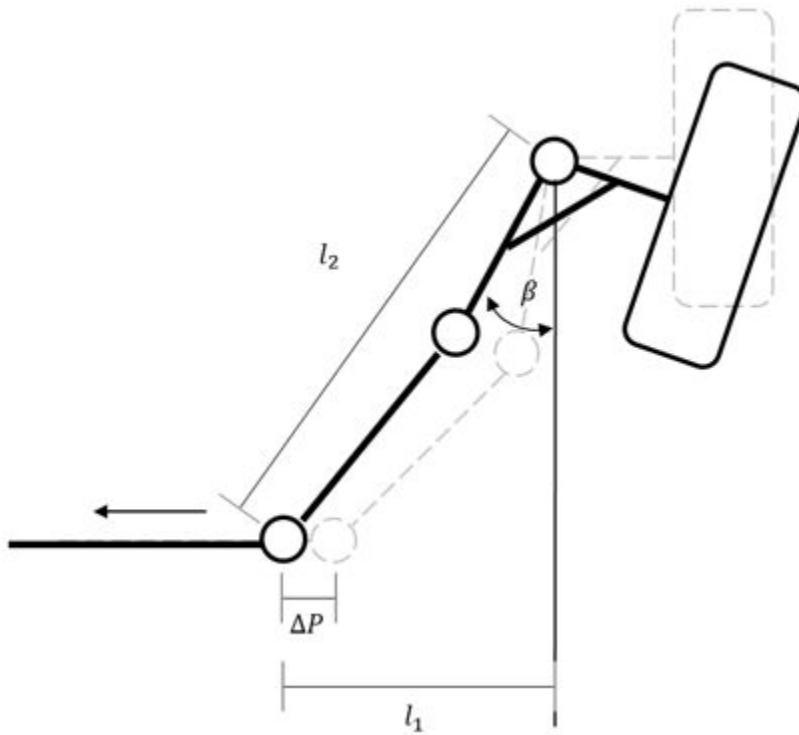
δ_{in} Steering angle

δ_L	Left wheel angle
δ_R	Right wheel angle
δ_{vir}	Virtual wheel angle
TW	Track width
WB	Wheel base
γ	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.

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

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

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

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

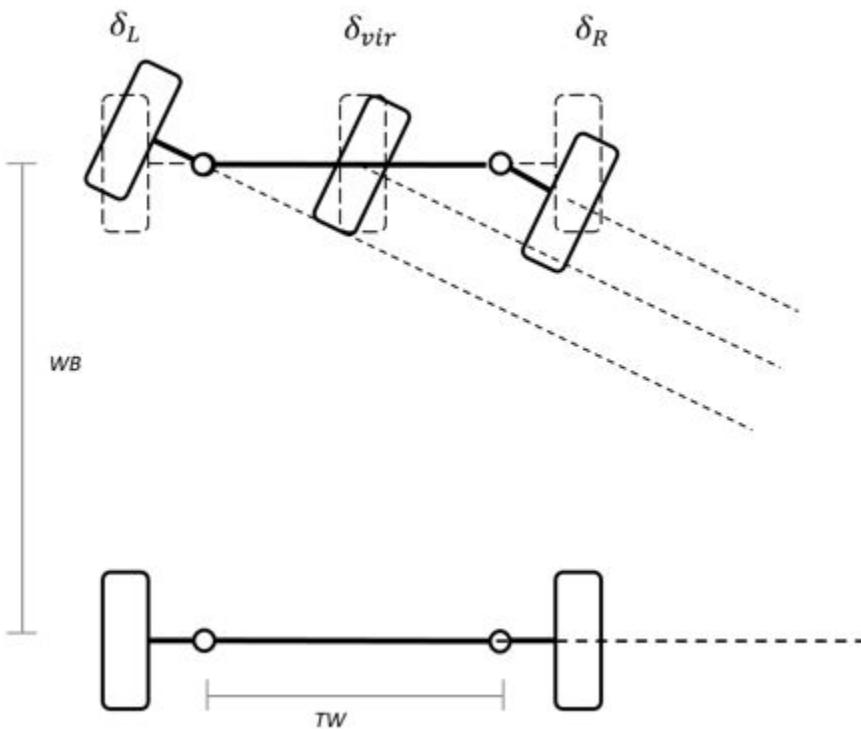
The illustration and equations use these variables.

δ_{in} Steering wheel angle

δ_L	Left wheel angle
δ_R	Right wheel angle
TW	Track width
r	Pinion radius
ΔP	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.

δ_{in}	Steering wheel angle
δ_L	Left wheel angle
δ_R	Right wheel angle
γ	Steering ratio

Ports

Input

TrqIn — Torque

scalar

Torque, τ_{in} , in N·m.**TrqLft — Left wheel torque**

scalar

Left wheel torque, τ_L , in N·m.**TrqRght — Right wheel torque**

scalar

Right wheel torque, τ_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

Signal	Description	Unit
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, δ_L , in rad.**AngRght — Right wheel angle**

scalar

Right wheel angle, δ_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.

Setting	Block Implementation
Parallel	Parallel steering. Wheel angles are equal.

Dependencies

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

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

Type	Parameterized By	Creates Parameters
	Lookup table	Track width, TrckWdth Steering range, StrgRng Steering angle breakpoints, StrgAngBpts Steering arm length, StrgArmLngh Rack casing length, RckCsLngh Tie rod length, TieRodLngh Distance between front axis and rack, D Pinion radius, PnnRadiusTbl
Parallel	Constant	Steering range, StrgRng Steering ratio, StrgRatio
	Lookup table	Steering range, StrgRng Steering angle breakpoints, StrgAngBpts Steering ratio table, StrgRatioTbl

Parametrized by — Select parameterization

Lookup table (default) | Constant

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.

Dependencies

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

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

Type	Parameterized By	Creates Parameters
	Lookup table	Track width, TrckWdth Steering range, StrgRng Steering angle breakpoints, StrgAngBpts Steering arm length, StrgArmLngh Rack casing length, RckCsLngh Tie rod length, TieRodLngh Distance between front axis and rack, D Pinion radius, PnnRadiusTbl
Parallel	Constant	Steering range, StrgRng Steering ratio, StrgRatio
	Lookup table	Steering range, StrgRng Steering angle breakpoints, StrgAngBpts Steering ratio table, StrgRatioTbl

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, τ_{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

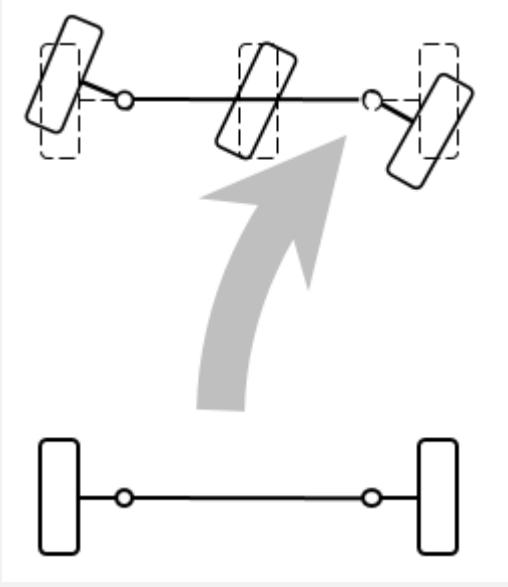
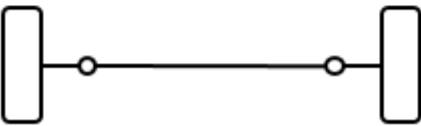
Selecting **Power assist** creates the VehSpd input port and these parameters.

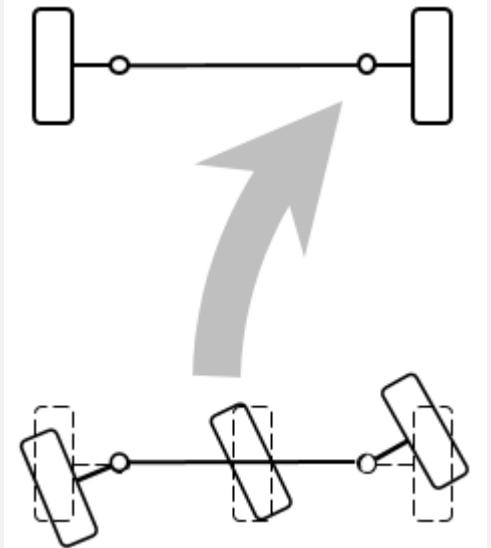
Power Assist	Parameters
on	Steering wheel torque breakpoints, TrqBpts Vehicle speed breakpoints, VehSpdBpts Assisting torque table, TrqTbl Assisting torque limit, TrqLmt Assisting power limit, PwrLmt Assisting torque efficiency, Eta Cutoff frequency, omega_c

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	Rear steering 

General

Track width, TrckWdth — Width
scalar

Track width, TW , in m.

Dependencies

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

Wheel base, WhlBase — Base
scalar

Wheel base, WB , in m.

Dependencies

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

Deadband, Db — Kinematic Steering block parameter
scalar

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

Steering range, StrgRng — Range
scalar

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

Steering ratio, StrgRatio — Ratio
scalar

Steering ratio, γ , dimensionless.

Dependencies

To create this parameter:

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

Steering angle breakpoints, StrgAngBpts — Breakpoints
vector

Steering angle breakpoints, in rad.

Dependencies

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

Steering ratio table, StrgRatioTbl — Table
vector

Steering ratio table, γ , 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
scalar

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

Dependencies

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

Rack casing length, RckCsLngth — Length
scalar

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

Dependencies

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

Tie rod length, TieRodLngth — Length
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
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
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
scalar

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
scalar

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

Steering mechanism inertia, J2 — Inertia
scalar

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

Upper hysteresis modifier, beta_u — Upper hysteresis modifier
scalar

Upper hysteresis modifier, β_u , dimensionless.

Lower hysteresis modifier, beta_l — Lower hysteresis modifier
scalar

Lower hysteresis modifier, β_l , dimensionless.

Hysteresis viscous damping, b1 — Damping
scalar

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

Hysteresis stiffness, k1 — Stiffness
scalar

Hysteresis stiffness, k_1 , in N·m/rad.

Steering wheel damping, b2 — Damping
scalar

Steering wheel damping, b_2 , in N·m·s/rad.

Steering mechanism damping, b3 — Damping
scalar

Steering mechanism damping, b_3 , in N·m·s/rad.

Initial steering angle, theta_o — Angle
scalar

Initial steering angle, θ_0 , in rad.

Initial steering angular velocity, omega_o — Angular velocity
scalar

Initial steering angular velocity, ω_0 , in rad/s.

Friction torque, FricTrq — Torque
scalar

Friction torque, τ_{fric} , in N·m.

Power Assist

Steering wheel torque breakpoints, TrqBpts — Breakpoints
vector

Steering wheel torque breakpoints, in N·m.

Dependencies

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

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

Vehicle speed breakpoints, VehSpdBpts — Breakpoints vector

Vehicle speed breakpoints, in m/s.

Dependencies

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

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

Assisting torque table, TrqTbl — Torque array

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, τ_{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	Steering wheel torque breakpoints, TrqBpts Vehicle speed breakpoints, VehSpdBpts Assisting torque table, TrqTbl Assisting torque limit, TrqLmt Assisting power limit, PwrLmt Assisting torque efficiency, Eta Cutoff frequency, omega_c

Assisting torque limit, TrqLmt — Torque limit scalar

Assisting torque limit, in N·m.

Dependencies

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

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

Assisting power limit, PwrLmt — Power limit
scalar

Assisting power limit, in N·m/s.

Dependencies

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

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

Assisting torque efficiency, Eta — Efficiency
scalar

Assisting torque efficiency, dimensionless.

Dependencies

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

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

Cutoff frequency, omega_c — Cutoff frequency scalar

Cutoff frequency, in rad/s.

Dependencies

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

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

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

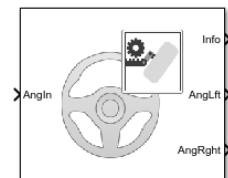
[“Coordinate Systems in Vehicle Dynamics Blockset”](#)

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.

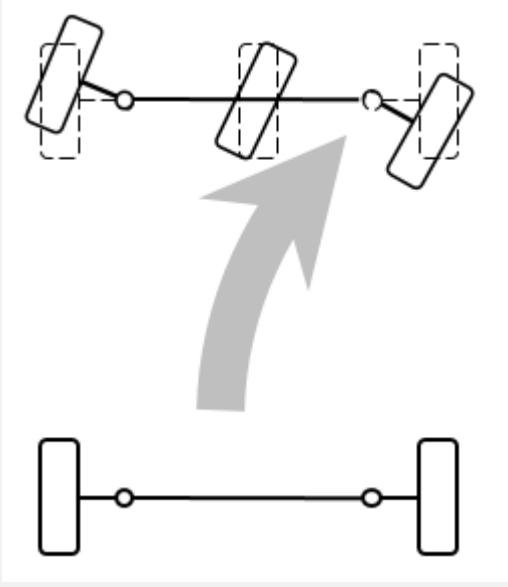
To specify the steering type, use the **Type** parameter.

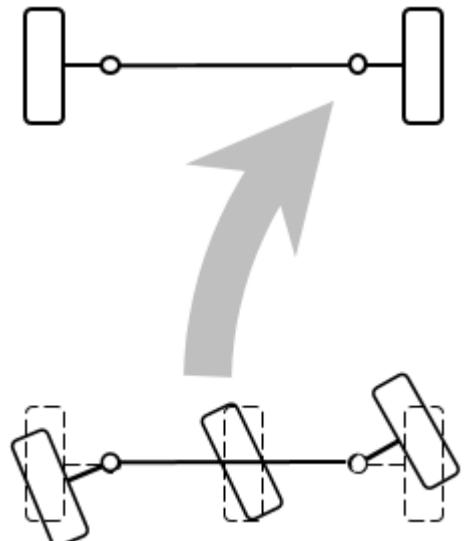
Setting	Block Implementation
Ackerman	Ideal Ackerman steering. Wheel angles have a common turning circle center.
Rack and pinion	Ideal rack-and-pinion steering. Gears convert the steering rotation into linear motion.
Parallel	Parallel steering. Wheel angles are equal.

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.

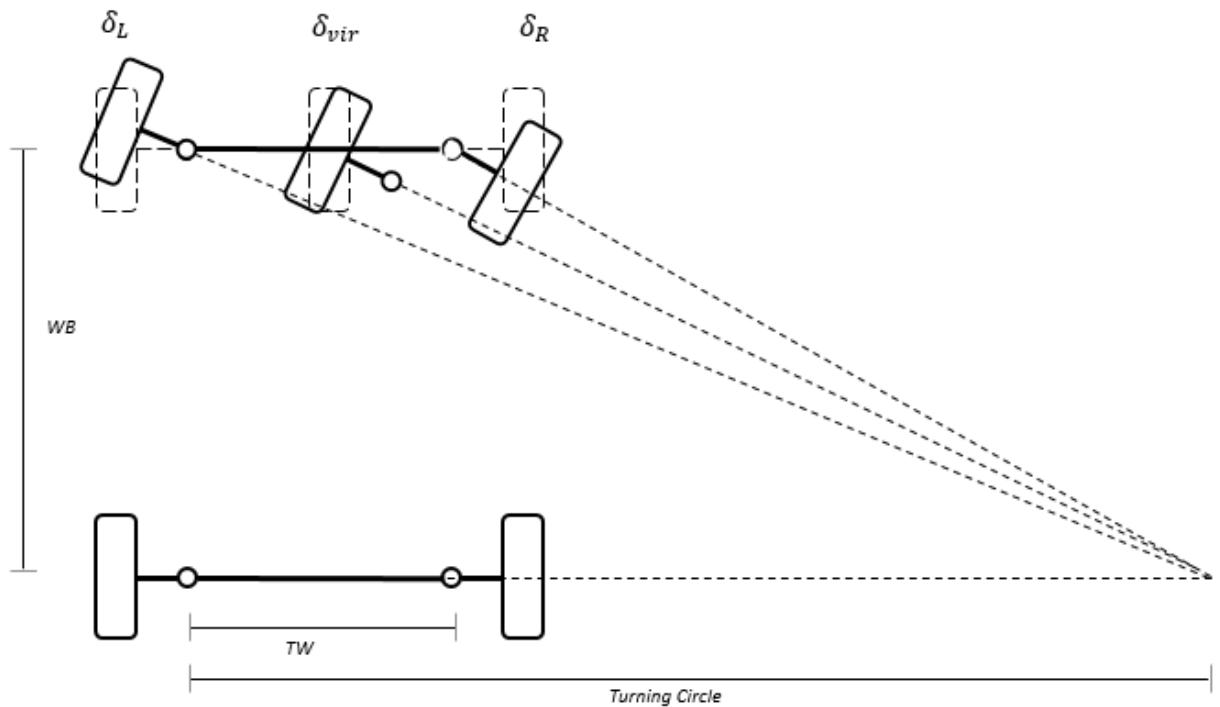
Setting	Implementation
Front	<p>Front steering</p>  <p>The diagram illustrates a front-steering kinematic linkage. It consists of three rectangular blocks connected by two horizontal lines. The leftmost block is connected to the middle block, and the middle block is connected to the rightmost block. Each block has a circular hole at its center, through which a horizontal line passes. A large, curved gray arrow points upwards and to the right, indicating the path of the middle block during steering. This visualizes how the straight-line motion of the wheels is converted into the curved path of the vehicle's center of gravity.</p>

Setting	Implementation
Rear	<p>Rear steering</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.

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

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

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

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

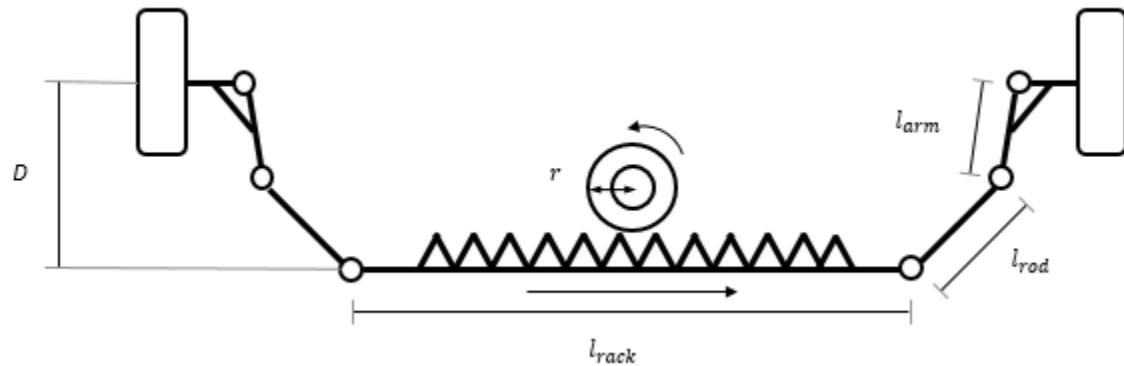
The illustration and equations use these variables.

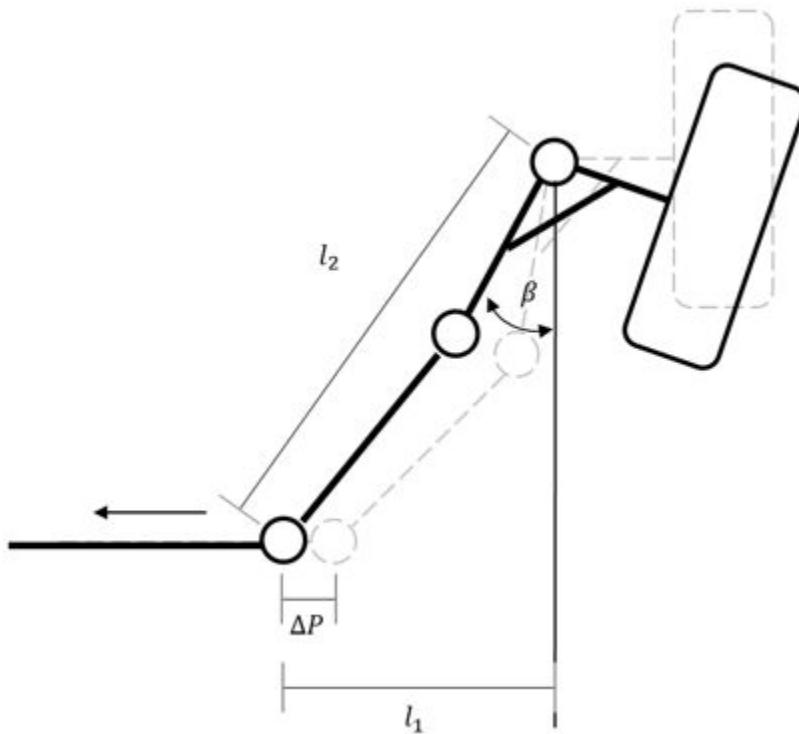
δ_{in} Steering angle

δ_L	Left wheel angle
δ_R	Right wheel angle
δ_{vir}	Virtual wheel angle
TW	Track width
WB	Wheel base
γ	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.

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

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

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

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

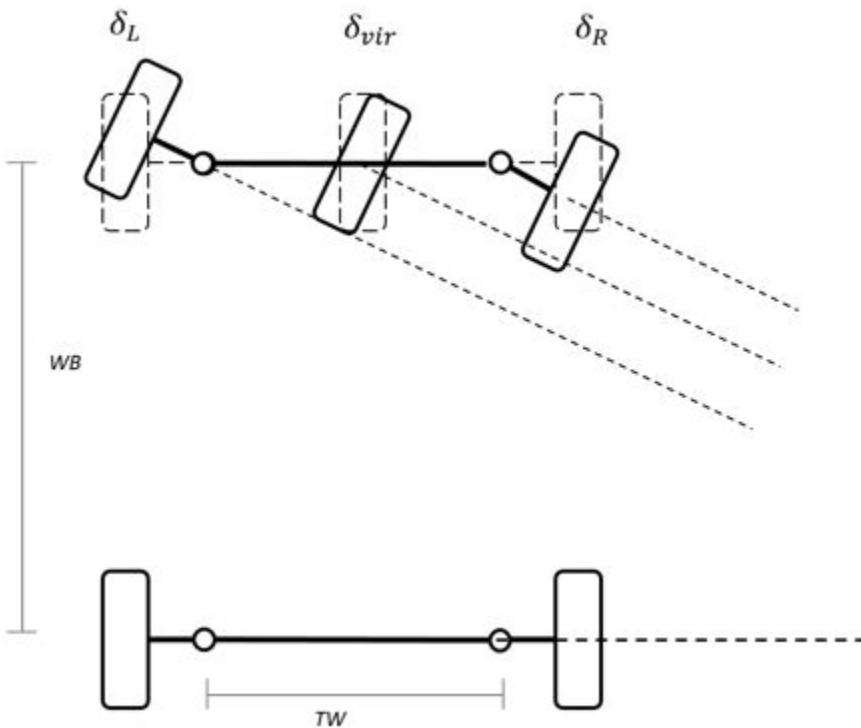
The illustration and equations use these variables.

δ_{in} Steering wheel angle

δ_L	Left wheel angle
δ_R	Right wheel angle
TW	Track width
r	Pinion radius
ΔP	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.

δ_{in}	Steering wheel angle
δ_L	Left wheel angle
δ_R	Right wheel angle
γ	Steering ratio

Ports

Input

AngIn — Steering angle
scalar

Steering angle, δ_{in} , in rad.

Output

Info — Bus signal
bus

Bus signal contains this block calculation.

Signal	Description	Variable	Unit
InstStrgRatio	Instantaneous steering ratio	γ	NA

AngLft — Left wheel angle
scalar

Left wheel angle, δ_L , in rad.

AngRght — Right wheel angle
scalar

Right wheel angle, δ_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 **Parametrized by** parameter dependencies.

Type	Parameterized By	Creates Parameters
Ackerman	Constant	Track width, TrckWdth Wheel base, WhlBase Deadband, Db Steering range, StrgRng Steering ratio, StrgRatio
	Lookup table	Track width, TrckWdth Wheel base, WhlBase Deadband, Db Steering range, StrgRng Steering angle breakpoints, StrgAngBpts Steering ratio table, StrgRatioTbl

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

Type	Parameterized By	Creates Parameters
	Lookup table	Deadband, Db Steering range, StrgRng Steering angle breakpoints, StrgAngBpts Steering ratio table, StrgRatioTbl

Parametrized by — Select parameterization

Constant (default) | Lookup table

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.

Dependencies

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

Type	Parameterized By	Creates Parameters
Ackerman	Constant	Track width, TrckWdth Wheel base, WhlBase Deadband, Db Steering range, StrgRng Steering ratio, StrgRatio

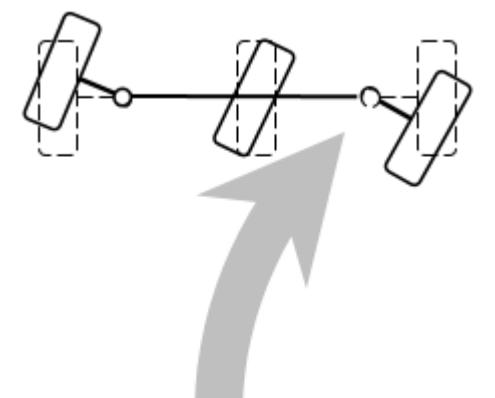
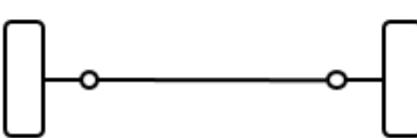
Type	Parameterized By	Creates Parameters
	Lookup table	Track width, TrckWdth Wheel base, WhlBase Deadband, Db Steering range, StrgRng Steering angle breakpoints, StrgAngBpts Steering ratio table, StrgRatioTbl
Rack and pinion	Constant	Track width, TrckWdth Deadband, Db Steering range, StrgRng Steering arm length, StrgArmLnghth Rack casing length, RckCsLnghth Tie rod length, TieRodLnghth Distance between front axis and rack, D Pinion radius, PnnRadius

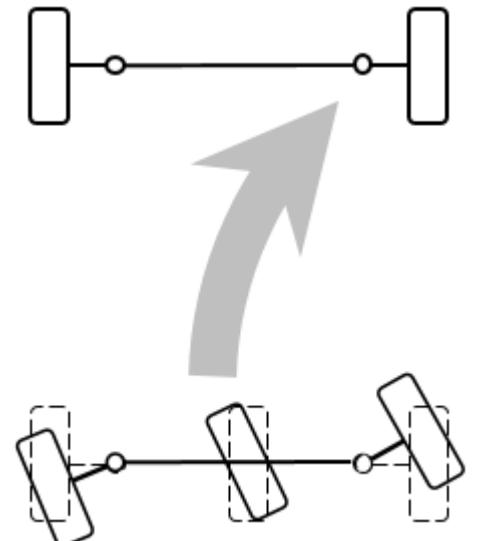
Type	Parameterized By	Creates Parameters
	Lookup table	Track width, TrckWdth Deadband, Db Steering range, StrgRng Steering angle breakpoints, StrgAngBpts Steering arm length, StrgArmLngh Rack casing length, RckCsLngh Tie rod length, TieRodLngh Distance between front axis and rack, D Pinion radius, PnnRadiusTbl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

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, γ 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	Block updates the Steering ratio, StrgRatio parameter to the normalized value, γ_{nrm} , specified by this equation.
Parallel	$\gamma_{nrm} = \frac{1}{Nrm_{Fctr}}$

Steering Type	Normalization
Rack and pinion	Block updates the Pinion radius, PnnRadius parameter to using the normalization factor, $NrmFctr$.

General

Track width, TrckWdth — Width
scalar

Track width, TW , in m.

Dependencies

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

Wheel base, WhlBase — Base
scalar

Wheel base, WB , in m.

Dependencies

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

Deadband, Db — Kinematic Steering block parameter
scalar

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

Steering range, StrgRng — Range
scalar

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

Steering ratio, StrgRatio — Ratio
scalar

Steering ratio, γ , dimensionless.

Dependencies

To create this parameter:

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

Steering angle breakpoints, StrgAngBpts — Breakpoints
vector

Steering angle breakpoints, in rad.

Dependencies

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

Steering ratio table, StrgRatioTbl — Table
vector

Steering ratio table, γ , dimensionless.

Dependencies

To create this parameter:

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

Rack-and-Pinion

Steering arm length, StrgArmLength — Length
scalar

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

Dependencies

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

Rack casing length, RckCsLength — Length
scalar

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

Dependencies

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

Tie rod length, TieRodLength — Length
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
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
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
scalar

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

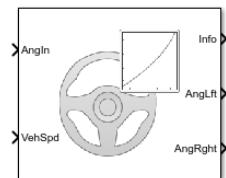
[“Coordinate Systems in Vehicle Dynamics Blockset”](#)

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

The equations use these variables.

δ_{in}	Steering wheel angle
δ_{SpdF}	Steering wheel angle speed factor
$\delta_{SuprImp}$	Superimposed steering wheel angle
δ_L, δ_R	Left and right wheel angles, respectively

Ports

Input

AngIn — Steering angle

scalar

Steering angle, δ_{in} , in rad.

VehSpd — Vehicle speed

scalar

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

Dependencies

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

Output

Info — Bus signal

bus

Bus signal containing these block calculations.

Signal	Description	Variable	Unit
AngLft	Left wheel angle	δ_L	rad
AngRght	Left wheel angle	δ_R	rad

AngLft — Left wheel angle

scalar

Left wheel angle, δ_L , in rad.

AngRght — Right wheel angle

scalar

Right wheel angle, δ_R , in rad.

Parameters

Steering angle breakpoints, StrgAngBpts — Steering angle breakpoints

vector

Steering angle breakpoints, in rad.

Left wheel angle table, WhlLftTbl — Left wheel angle table

vector

Left wheel angle table, δ_L , in rad.

Right wheel angle table, WhlRghtTbl — Right wheel angle table

vector

Right wheel angle table, δ_R , in rad.

Vehicle speed breakpoints, VehSpdBpts — Vehicle speed breakpoints

vector

Vehicle speed breakpoints, in m/s.

Dependencies

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

Superimposed speed factor table, SpdFctTbl — Speed factor

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.

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See Also

[Dynamic Steering](#) | [Kinematic Steering](#)

Topics

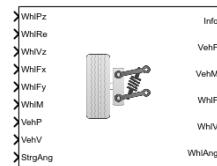
[“Coordinate Systems in Vehicle Dynamics Blockset”](#)

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">Multiple tracksAn anti-sway bar for axles with two tracksSuspension parameters
Track	<ul style="list-style-type: none">Steering angles

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
Number of axles, NumAxl	2
Number of tracks by axle, NumTracksByAxl	[2 2]
Steered axle enable by axle, StrgEnByAxl	[1 0]
Anti-sway axle enable by axle, AntiSwayEnByAxl	[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.

$$F_{wz_a,t} = F_{z0_a} + k_{z_a}(z_{v_a,t} - z_{w_a,t} + m_{hsteer_a}|\delta_{steer_a,t}|) + c(\dot{z}_{v_a,t} - \dot{z}_{w_a,t}) + F_{zhstopa,t} \\ + F_{zaswy_a,t}$$

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 vehicle-fixed z-axis
$F_{zaswy_{a,t}}$	Vertical anti-sway force at axle a, track t, along vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$x_{v_{a,t}}, \dot{x}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$x_{w_{a,t}}, \dot{x}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$y_{v_{a,t}}, \dot{y}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed y-axis
$y_{w_{a,t}}, \dot{y}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along 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

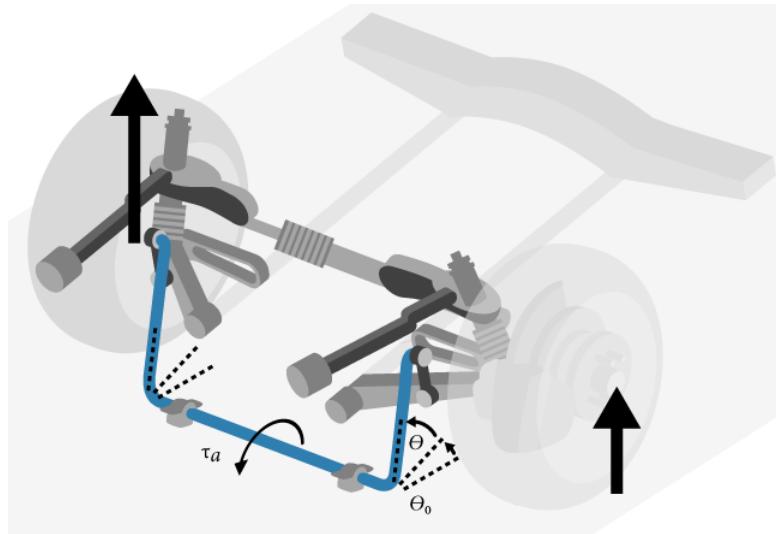
The hardstop feedback force, $F_{zhstop_{a,t}}$, that the block applies depends on whether the suspension is compressing or extending. The block applies the force:

- 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, $\Delta\theta_{a,t}$	$\theta_{0a} = \tan^{-1}\left(\frac{z_0}{r}\right)$ $\Delta\theta_{a,t} = \tan^{-1}\left(\frac{rtan\theta_{0a} - z_{w_{a,t}} + z_{v_{a,t}}}{r}\right)$

Calculation	Equation
Anti-sway bar twist angle, θ_a	$\theta_a = -\tan^{-1}\left(\frac{rtan\theta_{0a} - z_{w,a,1} + z_{v,a,1}}{r}\right)$ $-\tan^{-1}\left(\frac{rtan\theta_{0a} - z_{w,a,2} + z_{v,a,2}}{r}\right)$
Anti-sway bar torque, τ_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	$F_{zaswy,a,1} = \left(\frac{\tau_a}{r}\right) \cos\left(\theta_{0a} - \tan^{-1}\left(\frac{rtan\theta_{0a} - z_{w,a,1} + z_{v,a,1}}{r}\right)\right)$ $F_{zaswy,a,2} = \left(\frac{\tau_a}{r}\right) \cos\left(\theta_{0a} - \tan^{-1}\left(\frac{rtan\theta_{0a} - z_{w,a,2} + z_{v,a,2}}{r}\right)\right)$

The equations and figure use these variables.

τ_a	Anti-sway bar torque
θ	Anti-sway bar twist angle
θ_{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
$F_{zaswy,a,t}$	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 vehicle-fixed z-axis
$z_{w,a,t}$	Wheel displacement at axle a, track t, along 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 vehicle-fixed z-axis
$z_{w_{a,t}}$	Track displacement at axle a, track t, 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 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 vehicle-fixed z-axis
$z_{w_{a,t}}$	Track displacement at axle a, track t, along 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, $H_{a,t}$	$H_{a,t} = - \left(z_{v_{a,t}} - z_{w_{a,t}} + \frac{F_{z0_a}}{k_{za}} + m_{hsteer_a} \delta_{steer_{a,t}} \right)$
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 vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis

$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$ Track displacement and velocity at axle a , track t , along 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.

$$\text{WhlRe} = \text{Re}_w = [R_{e_{w1,1}} \ R_{e_{w1,2}} \ R_{e_{w2,1}} \ R_{e_{w2,2}}]$$

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 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 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
<code>WhlM(1,1)</code>	1	1	Vehicle-fixed x-axis (longitudinal)
<code>WhlM(1,2)</code>	1	2	
<code>WhlM(1,3)</code>	2	1	
<code>WhlM(1,4)</code>	2	2	
<code>WhlM(2,1)</code>	1	1	Vehicle-fixed y-axis (lateral)
<code>WhlM(2,2)</code>	1	2	
<code>WhlM(2,3)</code>	2	1	
<code>WhlM(2,4)</code>	2	2	
<code>WhlM(3,1)</code>	1	1	Vehicle-fixed z-axis (vertical)
<code>WhlM(3,2)</code>	1	2	
<code>WhlM(3,3)</code>	2	1	
<code>WhlM(3,4)</code>	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 vehicle-fixed x -axis

- $\text{VehP}(2, \dots)$ — Vehicle displacement from track, y_v , along vehicle-fixed y-axis
- $\text{VehP}(3, \dots)$ — Vehicle displacement from track, z_v , along 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
$\text{VehP}(1,1)$	1	1	Vehicle-fixed x-axis
$\text{VehP}(1,2)$	1	2	
$\text{VehP}(1,3)$	2	1	
$\text{VehP}(1,4)$	2	2	
$\text{VehP}(2,1)$	1	1	Vehicle-fixed y-axis
$\text{VehP}(2,2)$	1	2	
$\text{VehP}(2,3)$	2	1	
$\text{VehP}(2,4)$	2	2	
$\text{VehP}(3,1)$	1	1	Vehicle-fixed z-axis
$\text{VehP}(3,2)$	1	2	
$\text{VehP}(3,3)$	2	1	
$\text{VehP}(3,4)$	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 $a*t$.

- $\text{VehV}(1, \dots)$ — Vehicle velocity at track, x_v , along vehicle-fixed x-axis
- $\text{VehV}(2, \dots)$ — Vehicle velocity at track, y_v , along vehicle-fixed y-axis

- `VehV(3, ...)` — Vehicle velocity at track, z_v , along 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
<code>VehV(1,1)</code>	1	1	Vehicle-fixed x-axis
<code>VehV(1,2)</code>	1	2	
<code>VehV(1,3)</code>	2	1	
<code>VehV(1,4)</code>	2	2	
<code>VehV(2,1)</code>	1	1	Vehicle-fixed y-axis
<code>VehV(2,2)</code>	1	2	
<code>VehV(2,3)</code>	2	1	
<code>VehV(2,4)</code>	2	2	
<code>VehV(3,1)</code>	1	1	Vehicle-fixed z-axis
<code>VehV(3,2)</code>	1	2	
<code>VehV(3,3)</code>	2	1	
<code>VehV(3,4)</code>	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
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

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

Signal	Description	Array Signal	Variable	Units
Camber	Wheel angles according to the axle and track location.	1D	WhlAng[1, ...] = ξ = $[\xi_{a,t}]$	rad
Caster			WhlAng[2, ...] = η = $[\eta_{a,t}]$	
Toe			WhlAng[3, ...] = ζ = $[\zeta_{a,t}]$	
Height	Suspension height	1D	H	m
Power	Suspension power dissipation	1D	P_{susp}	W

1 Chassis Blocks — Alphabetical List

Signal	Description	Array Signal	Variable	Units
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> $\text{VehF} = F_v = \begin{bmatrix} F_{vx1,1} & F_{vx1,2} & F_{vx2,1} & F_{vx2,2} \\ F_{vy1,1} & F_{vy1,2} & F_{vy2,1} & F_{vy2,2} \\ F_{vz1,1} & F_{vz1,2} & F_{vz2,1} & F_{vz2,2} \end{bmatrix}$	N

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

Signal	Description	Array Signal	Variable	Units
WhlP	Track displacement	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlP} = \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix}$ <p>=</p> $\begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{wy2,2} \\ z_{wtr1,1} & z_{wtr1,2} & z_{wtr2,1} & z_{wtr2,2} \end{bmatrix}$	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> $\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix}$ $= \begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$	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.

- $\text{VehF}(1, \dots)$ — Suspension force applied to vehicle along vehicle-fixed x-axis (longitudinal)
- $\text{VehF}(2, \dots)$ — Suspension force applied to vehicle along vehicle-fixed y-axis (lateral)
- $\text{VehF}(3, \dots)$ — Suspension force applied to vehicle along 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
$\text{VehF}(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$\text{VehF}(1,2)$	1	2	
$\text{VehF}(1,3)$	2	1	
$\text{VehF}(1,4)$	2	2	
$\text{VehF}(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$\text{VehF}(2,2)$	1	2	
$\text{VehF}(2,3)$	2	1	
$\text{VehF}(2,4)$	2	2	
$\text{VehF}(3,1)$	1	1	Vehicle-fixed z-axis (vertical)
$\text{VehF}(3,2)$	1	2	
$\text{VehF}(3,3)$	2	1	
$\text{VehF}(3,4)$	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 vehicle-fixed x-axis (longitudinal)
- $\text{VehM}(2, \dots)$ — Suspension moment applied to the vehicle about vehicle-fixed y-axis (lateral)
- $\text{VehM}(3, \dots)$ — Suspension moment applied to the vehicle about 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
$\text{VehM}(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$\text{VehM}(1,2)$	1	2	
$\text{VehM}(1,3)$	2	1	
$\text{VehM}(1,4)$	2	2	
$\text{VehM}(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$\text{VehM}(2,2)$	1	2	
$\text{VehM}(2,3)$	2	1	
$\text{VehM}(2,4)$	2	2	
$\text{VehM}(3,1)$	1	1	Vehicle-fixed z-axis (vertical)

Array Element	Axle	Track	Moment Axis
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 vehicle-fixed x-axis (longitudinal)
- WhlF(2,...) — Suspension force on wheel along vehicle-fixed y-axis (lateral)
- WhlF(3,...) — Suspension force on wheel along 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	

Array Element	Axle	Track	Force Axis
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)

Array Element	Axle	Track	Force Axis
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

Array Element	Axle	Track	Angle
WhlAng(2,2)	1	2	Toe
WhlAng(2,3)	2	1	
WhlAng(2,4)	2	2	
WhlAng(3,1)	1	1	
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
scalar

Number of axles, N_a , dimensionless.

Number of tracks by axle, NumTracksByAxl — Number of tracks per axle
vector

Number of tracks per axle, Nt_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
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 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** 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** 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** 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
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**
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
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-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
scalar

Nominal suspension toe angle at zero steering angle, ζ_{0a} , in rad.

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

Nominal suspension caster angle at zero steering angle, η_{0a} , in rad.

Caster angle vs suspension height slope, CasterHslp – Caster angle versus suspension height slope
scalar | vector

Caster angle versus suspension height, $m_{hcaster_a}$, 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
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
scalar

Nominal suspension camber angle at zero steering angle, ξ_{0a} , in rad.

Camber angle vs suspension height slope, CamberHslp – Camber angle versus suspension height slope
scalar | vector

Camber angle versus suspension height, $m_{hcamber_a}$, 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

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

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
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
scalar | vector

Anti-sway arm neutral angle, θ_{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
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

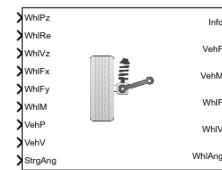
[Independent Suspension - MacPherson](#) | [Independent Suspension - Mapped](#)

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"> Multiple tracks An anti-sway bar for axles with two tracks Suspension parameters
Track	<ul style="list-style-type: none"> Steering angles

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
Number of axles, NumAxl	2
Number of tracks by axle, NumTracksByAxl	[2 2]
Steered axle enable by axle, StrgEnByAxl	[1 0]
Anti-sway axle enable by axle, AntiSwayEnByAxl	[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.

$$F_{wz_a,t} = F_{z0_a} + k_{z_a}(z_{v_a,t} - z_{w_a,t} + m_{hsteer_a}|\delta_{steer_a,t}|) + c(\dot{z}_{v_a,t} - \dot{z}_{w_a,t}) + F_{zhstopa,t} \\ + F_{zaswy_a,t}$$

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 vehicle-fixed z-axis
$F_{zaswy_{a,t}}$	Vertical anti-sway force at axle a, track t, along vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$x_{v_{a,t}}, \dot{x}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$x_{w_{a,t}}, \dot{x}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$y_{v_{a,t}}, \dot{y}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed y-axis
$y_{w_{a,t}}, \dot{y}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along 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

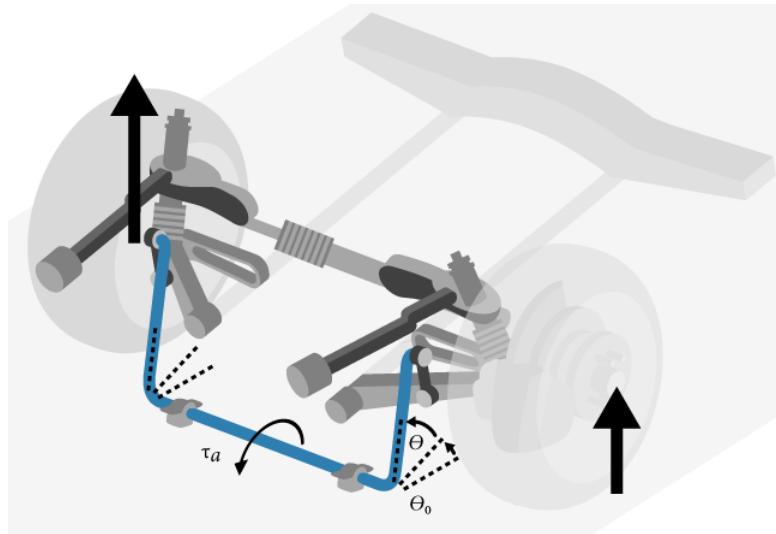
The hardstop feedback force, $F_{zhstop_{a,t}}$, that the block applies depends on whether the suspension is compressing or extending. The block applies the force:

- 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, $\Delta\theta_{a,t}$	$\theta_{0a} = \tan^{-1}\left(\frac{z_0}{r}\right)$ $\Delta\theta_{a,t} = \tan^{-1}\left(\frac{rtan\theta_{0a} - z_{w_{a,t}} + z_{v_{a,t}}}{r}\right)$

Calculation	Equation
Anti-sway bar twist angle, θ_a	$\theta_a = -\tan^{-1}\left(\frac{rtan\theta_{0a} - z_{w,a,1} + z_{v,a,1}}{r}\right)$ $-\tan^{-1}\left(\frac{rtan\theta_{0a} - z_{w,a,2} + z_{v,a,2}}{r}\right)$
Anti-sway bar torque, τ_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	$F_{zaswy,a,1} = \left(\frac{\tau_a}{r}\right) \cos\left(\theta_{0a} - \tan^{-1}\left(\frac{rtan\theta_{0a} - z_{w,a,1} + z_{v,a,1}}{r}\right)\right)$ $F_{zaswy,a,2} = \left(\frac{\tau_a}{r}\right) \cos\left(\theta_{0a} - \tan^{-1}\left(\frac{rtan\theta_{0a} - z_{w,a,2} + z_{v,a,2}}{r}\right)\right)$

The equations and figure use these variables.

τ_a	Anti-sway bar torque
θ	Anti-sway bar twist angle
θ_{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
$F_{zaswy,a,t}$	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 vehicle-fixed z-axis
$z_{w,a,t}$	Wheel displacement at axle a, track t, along 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 vehicle-fixed z-axis
$z_{w_{a,t}}$	Track displacement at axle a, track t, 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 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 vehicle-fixed z-axis
$z_{w_{a,t}}$	Track displacement at axle a, track t, along 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, $H_{a,t}$	$H_{a,t} = - \left(z_{v_{a,t}} - z_{w_{a,t}} + \frac{F_{z0_a}}{k_{za}} + m_{hsteer_a} \delta_{steer_{a,t}} \right)$
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 vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis

$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$ Track displacement and velocity at axle a , track t , along 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.

$$\text{WhlRe} = \text{Re}_w = [R_{e1,1} \ R_{e1,2} \ R_{e2,1} \ R_{e2,2}]$$

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 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 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)

- $\text{WhlM}(3, \dots)$ — 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 [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
$\text{WhlM}(1,1)$	1	1	Vehicle-fixed x -axis (longitudinal)
$\text{WhlM}(1,2)$	1	2	
$\text{WhlM}(1,3)$	2	1	
$\text{WhlM}(1,4)$	2	2	
$\text{WhlM}(2,1)$	1	1	Vehicle-fixed y -axis (lateral)
$\text{WhlM}(2,2)$	1	2	
$\text{WhlM}(2,3)$	2	1	
$\text{WhlM}(2,4)$	2	2	
$\text{WhlM}(3,1)$	1	1	Vehicle-fixed z -axis (vertical)
$\text{WhlM}(3,2)$	1	2	
$\text{WhlM}(3,3)$	2	1	
$\text{WhlM}(3,4)$	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.

- $\text{VehP}(1, \dots)$ — Vehicle displacement from track, x_v , along vehicle-fixed x -axis

- $\text{VehP}(2, \dots)$ — Vehicle displacement from track, y_v , along vehicle-fixed y-axis
- $\text{VehP}(3, \dots)$ — Vehicle displacement from track, z_v , along 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
$\text{VehP}(1,1)$	1	1	Vehicle-fixed x-axis
$\text{VehP}(1,2)$	1	2	
$\text{VehP}(1,3)$	2	1	
$\text{VehP}(1,4)$	2	2	
$\text{VehP}(2,1)$	1	1	Vehicle-fixed y-axis
$\text{VehP}(2,2)$	1	2	
$\text{VehP}(2,3)$	2	1	
$\text{VehP}(2,4)$	2	2	
$\text{VehP}(3,1)$	1	1	Vehicle-fixed z-axis
$\text{VehP}(3,2)$	1	2	
$\text{VehP}(3,3)$	2	1	
$\text{VehP}(3,4)$	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 $a*t$.

- $\text{VehV}(1, \dots)$ — Vehicle velocity at track, x_v , along vehicle-fixed x-axis
- $\text{VehV}(2, \dots)$ — Vehicle velocity at track, y_v , along vehicle-fixed y-axis

- `VehV(3, ...)` — Vehicle velocity at track, z_v , along 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
<code>VehV(1,1)</code>	1	1	Vehicle-fixed x-axis
<code>VehV(1,2)</code>	1	2	
<code>VehV(1,3)</code>	2	1	
<code>VehV(1,4)</code>	2	2	
<code>VehV(2,1)</code>	1	1	Vehicle-fixed y-axis
<code>VehV(2,2)</code>	1	2	
<code>VehV(2,3)</code>	2	1	
<code>VehV(2,4)</code>	2	2	
<code>VehV(3,1)</code>	1	1	Vehicle-fixed z-axis
<code>VehV(3,2)</code>	1	2	
<code>VehV(3,3)</code>	2	1	
<code>VehV(3,4)</code>	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
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

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

Signal	Description	Array Signal	Variable	Units
Camber	Wheel angles according to the axle and track location.	1D	WhlAng[1, ...] = ξ = $[\xi_{a,t}]$	rad
Caster			WhlAng[2, ...] = η = $[\eta_{a,t}]$	
Toe			WhlAng[3, ...] = ζ = $[\zeta_{a,t}]$	
Height	Suspension height	1D	H	m
Power	Suspension power dissipation	1D	P_{susp}	W

1 Chassis Blocks — Alphabetical List

Signal	Description	Array Signal	Variable	Units
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> $\text{VehF} = F_v = \begin{bmatrix} F_{vx1,1} & F_{vx1,2} & F_{vx2,1} & F_{vx2,2} \\ F_{vy1,1} & F_{vy1,2} & F_{vy2,1} & F_{vy2,2} \\ F_{vz1,1} & F_{vz1,2} & F_{vz2,1} & F_{vz2,2} \end{bmatrix}$	N

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

Signal	Description	Array Signal	Variable	Units
WhlP	Track displacement	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlP} = \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix}$ <p>=</p> $\begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{wy2,2} \\ z_{wtr1,1} & z_{wtr1,2} & z_{wtr2,1} & z_{wtr2,2} \end{bmatrix}$	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> $\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix}$ $= \begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$	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.

- $\text{VehF}(1, \dots)$ — Suspension force applied to vehicle along vehicle-fixed x-axis (longitudinal)
- $\text{VehF}(2, \dots)$ — Suspension force applied to vehicle along vehicle-fixed y-axis (lateral)
- $\text{VehF}(3, \dots)$ — Suspension force applied to vehicle along 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
$\text{VehF}(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$\text{VehF}(1,2)$	1	2	
$\text{VehF}(1,3)$	2	1	
$\text{VehF}(1,4)$	2	2	
$\text{VehF}(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$\text{VehF}(2,2)$	1	2	
$\text{VehF}(2,3)$	2	1	
$\text{VehF}(2,4)$	2	2	
$\text{VehF}(3,1)$	1	1	Vehicle-fixed z-axis (vertical)
$\text{VehF}(3,2)$	1	2	
$\text{VehF}(3,3)$	2	1	
$\text{VehF}(3,4)$	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 vehicle-fixed x-axis (longitudinal)
- $\text{VehM}(2, \dots)$ — Suspension moment applied to the vehicle about vehicle-fixed y-axis (lateral)
- $\text{VehM}(3, \dots)$ — Suspension moment applied to the vehicle about 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
$\text{VehM}(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$\text{VehM}(1,2)$	1	2	
$\text{VehM}(1,3)$	2	1	
$\text{VehM}(1,4)$	2	2	
$\text{VehM}(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$\text{VehM}(2,2)$	1	2	
$\text{VehM}(2,3)$	2	1	
$\text{VehM}(2,4)$	2	2	
$\text{VehM}(3,1)$	1	1	Vehicle-fixed z-axis (vertical)

Array Element	Axle	Track	Moment Axis
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 vehicle-fixed x-axis (longitudinal)
- WhlF(2,...) — Suspension force on wheel along vehicle-fixed y-axis (lateral)
- WhlF(3,...) — Suspension force on wheel along 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	

Array Element	Axle	Track	Force Axis
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)

Array Element	Axle	Track	Force Axis
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

Array Element	Axle	Track	Angle
WhlAng(2,2)	1	2	Toe
WhlAng(2,3)	2	1	
WhlAng(2,4)	2	2	
WhlAng(3,1)	1	1	
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
scalar

Number of axles, N_a , dimensionless.

Number of tracks by axle, NumTracksByAxl — Number of tracks per axle
vector

Number of tracks per axle, Nt_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
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 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** 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** 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** 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, H_{max} — Height 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 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 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-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
scalar

Nominal suspension toe angle at zero steering angle, ζ_{0a} , in rad.

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

Nominal suspension caster angle at zero steering angle, η_{0a} , in rad.

Caster angle vs suspension height slope, CasterHslp – Caster angle versus suspension height slope
scalar | vector

Caster angle versus suspension height, $m_{hcaster_a}$, 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
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
scalar

Nominal suspension camber angle at zero steering angle, ξ_{0a} , in rad.

Camber angle vs suspension height slope, CamberHslp – Camber angle versus suspension height slope
scalar | vector

Camber angle versus suspension height, $m_{hcamber_a}$, 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

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

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
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
scalar | vector

Anti-sway arm neutral angle, θ_{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
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

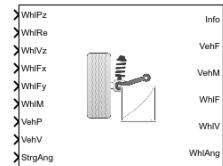
[Independent Suspension - Double Wishbone](#) | [Independent Suspension - Mapped](#)

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">Multiple tracksAn anti-sway bar for axles with two tracksSuspension parameters
Track	<ul style="list-style-type: none">Steering angles

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
Number of axles, NumAxl	2
Number of tracks by axle, NumTracksByAxl	[2 2]
Steered axle enable by axle, StrgEnByAxl	[1 0]
Anti-sway axle enable by axle, AntiSwayEnByAxl	[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

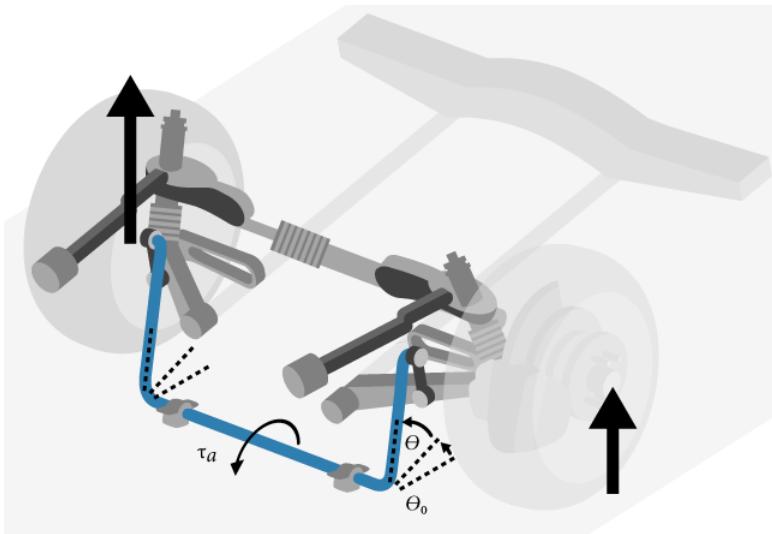
F_{z0_a} Vertical suspension spring preload force applied to the wheels on axle a

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 vehicle-fixed z-axis
$F_{zaswy_{a,t}}$	Vertical anti-sway force at axle a, track t, along vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$x_{v_{a,t}}, \dot{x}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$x_{w_{a,t}}, \dot{x}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$y_{v_{a,t}}, \dot{y}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed y-axis
$y_{w_{a,t}}, \dot{y}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along 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, $\Delta\theta_{a,t}$	$\theta_{0a} = \tan^{-1}\left(\frac{z_0}{r}\right)$ $\Delta\theta_{a,t} = \tan^{-1}\left(\frac{rtan\theta_{0a} - z_{w,a,t} + z_{v,a,t}}{r}\right)$
Anti-sway bar twist angle, θ_a	$\theta_a = -\tan^{-1}\left(\frac{rtan\theta_{0a} - z_{w,a,1} + z_{v,a,1}}{r}\right)$ $-\tan^{-1}\left(\frac{rtan\theta_{0a} - z_{w,a,2} + z_{v,a,2}}{r}\right)$
Anti-sway bar torque, τ_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	$F_{zaswy,a,1} = \left(\frac{\tau_a}{r}\right)\cos\left(\theta_{0a} - \tan^{-1}\left(\frac{rtan\theta_{0a} - z_{w,a,1} + z_{v,a,1}}{r}\right)\right)$ $F_{zaswy,a,2} = \left(\frac{\tau_a}{r}\right)\cos\left(\theta_{0a} - \tan^{-1}\left(\frac{rtan\theta_{0a} - z_{w,a,2} + z_{v,a,2}}{r}\right)\right)$

The equations and figure use these variables.

τ_a	Anti-sway bar torque
θ	Anti-sway bar twist angle
θ_{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
$F_{zsway_{a,t}}$	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 vehicle-fixed z-axis
$z_{w_{a,t}}$	Wheel displacement at axle a, track t, along vehicle-fixed z-axis

Camber, Caster, and Toe Angles

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

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

The equations use these variables.

$\xi_{a,t}$	Camber angle of wheel on axle 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
$\delta_{steer_{a,t}}$	Steering angle input for axle a, track t
$z_{v_{a,t}}$	Vehicle displacement at axle a, track t, along vehicle-fixed z-axis
$z_{w_{a,t}}$	Wheel displacement at axle a, track t, 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, $G_{alookup}$, that is a function of the suspension position and steering angle.

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

The equation uses these variables.

$\delta_{whlsteer_{a,t}}$	Wheel steering angle for axle 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 vehicle-fixed z-axis
$z_{w_{a,t}}$	Wheel displacement at axle a, track t, along 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 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 vehicle-fixed z-axis

$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along 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.

$$\text{WhlRe} = \text{Re}_w = [\text{Re}_{w1,1} \text{ } \text{Re}_{w1,2} \text{ } \text{Re}_{w2,1} \text{ } \text{Re}_{w2,2}]$$

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.

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

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 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 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
<code>WhlM(1,1)</code>	1	1	Vehicle-fixed x-axis (longitudinal)
<code>WhlM(1,2)</code>	1	2	
<code>WhlM(1,3)</code>	2	1	
<code>WhlM(1,4)</code>	2	2	
<code>WhlM(2,1)</code>	1	1	Vehicle-fixed y-axis (lateral)
<code>WhlM(2,2)</code>	1	2	
<code>WhlM(2,3)</code>	2	1	
<code>WhlM(2,4)</code>	2	2	
<code>WhlM(3,1)</code>	1	1	Vehicle-fixed z-axis (vertical)
<code>WhlM(3,2)</code>	1	2	
<code>WhlM(3,3)</code>	2	1	
<code>WhlM(3,4)</code>	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.

- $\text{VehP}(1, \dots)$ — Vehicle displacement from track, x_v , along vehicle-fixed x-axis
- $\text{VehP}(2, \dots)$ — Vehicle displacement from track, y_v , along vehicle-fixed y-axis
- $\text{VehP}(3, \dots)$ — Vehicle displacement from track, z_v , along 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
$\text{VehP}(1,1)$	1	1	Vehicle-fixed x-axis
$\text{VehP}(1,2)$	1	2	
$\text{VehP}(1,3)$	2	1	
$\text{VehP}(1,4)$	2	2	
$\text{VehP}(2,1)$	1	1	Vehicle-fixed y-axis
$\text{VehP}(2,2)$	1	2	
$\text{VehP}(2,3)$	2	1	
$\text{VehP}(2,4)$	2	2	
$\text{VehP}(3,1)$	1	1	Vehicle-fixed z-axis
$\text{VehP}(3,2)$	1	2	
$\text{VehP}(3,3)$	2	1	
$\text{VehP}(3,4)$	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 vehicle-fixed x -axis
- `VehV(2, ...)` — Vehicle velocity at track, y_v , along vehicle-fixed y -axis
- `VehV(3, ...)` — Vehicle velocity at track, z_v , along 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
<code>VehV(1,1)</code>	1	1	Vehicle-fixed x -axis
<code>VehV(1,2)</code>	1	2	
<code>VehV(1,3)</code>	2	1	
<code>VehV(1,4)</code>	2	2	
<code>VehV(2,1)</code>	1	1	Vehicle-fixed y -axis
<code>VehV(2,2)</code>	1	2	
<code>VehV(2,3)</code>	2	1	
<code>VehV(2,4)</code>	2	2	
<code>VehV(3,1)</code>	1	1	Vehicle-fixed z -axis
<code>VehV(3,2)</code>	1	2	
<code>VehV(3,3)</code>	2	1	
<code>VehV(3,4)</code>	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
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
(4, 4)	2	2

Signal	Description	Array Signal	Variable	Units
Camber	Wheel angles according to the axle and track location.	1D	WhlAng[1, ...] = ξ = $[\xi_{a,t}]$	rad
Caster			WhlAng[2, ...] = η = $[\eta_{a,t}]$	
Toe			WhlAng[3, ...] = ζ = $[\zeta_{a,t}]$	
Height	Suspension height	1D	H	m

Signal	Description	Array Signal	Variable	Units
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> $\text{VehF} = F_v = \begin{bmatrix} F_{vx1,1} & F_{vx1,2} & F_{vx2,1} & F_{vx2,2} \\ F_{vy1,1} & F_{vy1,2} & F_{vy2,1} & F_{vy2,2} \\ F_{vz1,1} & F_{vz1,2} & F_{vz2,1} & F_{vz2,2} \end{bmatrix}$	N

Signal	Description	Array Signal	Variable	Units
VehM	Suspension moments applied to vehicle	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{VehM} = M_v$ $=$ $\begin{bmatrix} M_{vx1,1} & M_{vx1,2} & M_{vx2,1} \\ M_{vy1,1} & M_{vy1,2} & M_{vy2,1} \\ M_{vz1,1} & M_{vz1,2} & M_{vz2,1} \end{bmatrix} \begin{matrix} M_{vx2,2} \\ M_{vy2,2} \\ M_{vz2,2} \end{matrix}$	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

Signal	Description	Array Signal	Variable	Units
WhlP	Track displacement	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlP} = \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix}$ <p>=</p> $\begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{wy2,2} \\ z_{wtr1,1} & z_{wtr1,2} & z_{wtr2,1} & z_{wtr2,2} \end{bmatrix}$	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> $\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix}$ $= \begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$	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.

- $\text{VehF}(1, \dots)$ — Suspension force applied to vehicle along vehicle-fixed x-axis (longitudinal)
- $\text{VehF}(2, \dots)$ — Suspension force applied to vehicle along vehicle-fixed y-axis (lateral)
- $\text{VehF}(3, \dots)$ — Suspension force applied to vehicle along 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
$\text{VehF}(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$\text{VehF}(1,2)$	1	2	
$\text{VehF}(1,3)$	2	1	
$\text{VehF}(1,4)$	2	2	
$\text{VehF}(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$\text{VehF}(2,2)$	1	2	
$\text{VehF}(2,3)$	2	1	
$\text{VehF}(2,4)$	2	2	
$\text{VehF}(3,1)$	1	1	Vehicle-fixed z-axis (vertical)
$\text{VehF}(3,2)$	1	2	
$\text{VehF}(3,3)$	2	1	
$\text{VehF}(3,4)$	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 vehicle-fixed x-axis (longitudinal)
- $\text{VehM}(2, \dots)$ — Suspension moment applied to the vehicle about vehicle-fixed y-axis (lateral)
- $\text{VehM}(3, \dots)$ — Suspension moment applied to the vehicle about 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
$\text{VehM}(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$\text{VehM}(1,2)$	1	2	
$\text{VehM}(1,3)$	2	1	
$\text{VehM}(1,4)$	2	2	
$\text{VehM}(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$\text{VehM}(2,2)$	1	2	
$\text{VehM}(2,3)$	2	1	
$\text{VehM}(2,4)$	2	2	
$\text{VehM}(3,1)$	1	1	Vehicle-fixed z-axis (vertical)

Array Element	Axle	Track	Moment Axis
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 vehicle-fixed x-axis (longitudinal)
- WhlF(2,...) — Suspension force on wheel along vehicle-fixed y-axis (lateral)
- WhlF(3,...) — Suspension force on wheel along 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	

Array Element	Axle	Track	Force Axis
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)

Array Element	Axle	Track	Force Axis
WhlV(2,2)	1	2	Vehicle-fixed <i>z</i> -axis (vertical)
WhlV(2,3)	2	1	
WhlV(2,4)	2	2	
WhlV(3,1)	1	1	
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

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

Parameters

Axes

Number of axles, NumAxl — Number of axles
scalar

Number of axles, N_a , dimensionless.

Number of tracks by axle, NumTracksByAxl — Number of tracks per axle
vector

Number of tracks per axle, Nt_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
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 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-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_fmq – Output array
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

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
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**
scalar | vector

Anti-sway arm neutral angle, θ_{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**
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

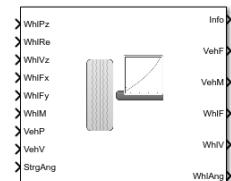
[Independent Suspension - Double Wishbone](#) | [Independent Suspension - MacPherson](#)

Introduced in R2018a

Solid Axle Suspension - Mapped

Mapped solid axle suspension

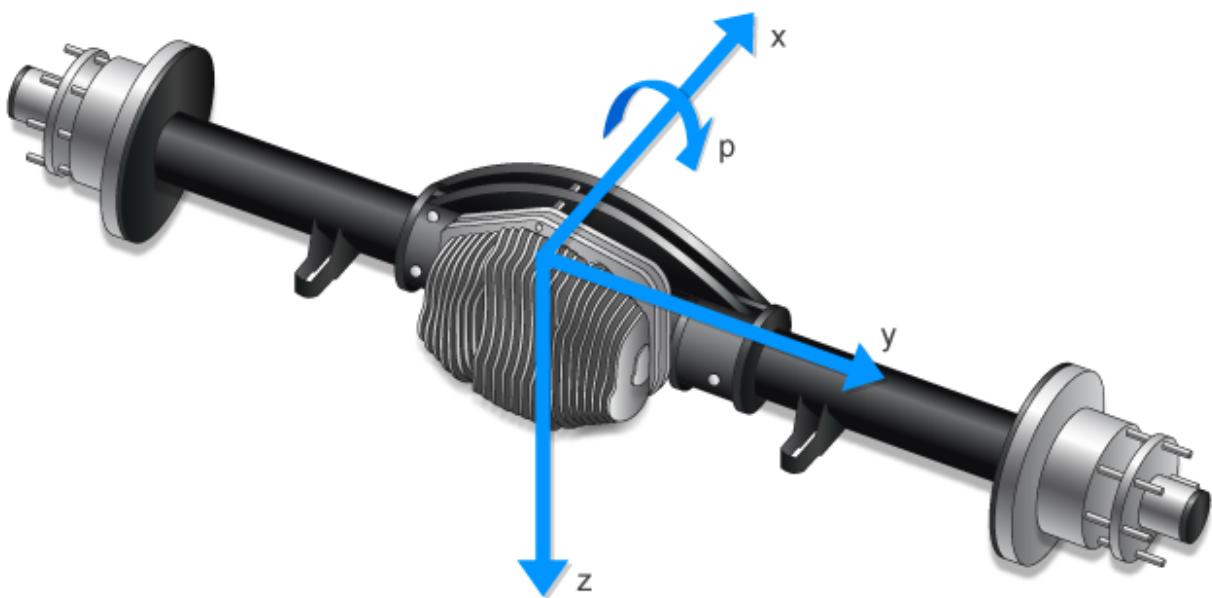
Library: Vehicle Dynamics Blockset / Suspension



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">• Multiple tracks.• Suspension parameters.
Track	<ul style="list-style-type: none">• Steering angles.

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

Parameter	Setting
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"> Longitudinal and lateral displacement and velocity of the vehicle. Longitudinal and lateral displacement and velocity of the track. Vertical wheel forces applied to the vehicle. 	<ul style="list-style-type: none"> Suspension forces applied to the axle center. Vertical displacements and velocities of the vehicle and track. Longitudinal, lateral, and vertical suspension forces and moments applied to the vehicle. Longitudinal, lateral, and vertical suspension forces and moments applied to the wheel.

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.

$$\begin{bmatrix} \ddot{x}_a \\ \ddot{y}_a \\ \ddot{z}_a \end{bmatrix} = \frac{1}{M_a} \begin{bmatrix} F_{xa} \\ F_{ya} \\ F_{za} \end{bmatrix} + \begin{bmatrix} \dot{x}_a \\ \dot{y}_a \\ \dot{z}_a \end{bmatrix} \times \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \frac{1}{M_a} \begin{bmatrix} 0 \\ 0 \\ F_{za} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{z}_a \end{bmatrix} \times \begin{bmatrix} p \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix} = \begin{bmatrix} 0 \\ p\dot{z}_a \\ \frac{F_{za}}{M_a} + g \end{bmatrix}$$

$$\begin{aligned} \begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} &= \begin{bmatrix} [M_x] \\ [M_y] \\ [M_z] \end{bmatrix} - \begin{bmatrix} p \\ q \\ r \end{bmatrix} \times \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}^{-1} \\ &= \begin{bmatrix} [M_x] \\ 0 \\ 0 \end{bmatrix} - \begin{bmatrix} p \\ q \\ 0 \end{bmatrix} \times \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} p \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}^{-1} = \begin{bmatrix} \frac{M_x}{I_{xx}} \\ 0 \\ 0 \end{bmatrix} \end{aligned}$$

For the forces and moments, the block uses lookup tables.

$$\begin{aligned} F_{wz_{a,t}} &= f(z_{v_{a,t}} - z_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}}) \\ M_{vz_{a,t}} &= f(z_{v_{a,t}} - z_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}}) \end{aligned}$$

The suspension forces and moments applied to the vehicle are equal to the suspension forces and moments applied to the wheel.

$$\begin{aligned} F_{vx_{a,t}} &= F_{wx_{a,t}} \\ F_{vy_{a,t}} &= F_{wy_{a,t}} \\ F_{vz_{a,t}} &= -F_{wz_{a,t}} \end{aligned}$$

$$\begin{aligned} M_{vx_{a,t}} &= M_{wx_{a,t}} + F_{wy_{a,t}}(Re_{wy_{a,t}} + H_{a,t}) \\ M_{vy_{a,t}} &= M_{wy_{a,t}} + F_{wx_{a,t}}(Re_{wx_{a,t}} + H_{a,t}) \\ M_{vz_{a,t}} &= M_{wz_{a,t}} \end{aligned}$$

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 vehicle-fixed z-axis
$F_{zaswy_{a,t}}$	Vertical anti-sway force at axle a, track t, along vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$x_{v_{a,t}}, \dot{x}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$x_{w_{a,t}}, \dot{x}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$y_{v_{a,t}}, \dot{y}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed y-axis
$y_{w_{a,t}}, \dot{y}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along 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

Camber, Caster, and Toe Angles

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

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

The equations use these variables.

$\xi_{a,t}$	Camber angle of wheel on axle 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
$\delta_{steer_{a,t}}$	Steering angle input for axle a, track t
$z_{v_{a,t}}$	Vehicle displacement at axle a, track t, along vehicle-fixed z-axis
$z_{w_{a,t}}$	Wheel displacement at axle a, track t, 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, $G_{a\text{lookup}}$, that is a function of the suspension position and steering angle.

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

The equation uses these variables.

$\delta_{whlsteer_{a,t}}$	Wheel steering angle for axle 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 vehicle-fixed z-axis
$z_{w_{a,t}}$	Wheel displacement at axle a, track t, along 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 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 vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along 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
<code>WhlVz(1,1)</code>	1	1
<code>WhlVz(1,2)</code>	1	2
<code>WhlVz(1,3)</code>	2	1
<code>WhlVz(1,4)</code>	2	2

WhlFx — Longitudinal wheel force on vehicle array

Longitudinal wheel force applied to vehicle, F_{wx} , along 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
<code>WhlFx(1,1)</code>	1	1
<code>WhlFx(1,2)</code>	1	2
<code>WhlFx(1,3)</code>	2	1
<code>WhlFx(1,4)</code>	2	2

WhlFy — Lateral wheel force on vehicle array

Lateral wheel force applied to vehicle, F_{wy} , along 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 vehicle-fixed x-axis
- VehP(2, ...) — Vehicle displacement from track, y_v , along vehicle-fixed y-axis
- VehP(3, ...) — Vehicle displacement from track, z_v , along 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 $a*t$.

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

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

- Signal dimensions are $[3 \times 4]$.
- 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
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

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

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

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

Signal	Description	Array Signal	Variable	Units
WhlF	Suspension force applied to wheel	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlF} = F_w$ <p style="text-align: center;">=</p> $\begin{bmatrix} F_{wx1,1} & F_{wx1,2} & F_{wx2,1} & F_{wx2,2} \\ F_{wy1,1} & F_{wy1,2} & F_{wy2,1} & F_{wy2,2} \\ F_{wz1,1} & F_{wz1,2} & F_{wz2,1} & F_{wz2,2} \end{bmatrix}$	N

Signal	Description	Array Signal	Variable	Units
WhlP	Track displacement	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlP} = \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix}$ <p>=</p> $\begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{wy2,2} \\ z_{wtr1,1} & z_{wtr1,2} & z_{wtr2,1} & z_{wtr2,2} \end{bmatrix}$	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> $\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix}$ $= \begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$	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.

- $\text{VehF}(1, \dots)$ — Suspension force applied to vehicle along vehicle-fixed x-axis (longitudinal)
- $\text{VehF}(2, \dots)$ — Suspension force applied to vehicle along vehicle-fixed y-axis (lateral)
- $\text{VehF}(3, \dots)$ — Suspension force applied to vehicle along 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
$\text{VehF}(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$\text{VehF}(1,2)$	1	2	
$\text{VehF}(1,3)$	2	1	
$\text{VehF}(1,4)$	2	2	
$\text{VehF}(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$\text{VehF}(2,2)$	1	2	
$\text{VehF}(2,3)$	2	1	
$\text{VehF}(2,4)$	2	2	
$\text{VehF}(3,1)$	1	1	Vehicle-fixed z-axis (vertical)
$\text{VehF}(3,2)$	1	2	
$\text{VehF}(3,3)$	2	1	
$\text{VehF}(3,4)$	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 vehicle-fixed x-axis (longitudinal)
- $\text{VehM}(2, \dots)$ — Suspension moment applied to the vehicle about vehicle-fixed y-axis (lateral)
- $\text{VehM}(3, \dots)$ — Suspension moment applied to the vehicle about 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
$\text{VehM}(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$\text{VehM}(1,2)$	1	2	
$\text{VehM}(1,3)$	2	1	
$\text{VehM}(1,4)$	2	2	
$\text{VehM}(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$\text{VehM}(2,2)$	1	2	
$\text{VehM}(2,3)$	2	1	
$\text{VehM}(2,4)$	2	2	
$\text{VehM}(3,1)$	1	1	Vehicle-fixed z-axis (vertical)

Array Element	Axle	Track	Moment Axis
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 vehicle-fixed x-axis (longitudinal)
- WhlF(2,...) — Suspension force on wheel along vehicle-fixed y-axis (lateral)
- WhlF(3,...) — Suspension force on wheel along 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	Vehicle-fixed y-axis (lateral)
WhlF(2,1)	1	1	
WhlF(2,2)	1	2	
WhlF(2,3)	2	1	

Array Element	Axle	Track	Force Axis
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)

Array Element	Axle	Track	Force Axis
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

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

Parameters

Axes

Number of axles, NumAxl — Number of axles
scalar

Number of axles, N_a , dimensionless.

Number of tracks by axle, NumTracksByAxl — Number of tracks per axle
vector

Number of tracks per axle, Nt_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
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 vector

Axle and wheels lumped principal moments of inertia about longitudinal axis, **AxeIxx** a , in kg*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 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 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 hardpoints 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

Array Element	Axle	Track	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

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 hardpoints 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

Array Element	Axle	Track	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 scalar

Wheel and axle interface compliance constant, K_z , in N/m.

Wheel and axle interface compliance preload, F0zWhlAxl – Spring rate scalar

Wheel and axle interface compliance preload, F_{0z} , in N.

Wheel and axle interface damping constant, CzWhlAxl – Damping scalar

Wheel and axle interface damping constant, C_z , in m.

Suspension

Mapped

Axle breakpoints, f_susp_axl_bp – Breakpoints
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_fmq — Output array

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

M-by-0-by-P-by-3 array

Array of geometric suspension values as a function of:

- Vertical suspension height, M
- Steering angle, O

- Axe, 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

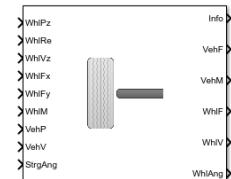
Solid Axle Suspension | Solid Axle Suspension - Coil Spring | Solid Axle Suspension - Leaf Spring

Introduced in R2018a

Solid Axle Suspension

Solid axle suspension for multiple axles

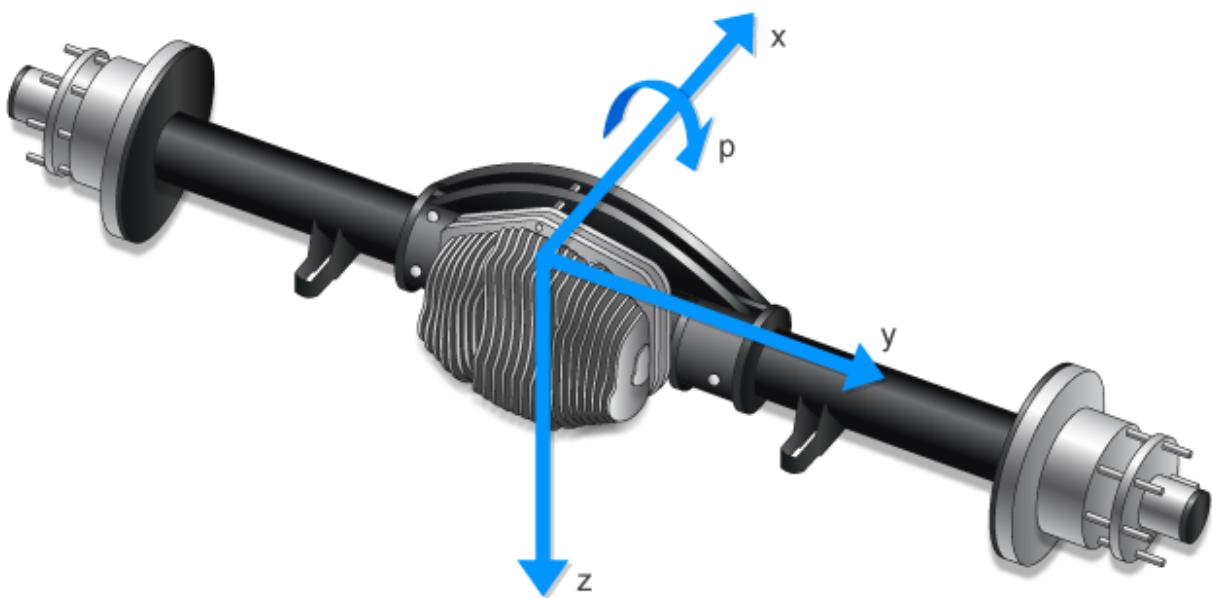
Library: Vehicle Dynamics Blockset / Suspension



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">• Multiple tracks.• Suspension parameters.
Track	<ul style="list-style-type: none">• Steering angles.

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

Parameter	Setting
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"> Longitudinal and lateral displacement and velocity of the vehicle. Longitudinal and lateral displacement and velocity of the track. Vertical wheel forces applied to the vehicle. 	<ul style="list-style-type: none"> Suspension forces applied to the axle center. Vertical displacements and velocities of the vehicle and track. Longitudinal, lateral and vertical suspension forces and moments applied to the vehicle. Longitudinal, lateral and vertical suspension forces and moments applied to the wheel.

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.

$$\begin{bmatrix} \ddot{x}_a \\ \ddot{y}_a \\ \ddot{z}_a \end{bmatrix} = \frac{1}{M_a} \begin{bmatrix} F_{xa} \\ F_{ya} \\ F_{za} \end{bmatrix} + \begin{bmatrix} \dot{x}_a \\ \dot{y}_a \\ \dot{z}_a \end{bmatrix} \times \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \frac{1}{M_a} \begin{bmatrix} 0 \\ 0 \\ F_{za} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{z}_a \end{bmatrix} \times \begin{bmatrix} p \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix} = \begin{bmatrix} 0 \\ p\dot{z}_a \\ \frac{F_{za}}{M_a} + g \end{bmatrix}$$

$$\begin{aligned} \begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} &= \begin{bmatrix} [M_x] \\ [M_y] \\ [M_z] \end{bmatrix} - \begin{bmatrix} p \\ q \\ r \end{bmatrix} \times \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}^{-1} \\ &= \begin{bmatrix} [M_x] \\ 0 \\ 0 \end{bmatrix} - \begin{bmatrix} p \\ q \\ 0 \end{bmatrix} \times \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} p \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}^{-1} = \begin{bmatrix} \frac{M_x}{I_{xx}} \\ 0 \\ 0 \end{bmatrix} \end{aligned}$$

The net vertical force on the axle center of mass is the sum of the wheel and suspension forces acting on the axle.

$$F_{za} = \sum_{t=1}^{Nta} (F_{wz_{a,t}} + F_{z0a} + k_{za}(z_{v_{a,t}} - z_{s_{a,t}} + m_{hsteer_a}|\delta_{steer_{a,t}}|) + c_{za}(\dot{z}_{v_{a,t}} - \dot{z}_{s_{a,t}}))$$

The net moment about the roll axis of the solid axle suspension accounts for the hardpoint coordinates of the suspension and tracks.

$$\begin{aligned} M_x &= \sum_{t=1}^{Nta} (F_{wz_{a,t}} y_{w_t} + (F_{z0a} + k_{za}(z_{v_{a,t}} - z_{s_{a,t}} + m_{hsteer_a}|\delta_{steer_{a,t}}|) \\ &\quad + c_{za}(\dot{z}_{v_{a,t}} - \dot{z}_{s_{a,t}})) y_{s_t} + M_{wx_{a,t}} \frac{I_{xx}}{I_{xx} + M_a y_{w_t}}) \end{aligned}$$

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.

$$F_{vz_a,t} = - (F_{z0_a} + k_{za}(z_{va,t} - z_{sa,t} + m_{hsteer_a} |\delta_{steer_a,t}|) + c_{za}(\dot{z}_{va,t} - \dot{z}_{sa,t}) + F_{zhstop_a,t})$$

The suspension forces and moments applied to the vehicle are equal to the suspension forces and moments applied to the wheel.

$$F_{vx_a,t} = F_{wx_a,t}$$

$$F_{vy_a,t} = F_{wy_a,t}$$

$$F_{vz_a,t} = - F_{wz_a,t}$$

$$M_{vx_a,t} = M_{wx_a,t} + F_{wy_a,t}(Re_{wy_a,t} + H_{a,t})$$

$$M_{vy_a,t} = M_{wy_a,t} + F_{wx_a,t}(Re_{wx_a,t} + H_{a,t})$$

$$M_{vz_a,t} = M_{wz_a,t}$$

To calculate the vertical force applied to the suspension at the track location, the block implements a stiff spring-damper.

$$F_{wz_a,t} = - F_{wa,z0} - k_{wa_z}(z_{wa,t} - z_{sa,t}) - c_{wa_z}(\dot{z}_{wa,t} - \dot{z}_{sa,t})$$

The equations use these variables.

$F_{wz_{a,t}}, M_{wz_{a,t}}$	Suspension force and moment applied to the wheel on axle 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 vehicle-fixed z-axis
$F_{zaswy_{a,t}}$	Vertical anti-sway force at axle a, track t, along vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$x_{v_{a,t}}, \dot{x}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$x_{w_{a,t}}, \dot{x}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$y_{v_{a,t}}, \dot{y}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed y-axis
$y_{w_{a,t}}, \dot{y}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along 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

$m_{cambersteer_a}$	Camber, caster, and toe angles, respectively, versus steering angle slope for axle a
$m_{castersteer_a}$, $m_{toesteer_a}$	
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 vehicle-fixed z-axis
$z_{w_{a,t}}$	Track displacement at axle a, track t, 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 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 vehicle-fixed z-axis
$z_{w_{a,t}}$	Track displacement at axle a, track t, along vehicle-fixed z-axis

Power and Energy

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

Calculation	Equation
Dissipated power, $P_{susp_{a,t}}$	$P_{susp_{a,t}} = F_{wzlookup_a}(\dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$

Calculation	Equation
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, $H_{a,t}$	$H_{a,t} = - \left(z_{v_{a,t}} - z_{w_{a,t}} + \frac{F_{z0_a}}{k_{za}} + m_{hsteer_a} \delta_{steer_{a,t}} \right)$
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 vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along 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 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 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.

- $\text{WhlM}(1, \dots)$ — Suspension moment applied to the wheel about the vehicle-fixed x-axis (longitudinal)
- $\text{WhlM}(2, \dots)$ — Suspension moment applied to the wheel about the vehicle-fixed y-axis (lateral)
- $\text{WhlM}(3, \dots)$ — 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 [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.

- $\text{VehP}(1, \dots)$ — Vehicle displacement from track, x_v , along vehicle-fixed x-axis
- $\text{VehP}(2, \dots)$ — Vehicle displacement from track, y_v , along vehicle-fixed y-axis
- $\text{VehP}(3, \dots)$ — Vehicle displacement from track, z_v , along 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 $a*t$.

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

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

- Signal dimensions are $[3 \times 4]$.
- 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
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

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

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

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

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

Signal	Description	Array Signal	Variable	Units
WhlP	Track displacement	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlP} = \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix}$ <p>=</p> $\begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{wy2,2} \\ z_{wtr1,1} & z_{wtr1,2} & z_{wtr2,1} & z_{wtr2,2} \end{bmatrix}$	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> $\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix}$ $= \begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$	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.

- $\text{VehF}(1, \dots)$ — Suspension force applied to vehicle along vehicle-fixed x-axis (longitudinal)
- $\text{VehF}(2, \dots)$ — Suspension force applied to vehicle along vehicle-fixed y-axis (lateral)
- $\text{VehF}(3, \dots)$ — Suspension force applied to vehicle along 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
$\text{VehF}(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$\text{VehF}(1,2)$	1	2	
$\text{VehF}(1,3)$	2	1	
$\text{VehF}(1,4)$	2	2	
$\text{VehF}(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$\text{VehF}(2,2)$	1	2	
$\text{VehF}(2,3)$	2	1	
$\text{VehF}(2,4)$	2	2	
$\text{VehF}(3,1)$	1	1	Vehicle-fixed z-axis (vertical)
$\text{VehF}(3,2)$	1	2	
$\text{VehF}(3,3)$	2	1	
$\text{VehF}(3,4)$	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 vehicle-fixed x-axis (longitudinal)
- $\text{VehM}(2, \dots)$ — Suspension moment applied to the vehicle about vehicle-fixed y-axis (lateral)
- $\text{VehM}(3, \dots)$ — Suspension moment applied to the vehicle about 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
$\text{VehM}(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$\text{VehM}(1,2)$	1	2	
$\text{VehM}(1,3)$	2	1	
$\text{VehM}(1,4)$	2	2	
$\text{VehM}(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$\text{VehM}(2,2)$	1	2	
$\text{VehM}(2,3)$	2	1	
$\text{VehM}(2,4)$	2	2	
$\text{VehM}(3,1)$	1	1	Vehicle-fixed z-axis (vertical)

Array Element	Axle	Track	Moment Axis
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 vehicle-fixed x-axis (longitudinal)
- WhlF(2,...) — Suspension force on wheel along vehicle-fixed y-axis (lateral)
- WhlF(3,...) — Suspension force on wheel along 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	

Array Element	Axle	Track	Force Axis
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)

Array Element	Axle	Track	Force Axis
WhlV(2,2)	1	2	
WhlV(2,3)	2	1	
WhlV(2,4)	2	2	
WhlV(3,1)	1	1	Vehicle-fixed <i>z</i> -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

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

Parameters

Axes

Number of axles, NumAxl — Number of axles
scalar

Number of axles, N_a , dimensionless.

Number of tracks by axle, NumTracksByAxl — Number of tracks per axle
vector

Number of tracks per axle, Nt_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
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 vector

Axle and wheels lumped principal moments of inertia about longitudinal axis, **AxeIxx** a , in kg*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 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

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 hardpoints 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

Array Element	Axle	Track	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

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 hardpoints 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

Array Element	Axle	Track	Axis
SuspCoords(2, 2)	1	2	Solid axle z-axis
SuspCoords(2, 3)	2	1	
SuspCoords(2, 4)	2	2	
SuspCoords(3, 1)	1	1	
SuspCoords(3, 2)	1	2	
SuspCoords(3, 3)	2	1	
SuspCoords(3, 4)	2	2	

Wheel and axle interface compliance constant, $K_{z\text{WhlAxl}}$ — Spring rate scalar

Wheel and axle interface compliance constant, K_z , in N/m.

Wheel and axle interface compliance preload, $F_{0z\text{WhlAxl}}$ — Spring rate scalar

Wheel and axle interface compliance preload, F_{0z} , in N.

Wheel and axle interface damping constant, $C_{z\text{WhlAxl}}$ — Damping scalar

Wheel and axle interface damping constant, C_z , in m.

Suspension

Compliance and Damping - Passive

Suspension spring constant, K_z — Suspension spring constant 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
scalar | vector

Vertical preload spring force applied to the wheels on the axle at wheel carrier reference coordinates, $F_{z0,i}$, 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
scalar | vector

Linear vertical damping constant for independent suspension tracks on axle a, c_{za} , 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
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.

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

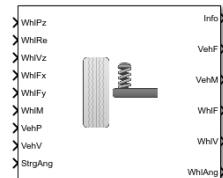
[Solid Axle Suspension - Coil Spring](#) | [Solid Axle Suspension - Leaf Spring](#) | [Solid Axle Suspension - Mapped](#)

Introduced in R2018a

Solid Axle Suspension - Coil Spring

Solid axle suspension with coil spring

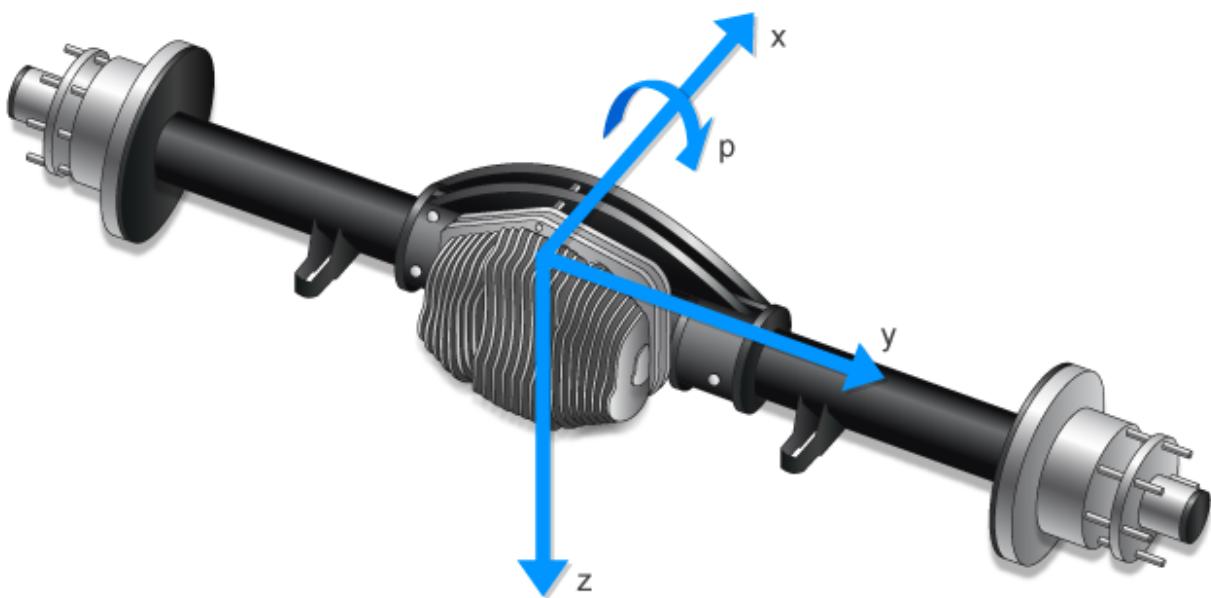
Library: Vehicle Dynamics Blockset / Suspension



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"> Multiple tracks. Suspension parameters.
Track	<ul style="list-style-type: none"> Steering angles.

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

Parameter	Setting
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">Longitudinal and lateral displacement and velocity of the vehicle.Longitudinal and lateral displacement and velocity of the track.Vertical wheel forces applied to the vehicle.	<ul style="list-style-type: none">Suspension forces applied to the axle center.Vertical displacements and velocities of the vehicle and track.Longitudinal, lateral and vertical suspension forces and moments applied to the vehicle.Longitudinal, lateral and vertical suspension forces and moments applied to the wheel.

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.

$$\begin{bmatrix} \ddot{x}_a \\ \ddot{y}_a \\ \ddot{z}_a \end{bmatrix} = \frac{1}{M_a} \begin{bmatrix} F_{xa} \\ F_{ya} \\ F_{za} \end{bmatrix} + \begin{bmatrix} \dot{x}_a \\ \dot{y}_a \\ \dot{z}_a \end{bmatrix} \times \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \frac{1}{M_a} \begin{bmatrix} 0 \\ 0 \\ F_{za} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{z}_a \end{bmatrix} \times \begin{bmatrix} p \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix} = \begin{bmatrix} 0 \\ p\dot{z}_a \\ \frac{F_{za}}{M_a} + g \end{bmatrix}$$

$$\begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} [M_x] \\ [M_y] \\ [M_z] \end{bmatrix} - \begin{bmatrix} p \\ q \\ r \end{bmatrix} \times \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}^{-1}$$

$$= \begin{bmatrix} [M_x] \\ 0 \\ 0 \end{bmatrix} - \begin{bmatrix} p \\ q \\ 0 \end{bmatrix} \times \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} p \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}^{-1} = \begin{bmatrix} \frac{M_x}{I_{xx}} \\ 0 \\ 0 \end{bmatrix}$$

The net vertical force on the axle center of mass is the sum of the wheel and suspension forces acting on the axle.

$$F_{za} = \sum_{t=1}^{Nta} (F_{wz_{a,t}} + F_{z0a} + k_{za}(z_{v_{a,t}} - z_{s_{a,t}} + m_{hsteer_a}|\delta_{steer_{a,t}}|) + c_{za}(\dot{z}_{v_{a,t}} - \dot{z}_{s_{a,t}}))$$

The net moment about the roll axis of the solid axle suspension accounts for the hardpoint coordinates of the suspension and tracks.

$$M_x = \sum_{t=1}^{Nta} (F_{wz_{a,t}} y_{w_t} + (F_{z0a} + k_{za}(z_{v_{a,t}} - z_{s_{a,t}} + m_{hsteer_a}|\delta_{steer_{a,t}}|) + c_{za}(\dot{z}_{v_{a,t}} - \dot{z}_{s_{a,t}})) y_{s_t} + M_{wx_{a,t}} \frac{I_{xx}}{I_{xx} + M_a y_{w_t}})$$

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.

$$F_{vz_a,t} = - (F_{z0a} + k_{za}(z_{va,t} - z_{sa,t} + m_{hsteera}|\delta_{steera}|) + c_{za}(\dot{z}_{va,t} - \dot{z}_{sa,t}) + F_{zhstopa,t})$$

The suspension forces and moments applied to the vehicle are equal to the suspension forces and moments applied to the wheel.

$$F_{vx_a,t} = F_{wx_a,t}$$

$$F_{vy_a,t} = F_{wy_a,t}$$

$$F_{vz_a,t} = - F_{wz_a,t}$$

$$M_{vx_a,t} = M_{wx_a,t} + F_{wy_a,t}(Re_{wy_a,t} + H_{a,t})$$

$$M_{vy_a,t} = M_{wy_a,t} + F_{wx_a,t}(Re_{wx_a,t} + H_{a,t})$$

$$M_{vz_a,t} = M_{wz_a,t}$$

To calculate the vertical force applied to the suspension at the track location, the block implements a stiff spring-damper.

$$F_{wz_a,t} = - F_{wa,z0} - k_{wa_z}(z_{wa,t} - z_{sa,t}) - c_{wa_z}(\dot{z}_{wa,t} - \dot{z}_{sa,t})$$

The equations use these variables.

$F_{wz_{a,t}}, M_{wz_{a,t}}$	Suspension force and moment applied to the wheel on axle 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 vehicle-fixed z-axis
$F_{zaswy_{a,t}}$	Vertical anti-sway force at axle a, track t, along vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$x_{v_{a,t}}, \dot{x}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$x_{w_{a,t}}, \dot{x}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$y_{v_{a,t}}, \dot{y}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed y-axis
$y_{w_{a,t}}, \dot{y}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along 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

$m_{cambersteer_a}$	Camber, caster, and toe angles, respectively, versus steering angle slope for axle a
$m_{castersteer_a}$, $m_{toesteer_a}$	
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 vehicle-fixed z-axis
$z_{w_{a,t}}$	Track displacement at axle a, track t, 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 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 vehicle-fixed z-axis
$z_{w_{a,t}}$	Track displacement at axle a, track t, along vehicle-fixed z-axis

Power and Energy

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

Calculation	Equation
Dissipated power, $P_{susp_{a,t}}$	$P_{susp_{a,t}} = F_{wzlookup_a} (\dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$

Calculation	Equation
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, $H_{a,t}$	$H_{a,t} = - \left(z_{v_{a,t}} - z_{w_{a,t}} + \frac{F_{z0_a}}{k_{za}} + m_{hsteer_a} \delta_{steer_{a,t}} \right)$
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 vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along 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 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 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.

- $\text{WhlM}(1, \dots)$ — Suspension moment applied to the wheel about the vehicle-fixed x-axis (longitudinal)
- $\text{WhlM}(2, \dots)$ — Suspension moment applied to the wheel about the vehicle-fixed y-axis (lateral)
- $\text{WhlM}(3, \dots)$ — 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 [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 vehicle-fixed x-axis
- VehP(2,...) — Vehicle displacement from track, y_v , along vehicle-fixed y-axis
- VehP(3,...) — Vehicle displacement from track, z_v , along 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 $3 \times a*t$.

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

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

- Signal dimensions are $[3 \times 4]$.
- 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
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

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

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

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

Signal	Description	Array Signal	Variable	Units
WhlF	Suspension force applied to wheel	3D	For a two-axle, two tracks per axle vehicle: $\text{WhlF} = F_w$ $=$ $\begin{bmatrix} F_{wx1,1} & F_{wx1,2} & F_{wx2,1} & F_{wx2,2} \\ F_{wy1,1} & F_{wy1,2} & F_{wy2,1} & F_{wy2,2} \\ F_{wz1,1} & F_{wz1,2} & F_{wz2,1} & F_{wz2,2} \end{bmatrix}$	N

Signal	Description	Array Signal	Variable	Units
WhlP	Track displacement	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlP} = \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix}$ <p>=</p> $\begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{wy2,2} \\ z_{wtr1,1} & z_{wtr1,2} & z_{wtr2,1} & z_{wtr2,2} \end{bmatrix}$	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> $\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix}$ $= \begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$	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.

- $\text{VehF}(1, \dots)$ — Suspension force applied to vehicle along vehicle-fixed x-axis (longitudinal)
- $\text{VehF}(2, \dots)$ — Suspension force applied to vehicle along vehicle-fixed y-axis (lateral)
- $\text{VehF}(3, \dots)$ — Suspension force applied to vehicle along 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
$\text{VehF}(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$\text{VehF}(1,2)$	1	2	
$\text{VehF}(1,3)$	2	1	
$\text{VehF}(1,4)$	2	2	
$\text{VehF}(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$\text{VehF}(2,2)$	1	2	
$\text{VehF}(2,3)$	2	1	
$\text{VehF}(2,4)$	2	2	
$\text{VehF}(3,1)$	1	1	Vehicle-fixed z-axis (vertical)
$\text{VehF}(3,2)$	1	2	
$\text{VehF}(3,3)$	2	1	
$\text{VehF}(3,4)$	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 vehicle-fixed x-axis (longitudinal)
- $\text{VehM}(2, \dots)$ — Suspension moment applied to the vehicle about vehicle-fixed y-axis (lateral)
- $\text{VehM}(3, \dots)$ — Suspension moment applied to the vehicle about 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
$\text{VehM}(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$\text{VehM}(1,2)$	1	2	
$\text{VehM}(1,3)$	2	1	
$\text{VehM}(1,4)$	2	2	
$\text{VehM}(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$\text{VehM}(2,2)$	1	2	
$\text{VehM}(2,3)$	2	1	
$\text{VehM}(2,4)$	2	2	
$\text{VehM}(3,1)$	1	1	Vehicle-fixed z-axis (vertical)

Array Element	Axle	Track	Moment Axis
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 vehicle-fixed x-axis (longitudinal)
- WhlF(2,...) — Suspension force on wheel along vehicle-fixed y-axis (lateral)
- WhlF(3,...) — Suspension force on wheel along 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	

Array Element	Axle	Track	Force Axis
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)

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

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

Parameters

Axes

Number of axles, NumAxl — Number of axles
scalar

Number of axles, N_a , dimensionless.

Number of tracks by axle, NumTracksByAxl — Number of tracks per axle
vector

Number of tracks per axle, Nt_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
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 vector

Axle and wheels lumped principal moments of inertia about longitudinal axis, AxleIxx a , in kg*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 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 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 hardpoints 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

Array Element	Axle	Track	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

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 hardpoints 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

Array Element	Axle	Track	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 scalar

Wheel and axle interface compliance constant, K_z , in N/m.

Wheel and axle interface compliance preload, F0zWhlAxl — Spring rate scalar

Wheel and axle interface compliance preload, F_{0z} , in N.

Wheel and axle interface damping constant, CzWhlAxl — Damping scalar

Wheel and axle interface damping constant, C_z , in m.

Suspension

Compliance and Damping - Passive

Suspension spring constant, Kz — Suspension spring constant 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, F_{0z} — Suspension spring preload
scalar | vector

Vertical preload spring force applied to the wheels on the axle at wheel carrier reference coordinates, $F_{z0,i}$, 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, C_z — Suspension shock damping constant
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, H_{max} — Height
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.

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

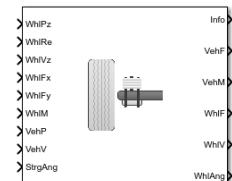
[Solid Axle Suspension](#) | [Solid Axle Suspension - Leaf Spring](#) | [Solid Axle Suspension - Mapped](#)

Introduced in R2018a

Solid Axle Suspension - Leaf Spring

Solid axle suspension with leaf spring

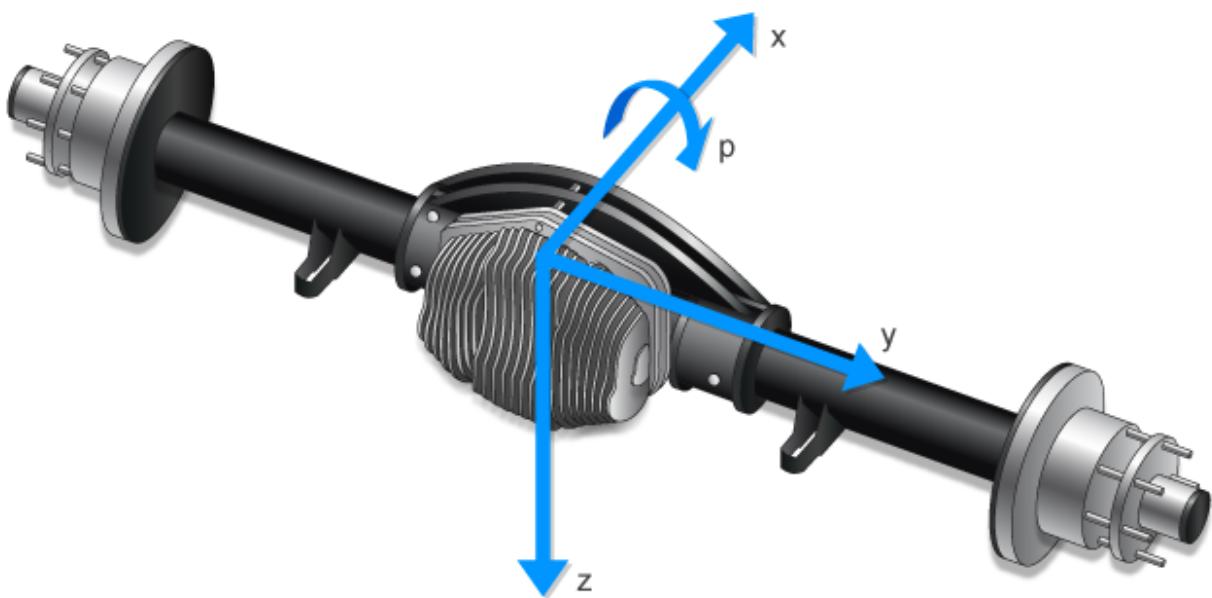
Library: Vehicle Dynamics Blockset / Suspension



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">Multiple tracks.Suspension parameters.
Track	<ul style="list-style-type: none">Steering angles.

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

Parameter	Setting
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"> Longitudinal and lateral displacement and velocity of the vehicle. Longitudinal and lateral displacement and velocity of the track. Vertical wheel forces applied to the vehicle. 	<ul style="list-style-type: none"> Suspension forces applied to the axle center. Vertical displacements and velocities of the vehicle and track. Longitudinal, lateral and vertical suspension forces and moments applied to the vehicle. Longitudinal, lateral and vertical suspension forces and moments applied to the wheel.

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.

$$\begin{bmatrix} \ddot{x}_a \\ \ddot{y}_a \\ \ddot{z}_a \end{bmatrix} = \frac{1}{M_a} \begin{bmatrix} F_{xa} \\ F_{ya} \\ F_{za} \end{bmatrix} + \begin{bmatrix} \dot{x}_a \\ \dot{y}_a \\ \dot{z}_a \end{bmatrix} \times \begin{bmatrix} p \\ q \\ r \end{bmatrix} = \frac{1}{M_a} \begin{bmatrix} 0 \\ 0 \\ F_{za} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dot{z}_a \end{bmatrix} \times \begin{bmatrix} p \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix} = \begin{bmatrix} 0 \\ p\dot{z}_a \\ \frac{F_{za}}{M_a} + g \end{bmatrix}$$

$$\begin{aligned} \begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} &= \begin{bmatrix} [M_x] \\ [M_y] \\ [M_z] \end{bmatrix} - \begin{bmatrix} p \\ q \\ r \end{bmatrix} \times \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}^{-1} \\ &= \begin{bmatrix} [M_x] \\ 0 \\ 0 \end{bmatrix} - \begin{bmatrix} p \\ q \\ 0 \end{bmatrix} \times \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} p \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}^{-1} = \begin{bmatrix} \frac{M_x}{I_{xx}} \\ 0 \\ 0 \end{bmatrix} \end{aligned}$$

The net vertical force on the axle center of mass is the sum of the wheel and suspension forces acting on the axle.

$$F_{za} = \sum_{t=1}^{Nta} (F_{wz_{a,t}} + F_{z0a} + k_{za}(z_{v_{a,t}} - z_{s_{a,t}} + m_{hsteer_a}|\delta_{steer_{a,t}}|) + c_{za}(\dot{z}_{v_{a,t}} - \dot{z}_{s_{a,t}}))$$

The net moment about the roll axis of the solid axle suspension accounts for the hardpoint coordinates of the suspension and tracks.

$$\begin{aligned} M_x &= \sum_{t=1}^{Nta} (F_{wz_{a,t}} y_{w_t} + (F_{z0a} + k_{za}(z_{v_{a,t}} - z_{s_{a,t}} + m_{hsteer_a}|\delta_{steer_{a,t}}|) \\ &\quad + c_{za}(\dot{z}_{v_{a,t}} - \dot{z}_{s_{a,t}})) y_{s_t} + M_{wx_{a,t}} \frac{I_{xx}}{I_{xx} + M_a y_{w_t}}) \end{aligned}$$

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.

$$F_{vz_a,t} = - (F_{z0a} + k_{za}(z_{va,t} - z_{sa,t} + m_{hsteera}|\delta_{steera}|) + c_{za}(\dot{z}_{va,t} - \dot{z}_{sa,t}) + F_{zhstopa,t})$$

The suspension forces and moments applied to the vehicle are equal to the suspension forces and moments applied to the wheel.

$$F_{vx_a,t} = F_{wx_a,t}$$

$$F_{vy_a,t} = F_{wy_a,t}$$

$$F_{vz_a,t} = - F_{wz_a,t}$$

$$M_{vx_a,t} = M_{wx_a,t} + F_{wy_a,t}(Re_{wy_a,t} + H_{a,t})$$

$$M_{vy_a,t} = M_{wy_a,t} + F_{wx_a,t}(Re_{wx_a,t} + H_{a,t})$$

$$M_{vz_a,t} = M_{wz_a,t}$$

To calculate the vertical force applied to the suspension at the track location, the block implements a stiff spring-damper.

$$F_{wz_a,t} = - F_{wa,z0} - k_{wa,z}(z_{wa,t} - z_{sa,t}) - c_{wa,z}(\dot{z}_{wa,t} - \dot{z}_{sa,t})$$

The equations use these variables.

$F_{wz_{a,t}}, M_{wz_{a,t}}$	Suspension force and moment applied to the wheel on axle 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 vehicle-fixed z-axis
$F_{zaswy_{a,t}}$	Vertical anti-sway force at axle a, track t, along vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$x_{v_{a,t}}, \dot{x}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$x_{w_{a,t}}, \dot{x}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$y_{v_{a,t}}, \dot{y}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed y-axis
$y_{w_{a,t}}, \dot{y}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along 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

$m_{cambersteer_a}$	Camber, caster, and toe angles, respectively, versus steering angle slope for axle a
$m_{castersteer_a}$, $m_{toesteer_a}$	
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 vehicle-fixed z-axis
$z_{w_{a,t}}$	Track displacement at axle a, track t, 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 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 vehicle-fixed z-axis
$z_{w_{a,t}}$	Track displacement at axle a, track t, along vehicle-fixed z-axis

Power and Energy

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

Calculation	Equation
Dissipated power, $P_{susp_{a,t}}$	$P_{susp_{a,t}} = F_{wzlookup_a}(\dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \dot{z}_{v_{a,t}} - \dot{z}_{w_{a,t}}, \delta_{steer_{a,t}})$

Calculation	Equation
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, $H_{a,t}$	$H_{a,t} = - \left(z_{v_{a,t}} - z_{w_{a,t}} + \frac{F_{z0_a}}{k_{za}} + m_{hsteer_a} \delta_{steer_{a,t}} \right)$
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 vehicle-fixed z-axis
$z_{v_{a,t}}, \dot{z}_{v_{a,t}}$	Vehicle displacement and velocity at axle a, track t, along vehicle-fixed z-axis
$z_{w_{a,t}}, \dot{z}_{w_{a,t}}$	Track displacement and velocity at axle a, track t, along 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 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 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.

- $\text{WhlM}(1, \dots)$ — Suspension moment applied to the wheel about the vehicle-fixed x-axis (longitudinal)
- $\text{WhlM}(2, \dots)$ — Suspension moment applied to the wheel about the vehicle-fixed y-axis (lateral)
- $\text{WhlM}(3, \dots)$ — 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 [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.

- $\text{VehP}(1, \dots)$ — Vehicle displacement from track, x_v , along vehicle-fixed x-axis
- $\text{VehP}(2, \dots)$ — Vehicle displacement from track, y_v , along vehicle-fixed y-axis
- $\text{VehP}(3, \dots)$ — Vehicle displacement from track, z_v , along 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 $a*t$.

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

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

- Signal dimensions are $[3 \times 4]$.
- 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
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

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

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

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

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

Signal	Description	Array Signal	Variable	Units
WhlP	Track displacement	3D	<p>For a two-axle, two tracks per axle vehicle:</p> $\text{WhlP} = \begin{bmatrix} x_w \\ y_w \\ z_w \end{bmatrix}$ <p>=</p> $\begin{bmatrix} x_{w1,1} & x_{w1,2} & x_{w2,1} & x_{w2,2} \\ y_{w1,1} & y_{w1,2} & y_{w2,1} & y_{wy2,2} \\ z_{wtr1,1} & z_{wtr1,2} & z_{wtr2,1} & z_{wtr2,2} \end{bmatrix}$	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> $\text{WhlAng} = \begin{bmatrix} \xi \\ \eta \\ \zeta \end{bmatrix}$ $= \begin{bmatrix} \xi_{1,1} & \xi_{1,2} & \xi_{2,1} & \xi_{2,2} \\ \eta_{1,1} & \eta_{1,2} & \eta_{2,1} & \eta_{2,2} \\ \zeta_{1,1} & \zeta_{1,2} & \zeta_{2,1} & \zeta_{2,2} \end{bmatrix}$	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.

- $\text{VehF}(1, \dots)$ — Suspension force applied to vehicle along vehicle-fixed x-axis (longitudinal)
- $\text{VehF}(2, \dots)$ — Suspension force applied to vehicle along vehicle-fixed y-axis (lateral)
- $\text{VehF}(3, \dots)$ — Suspension force applied to vehicle along 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
$\text{VehF}(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$\text{VehF}(1,2)$	1	2	
$\text{VehF}(1,3)$	2	1	
$\text{VehF}(1,4)$	2	2	
$\text{VehF}(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$\text{VehF}(2,2)$	1	2	
$\text{VehF}(2,3)$	2	1	
$\text{VehF}(2,4)$	2	2	
$\text{VehF}(3,1)$	1	1	Vehicle-fixed z-axis (vertical)
$\text{VehF}(3,2)$	1	2	
$\text{VehF}(3,3)$	2	1	
$\text{VehF}(3,4)$	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 vehicle-fixed x-axis (longitudinal)
- $\text{VehM}(2, \dots)$ — Suspension moment applied to the vehicle about vehicle-fixed y-axis (lateral)
- $\text{VehM}(3, \dots)$ — Suspension moment applied to the vehicle about 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
$\text{VehM}(1,1)$	1	1	Vehicle-fixed x-axis (longitudinal)
$\text{VehM}(1,2)$	1	2	
$\text{VehM}(1,3)$	2	1	
$\text{VehM}(1,4)$	2	2	
$\text{VehM}(2,1)$	1	1	Vehicle-fixed y-axis (lateral)
$\text{VehM}(2,2)$	1	2	
$\text{VehM}(2,3)$	2	1	
$\text{VehM}(2,4)$	2	2	
$\text{VehM}(3,1)$	1	1	Vehicle-fixed z-axis (vertical)

Array Element	Axle	Track	Moment Axis
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 vehicle-fixed x-axis (longitudinal)
- WhlF(2,...) — Suspension force on wheel along vehicle-fixed y-axis (lateral)
- WhlF(3,...) — Suspension force on wheel along 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	

Array Element	Axle	Track	Force Axis
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)

Array Element	Axle	Track	Force Axis
WhlV(2,2)	1	2	
WhlV(2,3)	2	1	
WhlV(2,4)	2	2	
WhlV(3,1)	1	1	Vehicle-fixed <i>z</i> -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

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

Parameters

Axes

Number of axles, NumAxl — Number of axles
scalar

Number of axles, N_a , dimensionless.

Number of tracks by axle, NumTracksByAxl — Number of tracks per axle
vector

Number of tracks per axle, Nt_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
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 vector

Axle and wheels lumped principal moments of inertia about longitudinal axis, **AxeIxx** a , in kg*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 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

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 hardpoints 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

Array Element	Axle	Track	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

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 hardpoints 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

Array Element	Axle	Track	Axis
SuspCoords(2, 2)	1	2	Solid axle z-axis
SuspCoords(2, 3)	2	1	
SuspCoords(2, 4)	2	2	
SuspCoords(3, 1)	1	1	
SuspCoords(3, 2)	1	2	
SuspCoords(3, 3)	2	1	
SuspCoords(3, 4)	2	2	

Wheel and axle interface compliance constant, $K_{z\text{WhlAxl}}$ — Spring rate scalar

Wheel and axle interface compliance constant, K_z , in N/m.

Wheel and axle interface compliance preload, $F_{0z\text{WhlAxl}}$ — Spring rate scalar

Wheel and axle interface compliance preload, F_{0z} , in N.

Wheel and axle interface damping constant, $C_{z\text{WhlAxl}}$ — Damping scalar

Wheel and axle interface damping constant, C_z , in m.

Suspension

Compliance and Damping - Passive

Suspension spring constant, K_z — Suspension spring constant 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, F_{0z} — Suspension spring preload
scalar | vector

Vertical preload spring force applied to the wheels on the axle at wheel carrier reference coordinates, $F_{z0,i}$, 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, C_z — Suspension shock damping constant
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, H_{max} — Height
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.

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 – Alphabetical List

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
PwrInf o	PwrTrnsfrd — Power transferred between blocks	PwrR	P_{TR}	$P_{TR} = T_R \omega$
	<ul style="list-style-type: none"> Positive signals indicate flow into block Negative signals indicate flow out of block 	Pwrc	P_{TC}	$P_{TC} = T_C \omega$

Bus Signal			Description	Variable	Equations
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred <ul style="list-style-type: none">• Positive signals indicate an input• Negative signals indicate a loss	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">• Positive signals indicate an increase• Negative signals indicate a decrease	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
ω	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 create this port, for **Port Configuration**, select **Simulink**.

CTrq — Output torque

scalar

Load driveshaft torque, T_C , in N·m.

Dependencies

To create 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 create this port, for **Port Configuration**, select **Two-way connection**.

Inertia — Input

scalar

Rotational inertia, in kg·m².

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	ω	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 create this port, select **Output Info bus**.

Spd — Driveshaft speed

scalar

Angular driveshaft speed, ω , in rad/s.

Dependencies

To create 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 create 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
scalar

Rotational inertia, in $\text{kg}\cdot\text{m}^2$.

Dependencies

To enable this parameter, clear **Input rotational inertia**.

Torsional damping, b — Damping
scalar

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

Initial velocity, omega_o — Angular
scalar

Initial angular velocity, in rad/s .

Extended Capabilities

C/C++ Code Generation

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

See Also

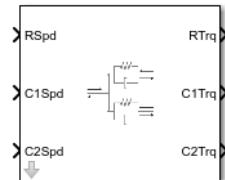
[Split Torsional Compliance](#) | [Torsional Compliance](#)

Introduced in R2017a

Split Torsional Compliance

Split torsional coupler

Library: Powertrain Blockset / Drivetrain / Couplings
Vehicle Dynamics Blockset / Powertrain / Drivetrain /
Couplings



Description

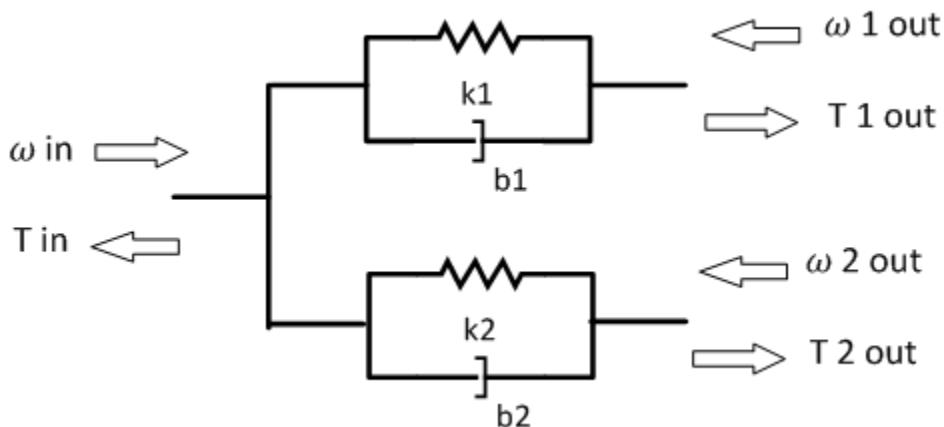
The Split Torsional Compliance block implements parallel spring-damper coupling between shafts. You can specify the type of coupling by selecting one of the **Coupling Configuration** parameters:

- **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.

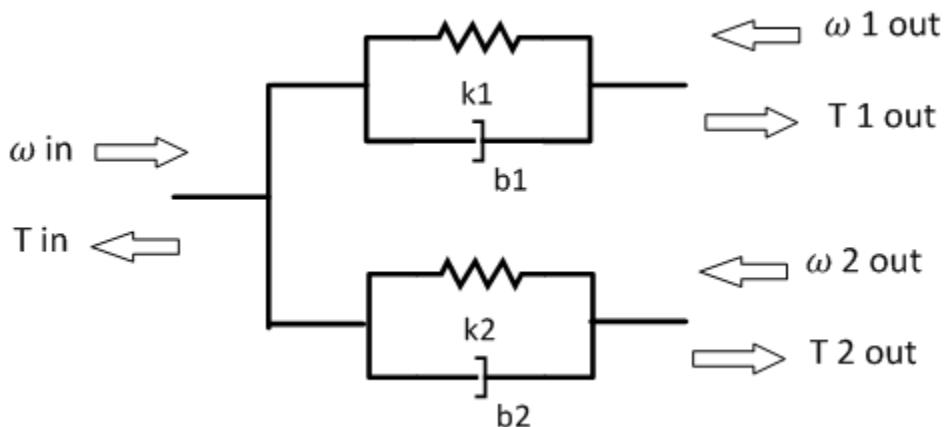
The equations use these variables.

T_{in}	Resulting applied input reaction torque
ω_{in}	Input shaft rotational velocity
T_{1out}	Resulting applied torque to first output shaft
ω_{1out}	First output shaft rotational velocity
T_{2out}	Resulting applied torque to second output shaft
ω_{2out}	Second output shaft rotational velocity
θ_1, θ_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.



$$T_{out} = (-\omega_{out} + \omega_{1in})b_1 + (-\omega_{out} + \omega_{2in})b_2 + \theta_1k_1 + \theta_2k_2$$

$$T_{1out} = (\omega_{out} - \omega_{1in})b_1 - \theta_1k_1$$

$$T_{2out} = (\omega_{out} - \omega_{2in})b_2 - \theta_2k_2$$

$$\dot{\theta}_1 = (\omega_{1in} - \omega_{out})$$

$$\dot{\theta}_2 = (\omega_{2in} - \omega_{out})$$

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

ω_{out} Output shaft rotational velocity

T_{1in} Resulting reaction torque to first input shaft

ω_{1in} First input shaft rotational velocity

T_{2in}	Resulting reaction torque to second input shaft
ω_{2in}	Second input shaft rotational velocity
θ_1, θ_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	PwrR	P_{TR}	$P_{TR} = -T_R\omega_R$
	<ul style="list-style-type: none"> Positive signals indicate flow into block Negative signals indicate flow out of block 	PwrC1	P_{TC1}	$P_{TC1} = -T_{C1}\omega_{C1}$
		PwrC2	P_{TC2}	$P_{TC2} = -T_{C2}\omega_{C2}$

Bus Signal		Description	Variable	Equations
	PwrC	For the Shaft merge configuration, mechanical power from output shaft	P_{TC}	$P_{TC} = T_C \omega_C$
	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"> Positive signals indicate an input Negative signals indicate a loss 	PwrDampLoss	Mechanical damping loss	P_d	$P_d = - (b_1 \dot{\theta}_1 ^2 + b_2 \dot{\theta}_2 ^2)$

Bus Signal		Description	Variable	Equations
PwrStored — Stored energy rate of change <ul style="list-style-type: none">• Positive signals indicate an increase• Negative signals indicate a decrease	PwrStoredShft	Rate change in spring energy	P_s	$P_s = (k_1\theta_1\dot{\theta}_1 + k_2\theta_2\dot{\theta}_2)$

The equations use these variables.

T_R	Shaft R torque
T_C	Shaft C torque
ω_R	Shaft R angular velocity
ω_C	Shaft C angular velocity
θ	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, ω_{in} , in rad/s.

Dependencies

To create 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, ω_{1out} , in rad/s.

Dependencies

To create 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, ω_{2out} , in rad/s.

Dependencies

To create this port, set both of these parameters:

- **Port Configuration** to Simulink
- **Coupling Configuration** to Shaft split

CSpd — Input speed

scalar

Output shaft rotational velocity, ω_{out} , in rad/s.

Dependencies

To create 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, ω_{1in} , in rad/s.

Dependencies

To create 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, ω_{2in} , in rad/s.

Dependencies

To create 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, ω_{in} , in rad/s and torque, T_{in} , in N·m.

Dependencies

To create 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, ω_{1in} , in rad/s and torque, T_{1in} , in N·m.

Dependencies

To create 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, ω_{2in} , in rad/s and torque, T_{2in} , in N·m.

Dependencies

To create 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		ω_{in}	rad/s
	C1	First output shaft angular velocity		ω_{1out}	rad/s

Signal		Description		Variable	Units
	C2	Second output shaft angular velocity		ω_{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
	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

Signal			Description	Variable	Units
Spd	C		Output shaft angular velocity	ω_{out}	rad/s
	R1		First input shaft angular velocity	ω_{1in}	rad/s
	R2		Second input shaft angular velocity	ω_{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 create this port, select **Output Info bus**.

RTrq — Input shaft torque
scalar

Input shaft torque, T_{in} , in N·m.

Dependencies

To create 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 create 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 create 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 create 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 create 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 create 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, ω_{1out} , in rad/s and torque, T_{1out} , in N·m.

Dependencies

To create 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, ω_{2out} , in rad/s and torque, T_{2out} , in N·m.

Dependencies

To create 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, ω_{out} , in rad/s and torque, T_{out} , in N·m.

Dependencies

To create 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**

scalar

Rotational inertia, k_1 , in N·m/rad.

Torsional damping, b1 — Damping

scalar

Torsional damping, b_1 , in N·m· s/rad.

Damping cutoff frequency, omega1_c — Frequency
scalar

Damping cutoff frequency, in rad/s.

Coupling 2

Torsional stiffness, k2 — Stiffness
scalar

Rotational inertia, k_2 , in N·m/rad.

Torsional damping, b2 — Damping
scalar

Torsional damping, b_2 , in N·m· s/rad.

Damping cutoff frequency, omega2_c — Frequency
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

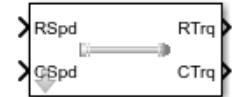
Introduced in R2017b

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	P_{TR}	$P_{TR} = T_R \omega_R$
	<ul style="list-style-type: none"> Positive signals indicate flow into block Negative signals indicate flow out of block 	PwrC	P_{TC}	$P_{TC} = T_c \omega_c$

Bus Signal		Description	Variable	Equation
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred <ul style="list-style-type: none"> Positive signals indicate an input Negative signals indicate a loss 	PwrDampLoss	P_d	$P_d = -b \dot{\theta} ^2$
	PwrStored — Stored energy rate of change <ul style="list-style-type: none"> Positive signals indicate an increase Negative signals indicate a decrease 	PwrStoredShft	P_s	$P_s = -\theta k \dot{\theta}$

The equations use these variables.

T_R	Driveshaft R torque
T_C	Driveshaft C torque
ω_R	Driveshaft R angular velocity
ω_C	Driveshaft C angular velocity
θ	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 create this port, for **Port Configuration**, select Simulink.

CSpd — Driveshaft C angular velocity
scalar

Output driveshaft angular velocity, in rad/s.

Dependencies

To create 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 create 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	Input driveshaft torque	T_R	N·m

Signal		Description		Variable	Units
	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	ω_R	rad/s	
	C	Output driveshaft angular velocity	ω_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 create this port, select **Output Info bus**.

RTrq — Driveshaft R torque
scalar

Input drive shaft torque, in N·m.

Dependencies

To create this port, for **Port Configuration**, select Simulink.

CTrq — Driveshaft C torque
scalar

Applied output driveshaft torque, in N·m.

Dependencies

To create 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 create 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
scalar

Torsional stiffness, in N·m/rad.

Torsional damping, b — Damping
scalar

Torsional damping, in N·m· s/rad.

Initial deflection, theta_o — Angular
scalar

Initial deflection, in rad.

Initial velocity difference, domega_o — Angular
scalar

Initial velocity difference, in rad/s.

Damping cut-off frequency, omega_c — Frequency
scalar

Damping cut-off frequency, in rad/s.

Extended Capabilities

C/C++ Code Generation

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

See Also

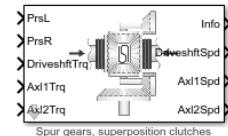
Rotational Inertia | Split Torsional Compliance

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 transmission 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

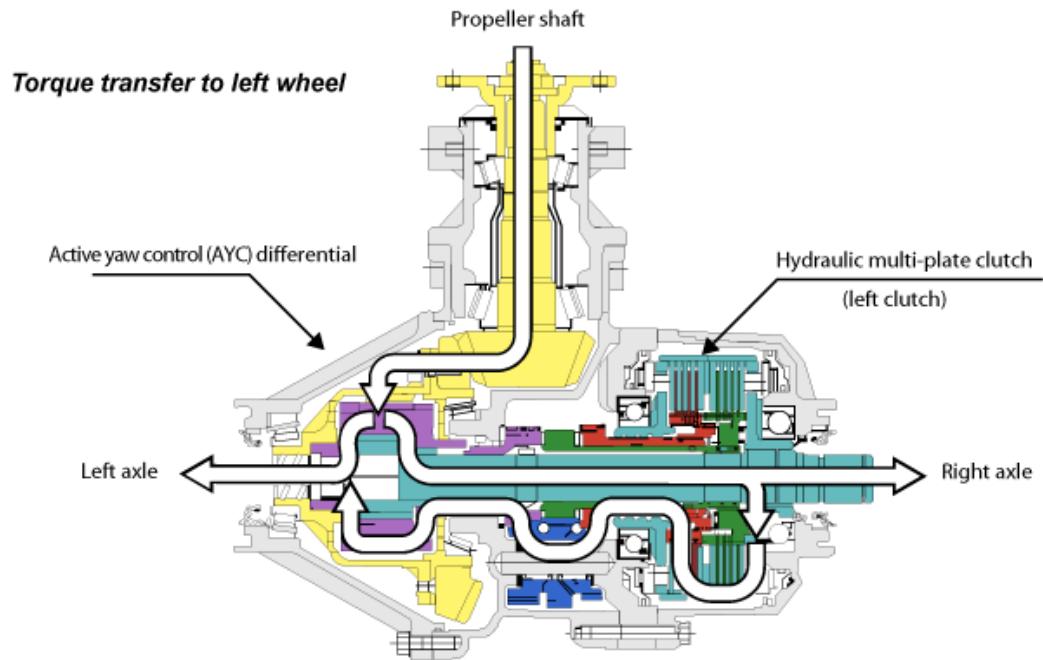
The Active Differential block implements these equations to represent the mechanical dynamic response for the superposition and stationary clutch configurations. To determine the gear ratios, the block uses the clutch speed and the number of teeth for each gear pair. The allowable wheel speed difference (AWS) limits the wheel speed difference for positive torque.

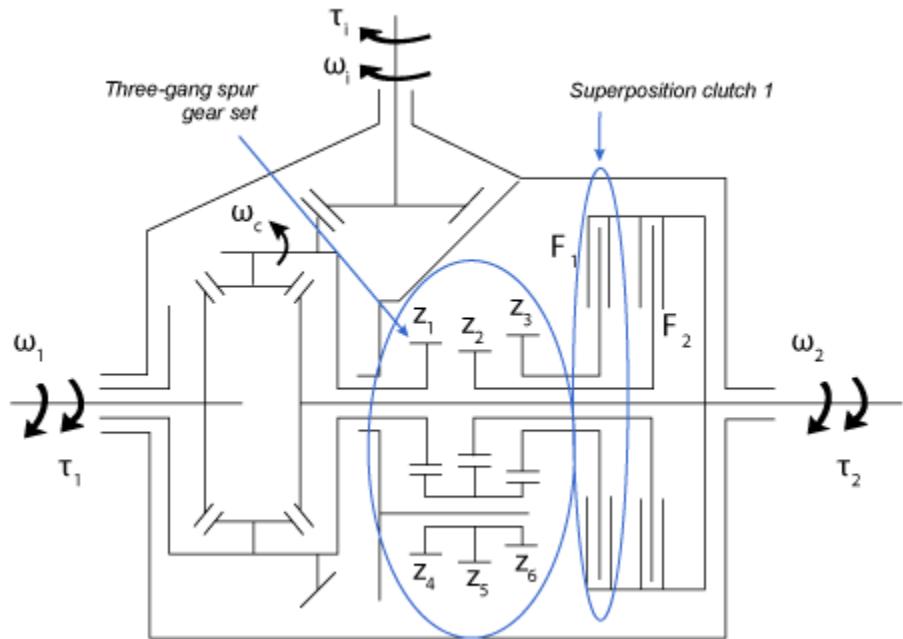
Mechanical Dynamic Response	Equations	
	Superposition Clutches and Spur Gearing	Stationary Clutches and Planetary Gearing
Crown gear	$\dot{\omega}_d(J_d + J_{gs}) = T_d - \omega_d b_d - T_i$	$\dot{\omega}_d(J_d + J_{s1} + J_{s2}) = T_d - \omega_d b_d - T_i$
Axle 1	$\dot{\omega}_1 J_1 = \eta T_1 - \omega_1 b_1 - T_{i1}$	$\dot{\omega}_1 (J_1 + J_{r1}) = T_1 - \omega_1 b_1 - T_{i1}$

Mechanical Dynamic Response	Equations	
	Superposition Clutches and Spur Gearing	Stationary Clutches and Planetary Gearing
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	$T_1 = \frac{NT_i}{2} - \frac{N_{s2}}{2} T_{cl2} + \frac{N_{s1}}{2} T_{cl1}$ $T_2 = \frac{NT_i}{2} + (1 - \frac{N_{s2}}{2}) T_{cl2} - (1 - \frac{N_{s1}}{2T_2}) T_{cl1}$ $\omega_d = \frac{N}{2}(\omega_1 + \omega_2)$	$T_1 = \frac{NT_i}{2} - \frac{N_{p2}}{(N_{p2} - 1)2} T_{cl2} + \frac{(2 - N_{p1})}{(N_{p1} - 1)2} T_{cl1}$ $T_2 = \frac{NT_i}{2} + \frac{(2 - N_{p2})}{(N_{p2} - 1)2} T_{cl2} - \frac{N_{p1}}{(N_{p1} - 1)2} T_{cl1}$ $\omega_d = \frac{N}{2}(\omega_1 + \omega_2)$
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

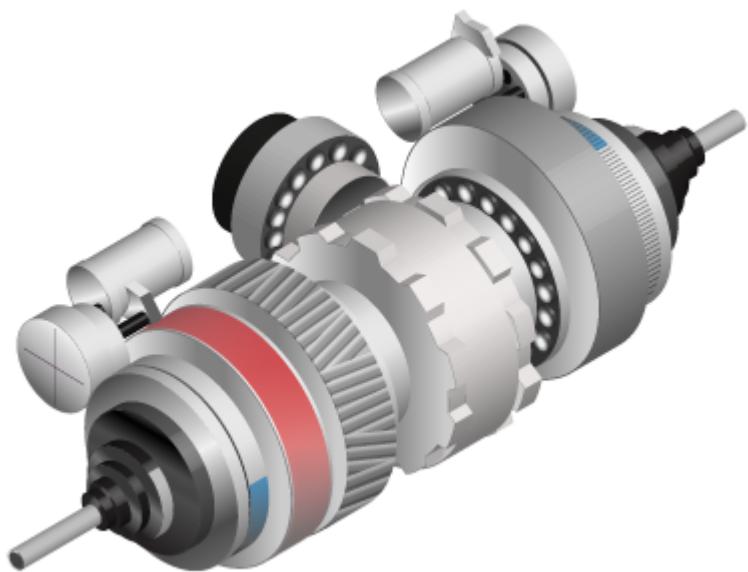
These superposition clutch illustrations show the clutch configuration and schematic for torque transfer to the left wheel.

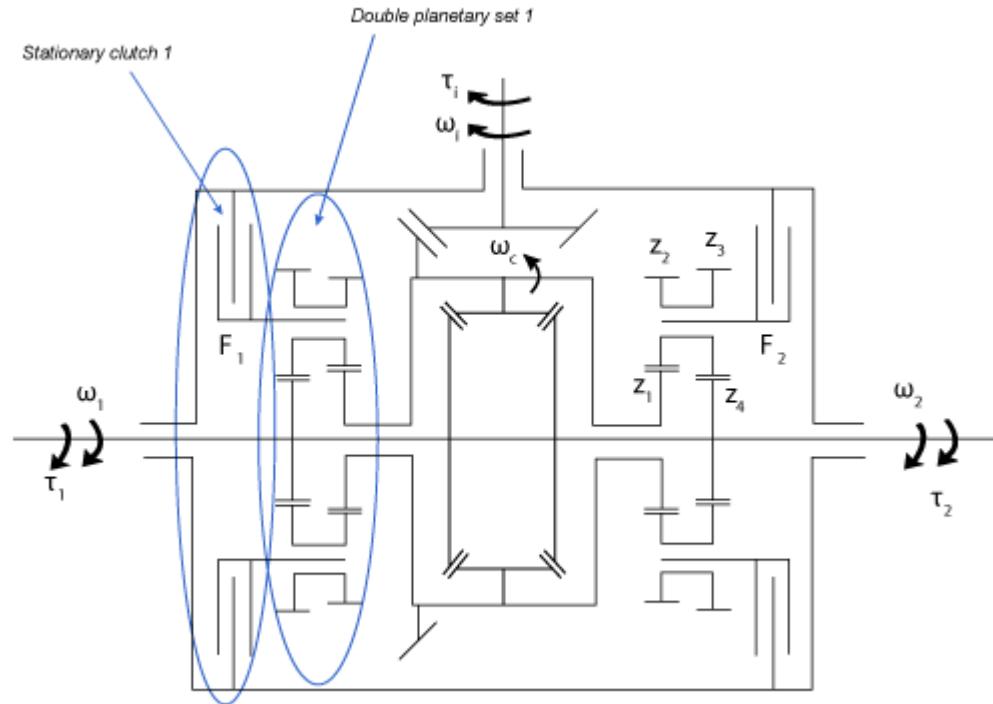




Stationary Clutches and Planetary Gearing

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.

$$\varpi = [\Delta\omega_{c1}, \Delta\omega_{c2}]$$

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.

$$T_C = T_C(\omega, \quad P_{1,2})$$

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
ω_d	Driveshaft angular velocity
ϖ	Slip speed
ω_1, ω_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
μ	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.

DriveshftTrq — 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, ω_d , in rad/s.

Ax1Spd — Angular velocity

scalar

Axe 1 angular velocity, ω_1 , in rad/s.**Ax2Spd — Angular velocity**

scalar

Axe 2 angular velocity, ω_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, Ns1 — Clutch 1-spur gear ratio

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, Ns2 — Clutch 2-spur gear ratio**

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.

Axle 1 three-gang gear inertia, J_{gc} — Rotational inertia 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 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 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 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
scalar

Planetary 1 ring gear inertia, J_{r1} , kg·m².

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

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

scalar

Planetary 2 sun gear inertia, J_{s2} , in kg·m².

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

scalar

Planetary 2 carrier inertia, J_{c2} , in kg·m².

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

scalar

Planetary 2 ring gear inertia, J_{r2} , in kg·m².

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

scalar

Carrier-to-drive shaft gear ratio, N .

Carrier inertia, Jd — Inertia

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

scalar

Crown gear linear viscous damping, b_d , in $\text{N}\cdot\text{m}\cdot\text{s}/\text{rad}$.

Axle 1 inertia, Jw1 — Inertia

scalar

Axle 1 rotational inertia, J_1 , in $\text{kg}\cdot\text{m}^2$.

Axle 1 damping, bw1 — Damping

scalar

Axle 1 linear viscous damping, b_1 , in $\text{N}\cdot\text{m}\cdot\text{s}/\text{rad}$.

Axle 2 inertia, Jw2 — Inertia

scalar

Axle 2 rotational inertia, J_2 , in $\text{kg}\cdot\text{m}^2$.

Axle 2 damping, bw2 — Damping scalar

Axle 2 linear viscous damping, b_2 , in N·m·s/rad.

Axle 1 initial velocity, omegaw1o — Angular velocity scalar

Axle 1 initial velocity, ω_{o1} , in rad/s.

Axle 2 initial velocity, omegaw2o — Angular velocity scalar

Axle 2 initial velocity, ω_{o2} , in rad/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
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 scalar

Effective applied pressure area, in N/m².

Dependencies

To enable the clutch parameters, select Ideal pre-loaded clutch for the **Coupling type** parameter.

Number of disks, Ndisks — Torque coupling scalar

Number of disks.

Dependencies

To enable the clutch parameters, select **Ideal pre-loaded clutch** for the **Coupling type** parameter.

Effective radius, R_{eff} — Radius 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, F_c — Force 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 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 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 array

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 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 vector

Slip speed breakpoints vector, ω , in rad/s.

Dependencies

To enable the slip speed parameters, select **Slip speed dependent torque data** for the **Coupling type** parameter.

Coupling time constant, tauC — Constant 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

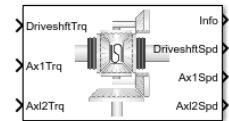
[Limited Slip Differential](#) | [Open Differential](#)

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:

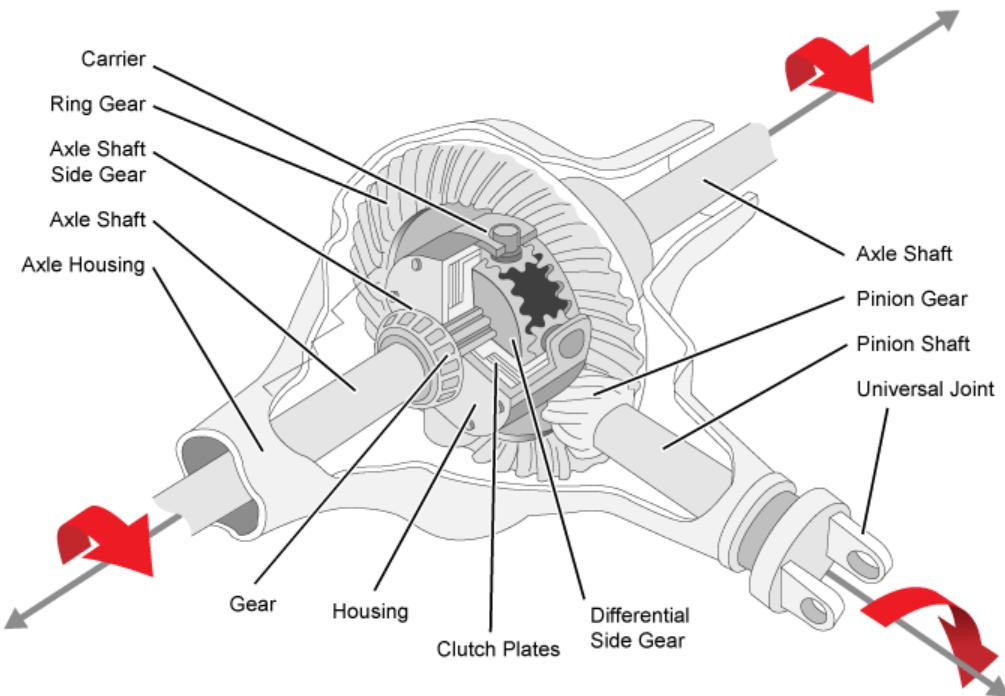
- Carrier-to-driveshaft ratio
- Crown wheel location
- Viscous and damping coefficients for the axles and carrier
- Type of slip coupling

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 Constant efficiency factor, eta parameter.

Setting	Implementation
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"> • Efficiency lookup table, eta_tbl • Efficiency torque breakpoints, Trq_bpts • Efficiency speed breakpoints, omega_bpts • Efficiency temperature breakpoints, Temp_bpts <p>For the air temperature, you can either:</p> <ul style="list-style-type: none"> • Select Input temperature to create an input port. • Set a Ambient temperature, Tamb parameter value. <p>To select the interpolation method, use the Interpolation method parameter. For more information, see “Interpolation Methods” (Simulink).</p>

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal		Description	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks	PwrDriveshaft	Mechanical power from driveshaft $\eta T_d \omega_d$
	<ul style="list-style-type: none"> • Positive signals indicate flow into block • Negative signals indicate flow out of block 	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	PwrMechLoss	Total power loss $\dot{W}_{loss} = - (P_t + P_d + P_c) + P_s$ $P_t = \eta(T_d \omega_d + T_1 \omega_1 + T_2 \omega_2)$

Bus Signal			Description	Equations
	block boundary, but not transferred	PwrDampLoss	Power loss due to damping	$P_d = -(b_1 \omega_1 + b_2 \omega_2 + b_d \omega_d)$
	<ul style="list-style-type: none"> Positive signals indicate an input Negative signals indicate a loss 	PwrCplngLoss	Power loss due to clutch	$P_c = T_c \bar{\omega} $
	PwrStored — Stored energy rate of change	PwrStoredShft	Rate change of stored internal energy	$P_s = -(\omega_1\dot{\omega}_1J_1 + \omega_2\dot{\omega}_2J_2 + \omega_d\dot{\omega}_dJ_d)$

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	$\dot{\omega}_dJ_d = \eta T_d - \omega_d b_d - T_i$
Left Axle	$\dot{\omega}_1J_1 = \eta T_1 - \omega_1 b_1 - T_{i1}$
Right Axle	$\dot{\omega}_2J_2 = \eta T_2 - \omega_2 b_2 - T_{i2}$

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
ω_d	Driveshaft angular speed
ϖ	Slip speed
J_1	Axle 1 rotational inertia
b_1	Axle 1 linear viscous damping
ω_1	Axle 1 speed
J_2	Axle 2 rotational inertia
b_2	Axle 2 linear viscous damping
ω_2	Axle 2 angular speed
η	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
μ	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
μ	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

DriveshftTrq — Torque

scalar

Applied input torque, typically from the engine crankshaft, in N·m.

Axle1Trq — Torque

scalar

Axle 1 torque, T_1 , in N·m.

Axle2Trq — Torque

scalar

Axle 2 torque, T_2 , in N·m.

Temp — Temperature

scalar

Temperature, in K.

Dependencies

To create 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	N·m

Signal		Description		Units
	DriveshftSpd	Driveshaft speed		rad/s
Axl1	Axl1Trq	Axe 1 torque		N·m
	Axl1Spd	Axe 1 speed		rad/s
Axl2	Axl2Trq	Axe 2 torque		N·m
	Axl2Spd	Axe 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
	PwrStoragedShft	PwrStoragedShft	Rate change of stored internal energy	W

DriveshftSpd — Angular speed

scalar

Driveshaft angular speed, ω_d , in rad/s.

Axl1Spd — Angular speed

scalar

Axe 1 angular speed, ω_1 , in rad/s.

Axl2Spd — Angular speed

scalar

Axe 2 angular speed, ω_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 Constant efficiency factor, eta 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"> • Efficiency lookup table, eta_tbl • Efficiency torque breakpoints, Trq_bpts • Efficiency speed breakpoints, omega_bpts • Efficiency temperature breakpoints, Temp_bpts <p>For the air temperature, you can either:</p> <ul style="list-style-type: none"> • Select Input temperature to create an input port. • Set a Ambient temperature, Tamb parameter value. <p>To select the interpolation method, use the Interpolation method parameter. For more information, see “Interpolation Methods” (Simulink).</p>

Interpolation method — Method

Flat (default) | Nearest | Linear point-slope | Linear Lagrange | Cubic spline

For more information, see “Interpolation Methods” (Simulink).

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

scalar

Carrier-to-driveshaft gear ratio, N .

Carrier inertia, J_d — Inertia

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, b_d — Damping

scalar

Crown gear linear viscous damping, b_d , in $\text{N}\cdot\text{m}\cdot\text{s}/\text{rad}$.

Axle 1 inertia, J_w1 — Inertia

scalar

Axle 1 rotational inertia, J_1 , in $\text{kg}\cdot\text{m}^2$.

Axle 1 damping, bw1 — Damping
scalar

Axle 1 linear viscous damping, b_1 , in N·m·s/rad.

Axle 2 inertia, Jw2 — Inertia
scalar

Axle 2 rotational inertia, J_2 , in kg·m².

Axle 2 damping, bw2 — Damping
scalar

Axle 2 linear viscous damping, b_2 , in N·m·s/rad.

Axle 1 initial velocity, omegaw1o — Angular velocity
scalar

Axle 1 initial velocity, ω_{o1} , in rad/s.

Axle 2 initial velocity, omegaw2o — Angular velocity
scalar

Axle 2 initial velocity, ω_{o2} , in rad/s.

Constant efficiency factor, eta — Efficiency
1 (default)

Constant efficiency, η .

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
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
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
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
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

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

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, F_c — Force 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, μ — Friction vector

Friction coefficient vector.

Dependencies

To enable the clutch parameters, select Pre-loaded ideal clutch for the **Coupling type** parameter.

Slip speed vector, d_w — Angular velocity 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 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_w^T — Angular velocity 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, TTin — Torque 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, Tin — Torque 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, tauC — Constant 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

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See Also

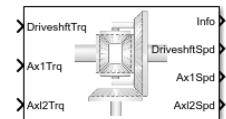
Open Differential

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:

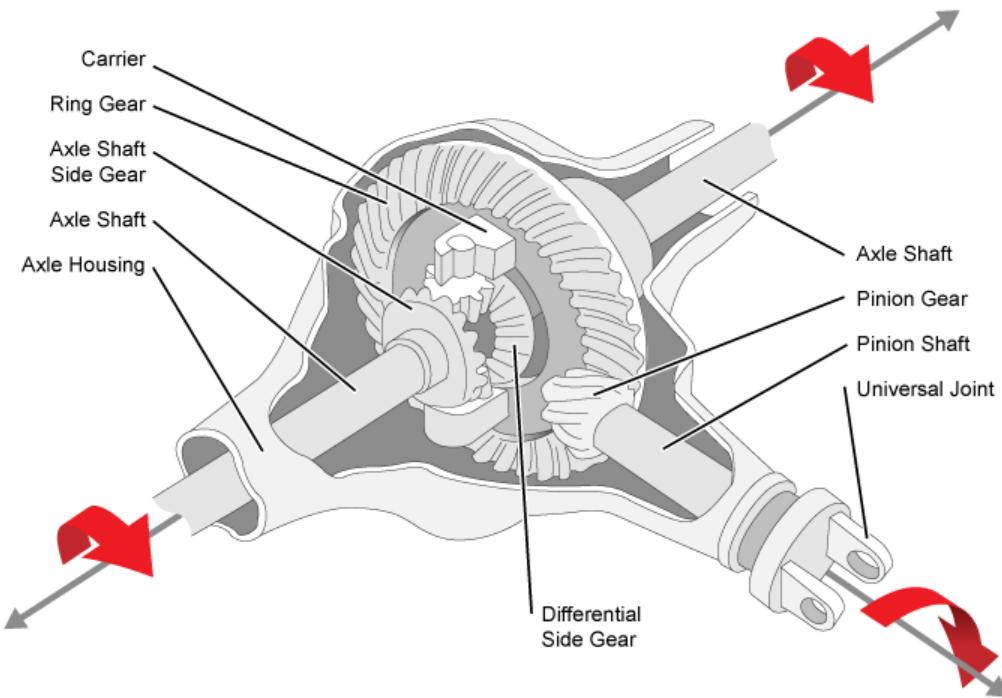
- Carrier-to-driveshaft ratio
- Crown wheel location
- Viscous and damping coefficients for the axles and carrier

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 Constant efficiency factor, eta parameter.

Setting	Implementation
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"> • Efficiency lookup table, eta_tbl • Efficiency torque breakpoints, Trq_bpts • Efficiency speed breakpoints, omega_bpts • Efficiency temperature breakpoints, Temp_bpts <p>For the air temperature, you can either:</p> <ul style="list-style-type: none"> • Select Input temperature to create an input port. • Set a Ambient temperature, Tamb parameter value. <p>To select the interpolation method, use the Interpolation method parameter. For more information, see “Interpolation Methods” (Simulink).</p>

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"> • Positive signals indicate flow into block • Negative signals indicate flow out of block 	PwrDriveshft	Mechanical power from driveshaft	$\eta T_d \omega_d$
	PwrAxl1	Mechanical power from axle 1	$\eta T_1 \omega_1$	
	PwrAxl2	Mechanical power from axle 2	$\eta T_2 \omega_2$	

Bus Signal	Description	Equations
PwrNotTrnsfrd — Power crossing the block boundary, but not transferred <ul style="list-style-type: none"> Positive signals indicate an input Negative signals indicate a loss 	PwrMechLoss	Total power loss $\dot{W}_{loss} = -(P_t + P_d) + P_s$ $P_t = \eta T_d \omega_d + \eta T_1 \omega_1 + \eta T_2 \omega_2$
	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"> Positive signals indicate an increase Negative signals indicate a decrease 	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
ω_d	Driveshaft angular speed
η	Differential efficiency
J_1	Axle 1 rotational inertia
b_1	Axle 1 linear viscous damping
ω_1	Axle 1 speed
J_2	Axle 2 rotational inertia
b_2	Axle 2 linear viscous damping
ω_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

DriveshftTrq — Torque

scalar

Applied input torque, typically from the engine crankshaft, in N·m.

Axle1Trq — 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 create 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
		PwrAxl1	Mechanical power from axle 1

Signal				Description	Units
PwrTrnsfrd		PwrAxl2	Mechanical power from axle 2	W	
	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, ω_d , in rad/s.**Ax1Spd — Angular speed**

scalar

Axe 1 angular speed, ω_1 , in rad/s.**AxL2Spd — Angular speed**

scalar

Axe 2 angular speed, ω_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 Constant efficiency factor, eta parameter.

Setting	Implementation
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">• Efficiency lookup table, eta_tbl• Efficiency torque breakpoints, Trq_bpts• Efficiency speed breakpoints, omega_bpts• Efficiency temperature breakpoints, Temp_bpts <p>For the air temperature, you can either:</p> <ul style="list-style-type: none">• Select Input temperature to create an input port.• Set a Ambient temperature, Tamb parameter value. <p>To select the interpolation method, use the Interpolation method parameter. For more information, see “Interpolation Methods” (Simulink).</p>

Interpolation method — Method

Flat (default) | Nearest | Linear point-slope | Linear Lagrange | Cubic spline

For more information, see “Interpolation Methods” (Simulink).

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, Ndif — Ratio
scalar

Carrier-to-driveshaft gear ratio, N , dimensionless.

Carrier inertia, Jd — Inertia
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
scalar

Crown gear linear viscous damping, b_d , in $\text{N}\cdot\text{m}\cdot\text{s}/\text{rad}$.

Axle 1 inertia, Jw1 — Inertia
scalar

Axle 1 rotational inertia, J_1 , in $\text{kg}\cdot\text{m}^2$.

Axle 1 damping, bw1 — Damping
scalar

Axle 1 linear viscous damping, b_1 , in $\text{N}\cdot\text{m}\cdot\text{s}/\text{rad}$.

Axle 2 inertia, Jw2 — Inertia
scalar

Axle 2 rotational inertia, J_2 , in $\text{kg}\cdot\text{m}^2$.

Axle 2 damping, bw2 — Damping
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
scalar

Axle 1 initial velocity, ω_{o1} , in rad/s.

Axle 2 initial velocity, ω_{o2} — Angular velocity scalar

Axle 2 initial velocity, ω_{o2} , in rad/s.

Efficiency

Constant efficiency factor, η — Efficiency

1 (default)

Constant efficiency, η .

Dependencies

To enable this parameter, set **Efficiency factors** to Constant.

Efficiency lookup table, η_{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, T_{bpts} — Torque breakpoints

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
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

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
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

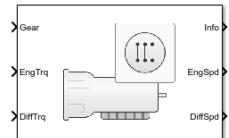
Limited Slip Differential

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"> • Gear • Input torque • Input speed • Oil temperature

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.

$$\dot{\omega}_{neutral} \frac{J_N}{N^2} = \eta_N \frac{T_o}{N} - \frac{\omega_{neutral}}{N^2} b_N$$

$$\omega_{neutral} = N\omega_o$$

$$\dot{\omega}_1 J_F = \eta_{@N=0} T_i - b_{@N=0} \omega_i$$

$$J_F = J_{@N=1} - J_{@N=0} = 0$$

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Variable	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks	PwrEng	Engine power	P_{eng}	$\omega_i T_i$
	<ul style="list-style-type: none"> Positive signals indicate flow into block Negative signals indicate flow out of block 	PwrDiffRntl	Differential power	P_{diff}	$\omega_o T_o$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred	PwrEffLoss	Mechanical power loss	$P_{effloss}$	$\omega_o T_o (\eta_N - 1)$

Bus Signal		Description	Variable	Equations
	<ul style="list-style-type: none"> Positive signals indicate an input Negative signals indicate a loss 	PwrDampLoss	P_{damp_loss}	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 <ul style="list-style-type: none"> Positive signals indicate an increase Negative signals indicate a decrease 	PwrStoredTrans	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
η_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
ω_0	Initial input drive shaft rotational velocity
$\omega_i, \dot{\omega}_i$	Applied drive shaft angular speed and acceleration
ω_{No}	Initial neutral gear input rotational velocity
$\omega_{neutral}$	Neutral gear drive shaft rotational velocity
τ_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 create 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	ω_i	rad/s
Diff	DiffTrq		Applied load torque, typically from the differential	T_o	N·m
	DiffSpd		Drive shaft angular speed output	ω_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	η_N	N/A
	TransGearCmd		Commanded gear	N_{cmd}	N/A
	TransGear		Engaged gear	N	N/A
PwrInfo	PwrTrnsfrd	PwrEng	Engine power	P_{eng}	W
		PwrDiffRndl	Differential power	P_{diff}	W

Signal			Description	Variable	Units
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, ω_i , in rad/s.

DiffSpd — Angular speed

scalar

Drive shaft angular speed output, ω_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.

Setting	Block Implementation
Gear, input torque, input speed, and temperature	<p>Efficiency determined from a 4D lookup table that is a function of:</p> <ul style="list-style-type: none"> • Gear • Input torque • Input speed • Oil temperature

Dependencies

Setting Parameter To	Enables
Gear only	Efficiency vector, eta
Gear, input torque, input speed, and temperature	Efficiency torque breakpoints, Trq_bpts Efficiency speed breakpoints, omega_bpts Efficiency temperature breakpoints, Temp_bpts Efficiency lookup table, eta_tbl

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 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]

To Specify	Set Gear number, G To
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 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 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 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 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 vector

Vector of gear rotational inertias, J_N , with indices corresponding to the inertias specified in **Gear number, G**, in kg*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 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 vector

Vector of gear mechanical efficiency, η_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, η_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 scalar

Initial gear number, G_o , dimensionless.

Initial input velocity, omega_o — Input speed scalar

Transmission initial input rotational velocity, ω_o , in rad/s.

Initial neutral input velocity, omegainN_o — Neutral gear input speed scalar

Initial neutral gear input rotational velocity, ω_{No} , in rad/s.

Shift time constant, tau_s — Time scalar

Shift time constant, τ_s , in s.

Extended Capabilities

C/C++ Code Generation

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

See Also

Limited Slip Differential | Open Differential

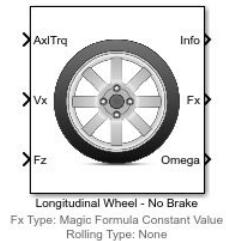
Introduced in R2017a

Drivetrain Blocks – Alphabetical List

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.

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.

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.

Setting	Block Implementation
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, $M_y = R_e \{a + b V_x + cV_x^2\} \{F_z \beta p_i^\alpha\} \tanh(4V_x)$
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	$T_f = T_k$ <p>where,</p> $T_k = F_c R_{eff} \mu_k \tanh[4(-\omega_d)]$ $T_s = F_c R_{eff} \mu_s$ $R_{eff} = \frac{2(R_o^3 - R_i^3)}{3(R_o^2 - R_i^2)}$	$\dot{\omega} J = -\omega b + T_i + T_o$
$\omega = 0$ and $T_S \geq T_i + T_f - \omega b $	Locked	$T_f = T_s$	$\omega = 0$

The equations use these variables.

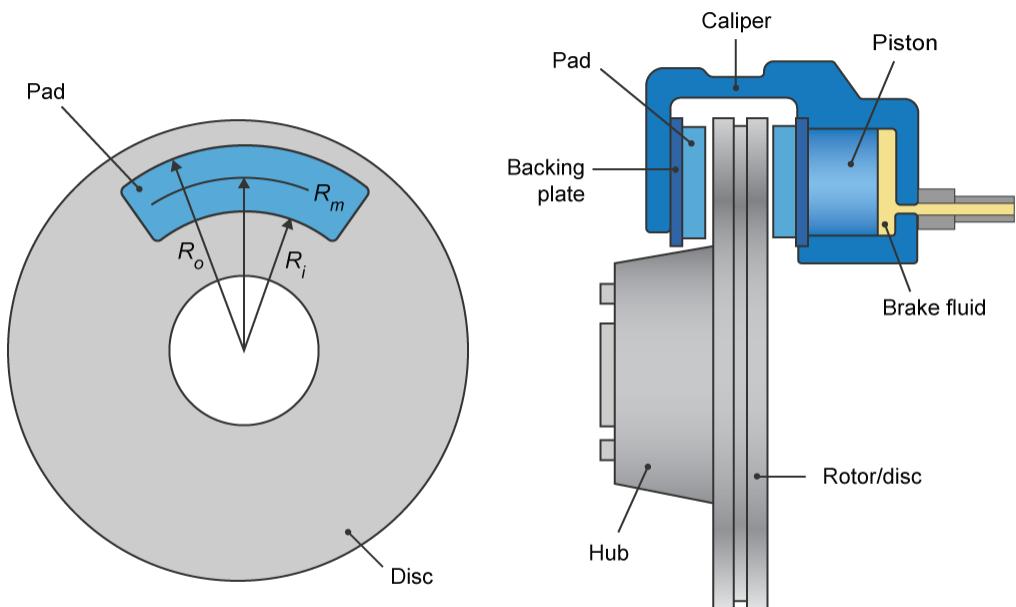
ω	Wheel angular velocity
a	Velocity-independent force component
b	Linear velocity force component
c	Quadratic velocity force component
L_e	Tire relaxation length
J	Moment of inertia
M_y	Rolling resistance torque
T_a	Applied axle torque
T_b	Braking torque
T_d	Combined tire torque
T_f	Frictional torque
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

α	Tire pressure exponent
β	Normal force exponent
p_i	Tire pressure
μ_s	Coefficient of static friction
μ_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
μ_{static}	Disc pad-rotor coefficient of static friction
μ	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.

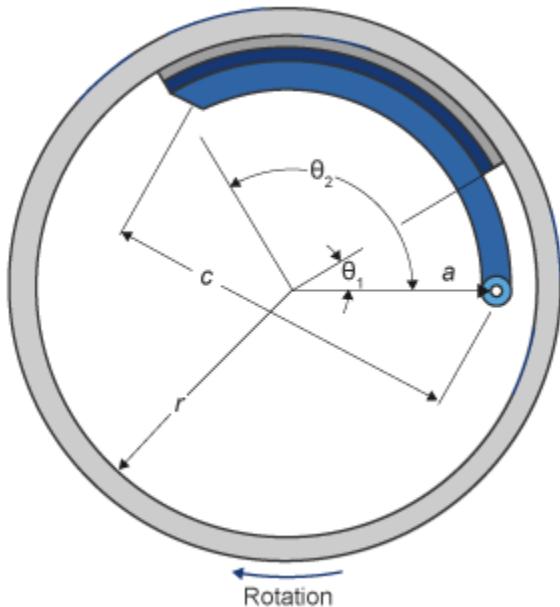
The simplex drum brake model uses the applied force and brake geometry to calculate a net torque for each brake shoe. The drum model assumes that the actuators and shoe geometry are symmetrical for both sides, allowing a single set of geometry and friction parameters to be used for both shoes.

The block implements equations that are derived from these equations in *Fundamentals of Machine Elements*.

$$T_{rshoe} = \left(\frac{\pi \mu c r (\cos \theta_2 - \cos \theta_1) B_d^2}{2\mu(2r(\cos \theta_2 - \cos \theta_1) + a(\cos^2 \theta_2 - \cos^2 \theta_1)) + ar(2\theta_1 - 2\theta_2 + \sin 2\theta_2 - \sin 2\theta_1)} \right) P$$

$$T_{lshoe} = \left(\frac{\pi \mu c r (\cos \theta_2 - \cos \theta_1) B_d^2}{-2\mu(2r(\cos \theta_2 - \cos \theta_1) + a(\cos^2 \theta_2 - \cos^2 \theta_1)) + ar(2\theta_1 - 2\theta_2 + \sin 2\theta_2 - \sin 2\theta_1)} \right) P$$

$$T = \begin{cases} T_{rshoe} + T_{lshoe} & \text{when } N \neq 0 \\ (T_{rshoe} + T_{lshoe}) \frac{\mu_{static}}{\mu} & \text{when } N = 0 \end{cases}$$



The equations use these variables.

T	Brake torque
P	Applied brake pressure
N	Wheel speed
μ_{static}	Disc pad-rotor coefficient of static friction
μ	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
Θ_1	Angle from shoe hinge pin center to start of brake pad material on shoe
Θ_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.

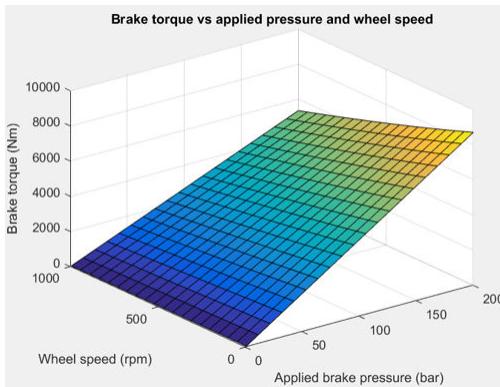
$$T = \begin{cases} f_{brake}(P, N) & \text{when } N \neq 0 \\ \left(\frac{\mu_{static}}{\mu}\right)f_{brake}(P, N) & \text{when } N = 0 \end{cases}$$

The equations use these variables.

T	Brake torque
$f_{brake}(P, N)$	Brake torque lookup table
P	Applied brake pressure
N	Wheel speed
μ_{static}	Friction coefficient of drum pad-face interface under static conditions
μ	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 κ



The Magic Formula model uses these variables.

Ω	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(C \tan^{-1}[\{B\kappa - E[B\kappa - \tan^{-1}(B\kappa)]\}\])$$

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:

$$F_{x0} = D_x \sin(C_x \tan^{-1} [\{ B_x K_x - E_x [B_x K_x - \tan^{-1}(B_x K_x)] \}]) + S_{Vx}$$

where:

$$K_x = \kappa + S_{Hx}$$

$$C_x = p_{Cx1} \lambda_{Cx}$$

$$D_x = \mu_x F_z \varsigma_1$$

$$\mu_x = (p_{Dx1} + p_{Dx2} df_z)(1 + p_{px3} dp_i + p_{px4} dp_i^2)(1 - p_{Dx3} \gamma^2) \lambda^{*}_{\mu x}$$

$$E_x = (p_{Ex1} + p_{Ex2} df_z + p_{Ex3} df_z^2)[1 - p_{Ex4} \text{sgn}(K_x)] \lambda_{Ex}$$

$$K_{xK} = F_z(p_{Kx1} + p_{Kx2} df_z) \exp(p_{Kx3} df_z)(1 + p_{px1} dp_i + p_{px2} dp_i^2)$$

$$B_x = K_{xK}/(C_x D_x + \varepsilon_x)$$

$$S_{Hx} = p_{Hx1} + p_{Hx2} df_z$$

$$S_{Vx} = F_z \cdot (p_{Vx1} + p_{Vx2} df_z) \lambda_{Vx} \lambda'_{\mu x} \varsigma_1$$

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. μ_x is the longitudinal load-dependent friction coefficient. ε_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.

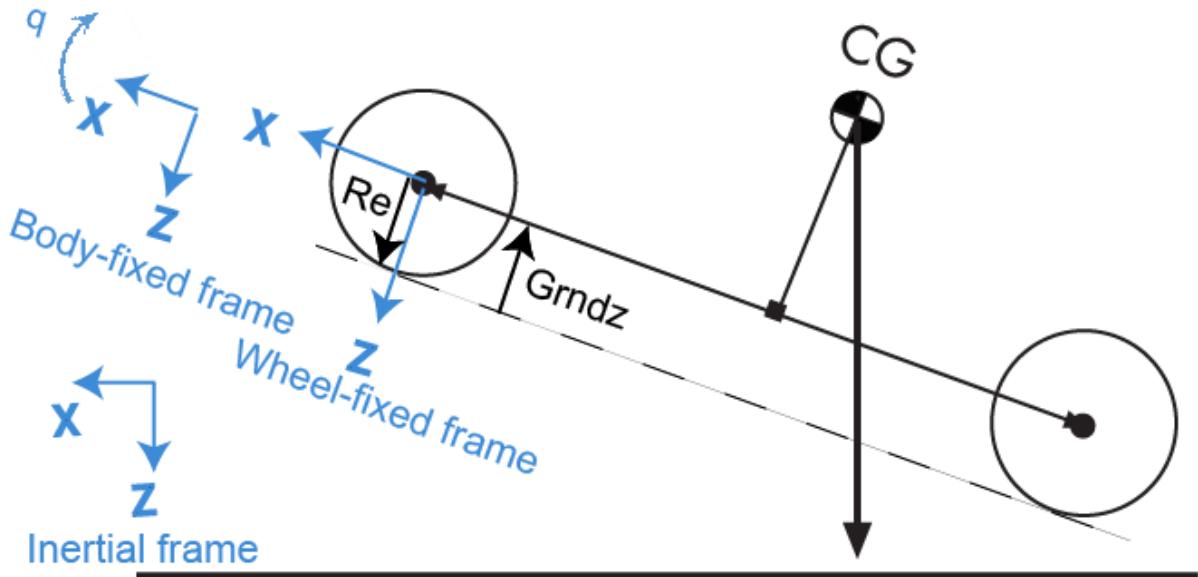
$$\ddot{z}m = F_{ztire} - F_z - mg$$

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
PwrIn fo	PwrTrnsfrd — Power transferred between blocks	PwrRoad	Tractive power applied from the axle	$P_{road} = F_x V_x$
	<ul style="list-style-type: none"> Positive signals indicate flow into block Negative signals indicate flow out of block 	PwrAxlTrq	External torque applied by the axle to the wheel	$P_T = T\omega$
		PwrFz	Vertical force applied to the wheel by the vehicle or suspension	$P_{Fz} = F_z \dot{z}$
		PwrSlip	Tractive power loss	$P_K = F_x V_x + (-F_{cp}R_e + M_y)\omega$
		PwrMyRoll	Rolling resistance power	$P_{My} = M_y \omega$
	<ul style="list-style-type: none"> Positive signals indicate an input Negative signals indicate a loss 	PwrMyBrk	Braking power	$P_{brk} = M_{brk}\omega$
		PwrMyb	Rolling viscous damping loss	$P_b = -b\omega^2$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred	PwrFzDamp	Vertical damping power	$P_{Fzb} = F_z b \dot{z}$
		PwrStored	Rate of change of vertical kinetic energy	$P_{\dot{z}} = m \ddot{z} \dot{z}$

Bus Signal	Description			Equations
<ul style="list-style-type: none"> Positive signals indicate an increase Negative signals indicate a decrease 	PwrStoredq	Rate of change of rotational kinetic energy	$P_\omega = I_{yy}\dot{\omega}\omega$	
	PwrStoredFsFzSprng	Rate of change of stored sidewall potential energy	$P_{Fzk} = F_{zk}\dot{z}_x$	
	PwrStoredGrvty	Rate of change of gravitational potential energy	$P_g = -mg\dot{Z}$	

The equations use these variables.

ω	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
ω	Wheel angular velocity
\dot{Z}	Vehicle vertical velocity along vehicle-fixed z -axis

Ports

Input

BrkPrs — Brake pressure

scalar

Brake pressure, in Pa.

Dependencies

To create 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

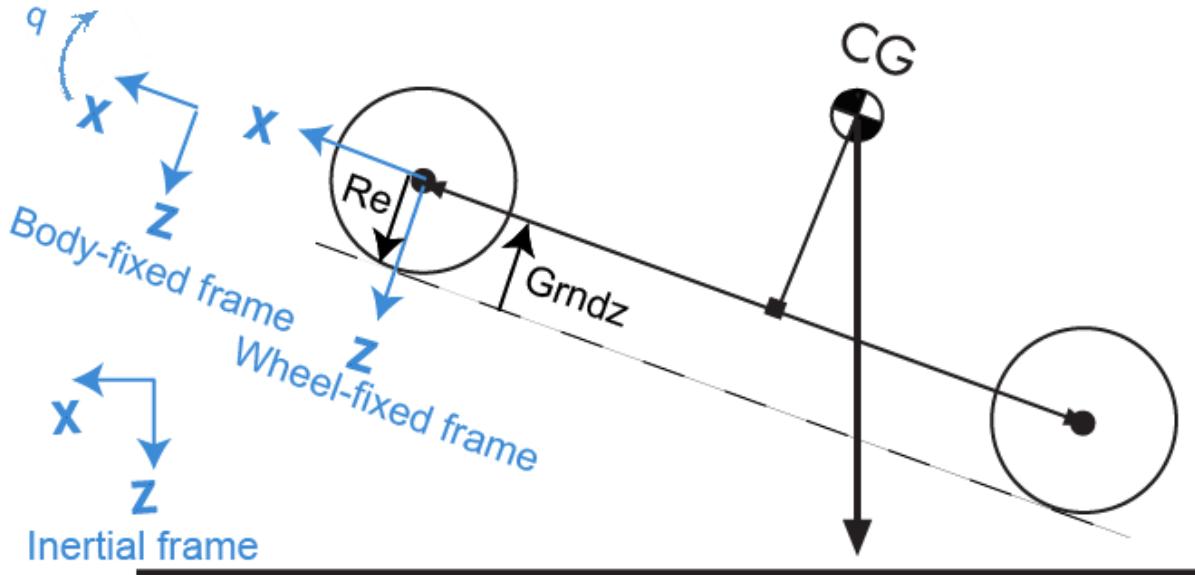
scalar

Absolute value of suspension or vehicle normal force along body-fixed z -axis, in N.

Gnd — Ground displacement

scalar

Ground displacement, $Grndz$, 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 create this port, select **Input friction scale factor**.

TirePrs — Tire pressure
scalar

Tire pressure, in Pa.

Dependencies

To create 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 create 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 ²

Signal	Description	Units
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
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 ²

Signal			Description	Units
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 create 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 create 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

Selecting	Enables These Parameters
Magic Formula constant value	Pure longitudinal peak factor, Dx Pure longitudinal shape factor, Cx Pure longitudinal stiffness factor, Bx Pure longitudinal curvature factor, Ex

Selecting	Enables These Parameters
Magic Formula pure longitudinal slip	Cfx shape factor, PCX1 Longitudinal friction at nominal normal load, PDX1 Frictional variation with load, PDX2 Frictional variation with camber, PDX3 Longitudinal curvature at nominal normal load, PEX1 Variation of curvature factor with load, PEX2 Variation of curvature factor with square of load, PEX3 Longitudinal curvature factor with slip, PEX4 Longitudinal slip stiffness at nominal normal load, PKX1 Variation of slip stiffness with load, PKX2 Slip stiffness exponent factor, PKX3 Horizontal shift in slip ratio at nominal normal load, PHX1 Variation of horizontal slip ratio with load, PHX2 Vertical shift in load at nominal normal load, PVX1 Variation of vertical shift with load, PVX2 Linear variation of longitudinal slip stiffness with tire pressure, PPX1 Quadratic variation of longitudinal slip stiffness with tire pressure, PPX2

Selecting	Enables These Parameters
	<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> <p>Longitudinal horizontal shift scaling factor, lam_Hx</p> <p>Longitudinal vertical shift scaling factor, lam_Vx</p>
Mapped force	<p>Slip ratio breakpoints, kappaFx</p> <p>Normal force breakpoints, FzFx</p> <p>Longitudinal force map, FxMap</p>

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

Setting	Block Implementation
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	Velocity independent force coefficient, aMy Linear velocity force component, bMy Quadratic velocity force component, cMy Tire pressure exponent, alphaMy Normal force exponent, betaMy
ISO 28580	Parasitic losses force, Fpl Rolling resistance constant, Cr Thermal correction factor, Kt Measured temperature, Tmeas Parasitic losses force, Fpl Ambient temperature, Tamb

Selecting	Parameters
Magic Formula	Rolling resistance torque coefficient, QSY Longitudinal force rolling resistance coefficient, QSY2 Linear rotational speed rolling resistance coefficient, QSY3 Quartic rotational speed rolling resistance coefficient, QSY4 Camber squared rolling resistance torque, QSY5 Load based camber squared rolling resistance torque, QSY6 Normal load rolling resistance coefficient, QSY7 Pressure load rolling resistance coefficient, QSY8 Rolling resistance scaling factor, lam_My
Mapped torque	Spin axis velocity breakpoints, VxMy Normal force breakpoints, FzMy Rolling resistance torque map, MyMap

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.

Block Name	Brake Type Setting	Brake Implementation
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.

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	Wheel and unsprung mass, m Initial deflection, zo Initial velocity, zdoto Gravitational acceleration, g Vertical deflection breakpoints, zFz Pressure breakpoints, pFz Force due to deflection, Fzz Vertical velocity breakpoints, zdotFz Force due to velocity, Fzzdot Ground displacement, Gndz Input ground displacement	z zdot

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 scalar

Axle viscous damping coefficient, br , in N·m·s/rad.

Wheel inertia, Iyy — Inertia scalar

Wheel inertia, in kg·m².

Wheel initial angular velocity, omegao — Wheel speed scalar

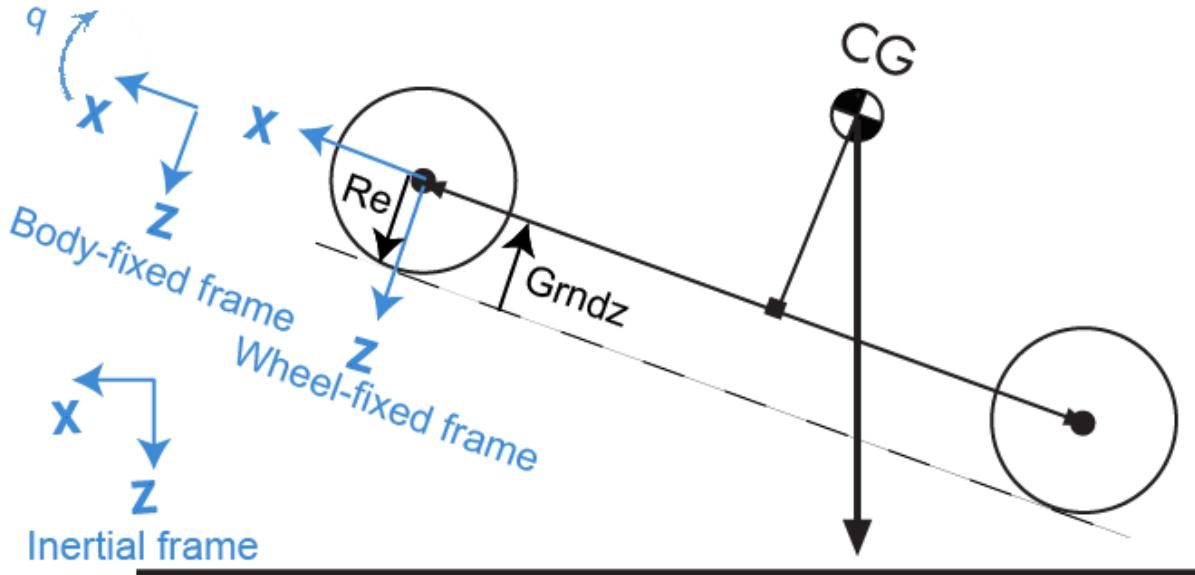
Initial angular velocity of wheel, along body-fixed y -axis, in rad/s.

Relaxation length, Lrel — Relaxation length scalar

Wheel relaxation length, in m.

Loaded radius, Re — Loaded radius scalar

Loaded wheel radius, Re , in m.



Unloaded radius, UNLOADED_RADIUS — Unloaded radius
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
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 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 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 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 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 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
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
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
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
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
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
scalar

Frictional variation with camber, PDX3, 1/rad².

Dependencies

To create this parameter, select the **Longitudinal Force** parameter Magic Formula pure longitudinal slip.

Longitudinal curvature at nominal normal load, PEX1 — Factor 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 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 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 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
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
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
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
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
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 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 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 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 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

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

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

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

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
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
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
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
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, aMy — Force coefficient
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
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 scalar

Quadratic velocity force component, c , in s²/m².

Dependencies

To create this parameter, select the **Rolling Resistance** parameter Pressure and velocity.

Tire pressure exponent, alphaMy — Pressure exponent scalar

Tire pressure exponent, α , dimensionless.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter Pressure and velocity.

Normal force exponent, betaMy — Force exponent scalar

Normal force exponent, β , dimensionless.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter Pressure and velocity.

ISO 28580

Parasitic losses force, Fpl — Force loss 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
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
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
scalar

Measured temperature, T_{meas} , in K.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

Ambient temperature, Tamb – Temperature
scalar

Measured temperature, T_{amb} , in K.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

Input ambient temperature – Selection
scalar

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
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
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
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
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
scalar

Camber squared rolling resistance torque, in 1/rad².

Dependencies

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

Load based camber squared rolling resistance torque, QSY6 — Load resistance torque
scalar

Load based camber squared rolling resistance torque, in 1/rad².

Dependencies

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

Normal load rolling resistance coefficient, QSY7 — Normal resistance coefficient
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
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
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
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
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
scalar

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
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 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 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 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 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
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
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
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
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
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 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

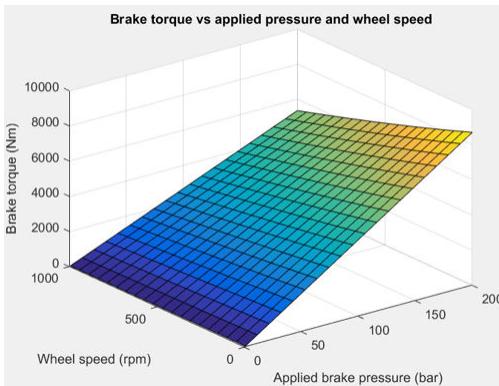
To enable the mapped brake parameters, select Mapped for the **Brake Type** parameter.

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 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, lam_Fzo — Factor 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
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, zo — Deflection
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, zdoto — Velocity
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
scalar

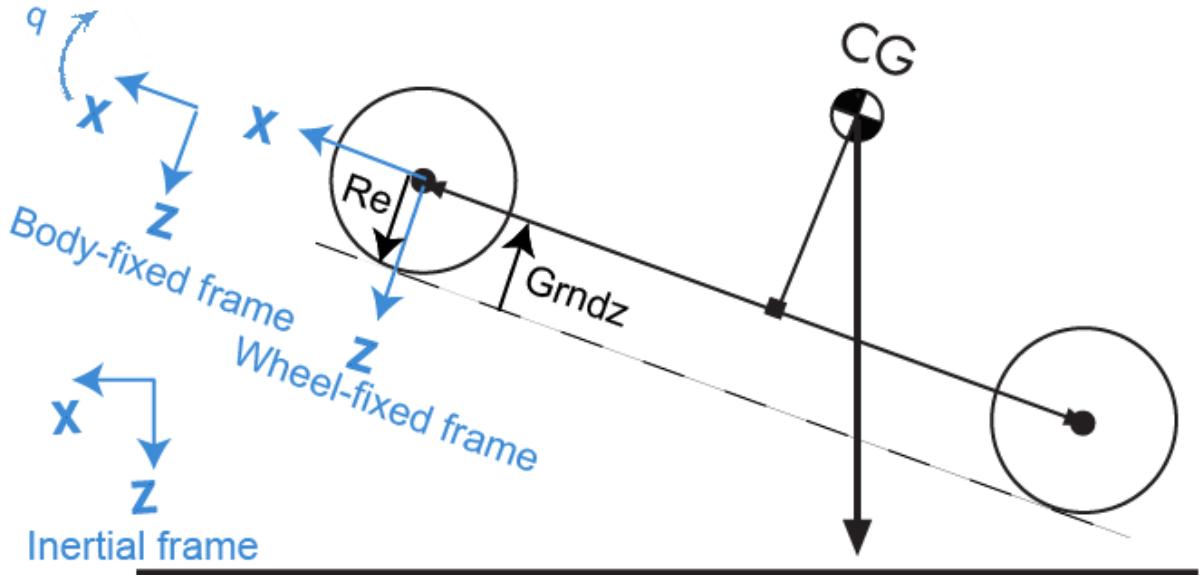
Gravitational acceleration, in m/s².

Dependencies

To enable this parameter, set **Vertical Motion** to Mapped stiffness and damping.

Ground displacement, Gndz — Displacement
scalar

Ground displacement, Grndz, 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
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
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
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
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
scalar

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
scalar

Minimum normal force, in N. Used with all vertical force calculations.

Maximum normal force, FZMAX — Force
scalar

Maximum normal force, in N. Used with all vertical force calculations.

Max allowable slip ratio (absolute), κ_{\max} — Ratio
scalar

Maximum allowable absolute slip ratio, dimensionless.

Velocity tolerance used to handle low velocity situations, V_{LOW} — Tolerance
scalar

Velocity tolerance used to handle low-velocity situations, in m/s.

Minimum ambient temperature, T_{MIN} — Tmin
scalar

Minimum ambient temperature, T_{MIN} , in K.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

Maximum ambient temperature, T_{MAX} — Tmax
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™.

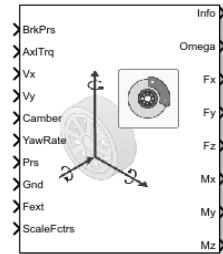
See Also

[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^[1] and ^[2]. 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^[1] and ^[2]. 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 **Apply**.
- 4** Select **Update mask values from file**. In the dialog box that prompts you for confirmation, click **OK**. The block updates the parameters.

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^[2]</i> equations 4.E9 through 4.E57
Lateral force - pure sideslip	<i>Tire and Vehicle Dynamics^[2]</i> equations 4.E19 through 4.E30
Lateral force - combined slip	<i>Tire and Vehicle Dynamics^[2]</i> equations 4.E58 through 4.E67
Vertical dynamics	<i>Tire and Vehicle Dynamics^[2]</i> equations 4.E68, 4.E1, 4.E2a, and 4.E2b
Overturning couple	<i>Tire and Vehicle Dynamics^[2]</i> equation 4.E69
Rolling resistance	<ul style="list-style-type: none"> • An improved Magic Formula/Swift tyre model that can handle inflation pressure changes^[1] equation 6.1.2 • <i>Tire and Vehicle Dynamics^[2]</i> equation 4.E70

Calculation	Equations
Aligning moment	<i>Tire and Vehicle Dynamics</i> ^[2] equation 4.E31 through 4.E49
Aligning torque - combined slip	<i>Tire and Vehicle Dynamics</i> ^[2] 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 $	Unlock ed	$T_f = T_k$ 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.

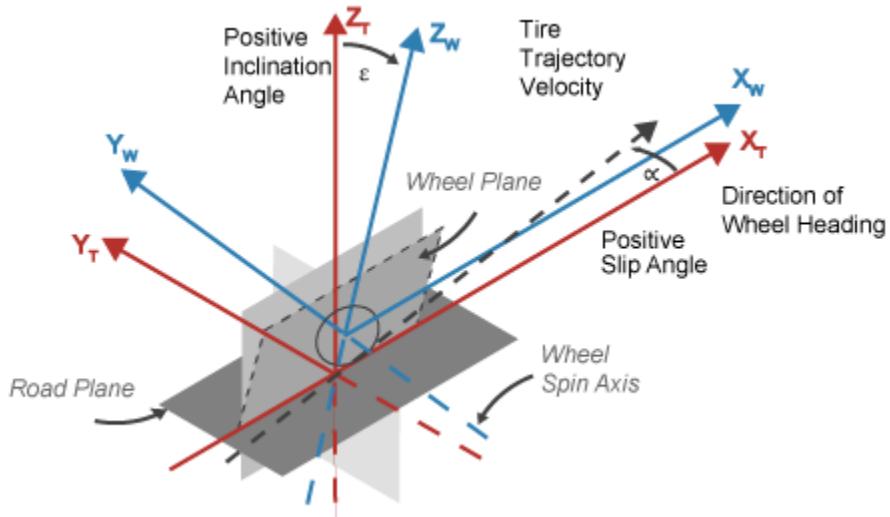
ω	Wheel angular velocity
a	Velocity independent force component
b	Linear velocity force component
c	Quadratic velocity force component
L_e	Tire relaxation length
J	Moment of inertia
M_y	Rolling resistance torque
T_a	Applied axle torque about wheel spin axis
T_b	Braking torque
T_d	Combined tire torque
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
α	Tire pressure exponent
β	Normal force exponent
p_i	Tire pressure
μ_s	Coefficient of static friction
μ_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 Orientation¹

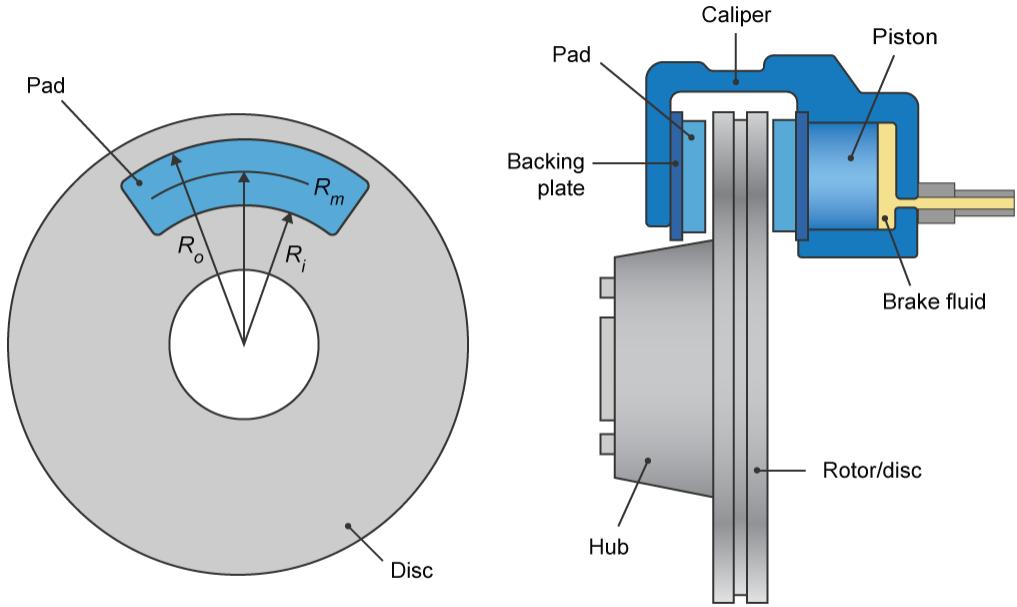


Brakes

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
μ_{static}	Disc pad-rotor coefficient of static friction
μ	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.

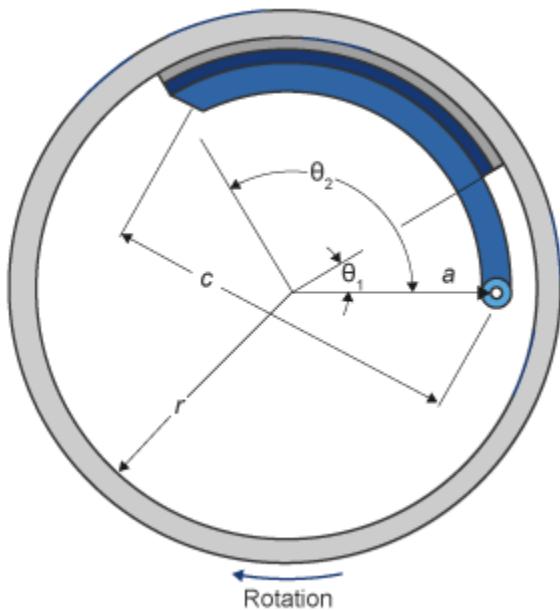
The simplex drum brake model uses the applied force and brake geometry to calculate a net torque for each brake shoe. The drum model assumes that the actuators and shoe geometry are symmetrical for both sides, allowing a single set of geometry and friction parameters to be used for both shoes.

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
μ_{static}	Disc pad-rotor coefficient of static friction
μ	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
Θ_1	Angle from shoe hinge pin center to start of brake pad material on shoe

Θ_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.

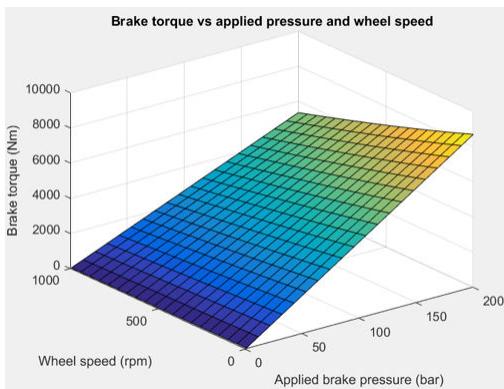
$$T = \begin{cases} f_{brake}(P, N) & \text{when } N \neq 0 \\ \left(\frac{\mu_{static}}{\mu}\right)f_{brake}(P, N) & \text{when } N = 0 \end{cases}$$

The equations use these variables.

T	Brake torque
$f_{brake}(P, N)$	Brake torque lookup table
P	Applied brake pressure
N	Wheel speed
μ_{static}	Friction coefficient of drum pad-face interface under static conditions
μ	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

Brake pressure, in Pa.

Dependencies

To create 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 — Longitudinal velocity
scalar

Axle longitudinal velocity, V_x , along tire-fixed x-axis, in m/s.

Vy — Lateral velocity

scalar

Axle lateral velocity, V_y , along tire-fixed y -axis, in m/s.

Camber — Camber angle

scalar

Camber angle, γ , in rad.

YawRate — Tire angular velocity

scalar

Tire angular velocity, r , about the tire-fixed z -axis (yaw rate), in rad/s.

Prs — Tire inflation pressure

scalar

Tire inflation pressure, p_i , in Pa.

Gnd — Ground displacement

scalar

Ground displacement along tire-fixed z -axis, in m. Positive input produces wheel lift.

Fext — Axle force applied to tire

scalar

Axle force applied to tire, F_{ext} , along vehicle-fixed z -axis (positive input compresses the tire), in N·m.

ScaleFctrs — Scale factors

array

Magic Formula scale factor array. Array dimensions are 27 by 1.

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

Array Element	Variable	Scale Factor
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
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 — Bus signal

bus

Bus signal containing these block calculations.

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
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

Signal	Description	Units
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

Wheel angular velocity, ω , about wheel-fixed y -axis, in rad/s.**Fx — Longitudinal axle force**

scalar

Longitudinal force acting on axle, F_x , along tire-fixed x -axis, in N. Positive force acts to move the vehicle forward.**Fy — Lateral axle force**

scalar

Lateral force acting on axle, F_y , along tire-fixed y -axis, in N.**Fz — Vertical axle force**

scalar

Vertical force acting on axle, F_z , along tire-fixed z -axis, in N.**Mx — Overturning moment**

scalar

Longitudinal moment acting on axle, M_x , about tire-fixed x -axis, in N·m.**My — Rolling resistive moment**

scalar

Lateral moment acting on axle, M_y , about tire-fixed y -axis, in N·m.**Mz — Aligning moment**

scalar

Vertical moment acting on axle, M_z , about tire-fixed z -axis, in N·m.

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 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 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
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
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
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
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
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
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
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
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
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.

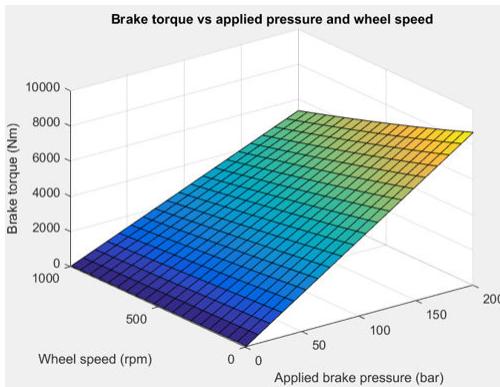
Dependencies

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 **Apply**.
- 4 Select **Update mask values from file**. In the dialog box that prompts you for confirmation, click **OK**. The block updates the parameters.

Simulation

Maximum pressure, PRESMAX — Pressure scalar

Maximum pressure, *PRESMAX*, in Pa.

Minimum pressure, PRESMIN — Pressure
scalar

Minimum pressure, $PRESMIN$, in Pa.

Maximum normal force, FZMAX — Force
scalar

Maximum normal force, $FZMAX$, in N.

Minimum normal force, FZMIN — Force
scalar

Minimum normal force, $FZMIN$, in N.

Velocity tolerance used to handle low velocity situations, VXLOW — Tolerance
scalar

Velocity tolerance used to handle low velocity situations, $VXLOW$, in m/s.

Max allowable slip ratio (absolute), KPUMAX — Ratio
scalar

Max allowable slip ratio (absolute), $KPUMAX$, dimensionless.

Minimum allowable slip ratio (absolute), KPUMIN — Ratio
scalar

Minimum allowable slip ratio (absolute), $KPUMIN$, dimensionless.

Max allowable slip angle (absolute), ALPMAX — Angle
scalar

Max allowable slip angle (absolute), $ALPMAX$, in rad.

Minimum allowable slip angle (absolute), ALPMIN — Angle
scalar

Minimum allowable slip angle (absolute), $ALPMIN$, in rad.

Maximum allowable camber angle, CAMMAX — Angle
scalar

Maximum allowable camber angle *CAMMAX*, in rad.

Minimum allowable camber angle, CAMMIN — Angle
scalar

Minimum allowable camber angle, *CAMMIN*, in rad.

Nominal longitudinal speed, LONGVL — Speed
scalar

Nominal longitudinal speed, *LONGVL*, in m/s.

Wheel

Initial rotational velocity, omegao — Velocity
scalar

Initial rotational velocity, in rad/s.

Rotational damping, br — Damping
scalar

Rotational damping, *br*, in N·m·s/rad.

Unloaded radius, UNLOADED_RADIUS — Radius
scalar

Unloaded radius, *UNLOADED_RADIUS*, in m.

Nominal pressure, NOMPRES — Pressure
scalar

Nominal pressure, *NOMPRES*, in Pa.

Nominal normal force, FNOMIN — Force
scalar

Nominal normal force, *FNOMIN*, in N.

Wheel width, WIDTH — Width
scalar

Wheel width, *WIDTH*, in m.

Inertial

Wheel mass, MASS — Mass
scalar

Wheel mass, *MASS*, in kg.

Rotational inertia (rolling axis), IYY — Inertia
scalar

Rotational inertia (rolling axis), *IYY*, in kg·m².

Gravity, GRAVITY — Gravity
scalar

Gravity, *GRAVITY*, in m/s².

Vertical

Initial tire deflection, zo — Deflection
scalar

Initial tire deflection, *zo*, in m.

Initial wheel vertical velocity (wheel fixed frame), zdoto — Velocity
scalar

Initial wheel vertical velocity (wheel fixed frame), *zdoto*, in m/s.

Effective rolling radius at low load stiffness, BREFF — Stiffness
scalar

Effective rolling radius at low load stiffness, *BREFF*, dimensionless.

Effective rolling radius peak value, DREFF — Radius
scalar

Effective rolling radius peak value, *DREFF*, dimensionless.

Effective rolling radius at high load stiffness, FREFF — Radius
scalar

Effective rolling radius at high load stiffness, $FREFF$, dimensionless.

Unloaded to nominal rolling radius ratio, Q_RE0 — Ratio scalar

Unloaded to nominal rolling radius ratio, Q_RE0 , dimensionless.

Radius rotational speed dependence, Q_V1 — Speed scalar

Radius rotational speed dependence, Q_V1 , dimensionless.

Stiffness rotational speed dependence, Q_V2 — Speed scalar

Stiffness rotational speed dependence, Q_V2 , dimensionless.

Linear load change with deflection, Q_FZ1 — Load change scalar

Linear load change with deflection, Q_FZ1 , dimensionless.

Quadratic load change with deflection, Q_FZ2 — Load change scalar

Quadratic load change with deflection, Q_FZ2 , dimensionless.

Linear load change with deflection and quadratic camber, Q_FZ3 — Load change scalar

Linear load change with deflection and quadratic camber, Q_FZ3 , dimensionless.

Load response to longitudinal force, Q_FCX — Force scalar

Load response to longitudinal force, Q_FCX , dimensionless.

Load response to lateral force, Q_FCY — Force scalar

Load response to lateral force, Q_FCY , dimensionless.

Vertical stiffness change due to lateral load dependency on lateral stiffness, Q_FCY2 — Stiffness
scalar

Vertical stiffness change due to lateral load dependency on lateral stiffness, Q_{FCY2} , dimensionless.

Stiffness response to pressure, PFZ1 — Stiffness
scalar

Stiffness response to pressure, $PFZ1$, dimensionless.

Vertical tire stiffness, VERTICAL_STIFFNESS — Stiffness
scalar

Vertical tire stiffness, $VERTICAL_STIFFNESS$, in N/m.

Vertical tire damping, VERTICAL_DAMPING — Damping
scalar

Vertical tire damping, $VERTICAL_DAMPING$, in N*s/m.

Structural

Longitudinal stiffness, LONGITUDINAL_STIFFNESS — Stiffness
scalar

Longitudinal stiffness, $LONGITUDINAL_STIFFNESS$, in N/m.

Longitudinal stiffness, LATERAL_STIFFNESS — Stiffness
scalar

Longitudinal stiffness, $LATERAL_STIFFNESS$, in N/m.

**Linear vertical deflection influence on longitudinal stiffness,
PCFX1 — Deflection influence**
scalar

Linear vertical deflection influence on longitudinal stiffness, $PCFX1$, dimensionless.

Quadratic vertical deflection influence on longitudinal stiffness, PCFX2 — Deflection influence
scalar

Quadratic vertical deflection influence on longitudinal stiffness, $PCFX2$, dimensionless.

Pressure dependency on longitudinal stiffness, PCFX3 — Pressure dependency
scalar

Pressure dependency on longitudinal stiffness, $PCFX3$, dimensionless.

Linear vertical deflection influence on lateral stiffness, PCFY1 — Deflection influence
scalar

Linear vertical deflection influence on lateral stiffness, $PCFY1$, dimensionless.

Quadratic vertical deflection influence on lateral stiffness, PCFY2 — Deflection influence
scalar

Quadratic vertical deflection influence on lateral stiffness, $PCFY2$, dimensionless.

Pressure dependency on longitudinal stiffness, PCFY3 — Pressure dependency
scalar

Pressure dependency on longitudinal stiffness, $PCFY3$, dimensionless.

Contact Patch

Contact length square root term, Q_RA1 — Length term
scalar

Contact length square root term, Q_RA1 , dimensionless.

Contact length linear term, Q_RA2 — Length term
scalar

Contact length linear term, Q_RA2 , dimensionless.

Contact width root term, Q_RB1 — Width term
scalar

Contact width root term, Q_{RB1} , dimensionless.

Contact width linear term, Q_RB2 — Width term
scalar

Contact width linear term Q_{RB2} , dimensionless.

Longitudinal

Cfx shape factor, PCX1 — Shape factor
scalar

Shape factor, C_{fx} , $PCX1$, dimensionless.

Longitudinal friction at nominal normal load, PDX1 — Friction
scalar

Longitudinal friction at nominal normal load, $PDX1$, dimensionless.

Frictional variation with load, PDX2 — Friction variation
scalar

Frictional variation with load, $PDX2$, dimensionless.

Frictional variation with camber, PDX3 — Friction variation
scalar

Frictional variation with camber, $PDX3$, in $1/\text{rad}^2$.

Longitudinal curvature at nominal normal load, PEX1 — Curvature
scalar

Longitudinal curvature at nominal normal load, $PEX1$, dimensionless.

Variation of curvature factor with load, PEX2 — Curvature variation
scalar

Variation of curvature factor with load, $PEX2$, dimensionless.

Variation of curvature factor with square of load, PEX3 — Curvature variation
scalar

Variation of curvature factor with square of load, *PEX3*, dimensionless.

Longitudinal curvature factor with slip, PEX4 — Curvature
scalar

Longitudinal curvature factor with slip, *PEX4*, dimensionless.

Longitudinal slip stiffness at nominal normal load, PKX1 — Stiffness
scalar

Longitudinal slip stiffness at nominal normal load, *PKX1*, dimensionless.

Variation of slip stiffness with load, PKX2 — Stiffness variation
scalar

Variation of slip stiffness with load, *PKX1*, dimensionless.

Slip stiffness exponent factor, PKX3 — Slip stiffness
scalar

Slip stiffness exponent factor, *PKX3*, dimensionless.

Horizontal shift in slip ratio at nominal normal load, PHX1 — Slip ratio shift
scalar

Horizontal shift in slip ratio at nominal normal load, *PHX1*, dimensionless.

Variation of horizontal slip ratio with load, PHX2 — Slip variation
scalar

Variation of horizontal slip ratio with load, *PHX2*, dimensionless.

Vertical shift in load at nominal normal load, PVX1 — Load shift
scalar

Vertical shift in load at nominal normal load, *PVX1*, dimensionless.

Variation of vertical shift with load, PVX2 — Load variation
scalar

Variation of vertical shift with load, $PVX2$, dimensionless.

**Linear variation of longitudinal slip stiffness with tire pressure,
PPX1 — Stiffness variation**
scalar

Linear variation of longitudinal slip stiffness with tire pressure, $PPX1$, dimensionless.

**Quadratic variation of longitudinal slip stiffness with tire
pressure, PPX2 — Stiffness variation**
scalar

Quadratic variation of longitudinal slip stiffness with tire pressure, $PPX2$, dimensionless.

**Linear variation of peak longitudinal friction with tire pressure,
PPX3 — Friction variation**
scalar

Linear variation of peak longitudinal friction with tire pressure, $PPX3$, dimensionless.

**Quadratic variation of peak longitudinal friction with tire
pressure, PPX4 — Friction variation**
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**
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**
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
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
scalar

Shape factor for combined slip longitudinal force, F_x , reduction, $RCX1$, dimensionless.

Combined F_x curvature factor, REX1 — Combined longitudinal force curvature factor
scalar

Combined longitudinal force, F_x , curvature factor, $REX1$, dimensionless.

Combined F_x curvature factor with load, REX2 — Combined longitudinal force curvature factor
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
scalar

Combined slip longitudinal force, F_x , shift factor reduction, $RHX1$, dimensionless.

Overspinning

Vertical shift of overspinning moment, QSX1 — Overspinning moment
scalar

Vertical shift of overspinning moment, $QSX1$, dimensionless.

Overspinning moment due to camber, QSX2 — Overspinning moment due to camber
scalar

Overspinning moment due to camber, $QSX2$, dimensionless.

OVERTURNING moment due to Fy, QSX3 – Overturning moment due to lateral force

scalar

Overturning moment due to lateral force, QSX3, dimensionless.

Mx combined lateral force load and camber, QSX4 – Overturning moment

scalar

Overturning moment, M_x , moment combined lateral force load and camber, QSX4, dimensionless.**Mx load effect due to lateral force and camber, QSX5 – Overturning moment**

scalar

Overturning moment, M_x , load effect due to lateral force and camber, QSX5, dimensionless.**Mx load effect due to B-factor, QSX6 – Overturning moment**

scalar

Overturning moment, M_x , load effect due to B-factor, QSX6, dimensionless.**Mx due to camber and load, QSX7 – Overturning moment**

scalar

Overturning moment, M_x , due to camber and load, QSX7, dimensionless.**Mx due to lateral force and load, QSX8 – Overturning moment**

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**

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**

scalar

Oversettning moment, M_x , due to vertical force and camber, *QSX10*, dimensionless.

M_x due to B-factor of vertical force and camber, QSX11 — Oversettning moment

scalar

Oversettning moment, M_x , due to B-factor of vertical force and camber, *QSX11*, dimensionless.

M_x due to squared camber, QSX12 — Oversettning moment

scalar

Oversettning moment, M_x , due to squared camber, *QSX12*, dimensionless.

M_x due to lateral force, QSX13 — Oversettning moment

scalar

Oversettning moment, M_x , due to lateral force, *QSX13*, dimensionless.

M_x due to lateral force with camber, QSX14 — Oversettning moment

scalar

Oversettning moment, M_x , due to lateral force with camber, *QSX14*, dimensionless.

M_x due to inflation pressure, PPMX1 — Oversettning moment due to pressure

scalar

Oversettning moment, M_x , due to inflation pressure, *PPMX1*, dimensionless.

Lateral

C_{fy} shape factor for lateral force, PCY1 — Lateral force shape factor

scalar

Shape factor for lateral force, C_{fy} , *PCY1*, dimensionless.

Lateral friction μ_y , PDY1 — Lateral friction

scalar

Lateral friction, μ_y , *PDY1*, dimensionless.

Lateral friction variation of μ_y with load, PDY2 — Lateral friction variation
scalar

Variation of lateral friction, μ_y , with load, $PDY2$, dimensionless.

Lateral friction variation of μ_y with squared camber, PDY3 — Lateral friction variation
scalar

Variation of lateral friction, μ_y , with squared camber, $PDY3$, dimensionless.

Efy lateral curvature at nominal force FZNOM, PEY1 — Lateral curvature at nominal force
scalar

Lateral curvature, Ef_y , at nominal force, F_{ZNOM} , $PEY1$, dimensionless.

Efy curvature variation with load PEY2 — Lateral curvature variation
scalar

Lateral curvature, Ef_y , variation with load, $PEY2$, dimensionless.

Efy curvature constant camber dependency, PEY3 — Lateral curvature constant
scalar

Lateral curvature, Ef_y , constant camber dependency, $PEY3$, dimensionless.

Efy curvature variation with camber, PEY4 — Lateral curvature variation
scalar

Lateral curvature, Ef_y , variation with camber, $PEY4$, dimensionless.

Efy curvature variation with camber squared, PEY5 — Lateral curvature variation
scalar

Lateral curvature, Ef_y , variation with camber squared, $PEY5$, dimensionless.

Maximum KFy/FZNOM stiffness, PKY1 — Maximum stiffness
scalar

Maximum lateral force stiffness, KF_y , to nominal force, F_{ZNOM} , ratio, $PKY1$, dimensionless.

Load at maximum KFy/FZNOM stiffness, PKY2 — Load 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 scalar

Lateral force stiffness, KF_y , to nominal force, F_{ZNOM} , stiffness variation with camber, $PKY3$, dimensionless.

KFy curvature, PKY4 — Lateral force stiffness curvature scalar

Lateral force stiffness, KF_y curvature, $PKY4$, dimensionless.

Variation of peak stiffness with squared camber, PKY5 — Stiffness variation scalar

Variation of peak stiffness with squared camber, $PKY5$, dimensionless.

Fy camber stiffness factor, PKY6 — Lateral force camber stiffness factor scalar

Lateral force, F_y , camber stiffness factor, $PKY6$, dimensionless.

Camber stiffness vertical load dependency, PKY7 — Stiffness scalar

Camber stiffness vertical load dependency, $PKY7$, dimensionless.

SHY horizontal shift at FZNOM, PHY1 — Horizontal shift at nominal force scalar

Horizontal shift, S_{HY} , at nominal force, F_{ZNOM} , $PHY1$, dimensionless.

SHY variation with load, PHY2 — Horizontal shift variation scalar

Horizontal shift, S_{HY} , variation with load, $PHY2$, dimensionless.

Svy/Fz vertical shift at FZNOM, PVY1 — Vertical shift at nominal force scalar

Vertical shift, S_{vy} , at nominal force, F_{ZNOM} , $PVY1$, dimensionless.

Svy/Fz variation with load, PVY2 — Vertical shift variation with load scalar

Vertical shift, S_{vy} , variation with load, $PVY2$, dimensionless.

Svy/Fz variation with camber, PVY3 — Vertical shift variation with camber 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 scalar

Vertical shift, S_{vy} , variation with load and camber, $PVY4$, dimensionless.

Cornering stiffness variation with inflation pressure, PPY1 — Stiffness variation with pressure scalar

Cornering stiffness variation with inflation pressure, $PPY1$, dimensionless.

Cornering stiffness variation with inflation pressure induced nominal load dependency, PPY2 — Stiffness variation with pressure scalar

Cornering stiffness variation with inflation pressure induced nominal load dependency, $PPY2$, dimensionless.

Linear inflation pressure on peak lateral friction, PPY3 — Pressure scalar

Linear inflation pressure on peak lateral friction, $PPY3$, dimensionless.

Quadratic inflation pressure on peak lateral friction, PPY4 — Pressure
scalar

Quadratic inflation pressure on peak lateral friction, $PPY4$, dimensionless.

Inflation pressure effect on camber stiffness, PPy5 — Pressure
scalar

Inflation pressure effect on camber stiffness, $PPY5$, dimensionless.

Combined Fy reduction slope factor, RBY1 — Combined lateral force reduction slope factor
scalar

Combined lateral force, F_y , reduction slope factor, $RBY1$, dimensionless.

Fy slope reduction with slip angle, RBY2 — Lateral force slope reduction with slip angle
scalar

Lateral force, F_y , slope reduction with slip angle, $RBY2$, dimensionless.

Fy shift reduction with slip angle, RBY3 — Lateral force shift reduction with slip angle
scalar

Lateral force, F_y , shift reduction with slip angle, $RBY3$, dimensionless.

Fy combined stiffness variation from camber, RBY4 — Lateral force combined stiffness variation from camber
scalar

Lateral force, F_y , combined stiffness variation from camber, $RBY4$, dimensionless.

Fy combined reduction shape factor, RCY1 — Lateral force combined reduction shape factor
scalar

Lateral force, F_y , combined reduction shape factor, $RCY1$, dimensionless.

Fy combined curvature factor, REY1 — Lateral force combined curvature factor
scalar

Lateral force, F_y , combined curvature factor, $REY1$, dimensionless.

Fy combined curvature factor with load, REY2 — Lateral force combined curvature factor with load
scalar

Lateral force, F_y , combined curvature factor with load, $REY2$, dimensionless.

Fy combined reduction shift factor, RHY1 — Lateral force combined reduction shift factor
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
scalar

Lateral force, F_y , combined reduction shift factor with load, $RHY2$, dimensionless.

Slip ratio side force Svyk/Muy*Fz at FZNOM, RVY1 — Slip ratio slide force at nominal force
scalar

Slip ratio side force at nominal force, F_{ZNOM} , $RVY1$, dimensionless.

Side force Svyk/Muy*Fz variation with load, RVY2 — Side force variation with load
scalar

Side force variation with load, $RVY2$, dimensionless.

Side force Svyk/Muy*Fz variation with camber, RVY3 — Side force variation with camber
scalar

Side force variation with camber, $RVY3$, dimensionless.

Side force Svyk/Muy*Fz variation with slip angle, RVY4 — Side force variation with slip angle
scalar

Side force variation with slip angle, *RVY4*, dimensionless.

Side force Svyk/Muy*Fz variation with slip ratio, RVY5 — Side force variation with slip ratio
scalar

Side force variation with slip ratio, *RVY5*, dimensionless.

Side force Svyk/Muy*Fz variation with slip ratio arctangent, RVY6 — Side force variation with slip ratio arctangent
scalar

Side force variation with slip ratio arctangent, *RVY6*, dimensionless.

Rolling

Torque resistance coefficient, QSY1 — Torque resistance
scalar

Torque resistance coefficient, *QSY1*, dimensionless.

Torque resistance due to Fx, QSY2 — Torque resistance due to longitudinal force
scalar

Torque resistance due to longitudinal force, F_x , *QSY2*, dimensionless.

Torque resistance due to speed, QSY3 — Torque resistance due to speed
scalar

Torque resistance due to speed, *QSY3*, dimensionless.

Torque resistance due to speed⁴, QSY4 — Torque resistance due to speed
scalar

Torque resistance due to speed⁴, *QSY4*, dimensionless.

Torque resistance due to square of camber, QSY5 — Torque resistance due to camber

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

scalar

Torque resistance due to square of camber and load, $QSY6$, dimensionless.

Torque resistance due to load, QSY7 — Torque resistance due to load

scalar

Torque resistance due to load, $QSY7$, dimensionless.

Torque resistance due to pressure, QSY8 — Torque resistance due to pressure

scalar

Torque resistance due to pressure, $QSY8$, dimensionless.

Aligning

Trail slope factor for trail Bpt at FZNOM, QBZ1 — Trail slope factor at nominal force

scalar

Trail slope factor for trail Bpt at nominal force, F_{ZNOM} , $QBZ1$, dimensionless.

Bpt slope variation with load, QBZ2 — Slope variation with load

scalar

Slope variation with load, $QBZ2$, dimensionless.

Bpt slope variation with square of load, QBZ3 — Slope variation with load

scalar

Slope variation with square of load, $QBZ3$, dimensionless.

Bpt slope variation with camber, QBZ4 — Slope variation with camber
scalar

Slope variation with camber, $QBZ4$, dimensionless.

Bpt slope variation with absolute value of camber, QBZ5 — Slope variation with camber
scalar

Slope variation with absolute value of camber, $QBZ5$, dimensionless.

Bpt slope variation with square of camber, QBZ6 — Slope variation with camber
scalar

Slope variation with square of camber, $QBZ6$, dimensionless.

Br of Mzr slope scaling factor, QBZ9 — Slope scaling factor
scalar

Slope scaling factor, $QBZ9$, dimensionless.

Br of Mzr cornering stiffness factor, QBZ10 — Cornering stiffness factor
scalar

Br of Mzr cornering stiffness factor, $QBZ10$, dimensionless.

Cpt pneumatic trail shape factor, QCZ1 — Pneumatic trail shape factor
scalar

Pneumatic trail shape factor, C_{pt} , $QCZ1$, dimensionless.

Dpt peak trail, QDZ1 — Peak trail
scalar

Peak trail, D_{pt} , $QDZ1$, dimensionless.

Dpt peak trail variation with load, QDZ2 — Peak trail variation with load
scalar

Peak trail, D_{pt} , variation with load, $QDZ2$, dimensionless.

Dpt peak trail variation with camber, QDZ3 — Peak trail variation with camber
scalar

Peak trail, D_{pt} , variation with camber, $QDZ3$, dimensionless.

Dpt peak trail variation with square of camber, QDZ4 — Peak trail variation with square of camber
scalar

Peak trail, D_{pt} , variation with square of camber, $QDZ4$, dimensionless.

Dmr peak residual torque, QDZ6 — Peak residual torque
scalar

Peak residual torque, D_{mr} , $QDZ6$, dimensionless.

Dmr peak residual torque variation with load, QDZ7 — Peak residual torque variation with load
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
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
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 square of camber
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 scalar

Peak residual torque, D_{mr} , variation with square of load, $QDZ11$, dimensionless.

Ept trail curvature at FZNOM, QEZ1 — Trail curvature at nominal force scalar

Trail curvature, E_{pt} , at nominal force, F_{ZNOM} , $QEZ1$, dimensionless.

Ept variation with load, QEZ2 — Trail curvature variation with load scalar

Trail curvature, E_{pt} variation with load, $QEZ2$, dimensionless.

Ept variation with square of load, QEZ3 — Trail curvature variation with load scalar

Trail curvature, E_{pt} variation with square of load, $QEZ3$, dimensionless.

Ept variation with sign of alpha-t, QEZ4 — Trail curvature variation scalar

Trail curvature, E_{pt} variation with sign of alpha-t, $QEZ4$, dimensionless.

Ept variation with sign of alpha-t and camber, QEZ5 — Variation 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 scalar

Horizontal trail shift, Sh_t , at nominal load, F_{ZNOM} , $QHZ1$, dimensionless.

Sht variation with load, QHZ2 — Horizontal trail shift variation with load scalar

Horizontal trail shift, Sh_t , variation with load, $QHZ2$, dimensionless.

Sht variation with camber, QHZ3 — Horizontal trail shift variation with camber

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

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

scalar

Inflation pressure influence on trail length, $PPZ1$, dimensionless.

Inflation pressure influence on residual aligning torque, PPZ2 — Pressure influence on aligning torque

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

scalar

Nominal value of s/R_0 : 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

scalar

Variation with lateral to nominal force ratio, $SSZ2$, dimensionless.

s/R0 variation with camber, SSZ3 — Variation with camber

scalar

Variation with camber, $SSZ3$, dimensionless.

s/R0 variation with camber and load, SSZ4 — Variation with camber and load
scalar

Variation with camber and load, *SSZ4*, dimensionless.

Turnslip

Fx peak reduction due to spin, PDXP1 — Longitudinal force peak reduction due to spin
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
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
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
scalar

Cornering stiffness reduction due to spin, *PKYP1*, dimensionless.

Fy peak reduction due to spin, PDYP1 — Lateral force peak reduction due to spin
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
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
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
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
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
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
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
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
scalar

Camber stiffness reduction due to spin, $PECP1$, dimensionless.

Camber stiffness reduction due to spin with load, PECP2 — Camber stiffness reduction
scalar

Camber stiffness reduction due to spin with load, $PECP2$, dimensionless.

Turn slip pneumatic trail reduction factor, QDTP1 — Turn slip pneumatic trail reduction factor
scalar

Turn slip pneumatic trail reduction factor, $QDTP1$, dimensionless.

Turn moment for constant turning and zero longitudinal speed, QCRP1 — Turn moment for constant turning
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
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
scalar

Residual spin torque reduction from side slip, $QBRP1$, dimensionless.

Turn slip moment peak magnitude, QDRP1 — Turn slip moment peak magnitude
scalar

Turn slip moment peak magnitude, $QDRP1$, dimensionless.

Turn slip moment curvature, QDRP2 — Turn slip moment curvature
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

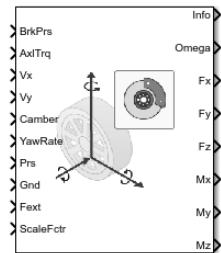
"Coordinate Systems in Vehicle Dynamics Blockset"

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^[1]. 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
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.

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, $M_y = R_e \{a + b V_x + cV_x^2\} \{F_z \beta p_i^\alpha\} \tanh(4V_x)$

Setting	Block Implementation
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	$T_f = T_k$ <p>where,</p> $T_k = F_c R_{eff} \mu_k \tanh[4(-\omega_d)]$ $T_s = F_c R_{eff} \mu_s$ $R_{eff} = \frac{2(R_o^3 - R_i^3)}{3(R_o^2 - R_i^2)}$	$\dot{\omega} J = -\omega b + T_i + T_o$
$\omega = 0$ and $T_S \geq T_i + T_f - \omega b $	Locked	$T_f = T_s$	$\omega = 0$

The equations use these variables.

ω 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
α	Tire pressure exponent
β	Normal force exponent
p_i	Tire pressure
μ_s	Coefficient of static friction

μ_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	$\kappa'_{Critical} = \left \frac{\mu F_z}{2C_K} \right $
Longitudinal force	$F_x = \begin{cases} C_k & \kappa' \\ \tanh(4\kappa') \left(\mu F_z - \left \frac{(\mu F_z)^2}{4\kappa' C_K} \right \right) & \text{when } \kappa' \leq \kappa'_{Critical} \\ & \text{when } \kappa' > \kappa'_{Critical} \end{cases}$
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.

κ'	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,
μ	Friction coefficient
μ_s	Coefficient of static friction
μ_k	Coefficient of kinetic friction
κ_{ka}	Comprehensive slip coefficient
α'	Slip angle state
λ_μ	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	$\alpha'_{Critical} = \tan(\frac{3\mu F_z }{C_a})$
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.

α'	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_γ	Camber stiffness
C_α	Lateral stiffness per slip angle
μ	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

ρ_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. $M_z = \begin{cases} \psi b_{M_z} & \text{when } \alpha' > \alpha'_{Critical} \\ \tanh(4\alpha') w \mu F_z (1 - \xi) \xi^3 + \psi b_{M_z} & \text{when } \alpha' \leq \alpha'_{Critical} \end{cases}$ $\xi = 1 - \frac{C_a \tan(\alpha') }{3\mu F_z }$
Friction scaling	To vary the coefficient of friction, use the ScaleFctr 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
γ	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
α'	Slip angle state
b_{Mz}	Linear yaw rate resistance
F_y	Lateral force acting on axle along tire-fixed y -axis
C_y	Camber stiffness
C_α	Lateral stiffness per slip angle
μ	Friction coefficient
F_z	Vertical contact patch normal force along tire-fixed z -axis

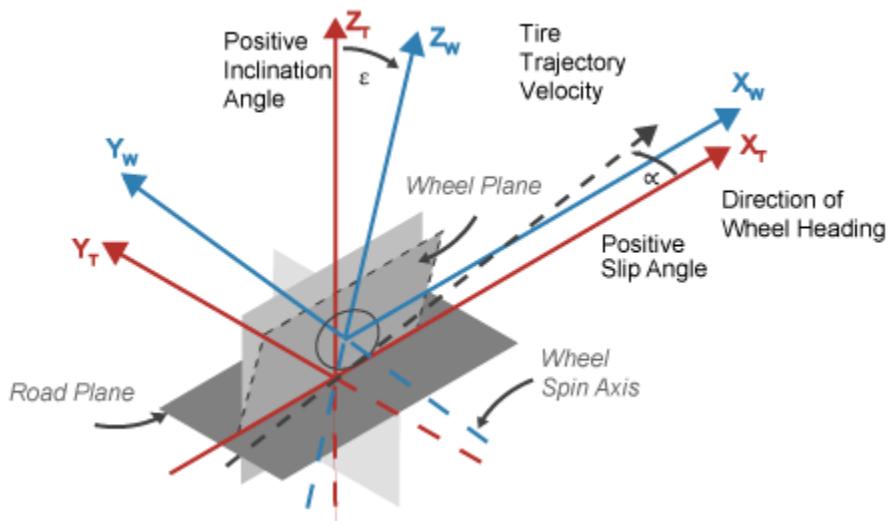
Tire and Wheel Coordinate Systems

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 Orientation²

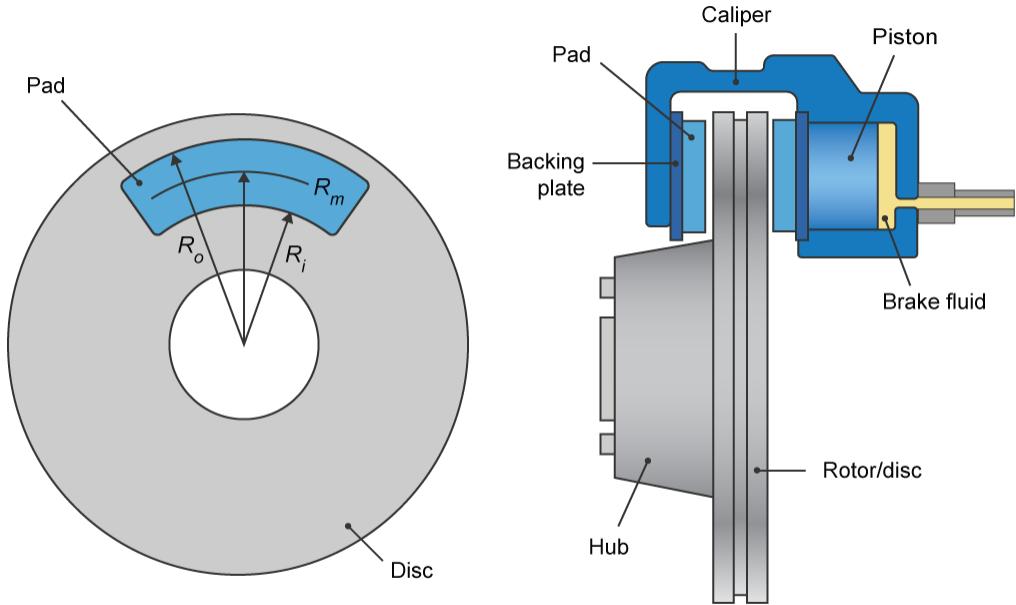
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Brakes

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.

$$T = \begin{cases} \frac{\mu P \pi B_a^2 R_m N_{pads}}{4} & \text{when } N \neq 0 \\ \frac{\mu_{static} P \pi B_a^2 R_m N_{pads}}{4} & \text{when } N = 0 \end{cases}$$

$$Rm = \frac{R_o + R_i}{2}$$

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
μ_{static}	Disc pad-rotor coefficient of static friction
μ	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.

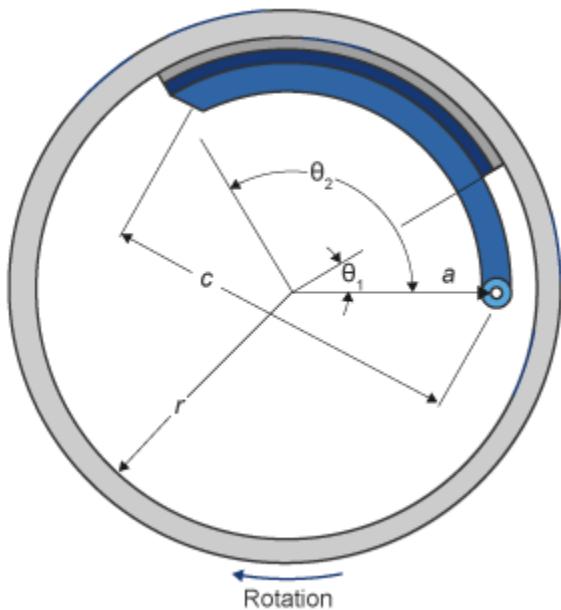
The simplex drum brake model uses the applied force and brake geometry to calculate a net torque for each brake shoe. The drum model assumes that the actuators and shoe geometry are symmetrical for both sides, allowing a single set of geometry and friction parameters to be used for both shoes.

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
μ_{static}	Disc pad-rotor coefficient of static friction
μ	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
Θ_1	Angle from shoe hinge pin center to start of brake pad material on shoe

Θ_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.

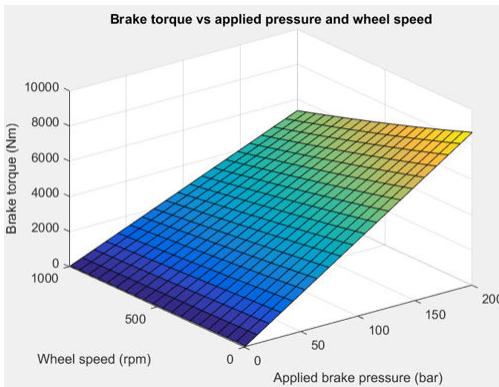
$$T = \begin{cases} f_{brake}(P, N) & \text{when } N \neq 0 \\ \left(\frac{\mu_{static}}{\mu}\right)f_{brake}(P, N) & \text{when } N = 0 \end{cases}$$

The equations use these variables.

T	Brake torque
$f_{brake}(P, N)$	Brake torque lookup table
P	Applied brake pressure
N	Wheel speed
μ_{static}	Friction coefficient of drum pad-face interface under static conditions
μ	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

Brake pressure, in Pa.

Dependencies

To create 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 — Longitudinal velocity
scalar

Axle longitudinal velocity, V_x , along tire-fixed x-axis, in m/s.

Vy — Lateral velocity

scalar

Axe lateral velocity, V_y , along tire-fixed y -axis, in m/s.**Camber — Camber angle**

scalar

Camber angle, γ , in rad.**YawRate — Tire angular velocity**

scalar

Tire angular velocity, r , about the tire-fixed z -axis (yaw rate), in rad/s.**Prs — Tire inflation pressure**

scalar

Tire inflation pressure, p_i , in Pa.**Gnd — Ground displacement**

scalar

Ground displacement along tire-fixed z -axis, in m. Positive input produces wheel lift.**Fext — Axle force applied to tire**

scalar

Axe force applied to tire, F_{ext} , along vehicle-fixed z -axis (positive input compresses the tire), in N·m.**ScaleFctr — Scale factor**

scalar

Scale factor to account for variations in the coefficient of friction.

Output

Info — Bus signal

bus

Bus signal containing these block calculations.

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
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

Wheel angular velocity, ω , about wheel-fixed y -axis, in rad/s.

Fx — Longitudinal axle force

scalar

Longitudinal force acting on axle, F_x , along tire-fixed x -axis, in N. Positive force acts to move the vehicle forward.

Fy — Lateral axle force

scalar

Lateral force acting on axle, F_y , along tire-fixed y -axis, in N.

Fz — Vertical axle force

scalar

Vertical force acting on axle, F_z , along tire-fixed z -axis, in N.

Mx — Overturning moment

scalar

Longitudinal moment acting on axle, M_x , about tire-fixed x -axis, in N·m.

My — Rolling resistive moment

scalar

Lateral moment acting on axle, M_y , about tire-fixed y -axis, in N·m.

Mz — Aligning moment

scalar

Vertical moment acting on axle, M_z , about tire-fixed z -axis, in N·m.

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

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> .

Setting	Block Implementation
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	Velocity independent force coefficient, aMy Linear velocity force component, bMy Quadratic velocity force component, cMy Tire pressure exponent, alphaMy Normal force exponent, betaMy
ISO 28580	Parasitic losses force, Fpl Rolling resistance constant, Cr Thermal correction factor, Kt Measured temperature, Tmeas Parasitic losses force, Fpl Ambient temperature, Tamb

Selecting	Parameters
Magic Formula	Rolling resistance torque coefficient, QSY Longitudinal force rolling resistance coefficient, QSY2 Linear rotational speed rolling resistance coefficient, QSY3 Quartic rotational speed rolling resistance coefficient, QSY4 Camber squared rolling resistance torque, QSY5 Load based camber squared rolling resistance torque, QSY6 Normal load rolling resistance coefficient, QSY7 Pressure load rolling resistance coefficient, QSY8 Rolling resistance scaling factor, lam_My
Mapped torque	Spin axis velocity breakpoints, VxMy Normal force breakpoints, FzMy Rolling resistance torque map, MyMap

Brake

Static friction coefficient, mu_static – Static friction 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 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 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 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 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
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
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
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
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
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 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.

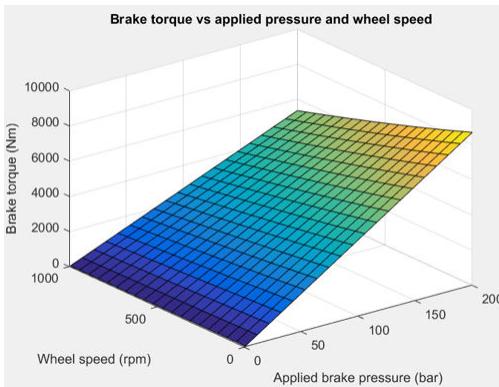
Dependencies

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.

Longitudinal and Lateral

Longitudinal stiffness, Ckappa — Longitudinal stiffness
scalar

Longitudinal stiffness, C_k , in N.

Lateral stiffness per slip angle, Calpha — Lateral stiffness
scalar

Lateral stiffness per slip angle, C_α , in N/rad.

Camber stiffness, Cgamma — Camber stiffness
scalar

Camber stiffness, C_y , in N/rad.

Kinematic friction, muMin — Friction
scalar

Kinematic friction, μ_k , dimensionless.

Static friction, muMax — Friction
scalar

Static friction, μ_s , dimensionless.

Longitudinal relaxation length, Lrelx — Length scalar

Longitudinal relaxation length, L_{relx} , in m.

Lateral relaxation length, Lrelx — Length scalar

Lateral relaxation length, L_{relx} , in m/rad.

Rolling

Rotational damping, br — Damping scalar

Rotational damping, br , in N·m·s/rad.

Rotational inertia (rolling axis), IYY — Inertia scalar

Rotational inertia (rolling axis), I_{YY} , in kg·m².

Initial rotational velocity, omegao — Velocity scalar

Initial rotational velocity, in rad/s.

Pressure and Velocity

Velocity independent force coefficient, aMy — Force coefficient 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 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 scalar

Quadratic velocity force component, c , in s²/m².

Dependencies

To create this parameter, select the **Rolling Resistance** parameter Pressure and velocity.

Tire pressure exponent, alphaMy — Pressure exponent scalar

Tire pressure exponent, α , dimensionless.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter Pressure and velocity.

Normal force exponent, betaMy — Force exponent scalar

Normal force exponent, β , dimensionless.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter Pressure and velocity.

ISO 28580

Parasitic losses force, Fpl — Force loss 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
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
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
scalar

Measured temperature, T_{meas} , in K.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

Ambient temperature, Tamb – Temperature
scalar

Measured temperature, T_{amb} , in K.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

Input ambient temperature – Selection
scalar

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
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
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
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
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

scalar

Camber squared rolling resistance torque, in 1/rad².

Dependencies

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

Load based camber squared rolling resistance torque, QSY6 — Load resistance torque

scalar

Load based camber squared rolling resistance torque, in 1/rad².

Dependencies

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

Normal load rolling resistance coefficient, QSY7 — Normal resistance coefficient

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

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

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
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
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
scalar

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
scalar

Wheel width, $WIDTH$, in m.

Linear yaw rate resistance, bMz — Resistance
scalar

Linear yaw rate resistance, b_{Mz} , in N·m·s/rad.

Simulation

Maximum normal force, FZMAX — Force scalar

Maximum normal force, in N. Used with all vertical force calculations.

Minimum normal force, FZMIN — Force scalar

Minimum normal force, in N. Used with all vertical force calculations.

Maximum pressure, PRESMAX — Pressure scalar

Maximum pressure, *PRESMAX*, in Pa.

Minimum pressure, PRESMIN — Pressure scalar

Minimum pressure, *PRESMIN*, in Pa.

Max allowable slip ratio (absolute), KPUMAX — Ratio scalar

Max allowable slip ratio (absolute), *KPUMAX*, dimensionless.

Minimum allowable slip ratio (absolute), KPUMIN — Ratio scalar

Minimum allowable slip ratio (absolute), *KPUMIN*, dimensionless.

Max allowable slip angle (absolute), ALPMAX — Angle scalar

Max allowable slip angle (absolute), *ALPMAX*, in rad.

Minimum allowable slip angle (absolute), ALPMIN — Angle scalar

Minimum allowable slip angle (absolute), *ALPMIN*, in rad.

Maximum allowable camber angle, CAMMAX — Angle
scalar

Maximum allowable camber angle $CAMMAX$, in rad.

Minimum allowable camber angle, CAMMIN — Angle
scalar

Minimum allowable camber angle, $CAMMIN$, in rad.

Minimum ambient temperature, TMIN — Tmin
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
scalar

Maximum ambient temperature, T_{MAX} , in K.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

References

- [1] Fiala, E. "Seitenkrafte 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”

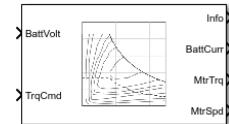
Introduced in R2019a

Propulsion Blocks – Alphabetical List

Mapped Motor

Mapped motor and drive electronics operating in torque-control mode

Library: Powertrain Blockset / Propulsion / Electric Motors
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.

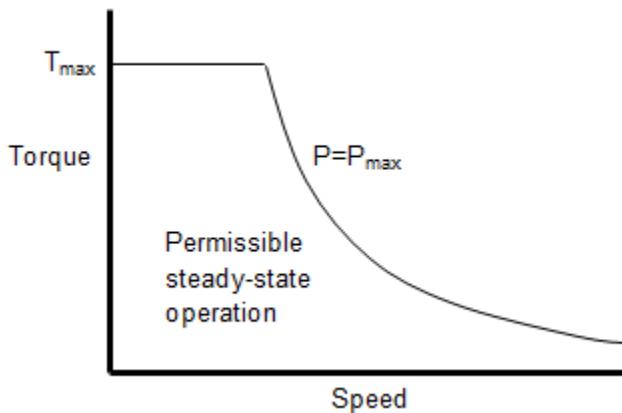
Electrical Torque

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.

Setting	Block Implementation
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"> • Fixed losses independent of torque and speed, P_0. Use P_0 to account for fixed converter losses. • A torque-dependent electrical loss $k\tau^2$, where k is a constant and τ is the torque. Represents ohmic losses in the copper windings. • A speed-dependent electrical loss $k_w\omega^2$, where k_w is a constant and ω is the speed. Represents iron losses due to eddy currents.

Setting	Block Implementation
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 Calibrate Maps 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 Calibrate Maps 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">Converts the efficiency values you provide into losses and uses the tabulated losses for simulation.Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero.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.Does not extrapolate loss values for speed and torque magnitudes that exceed the range of the table.

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"> Converts the efficiency values you provide into losses and uses the tabulated losses for simulation. Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero. 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. Does not extrapolate loss values for speed, torque, or temperature magnitudes that exceed the range of the table.

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.

Virtual Calibration

If you have Model-Based Calibration Toolbox, you can virtually calibrate the measured loss lookup tables.

- On the **Electrical Losses** tab, set **Parameterize losses by** to either:
 - Tabulated loss data
 - Tabulated loss data with temperature
- 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><matlabroot>/toolbox/autoblks/autoblksshared/mbctemplates/MappedMotorDataset.xlsx</code>.</p> <p>For more information, see “Using Data” (Model-Based Calibration Toolbox).</p>
Parameterize losses by	Required Data
Tabulated loss data	<ul style="list-style-type: none"> • Motor speed, rad/s • Motor torque, N·m • Power loss, W
Tabulated loss data with temperature	<ul style="list-style-type: none"> • Motor speed, rad/s • Motor torque, N·m • Motor temperature, K • Power loss, W
Generate Response Models	<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 Edit in Application. The Model-Based Calibration Toolbox Data Editor opens.</p>
	<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 Edit in Application. The Model-Based Calibration Toolbox Model Browser opens. For more information, see “Model Assessment” (Model-Based Calibration Toolbox).</p>

Task	Description						
Generate Calibration	<p>Model-Based Calibration Toolbox calibrates the response models and generates calibrated tables.</p> <p>To assess or adjust the calibration, select Edit in Application. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration Tables” (Model-Based Calibration Toolbox).</p>						
Update block parameters	<p>Update these parameters with the calibration.</p> <table border="1"> <thead> <tr> <th>Parameterize losses by</th><th>Parameters</th></tr> </thead> <tbody> <tr> <td>Tabulated loss data</td><td> <ul style="list-style-type: none"> Vector of speeds(w) for tabulated losses, w_eff_bp Vector of torques (T) for tabulated losses, T_eff_bp Corresponding losses, losses_table </td></tr> <tr> <td>Tabulated loss data with temperature</td><td> <ul style="list-style-type: none"> Vector of speeds(w) for tabulated losses, w_eff_bp Vector of torques (T) for tabulated losses, T_eff_bp Vector of temperatures for tabulated losses, Temp_eff_bp Corresponding losses, losses_table_3d </td></tr> </tbody> </table>	Parameterize losses by	Parameters	Tabulated loss data	<ul style="list-style-type: none"> Vector of speeds(w) for tabulated losses, w_eff_bp Vector of torques (T) for tabulated losses, T_eff_bp Corresponding losses, losses_table 	Tabulated loss data with temperature	<ul style="list-style-type: none"> Vector of speeds(w) for tabulated losses, w_eff_bp Vector of torques (T) for tabulated losses, T_eff_bp Vector of temperatures for tabulated losses, Temp_eff_bp Corresponding losses, losses_table_3d
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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.

$$\text{BattAmp} = \frac{\text{MechPwr} + \text{PwrLoss}}{\text{BattVolt}}$$

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
PwrInfo	PwrTrnsfrd	PwrMtr	Mechanical power	P_{mot}	$P_{mot} = \omega_m T_e$
	<ul style="list-style-type: none"> Positive signals indicate power flow into the block. Negative signals indicate power flow out of the block. 	PwrBus	Electrical power	P_{bus}	$P_{bus} = P_{mot} + P_{loss}$
	PwrNotTrnsfrd	PwrLoss	Motor power loss	P_{loss}	$P_{stored} = \omega_m \dot{\omega}_m J$
	PwrStored	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
ω	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		
PwrInf o	PwrTrnsfrd	PwrMtr	Mechanical power	W

Signal		Description	Units
	PwrBus	Electrical power	W
	PwrNotTrnsf rd	Motor power loss	W
	PwrStored	Motor power stored	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	Outpost 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	
	Parameterize losses by	Required Data
Import Loss Data	Tabulated loss data	<ul style="list-style-type: none"> • Motor speed, rad/s • Motor torque, N·m • Power loss, W
	Tabulated loss data with temperature	<ul style="list-style-type: none"> • Motor speed, rad/s • Motor torque, N·m • Motor temperature, K • Power loss, W
Collect motor data at steady-state operating conditions. Data should cover the motor speed, torque, and temperature operating range.		
To filter or edit the data, select Edit in Application . The Model-Based Calibration Toolbox Data Editor opens.		

Task	Description						
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 Edit in Application. 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 Edit in Application. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration Tables” (Model-Based Calibration Toolbox).</p>						
Update block parameters	<p>Update these parameters with the calibration.</p> <table border="1"> <thead> <tr> <th>Parameterize losses by</th><th>Parameters</th></tr> </thead> <tbody> <tr> <td>Tabulated loss data</td><td> <ul style="list-style-type: none"> Vector of speeds(w) for tabulated losses, <code>w_eff_bp</code> Vector of torques (T) for tabulated losses, <code>T_eff_bp</code> Corresponding losses, <code>losses_table</code> </td></tr> <tr> <td>Tabulated loss data with temperature</td><td> <ul style="list-style-type: none"> Vector of speeds(w) for tabulated losses, <code>w_eff_bp</code> Vector of torques (T) for tabulated losses, <code>T_eff_bp</code> Vector of temperatures for tabulated losses, <code>Temp_eff_bp</code> Corresponding losses, <code>losses_table_3d</code> </td></tr> </tbody> </table>	Parameterize losses by	Parameters	Tabulated loss data	<ul style="list-style-type: none"> Vector of speeds(w) for tabulated losses, <code>w_eff_bp</code> Vector of torques (T) for tabulated losses, <code>T_eff_bp</code> Corresponding losses, <code>losses_table</code> 	Tabulated loss data with temperature	<ul style="list-style-type: none"> Vector of speeds(w) for tabulated losses, <code>w_eff_bp</code> Vector of torques (T) for tabulated losses, <code>T_eff_bp</code> Vector of temperatures for tabulated losses, <code>Temp_eff_bp</code> Corresponding losses, <code>losses_table_3d</code>
Parameterize losses by	Parameters						
Tabulated loss data	<ul style="list-style-type: none"> Vector of speeds(w) for tabulated losses, <code>w_eff_bp</code> Vector of torques (T) for tabulated losses, <code>T_eff_bp</code> Corresponding losses, <code>losses_table</code> 						
Tabulated loss data with temperature	<ul style="list-style-type: none"> Vector of speeds(w) for tabulated losses, <code>w_eff_bp</code> Vector of torques (T) for tabulated losses, <code>T_eff_bp</code> Vector of temperatures for tabulated losses, <code>Temp_eff_bp</code> Corresponding losses, <code>losses_table_3d</code> 						

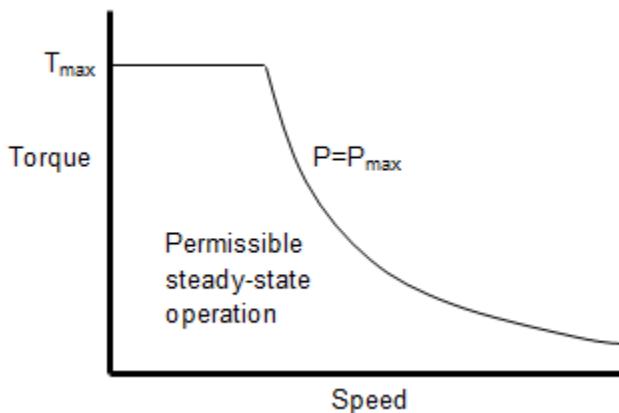
Electrical Torque

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 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 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, torque_max — Torque 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, power_max — Power 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, Tc — Time constant 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"> • Fixed losses independent of torque and speed, P_0. Use P_0 to account for fixed converter losses. • A torque-dependent electrical loss $k\tau^2$, where k is a constant and τ is the torque. Represents ohmic losses in the copper windings. • A speed-dependent electrical loss $k_w\omega^2$, where k_w is a constant and ω is the speed. Represents iron losses due to eddy currents.
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 Calibrate Maps 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 Calibrate Maps 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">Converts the efficiency values you provide into losses and uses the tabulated losses for simulation.Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero.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.Does not extrapolate loss values for speed and torque magnitudes that exceed the range of the table.
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">Converts the efficiency values you provide into losses and uses the tabulated losses for simulation.Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero.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.Does not extrapolate loss values for speed, torque, or temperature magnitudes that exceed the range of the table.

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.

Motor and drive overall efficiency, eff – Efficiency 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.

τ_0	Torque at which efficiency is measured
ω_0	Speed at which efficiency is measured
P_0	Fixed losses independent of torque or speed
$k \tau_0^2$	Torque-dependent electrical losses
$k_w \omega^2$	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 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_eff – Torque 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, Piron — Power 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, Pbase — Power 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_eff_bp — Breakpoints 1-by-M array

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_eff_bp — Breakpoints 1-by-N array

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

1-by-L array

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 array

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 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, 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**Rotational inertia, J — Inertia**
scalar

Rotor resistance to change in motor motion, in kg*m². The value can be zero.

Dependencies

To create this parameter, for the **Port configuration** parameter, select Torque.

Rotor damping, b — Damping
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
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

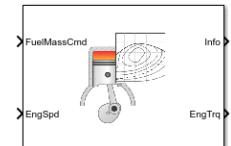
Mapped CI Engine

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	$f(FN)$
	on	$f(FN, \text{Temp}_{\text{Eng}})$
Torque	off	$f(TN)$
	on	$f(TN, \text{Temp}_{\text{Eng}})$

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 (CO₂) 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	Import this firing data from a file. For more information, see “Using Data” (Model-Based Calibration Toolbox).		
Input command	Required Data	Optional Data	
	Fuel mass	<ul style="list-style-type: none"> • Engine speed, rpm • Commanded fuel mass per injection, mg • Engine torque, N·m 	<ul style="list-style-type: none"> • Air mass flow rate, kg/s • Brake specific fuel consumption, g/(kW·h) • CO₂ mass flow rate, kg/s • CO mass flow rate, kg/s • Exhaust temperature, K • Fuel mass flow rate, kg/s • HC mass flow rate, kg/s • NO_x mass flow rate, kg/s • Particulate matter mass flow rate, kg/s
	Torque	<ul style="list-style-type: none"> • Engine speed, rpm • Engine torque, N·m 	
	<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 Edit in Application. The Model-Based Calibration Toolbox Data Editor opens.</p>		
Import non-firing data	<p>Import this non-firing data from a file.</p> <ul style="list-style-type: none"> • Engine speed, rpm • Engine torque, N·m 		
	<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 Edit in Application . 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 Edit in Application . The Model-Based Calibration Toolbox CAGE Brower opens. For more information, see “Calibration 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	$\tau_{bst} = \begin{cases} \tau_{bst, rising} & \text{when } F_{cmd} > F_{max} \\ \tau_{bst, falling} & \text{when } F_{cmd} \leq F_{max} \end{cases}$	$\tau_{bst} = \begin{cases} \tau_{bst, rising} & \text{when } T_{cmd} > T_{max} \\ \tau_{bst, falling} & \text{when } T_{cmd} \leq T_{max} \end{cases}$

Calculation	Input command Parameter Setting	
	Fuel mass	Torque
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
τ_{bst}	Boost time constant
$\tau_{bst,rising}, \tau_{bst,falling}$	Boost rising and falling time constant, respectively
τ_{eng}	Final time constant
τ_{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
PwrIn fo	PwrTrnsfrd — Power transferred between blocks <ul style="list-style-type: none"> Positive signals indicate flow into block Negative signals indicate flow out of block 	PwrCrkshft	Crankshaft power	$-\tau_{eng}\omega$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred <ul style="list-style-type: none"> Positive signals indicate an input Negative signals indicate a loss 		PwrFuel	$\dot{m}_{fuel}LHV$
	PwrStored — Stored energy rate of change <ul style="list-style-type: none"> Positive signals indicate an increase Negative signals indicate a decrease 		PwrLoss	$\tau_{eng}\omega - \dot{m}_{fuel}LHV$
			<i>Not used</i>	

The equations use these variables.

LHV	Fuel lower heating value
ω	Engine speed, rad/s
\dot{m}_{fuel}	Fuel mass flow
τ_{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 create this port, for **Input command**, select Fuel mass.

TrqCmd — Torque command
scalar

Torque command, T , in N·m.

Dependencies

To create 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 create 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 ³ /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
EoPM	Engine out particulate matter emission mass flow			kg/s
PwrInf 0	PwrTrnsfrd	PwrCrkshft	Crankshaft power	W
	PwrNotTrns frd	PwrFuel	Fuel input power	W
		PwrLoss	Power loss	W

Signal	Description	Units
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

τ_{bst}	Boost time constant
$\tau_{bst,rising}, \tau_{bst,falling}$	Boost rising and falling time constant, respectively
τ_{eng}	Final time constant
τ_{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		
	Input command	Required Data	Optional Data
Import firing data	Fuel mass	<ul style="list-style-type: none"> • Engine speed, rpm • Commanded fuel mass per injection, mg • Engine torque, N·m 	<ul style="list-style-type: none"> • Air mass flow rate, kg/s • Brake specific fuel consumption, g/(kW·h) • CO₂ mass flow rate, kg/s • CO mass flow rate, kg/s • Exhaust temperature, K • Fuel mass flow rate, kg/s • HC mass flow rate, kg/s • NO_x mass flow rate, kg/s • Particulate matter mass flow rate, kg/s
Import firing data	Torque	<ul style="list-style-type: none"> • Engine speed, rpm • Engine torque, N·m 	
<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 Edit in Application. The Model-Based Calibration Toolbox Data Editor opens.</p>			

Task	Description
Import non-firing data	<p>Import this non-firing data from a file.</p> <ul style="list-style-type: none"> • Engine speed, rpm • Engine torque, N·m <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 Edit in Application. 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 Edit in Application. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration 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_tbake_f_bpt – Breakpoints
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
vector

Breakpoints, in N·m.

Dependencies

Setting **Input command** to Torque enables this parameter.

Breakpoints for engine speed input, f_tbrake_n_bpt – Breakpoints
vector

Breakpoints, in rpm.

Breakpoints for temperature input, f_tbrake_engtmp_bpt – Breakpoints
vector

Breakpoints, in K.

Dependencies

To enable this parameter, select **Input engine temperature**.

Number of cylinders, NCyl – Number
scalar

Number of cylinders.

Crank revolutions per power stroke, Cps – Crank revolutions
scalar

Crank revolutions per power stroke.

Total displaced volume, Vd – Volume
scalar

Volume displaced by engine, in m³.

Fuel lower heating value, Lhv – Heating value
scalar

Fuel lower heating value, *LHV*, in J/kg.

Fuel specific gravity, Sg — Specific gravity
scalar

Specific gravity of fuel, Sg_{fuel} , dimensionless.

Ideal gas constant air, Rair — Constant
scalar

Ideal gas constant of air and residual gas entering the engine intake port, in J/(kg·K).

Air standard pressure, Pstd — Pressure
scalar

Standard air pressure, in Pa.

Air standard temperature, Tstd — Temperature
scalar

Standard air temperature, in K.

Boost torque line, f_tbrake_bst — Boost lag
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
scalar

Time constant below boost line, τ_{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
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
scalar

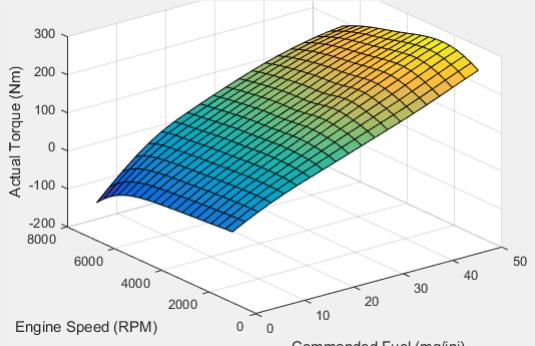
Falling maximum fuel mass boost time constant, $\tau_{bst,falling}$, in s.

Dependencies

To enable this parameter, select **Include turbocharger lag effect**.

Power

Brake torque map, f_tbrake — 2D lookup table
array

Input Command Setting	Description
Fuel mass	<p>The engine brake torque lookup table is a function of commanded fuel mass and engine speed, $T_{brake} = f(F, N)$, where:</p> <ul style="list-style-type: none"> • T_{brake} is engine torque, in N·m. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. 

Input Command Setting	Description
Torque	<p>The engine brake torque lookup table is a function of target torque and engine speed, $T_{brake} = f(T_{target}, N)$, where:</p> <ul style="list-style-type: none"> • T_{brake} is engine torque, in N·m. • T_{target} is target torque, in N·m. • N is engine speed, in rpm.

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_tbroke_3d — 3D lookup table
array

Input Command Setting	Description
Fuel mass	<p>The engine brake torque lookup table is a function of commanded fuel mass and engine speed, $T_{brake} = f(F, N, Temp_{Eng})$, where:</p> <ul style="list-style-type: none"> • T_{brake} is engine torque, in N·m. • F is commanded fuel mass, in mg per injection. • $Temp_{Eng}$ is engine temperature, in K.

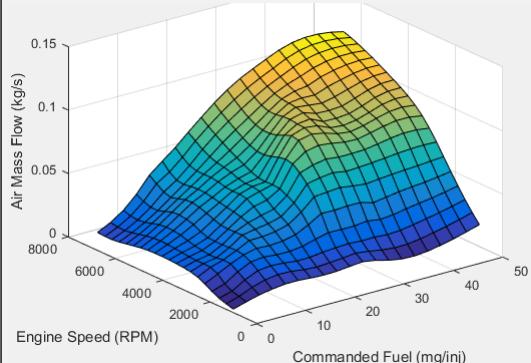
Input Command Setting	Description
Torque	<p>The engine brake torque lookup table is a function of target torque and engine speed, $T_{brake} = f(T_{target}, N, Temp_{Eng})$, where:</p> <ul style="list-style-type: none">• T_{brake} is engine torque, in N·m.• T_{target} is target torque, in N·m.• N is 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 array

Input Command Setting	Description
Fuel mass	<p>The air mass flow lookup table is a function of commanded fuel mass and engine speed, $\dot{m}_{intk} = f(F_{max}, N)$, where:</p> <ul style="list-style-type: none"> • \dot{m}_{intk} is engine air mass flow, in kg/s. • F_{max} is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. 
Torque	<p>The air mass flow lookup table is a function of maximum torque and engine speed, $\dot{m}_{intk} = f(T_{max}, N)$, where:</p> <ul style="list-style-type: none"> • \dot{m}_{intk} is engine air mass flow, in kg/s. • T_{max} is maximum 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 array

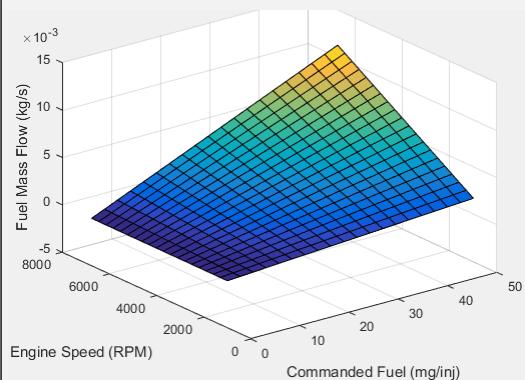
Input Command Setting	Description
Fuel mass	The air mass flow lookup table is a function of commanded fuel mass and engine speed, $\dot{m}_{intk} = f(F_{max}, N, Temp_{Eng})$, where: <ul style="list-style-type: none"> • \dot{m}_{intk} is engine air mass flow, in kg/s. • F_{max} is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.
Torque	The air mass flow lookup table is a function of maximum torque and engine speed, $\dot{m}_{intk} = f(T_{max}, N, Temp_{Eng})$, where: <ul style="list-style-type: none"> • \dot{m}_{intk} is engine air mass flow, in kg/s. • T_{max} is maximum 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 array

Input Command Setting	Description
Fuel mass	<p>The engine fuel flow lookup table is a function of commanded fuel mass and engine speed, $MassFlow = f(F, N)$, where:</p> <ul style="list-style-type: none"> • $MassFlow$ is engine fuel mass flow, in kg/s. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. 
Torque	<p>The engine fuel flow lookup table is a function of target torque and engine speed, $MassFlow = f(T_{target}, N)$, where:</p> <ul style="list-style-type: none"> • $MassFlow$ is engine fuel mass flow, in kg/s. • T_{target} is target 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
array

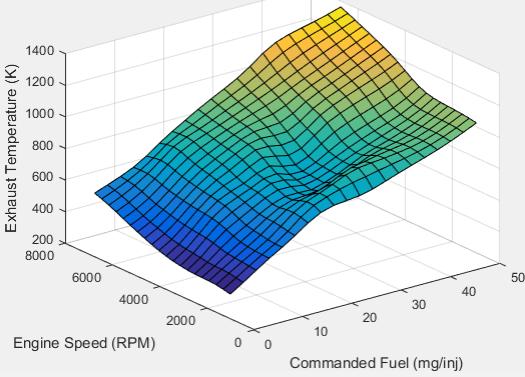
Input Command Setting	Description
Fuel mass	The engine fuel flow lookup table is a function of commanded fuel mass, engine speed, and engine temperature, $MassFlow = f(F, N, Temp_{Eng})$, where: <ul style="list-style-type: none"> • $MassFlow$ is engine fuel mass flow, in kg/s. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.
Torque	The engine fuel flow lookup table is a function of target torque and engine speed, and engine temperature, $MassFlow = f(T_{target}, N, Temp_{Eng})$, where: <ul style="list-style-type: none"> • $MassFlow$ is engine fuel mass flow, in kg/s. • T_{target} is target 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
array

Input Command Setting	Description
Fuel mass	<p>The engine exhaust temperature table is a function of commanded fuel mass and engine speed, $T_{exh} = f(F, N)$, where:</p> <ul style="list-style-type: none"> • T_{exh} is exhaust temperature, in K. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. 
Torque	<p>The engine exhaust temperature table is a function of target torque and engine speed, $T_{exh} = f(T_{target}, N)$, where:</p> <ul style="list-style-type: none"> • T_{exh} is exhaust temperature, in K. • T_{target} is target 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

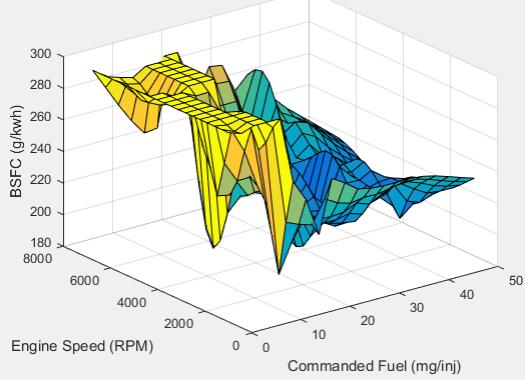
Input Command Setting	Description
Fuel mass	The engine exhaust temperature table is a function of commanded fuel mass and engine speed, $T_{exh} = f(F, N, Temp_{Eng})$, where: <ul style="list-style-type: none"> • T_{exh} is exhaust temperature, in K. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.
Torque	The engine exhaust temperature table is a function of target torque and engine speed, $T_{exh} = f(T_{target}, N, Temp_{Eng})$, where: <ul style="list-style-type: none"> • T_{exh} is exhaust temperature, in K. • T_{target} is target 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 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, $BSFC = f(F, N)$, where:</p> <ul style="list-style-type: none"> • $BSFC$ is BSFC, in g/kWh. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. 
Torque	<p>The brake-specific fuel consumption (BSFC) efficiency is a function of target torque and engine speed, $BSFC = f(T_{target}, N)$, where:</p> <ul style="list-style-type: none"> • $BSFC$ is BSFC, in g/kWh. • T_{target} is target 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 array

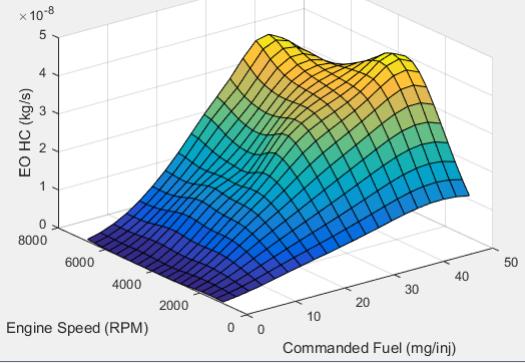
Input Command Setting	Description
Fuel mass	The brake-specific fuel consumption (BSFC) efficiency is a function of commanded fuel mass and engine speed, $BSFC = f(F, N, Temp_{Eng})$, where: <ul style="list-style-type: none"> • $BSFC$ is BSFC, in g/kWh. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.
Torque	The brake-specific fuel consumption (BSFC) efficiency is a function of target torque and engine speed, $BSFC = f(T_{target}, N, Temp_{Eng})$, where: <ul style="list-style-type: none"> • $BSFC$ is BSFC, in g/kWh. • T_{target} is target 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 array

Input Command Setting	Description
Fuel mass	<p>The engine-out hydrocarbon emissions are a function of commanded fuel mass and engine speed, $EO\ HC = f(F, N)$, where:</p> <ul style="list-style-type: none"> • $EO\ HC$ is engine-out hydrocarbon emissions, in kg/s. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. 
Torque	<p>The engine-out hydrocarbon emissions are a function of target torque and engine speed, $EO\ HC = f(T_{target}, N)$, where:</p> <ul style="list-style-type: none"> • $EO\ HC$ is engine-out hydrocarbon emissions, in kg/s. • T_{target} is target 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**.

EO HC map, f_hc_3d — 3D lookup table
array

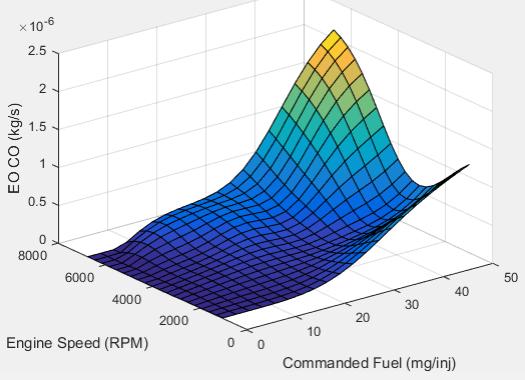
Input Command Setting	Description
Fuel mass	The engine-out hydrocarbon emissions are a function of commanded fuel mass and engine speed, $EO\ HC = f(F, N, Temp_{Eng})$, where: <ul style="list-style-type: none"> • $EO\ HC$ is engine-out hydrocarbon emissions, in kg/s. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.
Torque	The engine-out hydrocarbon emissions are a function of target torque and engine speed, $EO\ HC = f(T_{target}, N, Temp_{Eng})$, where: <ul style="list-style-type: none"> • $EO\ HC$ is engine-out hydrocarbon emissions, in kg/s. • T_{target} is target 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

EO CO map, f_co — 2D lookup table
array

Input Command Setting	Description
Fuel mass	<p>The engine-out carbon monoxide emissions are a function of commanded fuel mass and engine speed, $EO\ CO = f(F, N)$, where:</p> <ul style="list-style-type: none"> • $EO\ CO$ is engine-out carbon monoxide emissions, in kg/s. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. 
Torque	<p>The engine-out carbon monoxide emissions are a function of target torque and engine speed, $EO\ CO = f(T_{target}, N)$, where:</p> <ul style="list-style-type: none"> • $EO\ CO$ is engine-out carbon monoxide emissions, in kg/s. • T_{target} is target torque, in N·m. • N is engine speed, in rpm.

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 array

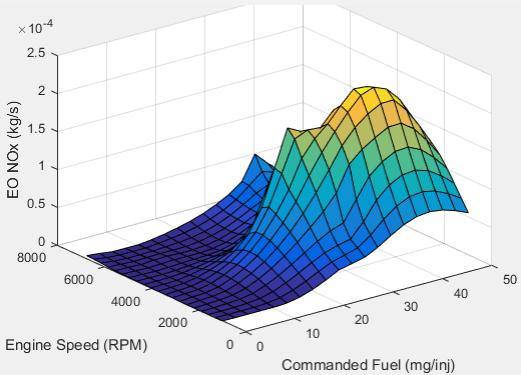
Input Command Setting	Description
Fuel mass	The engine-out carbon monoxide emissions are a function of commanded fuel mass and engine speed, $EO\ CO = f(F, N, Temp_{Eng})$, where: <ul style="list-style-type: none"> • $EO\ CO$ is engine-out carbon monoxide emissions, in kg/s. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.
Torque	The engine-out carbon monoxide emissions are a function of target torque and engine speed, $EO\ CO = f(T_{target}, N, Temp_{Eng})$, where: <ul style="list-style-type: none"> • $EO\ CO$ is engine-out carbon monoxide emissions, in kg/s. • T_{target} is target 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

EO NOx map, f_nox — 2D lookup table array

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, $EO\ NOx = f(F, N)$, where:</p> <ul style="list-style-type: none"> • $EO\ NOx$ is engine-out nitric oxide and nitrogen dioxide emissions, in kg/s. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. 
Torque	<p>The engine-out nitric oxide and nitrogen dioxide emissions are a function of target torque and engine speed, $EO\ NOx = f(T_{target}, N)$, where:</p> <ul style="list-style-type: none"> • $EO\ NOx$ is engine-out nitric oxide and nitrogen dioxide emissions, in kg/s. • T_{target} is target torque, in N·m. • N is engine speed, in rpm.

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**.

E0 NOx map, f_nox_3d – 3D lookup table array

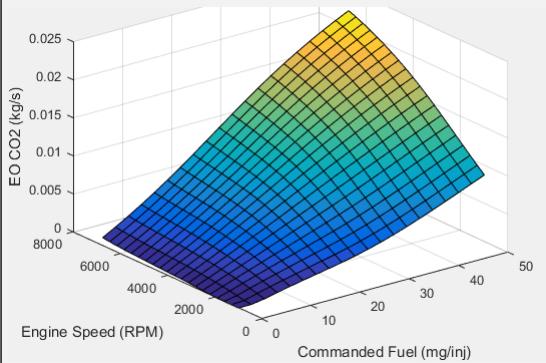
Input Command Setting	Description
Fuel mass	<p>The engine-out nitric oxide and nitrogen dioxide emissions are a function of commanded fuel mass, engine speed, and engine temperature, $EO\ NOx = f(F, N, Temp_{Eng})$, where:</p> <ul style="list-style-type: none"> • $EO\ NOx$ is engine-out nitric oxide and nitrogen dioxide emissions, in kg/s. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.
Torque	<p>The engine-out nitric oxide and nitrogen dioxide emissions are a function of target torque, engine speed, and engine temperature, $EO\ NOx = f(T_{target}, N, Temp_{Eng})$, where:</p> <ul style="list-style-type: none"> • $EO\ NOx$ is engine-out nitric oxide and nitrogen dioxide emissions, in kg/s. • T_{target} is target 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 array

Input Command Setting	Description
Fuel mass	<p>The engine-out carbon dioxide emissions are a function of commanded fuel mass and engine speed, $EO\ CO2 = f(F, N)$, where:</p> <ul style="list-style-type: none"> • $EO\ CO2$ is engine-out carbon dioxide emissions, in kg/s. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. 
Torque	<p>The engine-out carbon dioxide emissions are a function of target torque and engine speed, $EO\ CO2 = f(T_{target}, N)$, where:</p> <ul style="list-style-type: none"> • $EO\ CO2$ is engine-out carbon dioxide emissions, in kg/s. • T_{target} is target 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
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, $EO\ CO2 = f(F, N, Temp_{Eng})$, where:</p> <ul style="list-style-type: none"> • $EO\ CO2$ is engine-out carbon dioxide emissions, in kg/s. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.
Torque	<p>The engine-out carbon dioxide emissions are a function of target torque, engine speed, and engine temperature, $EO\ CO2 = f(T_{target}, N, Temp_{Eng})$, where:</p> <ul style="list-style-type: none"> • $EO\ CO2$ is engine-out carbon dioxide emissions, in kg/s. • T_{target} is target 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
array

Input Command Setting	Description
Fuel mass	The engine-out PM emissions are a function of commanded fuel mass and engine speed, where: <ul style="list-style-type: none">• $EO\ PM$ is engine-out PM emissions, in kg/s.• F is commanded fuel mass, in mg per injection.• N is engine speed, in rpm.
Torque	The engine-out PM emissions are a function of target torque and engine speed, $EO\ PM = f(T_{target}, N)$, where: <ul style="list-style-type: none">• $EO\ PM$ is engine-out PM emissions, in kg/s.• T_{target} is target torque, in N·m.• N is engine speed, in rpm.

Dependencies

To enable this parameter, clear **Input engine temperature**.

Plot EO PM map — Plot table
button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

EO PM map, f_pm_3d — 3D lookup table
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"> • $EO\ PM$ is engine-out PM emissions, in kg/s. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.
Torque	<p>The engine-out PM emissions are a function of target torque, engine speed, and engine temperature, $EO\ PM = f(T_{target}, N, T)$, where:</p> <ul style="list-style-type: none"> • $EO\ PM$ is engine-out PM emissions, in kg/s. • T_{target} is target 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

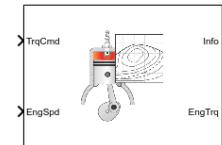
Mapped Motor | Mapped SI Engine

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		

Table	Input Engine Temperature Parameter Setting	
	off	on
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 firing data from a file. 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"> • Engine speed, rpm • Engine torque, N·m </td><td> <ul style="list-style-type: none"> • Air mass flow rate, kg/s • Brake specific fuel consumption, g/(kW·h) • CO₂ mass flow rate, kg/s • CO mass flow rate, kg/s • Exhaust temperature, K • Fuel mass flow rate, kg/s • HC mass flow rate, kg/s • NO_x mass flow rate, kg/s • Particulate matter mass flow rate, kg/s </td></tr> </tbody> </table>		Required Data	Optional Data	<ul style="list-style-type: none"> • Engine speed, rpm • Engine torque, N·m 	<ul style="list-style-type: none"> • Air mass flow rate, kg/s • Brake specific fuel consumption, g/(kW·h) • CO₂ mass flow rate, kg/s • CO mass flow rate, kg/s • Exhaust temperature, K • Fuel mass flow rate, kg/s • HC mass flow rate, kg/s • NO_x mass flow rate, kg/s • Particulate matter mass flow rate, kg/s
Required Data	Optional Data					
<ul style="list-style-type: none"> • Engine speed, rpm • Engine torque, N·m 	<ul style="list-style-type: none"> • Air mass flow rate, kg/s • Brake specific fuel consumption, g/(kW·h) • CO₂ mass flow rate, kg/s • CO mass flow rate, kg/s • Exhaust temperature, K • Fuel mass flow rate, kg/s • HC mass flow rate, kg/s • NO_x mass flow rate, kg/s • Particulate matter mass flow rate, kg/s 					
	<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 Edit in Application. The Model-Based Calibration Toolbox Data Editor opens.</p>					
Import non-firing data	<p>Import this non-firing data from a file.</p> <ul style="list-style-type: none"> • Engine speed, rpm • Engine torque, N·m <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 Edit in Application . 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 Edit in Application . The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration 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**. 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
T_{stdy}	Steady-state target torque
τ_{bst}	Boost time constant
$\tau_{bst,rising},$ $\tau_{bst,falling}$	Boost rising and falling time constant, respectively
τ_{eng}	Final time constant
τ_{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.

$$Q_{fuel} = \frac{\dot{m}_{fuel}}{\left(\frac{1000\text{kg}}{m^3}\right)Sg_{fuel}}$$

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
PwrIn fo	PwrTrnsfrd — Power transferred between blocks	PwrCrkshft	Crankshaft power	$-\tau_{eng}\omega$
	<ul style="list-style-type: none"> Positive signals indicate flow into block Negative signals indicate flow out of block 			
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred	PwrFuel PwrLoss	Fuel input power Power loss	$\dot{m}_{fuel}LHV$ $\tau_{eng}\omega$ $-\dot{m}_{fuel}LHV$
PwrStored — Stored energy rate of change			<i>Not used</i>	
<ul style="list-style-type: none"> Positive signals indicate an increase Negative signals indicate a decrease 				

The equations use these variables.

LHV	Fuel lower heating value
ω	Engine speed, rad/s
\dot{m}_{fuel}	Fuel mass flow
τ_{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 create 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 ³ /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
EoPM	Engine out particulate matter emission mass flow		kg/s
PwrInf 0	PwrTrnsfrd	PwrCrkshft	Crankshaft power
	PwrNotTrnsfrd	PwrFuel	Fuel input power
		PwrLoss	Power loss

Signal	Description	Units
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	$\frac{dT_{brake}}{dt} = \frac{1}{\tau_{eng}}(T_{stdy} - T_{brake})$
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 |
| τ_{bst} | Boost time constant |
| $\tau_{bst,rising},$
$\tau_{bst,falling}$ | Boost rising and falling time constant, respectively |
| τ_{eng} | Final time constant |

τ_{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		
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					
	Required Data	Optional Data				
Import firing data	<p>Import this firing data from a file. 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">Engine speed, rpmEngine torque, N·m</td><td><ul style="list-style-type: none">Air mass flow rate, kg/sBrake specific fuel consumption, g/(kW·h)CO₂ mass flow rate, kg/sCO mass flow rate, kg/sExhaust temperature, KFuel mass flow rate, kg/sHC mass flow rate, kg/sNO_x mass flow rate, kg/sParticulate matter mass flow rate, kg/s</td></tr></tbody></table>		Required Data	Optional Data	<ul style="list-style-type: none">Engine speed, rpmEngine torque, N·m	<ul style="list-style-type: none">Air mass flow rate, kg/sBrake specific fuel consumption, g/(kW·h)CO₂ mass flow rate, kg/sCO mass flow rate, kg/sExhaust temperature, KFuel mass flow rate, kg/sHC mass flow rate, kg/sNO_x mass flow rate, kg/sParticulate matter mass flow rate, kg/s
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<ul style="list-style-type: none">Engine speed, rpmEngine torque, N·m	<ul style="list-style-type: none">Air mass flow rate, kg/sBrake specific fuel consumption, g/(kW·h)CO₂ mass flow rate, kg/sCO mass flow rate, kg/sExhaust temperature, KFuel mass flow rate, kg/sHC mass flow rate, kg/sNO_x mass flow rate, kg/sParticulate matter mass flow rate, kg/s					
	<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 Edit in Application. The Model-Based Calibration Toolbox Data Editor opens.</p>					

Task	Description
Import non-firing data	<p>Import this non-firing data from a file.</p> <ul style="list-style-type: none"> • Engine speed, rpm • Engine torque, N·m <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 Edit in Application. 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 Edit in Application. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration 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_tbroke_t_bpt — Breakpoints vector

Breakpoints, in N·m.

Breakpoints for engine speed input, f_tbroke_n_bpt — Breakpoints vector

Breakpoints, in rpm.

Breakpoints for temperature input, f_tbrake_engtmp_bpt — Breakpoints vector

Breakpoints, in K.

Dependencies

To enable this parameter, select **Input engine temperature**.

Number of cylinders, NCyl — Number scalar

Number of cylinders.

Crank revolutions per power stroke, Cps — Crank revolutions scalar

Crank revolutions per power stroke.

Total displaced volume, Vd — Volume scalar

Volume displaced by engine, in m³.

Fuel lower heating value, Lhv — Heating value scalar

Fuel lower heating value, *LHV*, in J/kg.

Fuel specific gravity, Sg — Specific gravity scalar

Specific gravity of fuel, *Sg_{fuel}*, dimensionless.

Ideal gas constant air, Rair — Constant scalar

Ideal gas constant of air and residual gas entering the engine intake port, in J/(kg*K).

Air standard pressure, Pstd — Pressure scalar

Standard air pressure, in Pa.

Air standard temperature, Tstd — Temperature
scalar

Standard air temperature, in K.

Boost torque line, f_tbrake_bst — Boost lag
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
scalar

Time constant below boost line, τ_{thr} , in s.

Dependencies

To enable this parameter, select **Include turbocharger lag effect**.

Rising torque boost time constant, tau_bst_rising — Rising time
constant
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
scalar

Falling torque boost time constant, $\tau_{bst,falling}$, in s.

Dependencies

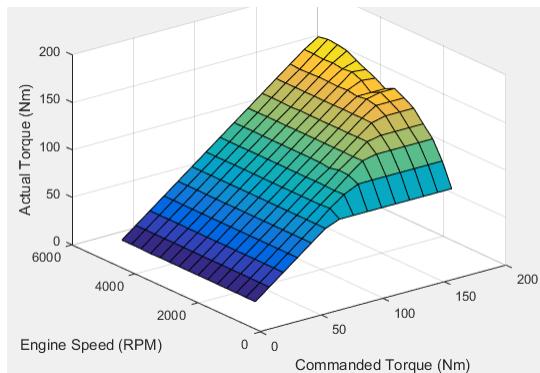
To enable this parameter, select **Include turbocharger lag effect**.

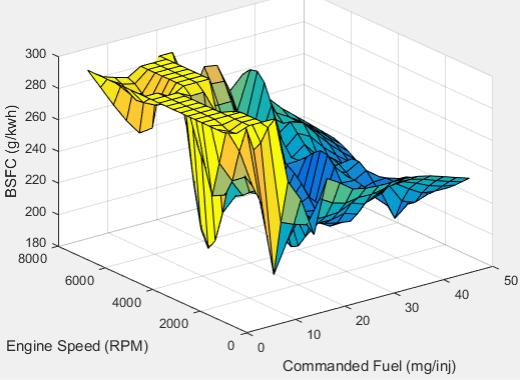
Power

Brake torque map, f_{tbrake} — 2D lookup table array

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.



Input Command Setting	Description
Fuel mass	<p>The brake-specific fuel consumption (BSFC) efficiency is a function of commanded fuel mass and engine speed, $BSFC = f(F, N)$, where:</p> <ul style="list-style-type: none"> • $BSFC$ is BSFC, in g/kWh. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. 
Torque	<p>The brake-specific fuel consumption (BSFC) efficiency is a function of target torque and engine speed, $BSFC = f(T_{target}, N)$, where:</p> <ul style="list-style-type: none"> • $BSFC$ is BSFC, in g/kWh. • T_{target} is target 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 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.

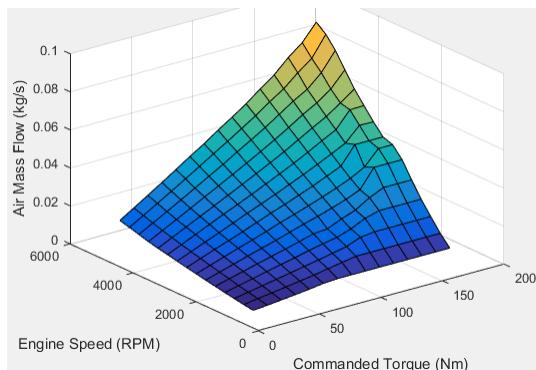
Dependencies

To enable this parameter, select **Input engine temperature**.

Air**Air mass flow map, f_air — 2D lookup table array**

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 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

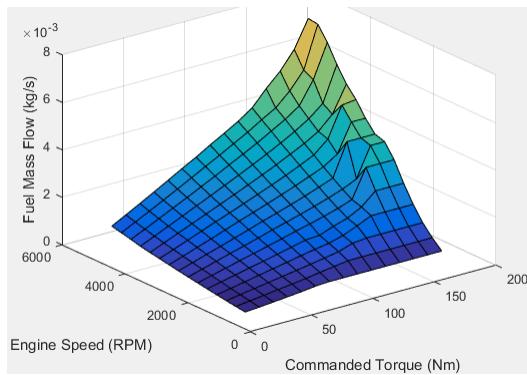
To enable this parameter, select **Input engine temperature**.

Fuel

Fuel flow map, f_fuel — 2D lookup table array

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
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

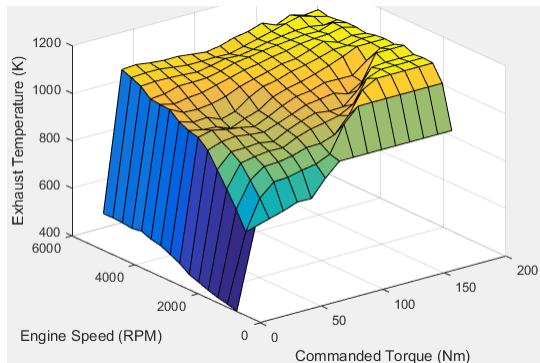
To enable this parameter, select **Input engine temperature**.

Temperature

Exhaust temperature map, f_{texh} – 2D lookup table array

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

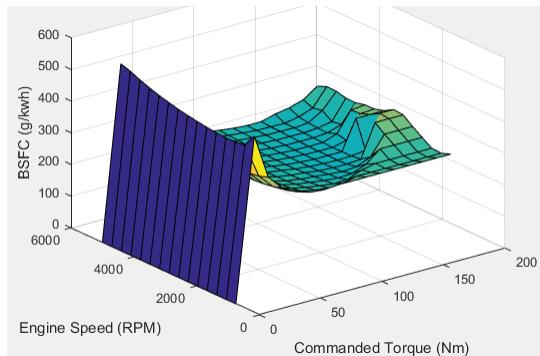
To enable this parameter, select **Input engine temperature**.

Efficiency

BSFC map, f_eff — 2D lookup table 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 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

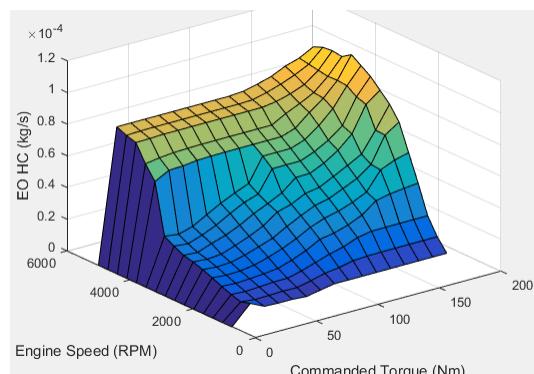
To enable this parameter, select **Input engine temperature**.

HC

E0 HC map, f_hc – 2D lookup table array

The engine-out hydrocarbon emissions are a function of commanded engine torque and engine speed, $E0 HC = f(T_{cmd}, N)$, where:

- $E0 HC$ 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 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

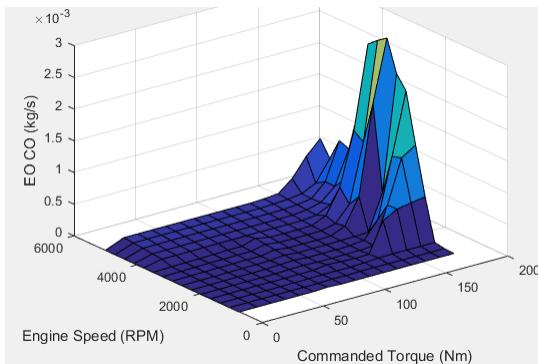
To enable this parameter, select **Input engine temperature**.

CO

E0 CO map, f_co — 2D lookup table array

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

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.

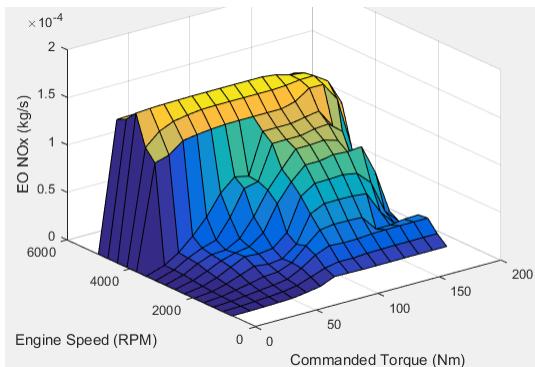
Dependencies

To enable this parameter, select **Input engine temperature**.

NOx**E0 NOx map, f_nox — 2D lookup table array**

The engine-out nitric oxide and nitrogen dioxide emissions are a function of commanded engine torque and engine speed, $E0 NOx = f(T_{cmd}, N)$, where:

- $E0 NOx$ 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 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

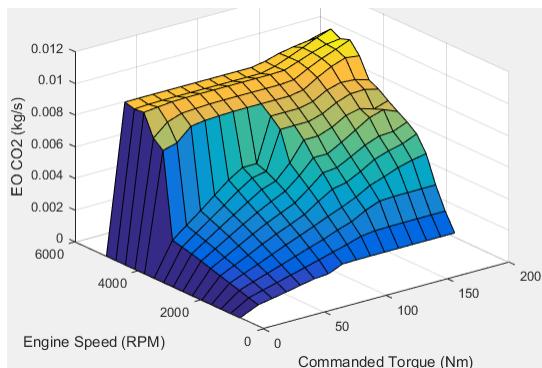
To enable this parameter, select **Input engine temperature**.

CO₂

E0 CO₂ map, f_co2 — 2D lookup table array

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

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

array

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**.

EO PM map, f_pm_3d – 3D lookup table 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

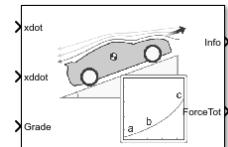
Introduced in R2017a

Vehicle Dynamics Blocks – Alphabetical List

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.

$$F_{road} = a + b\dot{x} + c\dot{x}^2 + mgsin(\theta)$$

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"> Positive signals indicate flow into block Negative signals indicate flow out of block 	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"> Positive signals indicate an input Negative signals indicate a loss 	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"> Positive signals indicate an increase Negative signals indicate a decrease 	wrStoredGrvty	Rate change in gravitational potential energy	P_g	$P_g = -mg\dot{Z}$

Bus Signal	Description	Variable	Equations	
	PwrSt oredx dot	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 vehicle-fixed frame
\dot{x}	Vehicle longitudinal velocity with respect to ground, in vehicle-fixed frame
\ddot{x}	Vehicle longitudinal acceleration with respect to ground, vehicle-fixed frame
m	Vehicle body mass
Θ	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 vehicle-fixed z-axis

Ports

Input

xdot — Vehicle longitudinal velocity
scalar

Vehicle total longitudinal velocity, \dot{x} , in m/s.

Dependencies

To create this port, for the **Input Mode** parameter, select Kinematic.

xddot — Vehicle longitudinal acceleration

scalar

Vehicle total longitudinal acceleration, \ddot{x} , in m/s².

Dependencies

To create this port, for the **Input Mode** parameter, select Kinematic.

PwrTot — Tractive input power

scalar

Tractive input power, P_{total} , in W.

Dependencies

To create this port, for the **Input Mode** parameter, select Power.

ForceTot — Tractive input force

scalar

Tractive input force, F_{total} , in N.

Dependencies

To create this port, for the **Input Mode** parameter, select Force.

Grade — Road grade angle

scalar

Road grade angle, Θ , in deg.

Output

Info — Bus signal

bus

Bus signal containing these block calculations.

Signal			Description		Value	Units
Inner Frame	Cg	Disp	X	Vehicle CG displacement along earth-fixed X-axis	Computed	m
			Y	Vehicle CG displacement along earth-fixed Y-axis	θ	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	θ	m/s	
		Zdot	Vehicle CG velocity along earth-fixed Z-axis	Computed	m/s	
	Ang	phi	Rotation of vehicle-fixed frame about earth-fixed X-axis (roll)	θ	rad	
		theta	Rotation of vehicle-fixed frame about earth-fixed Y-axis (pitch)	Computed	rad	
		psi	Rotation of vehicle-fixed frame about earth-fixed Z-axis (yaw)	θ	rad	
Body Frame	Cg	Disp	x	Vehicle CG displacement along vehicle-fixed x-axis	Computed	m
			y	Vehicle CG displacement along vehicle-fixed y-axis	θ	m
			z	Vehicle CG displacement along vehicle-fixed z-axis	θ	m
	Vel	xdot	Vehicle CG velocity along vehicle-fixed x-axis	Computed	m/s	
		ydot	Vehicle CG velocity along vehicle-fixed y-axis	θ	m/s	
		zdot	Vehicle CG velocity along vehicle-fixed z-axis	θ	m/s	
	Acc	ax	Vehicle CG acceleration along vehicle-fixed x-axis	Computed	gn	

Signal		Description		Value	Units
For ces		ay	Vehicle CG acceleration along vehicle-fixed y-axis	0	gn
		az	Vehicle CG acceleration along vehicle-fixed z-axis	0	gn
	Body	Fx	Net force on vehicle CG along vehicle-fixed x-axis	Computed	N
		Fy	Net force on vehicle CG along vehicle-fixed y-axis	0	N
		Fz	Net force on vehicle CG along vehicle-fixed z-axis	0	N
	Ext	Fx	External force on vehicle CG along vehicle-fixed x-axis	Computed	N
		Fy	External force on vehicle CG along vehicle-fixed y-axis	0	N
		Fz	External force on vehicle CG along vehicle-fixed z-axis	0	N
	Drag	Fx	Drag force on vehicle CG along vehicle-fixed x-axis	Computed	N
		Fy	Drag force on vehicle CG along vehicle-fixed y-axis	0	N
		Fz	Drag force on vehicle CG along vehicle-fixed z-axis	0	N
	Grvty	Fx	Gravity force on vehicle CG along vehicle-fixed x-axis	Computed	N
		Fy	Gravity force on vehicle CG along vehicle-fixed y-axis	0	N
		Fz	Gravity force on vehicle CG along vehicle-fixed z-axis	Computed	N
Pwr	PwrExt	Applied external power		Computed	W
	Drag	Power loss due to drag		Computed	W

Signal		Description	Value	Units	
P w r I	Pwr Trn sfr d	PwrFxExt	Externally applied force power	P_{FxExt}	W
n f o	Pwr Not Trn sfr d	PwrFxDrag	Drag force power	P_D	W
Pwr Sto red	wrStoredG rvty	wrStoredG	Rate change in gravitational potential energy	P_g	W
	PwrStored xdot	xdot	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 create 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 create 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	x_{dot} x_{ddot}
Force	Force
Power	Power

Mass — Vehicle body mass

scalar

Vehicle body mass, m , in kg.

Rolling resistance coefficient, a — Rolling

scalar

Steady-state rolling resistance coefficient, a , in N.

Rolling and driveline resistance coefficient, b — Rolling and driveline

scalar

Viscous driveline and rolling resistance coefficient, b , in N*s/m.

Aerodynamic drag coefficient, c — Drag

scalar

Aerodynamic drag coefficient, c , in N·s²/m.

Gravitational acceleration, g — Gravity scalar

Gravitational acceleration, g , in m/s².

Initial velocity, xdot_o — Velocity 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

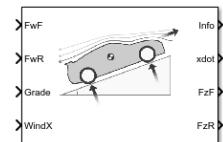
“Coordinate Systems in Vehicle Dynamics Blockset”

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.

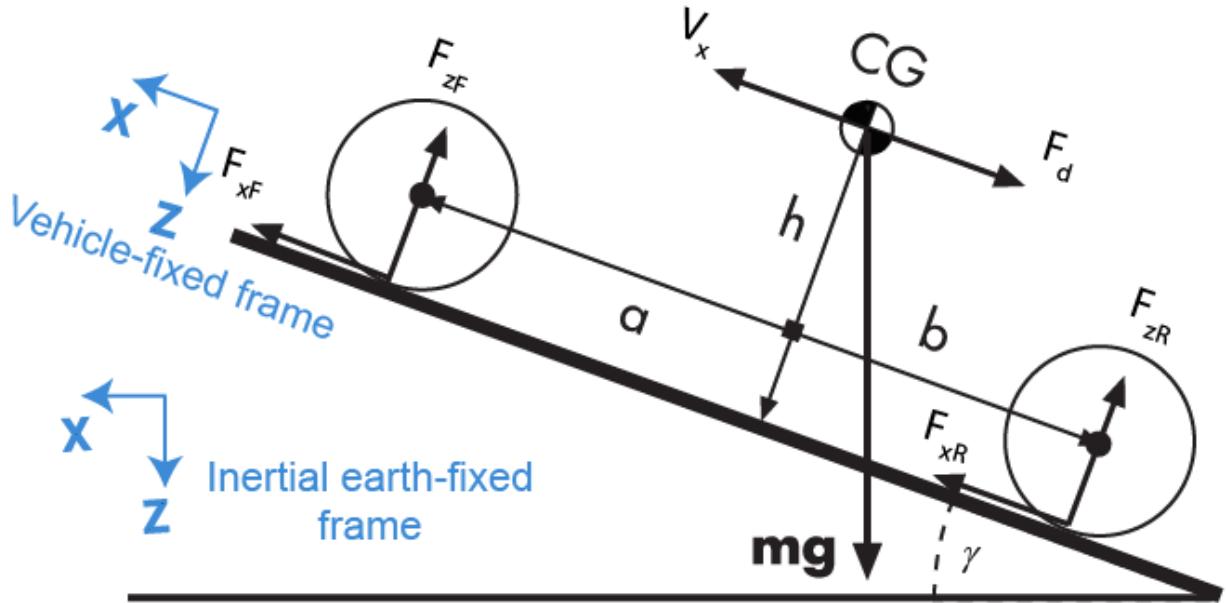
Block Option Setting	External Input Ports	Description
External forces	FExt	External force applied to vehicle CG in vehicle-fixed frame.
External moments	MExt	External moment about vehicle CG in vehicle-fixed frame.
Air temperature	AirTemp	Ambient air temperature. Consider this option if you want to vary the temperature during run-time.

Block Option Setting	External Input Ports	Description
Wind X,Y,Z	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 CG.



The Vehicle Body 1DOF Longitudinal block implements these equations.

$$F_b = m\ddot{x}$$

$$F_b = Fw_F + Fw_R - F_{d,x} + F_{ext,x} - mgsin\gamma$$

Zero normal acceleration and zero pitch torque determine the normal force on each front and rear axles.

$$F_{zF} = \frac{-M_{ext,y} - M_{d,y} + \dot{x}^2}{N_F(a+b)} b(F_{d,z} + F_{ext,z} - mgcos\gamma) - F_bh$$

$$F_{zR} = \frac{M_{ext,y} + M_{d,y} + \dot{x}^2}{N_R(a+b)} a(F_{dragz} + F_{ext,z} - mgcos\gamma) + F_bh$$

The wheel normal forces satisfy this equation.

$$N_F F_{zF} + N_R F_{zR} = mg \cos \gamma$$

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 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
PwrIn fo	PwrTrnsfrd — Power transferred between blocks	PwrFxExt	$P_{FxExt} = F_{xExt} \dot{x}$
	<ul style="list-style-type: none"> Positive signals indicate flow into block Negative signals indicate flow out of block 	PwrFwFx	$P_{FwFx} = F_{wFx} \dot{x}$
		PwrFwRx	$P_{FwRx} = F_{wRx} \dot{x}$

Bus Signal	Description	Equations
PwrNotTrnsfrd — Power crossing the block boundary, but not transferred <ul style="list-style-type: none"> • Positive signals indicate an input • Negative signals indicate a loss 	PwrFxDrag	Drag force power $P_d = - \frac{0.5 C_d A_f P_{abs} (\dot{x}^2 - w_x)^2}{287.058 T} \dot{x}$
PwrStored — Stored energy rate of change <ul style="list-style-type: none"> • Positive signals indicate an increase • Negative signals indicate a decrease 	wrStoredGrvty	Rate change in gravitational potential energy $P_g = - mg \dot{Z}$
	PwrStoredxdo t	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 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 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
γ	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
ρ	Mass density of air
x, \dot{x}, \ddot{x}	Vehicle longitudinal position, velocity, and acceleration along vehicle-fixed x -axis
w_x	Wind speed along vehicle-fixed x -axis
\dot{z}	Vehicle vertical velocity along 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 create this port, select **External forces**.

MExt — External moment about vehicle CG array

External moment about vehicle CG, M_x , M_y , M_z , in vehicle-fixed frame, in N·m. Signal vector dimensions are [1x3] or [3x1].

Dependencies

To create this port, select **External moments**.

FwF — Total longitudinal force on front axle scalar

Longitudinal force on the front axle, F_{xf} , 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, γ , in deg.

WindX — Longitudinal wind speed scalar

Longitudinal wind speed, W_w , along earth-fixed X-axis, in m/s.

Dependencies

To create 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 create 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 create this port, select **Air temperature**.

Output

Info — Bus signal

bus

Bus signal containing these block values.

Signal				Description	Value	Units
InertFr m	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

Signal				Description	Value	Units
Front Axle	Ang	Zdot	Zdot	Vehicle CG velocity along earth-fixed Z-axis	Computed	m/s
			phi	Rotation of vehicle-fixed frame about earth-fixed X-axis (roll)	0	rad
			theta	Rotation of vehicle-fixed frame about earth-fixed Y-axis (pitch)	Computed (input - grade angle)	rad
			psi	Rotation of vehicle-fixed frame about earth-fixed Z-axis (yaw)	0	rad
	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	
Rear Axle	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	

Signal				Description	Value	Units	
BdyFrm	Cg	Disp	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
			Vel	Ydot	Rear axle velocity along the earth-fixed Y-axis	0	m/s
			Vel	Zdot	Rear axle velocity along the earth-fixed Z-axis	Computed	m/s
		Disp	x	Vehicle CG displacement along vehicle-fixed x-axis	Computed	m	
			y	Vehicle CG displacement along vehicle-fixed y-axis	0	m	
			z	Vehicle CG displacement along vehicle-fixed z-axis	0	m	
		Vel	x	Vehicle CG velocity along vehicle-fixed x-axis	Computed	m/s	
			y	Vehicle CG velocity along vehicle-fixed y-axis	0	m/s	
			z	Vehicle CG velocity along 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	

Signal				Description	Value	Units
			r	Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate)	0	rad/s
			Accel	ax	Vehicle CG acceleration along vehicle-fixed x-axis	Computed
				ay	Vehicle CG acceleration along vehicle-fixed y-axis	0
				az	Vehicle CG acceleration along vehicle-fixed z-axis	0
	Forces	Body	Fx	Net force on vehicle CG along vehicle-fixed x-axis	0	N
			Fy	Net force on vehicle CG along vehicle-fixed y-axis	0	N
			Fz	Net force on vehicle CG along vehicle-fixed z-axis	0	N
	Ext		Fx	External force on vehicle CG along vehicle-fixed x-axis	Computed	N
			Fy	External force on vehicle CG along vehicle-fixed y-axis	Computed	N
			Fz	External force on vehicle CG along vehicle-fixed z-axis	Computed	N
	FrntAx _l	Fx	Longitudinal force on front axle, along the vehicle-fixed x-axis	0		N

Signal				Description	Value	Units
	RearAxle	Fy	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
		Fx	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 vehicle-fixed x-axis	0	N
			Fy	Front tire force, along vehicle-fixed y-axis	0	N
			Fz	Front tire force, along vehicle-fixed z-axis	Computed	N
		RearTire	Fx	Rear tire force, along vehicle-fixed x-axis	0	N
			Fy	Rear tire force, along vehicle-fixed y-axis	0	N
			Fz	Rear tire force, along vehicle-fixed z-axis	Computed	N
	Drag	Fx		Drag force on vehicle CG along vehicle-fixed x-axis	Computed	N
		Fy		Drag force on vehicle CG along vehicle-fixed y-axis	Computed	N

Signal				Description	Value	Units
Moment s	Grvty		Fz	Drag force on vehicle CG along vehicle-fixed z-axis	Computed	N
			Fx	Gravity force on vehicle CG along vehicle-fixed x-axis	Computed	N
			Fy	Gravity force on vehicle CG along vehicle-fixed y-axis	0	N
			Fz	Gravity force on vehicle CG along vehicle-fixed z-axis	Computed	N
	Body		Mx	Net moment on vehicle CG about vehicle-fixed x-axis	0	N·m
			My	Net moment on vehicle CG about vehicle-fixed y-axis	0	N·m
			Mz	Net moment on vehicle CG about vehicle-fixed z-axis	0	N·m
	Drag		Mx	Drag moment on vehicle CG about vehicle-fixed x-axis	Computed	N·m
			My	Drag moment on vehicle CG about vehicle-fixed y-axis	Computed	N·m
			Mz	Drag moment on vehicle CG about vehicle-fixed z-axis	Computed	N·m
	Ext	Fx		External moment on vehicle CG about vehicle-fixed x-axis	Computed	N·m

Signal			Description		Value	Units
FrntAxle	Disp	Fy	External moment on vehicle CG about vehicle-fixed y-axis	Computed	N·m	
		Fz	External moment on vehicle CG about vehicle-fixed z-axis	Computed	N·m	
		x	Front axle displacement along the vehicle-fixed x-axis	Computed	m	
	Vel	y	Front axle displacement along the vehicle-fixed y-axis	θ	m	
		z	Front axle displacement along the vehicle-fixed z-axis	Computed	m	
		xdot	Front axle velocity along the vehicle-fixed x-axis	Computed	m/s	
	Steer	ydot	Front axle velocity along the vehicle-fixed y-axis	θ	m/s	
		zdot	Front axle velocity along the vehicle-fixed z-axis	Computed	m/s	
		WhlAngFL	Front left wheel steering angle	Computed	rad	
		WhlAngFR	Front right wheel steering angle	Computed	rad	
	RearAxle	Disp	x	Rear axle displacement along the vehicle-fixed x-axis	Computed	m
		y	Rear axle displacement along the vehicle-fixed y-axis	θ	m	

Signal				Description	Value	Units	
			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	θ	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	
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	

Signal			Description	Value	Units
		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 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
scalar

Number of wheels on front axle, N_F , dimensionless.

Number of wheels on rear axle, NR — Rear wheel count
scalar

Number of wheels on rear axle, N_R , dimensionless.

Mass, m — Vehicle mass
scalar

Vehicle mass, M , in kg.

Horizontal distance from CG to front axle, a — Front axle distance
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
scalar

Horizontal distance b from the vehicle CG to the rear wheel axle, in m.

CG height above axles, h — Height
scalar

Height of vehicle CG above the ground, h , in m.

Drag coefficient, Cd — Drag
scalar

Air drag coefficient, C_d .

Frontal area, Af — Area
scalar

Effective vehicle cross-sectional area, A , to calculate the aerodynamic drag force on the vehicle, in m^2 .

Initial position, x_o — Position
scalar

Vehicle body longitudinal initial position along the vehicle-fixed x -axis, x_o , in m.

Initial velocity, \dot{x}_o — Velocity
scalar

Vehicle body longitudinal initial velocity along the vehicle-fixed x -axis, \dot{x}_o , in m/s.

Environment

Absolute air pressure, P_{abs} — Pressure
scalar

Environmental air absolute pressure, P_{abs} , in Pa.

Air temperature, T — Ambient air temperature
scalar

Ambient air temperature, T_{air} , in K.

Dependencies

To enable this parameter, clear **Air temperature**.

Gravitational acceleration, g — Gravity
scalar

Gravitational acceleration, g , in m/s².

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

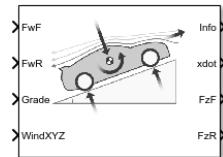
“Coordinate Systems in Vehicle Dynamics Blockset”

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.

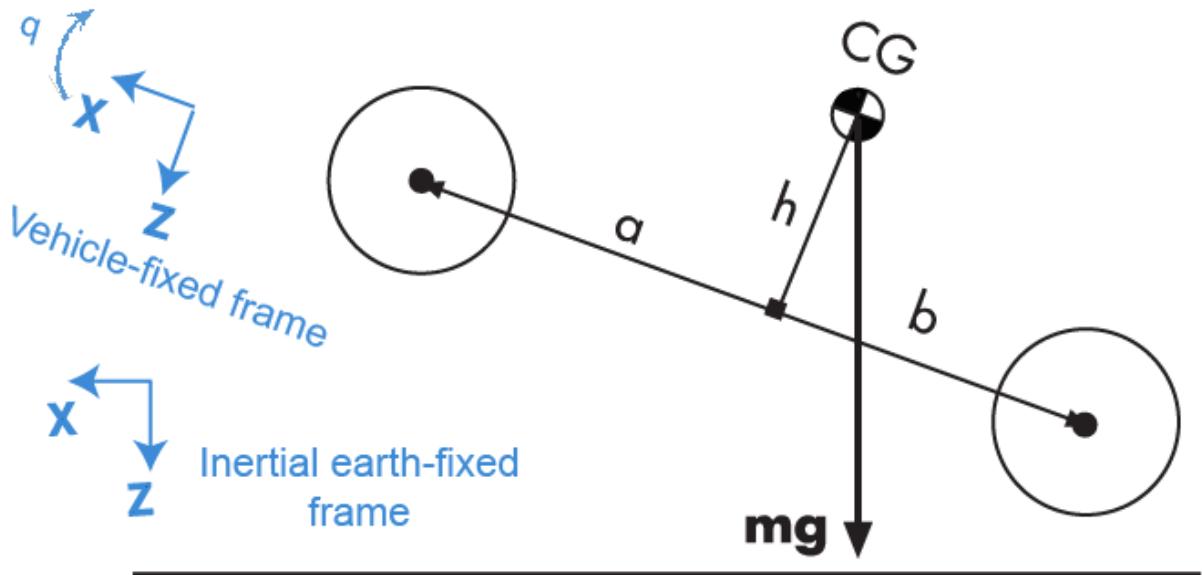
If the weight transfer from vertical and pitch motions are not negligible, consider using this block to represent vehicle motion in powertrain and fuel economy studies. For example, in studies with heavy breaking or acceleration or road profiles that contain larger vertical changes.

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:

$$Fs_F = N_F[Fk_F + Fb_F]$$

$$Fs_R = N_R[Fk_R + Fb_R]$$

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 0.

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
PwrIn fo	PwrTrnsfrd – Power transferred between blocks <ul style="list-style-type: none"> • Positive signals 	PwrFxExt	Externally applied longitudinal force power $P_{FxExt} = F_{xExt}\dot{x}$

Bus Signal		Description	Equations
	indicate flow into block • Negative signals indicate flow out of block	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 $P_{FwFx} = F_{wF}\dot{x}$
		PwrFwRx	Longitudinal force applied at the rear axle $P_{FwRx} = F_{wR}\dot{x}$
PwrNotTrnsfrd	— Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	PwrFsF	Internal power transferred between suspension and vehicle body at the front axle $P_{Fs,F} = -P_{FwFx} + P_{Fsb,F} + P_{Fsk,F} + F_{xF}\dot{x}_F + F_{zF}\dot{z}_F$
		PwrFsR	Internal power transferred between suspension and vehicle body at the rear axle $P_{Fs,R} = -P_{FwRx} + P_{Fsb,R} + P_{Fsk,R} + F_{xF}\dot{x}_F + F_{zF}\dot{z}_F$
		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 $P_{Fsb} = \sum_{i=F,R} F_{sb,i}\dot{z}_i$

Bus Signal		Description	Equations
	PwrStored — Stored energy rate of change	PwrStoredGrvt y	Rate change in gravitational potential energy $P_g = -mg\dot{Z}$
	• Positive signals indicate an increase	PwrStoredxdot	Rate of change of longitudinal kinetic energy $P_x = m\ddot{x}\dot{x}$
	• Negative signals indicate a decrease	PwrStoredzdot	Rate of change of longitudinal kinetic energy $P_z = m\ddot{z}\dot{z}$
		PwrStoredq	Rate of change of rotational pitch kinetic energy $P_{\dot{\theta}} = I_{yy}\ddot{\theta}\dot{\theta}$
		PwrStoredFsFz Sprng	Stored spring energy from front suspension $P_{FsF} = F_{sk,F}\dot{Z}_F$
		PwrStoredFsRz Sprng	Stored spring energy from rear suspension $P_{FsR} = F_{sk,R}\dot{Z}_R$

The equations use these variables.

F_x	Longitudinal force on vehicle
F_z	Normal force on vehicle
M_y	Torque on vehicle about 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 vehicle-fixed frame

$M_{d,y}$	Torque due to drag on vehicle about 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_{S_F}, F_{S_R}	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
Θ	Vehicle pitch angle about 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 vehicle-fixed x -axis
z, \dot{z}, \ddot{z}	Vehicle normal position, velocity, and acceleration along 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 vehicle-fixed x -axis
C_l	Lateral air drag coefficient acting along vehicle-fixed z -axis
C_{pm}	Air drag pitch moment acting about 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 vehicle-fixed x -axis

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 create this port, select **External forces**.

MExt — External moment about vehicle CG
array

External moment about vehicle CG, M_x , M_y , M_z , in vehicle-fixed frame, in N·m. Signal vector dimensions are [1x3] or [3x1].

Dependencies

To create this port, select **External moments**.

FwF — Total longitudinal force on the front axle
scalar

Longitudinal force on the front axle, F_{w_F} , along vehicle-fixed x -axis, in N.

FwR — Total longitudinal force on the rear axle
scalar

Longitudinal force on the rear axle, F_{w_R} , along vehicle-fixed x -axis, in N.

Grade — Road grade angle
scalar

Road grade angle, γ , in deg.

FsF — Suspension force on front axle per wheel

vector

Suspension force on front axle, F_{sF} , along vehicle-fixed z -axis, in N.

Dependencies

To create 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_{sR} , along vehicle-fixed z -axis, in N.

Dependencies

To create 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 [1x3] or [3x1].

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 create 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 create 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{Z}_F, \dot{Z}_R , in m/s.

Dependencies

To create 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
InertFr m	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 earth-fixed X-axis (roll)	0		rad

Signal			Description		Value	Units
FrontAxle	Disp	theta	Rotation of vehicle-fixed frame about earth-fixed Y-axis (pitch)	Computed	rad	
			psi	0	rad	
		X	Front axle displacement along the earth-fixed X-axis	Computed	m	
			Y	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	
	RearAxle	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

Signal			Description		Value	Units
BdyFrm	Cg	Disp	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
			x	Vehicle CG displacement along vehicle-fixed x-axis	Computed	m
		Vel	y	Vehicle CG displacement along vehicle-fixed y-axis	0	m
			z	Vehicle CG displacement along vehicle-fixed z-axis	Computed	m
			xdot	Vehicle CG velocity along vehicle-fixed x-axis	Computed	m/s
		AngVel	ydot	Vehicle CG velocity along vehicle-fixed y-axis	0	m/s
			zdot	Vehicle CG velocity along vehicle-fixed z-axis	Computed	m/s
			p	Vehicle angular velocity about the vehicle-fixed x-axis (roll rate)	0	rad/s
		Accel	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
			ax	Vehicle CG acceleration along vehicle-fixed x-axis	Computed	gn

Signal			Description	Value	Units
Forces	Body	ay	Vehicle CG acceleration along vehicle-fixed y-axis	0	gn
		az	Vehicle CG acceleration along vehicle-fixed z-axis	Computed	gn
	Body	Fx	Net force on vehicle CG along vehicle-fixed x-axis	Computed	N
		Fy	Net force on vehicle CG along vehicle-fixed y-axis	0	N
		Fz	Net force on vehicle CG along vehicle-fixed z-axis	Computed	N
	Ext	Fx	External force on vehicle CG along vehicle-fixed x-axis	Computed	N
		Fy	External force on vehicle CG along vehicle-fixed y-axis	Computed	N
		Fz	External force on vehicle CG along vehicle-fixed z-axis	Computed	N
	FrntAx _l	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

Signal				Description	Value	Units
	RearAxle	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 vehicle-fixed x-axis	0	N
			Fy	Front tire force, along vehicle-fixed y-axis	0	N
			Fz	Front tire force, along vehicle-fixed z-axis	Computed	N
		RearTire	Fx	Rear tire force, along vehicle-fixed x-axis	0	N
			Fy	Rear tire force, along vehicle-fixed y-axis	0	N
			Fz	Rear tire force, along vehicle-fixed z-axis	Computed	N
	Drag	Fx	Drag force on vehicle CG along vehicle-fixed x-axis	Computed	N	
			Fy	Drag force on vehicle CG along vehicle-fixed y-axis	Computed	N
			Fz	Drag force on vehicle CG along vehicle-fixed z-axis	Computed	N
	Grvty	Fx	Gravity force on vehicle CG along vehicle-fixed x-axis	Computed	N	

Signal			Description	Value	Units
Moment s	Body	Fy	Gravity force on vehicle CG along vehicle-fixed y-axis	0	N
		Fz	Gravity force on vehicle CG along vehicle-fixed z-axis	Compute d	N
	Body	Mx	Body moment on vehicle CG about vehicle-fixed x-axis	0	N·m
		My	Body moment on vehicle CG about vehicle-fixed y-axis	Compute d	N·m
		Mz	Body moment on vehicle CG about vehicle-fixed z-axis	0	N·m
	Drag	Mx	Drag moment on vehicle CG about vehicle-fixed x-axis	0	N·m
		My	Drag moment on vehicle CG about vehicle-fixed y-axis	Compute d	N·m
		Mz	Drag moment on vehicle CG about vehicle-fixed z-axis	0	N·m
	Ext	Fx	External moment on vehicle CG about vehicle-fixed x-axis	Compute d	N·m
		Fy	External moment on vehicle CG about vehicle-fixed y-axis	Compute d	N·m
		Fz	External moment on vehicle CG about vehicle-fixed z-axis	Compute d	N·m

Signal				Description	Value	Units
Front Axle	Disp	x	Front axle displacement along the vehicle-fixed x-axis	Computed	m	
			Front axle displacement along the vehicle-fixed y-axis	0	m	
			Front axle displacement along the vehicle-fixed z-axis	Computed	m	
	Vel	x $\dot{}$	Front axle velocity along the vehicle-fixed x-axis	Computed	m/s	
		y $\dot{}$	Front axle velocity along the vehicle-fixed y-axis	0	m/s	
		z $\dot{}$	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	
	Rear Axle	Disp	Rear axle displacement along the vehicle-fixed x-axis	Computed	m	
			Rear axle displacement along the vehicle-fixed y-axis	0	m	
			Rear axle displacement along the vehicle-fixed z-axis	Computed	m	
	Vel	x $\dot{}$	Rear axle velocity along the vehicle-fixed x-axis	Computed	m/s	
		y $\dot{}$	Rear axle velocity along the vehicle-fixed y-axis	0	m/s	

Signal				Description	Value	Units
PwrInfo	Steer		zdot	Rear axle velocity along the vehicle-fixed z-axis	Computed	m/s
		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
	PwrTrnsfrd	PwrFxExt		Externally applied longitudinal force power	Computed	W
		PwrFzExt		Externally applied longitudinal force power	Computed	W
		PwrMyExt		Externally applied pitch moment power	Computed	W
		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

Signal		Description	Value	Units
PwrSto red	PwrMyDrag	Drag pitch moment power	Computed	W
	PwrFsb	Total suspension damping power	Computed	W
	PwrStoredGrvty	Rate change in gravitational potential energy	Computed	W
	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
	PwrStoredFsFzSp rng	Stored spring energy from front suspension	Computed	W
	PwrStoredFsRzSp rng	Stored spring energy from rear suspension	Computed	W

xdot — Vehicle longitudinal velocity
scalar

Vehicle CG velocity along vehicle-fixed x-axis, in m/s.

FzF — Front axle normal force
scalar

Normal force on front axle, F_{z_F} , along vehicle-fixed z-axis, in N.

FzR — Rear axle normal force
scalar

Normal force on rear axle, F_{z_R} , along 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

scalar

Number of wheels on front axle, N_F , dimensionless.

Number of wheels on rear axle, NR — Rear wheel count

scalar

Number of wheels on rear axle, N_R , dimensionless.

Mass, m — Vehicle mass

scalar

Vehicle mass, m , in kg.

Horizontal distance from CG to front axle, a — Front axle distance

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

scalar

Horizontal distance b from the vehicle CG to the rear wheel axle, in m.

CG height above axles, h — Height
scalar

Height of vehicle CG above the axles, h , in m.

Drag coefficient, C_d — Drag
scalar

Air drag coefficient, C_d , dimensionless.

Frontal area, A_f — Area
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
scalar

Vehicle body longitudinal initial position along earth-fixed x -axis, x_o , in m.

Initial velocity, x_{dot_o} — Velocity
scalar

Vehicle body longitudinal initial velocity along earth-fixed x -axis, \dot{x}_o , in m/s.

Vertical

Lift coefficient, C_l — Lift
scalar

Lift coefficient, C_l , dimensionless.

Initial vertical position, z_o — Position
scalar

Initial vertical CG position, z_o , along the vehicle-fixed z -axis, in m.

Initial vertical velocity, z_{dot_o} — Velocity
scalar

Initial vertical CG velocity, z_{dot_o} , along the vehicle-fixed z -axis, in m.

Pitch

Inertia, Iyy — About body y-axis
scalar

Vehicle body moment of inertia about body z -axis.

Pitch drag moment coefficient, Cpm — Drag coefficient
scalar

Pitch drag moment coefficient, dimensionless.

Initial pitch angle, theta_o — Pitch
scalar

Initial pitch angle about body z -axis, in rad.

Initial angular velocity, q_o — Pitch velocity
scalar

Initial vehicle body angular velocity about body z -axis, in rad/s.

Suspension

Front axle stiffness force data, FskF — Force
vector

Front axle stiffness force data, F_{k_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
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 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 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 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 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 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 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 scalar

Environmental air absolute pressure, P_{abs} , in Pa.

Air temperature, Tair — Ambient air temperature scalar

Ambient air temperature, T_{air} , in K.

Dependencies

To enable this parameter, clear **Air temperature**.

Gravitational acceleration, g — Gravity scalar

Gravitational acceleration, g , in m/s².

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

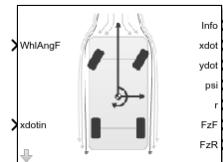
[“Coordinate Systems in Vehicle Dynamics Blockset”](#)

Introduced in R2017a

Vehicle Body 3DOF

3DOF rigid vehicle body to calculate longitudinal, lateral, and yaw motion

Library: Vehicle Dynamics Blockset / Vehicle Body



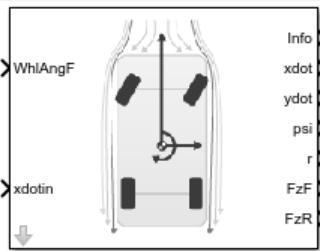
Description

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"> Forces act along the center line at the front and rear axles. No lateral load transfer.

Block	Vehicle Track Setting	Implementation
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"> Block assumes that the external longitudinal velocity is quasi-steady state so the longitudinal acceleration is approximately zero. Since the motion is quasi-steady, the block calculates lateral forces using the tire slip angles and linear cornering stiffness. Consider this setting when you want to: <ul style="list-style-type: none"> Generate virtual sensor signal data. Conduct high-level software studies that are not impacted by driveline or nonlinear tire responses.

Axle Forces Setting	Implementation
External longitudinal force	<ul style="list-style-type: none"> Block uses the external longitudinal force to accelerate or brake the vehicle. Block calculates lateral forces using the tire slip angles and linear cornering stiffness. Consider this setting when you want to: <ul style="list-style-type: none"> Account for changes in the longitudinal velocity on the lateral and yaw motion. Specify the external longitudinal motion through a force instead of an external longitudinal velocity. Connect the block to tractive actuators, wheels, and brakes.
External forces	<ul style="list-style-type: none"> Block uses the external lateral and longitudinal forces to steer, accelerate, or brake the vehicle. Block does not use the steering input to calculate vehicle motion. Consider this setting when you need more accurate nonlinear combined lateral and longitudinal slip tire models.

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, δ_F
External wind	WindXYZ	Wind speed, W_X , W_Y , W_Z , in inertial reference frame
External forces	FExt	External force on vehicle center of gravity (CG), F_x , F_y , F_z , in vehicle-fixed frame
Rear wheel steering	WhlAngR	Rear wheel angle, δ_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
Initial longitudinal position	X_o	Initial vehicle CG displacement along earth-fixed X-axis, in m
Initial lateral position	Y_o	Initial vehicle CG displacement along earth-fixed Y-axis, in m
Initial longitudinal velocity	xdot_o	Initial vehicle CG velocity along vehicle-fixed x-axis, in m/s
Initial lateral velocity	ydot_o	Initial vehicle CG velocity along vehicle-fixed y-axis, in m/s
Initial yaw angle	psi_o	Initial rotation of vehicle-fixed frame about earth-fixed Z-axis (yaw), in rad
Initial yaw rate	r_o	Initial vehicle angular velocity about the vehicle-fixed z-axis (yaw rate), in rad/s
Air temperature	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.

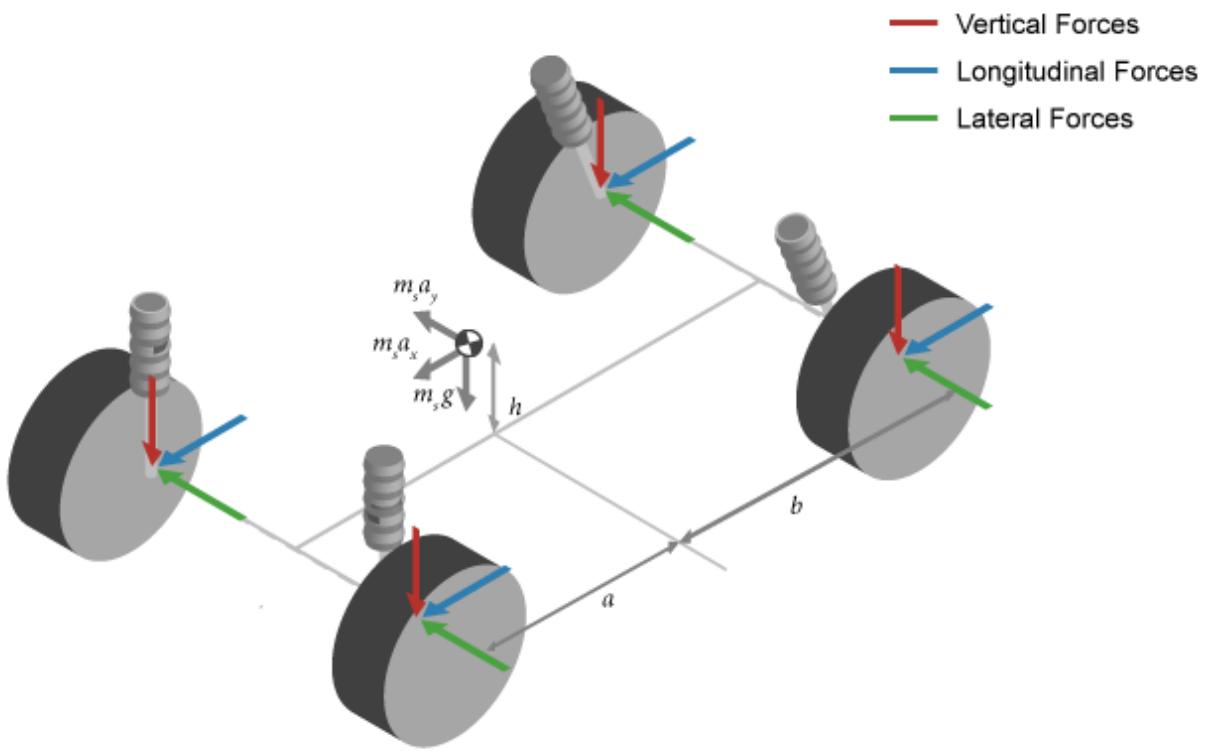
Single Track

Calculation	Description
<i>Dynamics</i>	<p>The block uses these equations to calculate the rigid body planar dynamics.</p> $\ddot{y} = -\dot{x}r + \frac{F_{yf} + F_{yr} + F_{yext}}{m}$ $\dot{r} = \frac{aF_{yf} - bF_{yr} + M_{zext}}{I_{zz}}$ $r = \psi$ <p>If you set Axle forces 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 Axle forces 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> $F_{x,y,z \text{ ext}} = F_{d \text{ x},y,z} + F_{x,y,z \text{ input}}$ $M_{x,y,z \text{ ext}} = M_{d \text{ x},y,z} + M_{x,y,z \text{ input}}$ <p>If you set Axle forces 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 Axle forces to External longitudinal velocity, the block uses these equations.</p> $F_{xft} = 0$ $F_{yft} = -C_{yf}\alpha_f\mu_f \frac{F_{zf}}{F_{znom}}$ $F_{xft} = 0$ $F_{yrt} = -C_{yr}\alpha_r\mu_r \frac{F_{zr}}{F_{znom}}$ <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
<p><i>Tire forces</i></p> <p>The block uses the ratio of the local and longitudinal and lateral velocities to determine the slip angles.</p> $\alpha_f = \tan\left(\frac{\dot{y} + ar}{\dot{x}}\right) - \delta_f$ $\alpha_r = \tan\left(\frac{\dot{y} - br}{\dot{x}}\right) - \delta_r$ <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 Axle forces to External forces, the block sets the tire forces equal to the external input force.</p> $F_{xf} = F_{xft} = F_{xfinput}$ $F_{yf} = F_{yft} = F_{yfinput}$ $F_{xr} = F_{xrt} = F_{xrininput}$ $F_{yr} = F_{yrt} = F_{yrinput}$	

Dual Track



Calculation	Description
<p><i>Dynamics</i></p> <p>The block uses these equations to calculate the rigid body planar dynamics.</p> $\ddot{x} = \dot{y}r + \frac{F_{xfl} + F_{xfr} + F_{xrl} + F_{xrr} + F_{xext}}{m}$ $\ddot{y} = -\dot{x}r + \frac{F_{yfl} + F_{yfr} + F_{yrl} + F_{yrr} + F_{yext}}{m}$ $\dot{r} = \frac{a(F_{yfl} + F_{yfr}) - b(F_{yrl} + F_{yrr}) + \frac{w_f}{2(F_{xfl} - F_{xfr})} + \frac{w_r}{2(F_{xrl} - F_{xrr})} + M_{zext}}{I_{zz}}$ $r = \psi$ <p>If you set Axle forces 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> $F_{x,y,z \text{ ext}} = F_{d \text{ x},y,z} + F_{x,y,z \text{ input}}$ $M_{x,y,z \text{ ext}} = M_{d \text{ x},y,z} + M_{x,y,z \text{ input}}$ <p>If you set Axle forces to External longitudinal forces, the block uses these equations.</p> $F_{xflt} = F_{xflinput}$ $F_{yflt} = - C_{yfl} \alpha_{fl} \mu_{fl} \frac{F_{zfl}}{2F_{znom}}$ $F_{xfrc} = F_{xlrinput}$ $F_{yfrc} = - C_{yfr} \alpha_{fr} \mu_{fr} \frac{F_{zfr}}{2F_{znom}}$ $F_{xrlt} = F_{xrlinput}$ $F_{yrlt} = - C_{yrl} \alpha_{rl} \mu_{rl} \frac{F_{zrl}}{2F_{znom}}$ $F_{xrrt} = F_{xrrinput}$ $F_{yrrt} = - C_{yrr} \alpha_{rr} \mu_{rr} \frac{F_{zrr}}{2F_{znom}}$ <p>If you set Axle forces to External longitudinal velocity, the block uses these equations.</p>	

Calculation	Description
	$F_{xflt} = 0$ $F_{yflt} = - C_{yfl} \alpha_{fl} \mu_{fl} \frac{F_{zfl}}{2F_{znom}}$ $F_{xfrt} = 0$ $F_{yfrt} = - C_{yfr} \alpha_{fr} \mu_{fr} \frac{F_{zfr}}{2F_{znom}}$ $F_{xrlt} = 0$ $F_{yrlt} = - C_{yrl} \alpha_{rl} \mu_{rl} \frac{F_{zrl}}{2F_{znom}}$ $F_{xrrt} = 0$ $F_{yrrt} = - C_{yrr} \alpha_{rr} \mu_{rr} \frac{F_{zrr}}{2F_{znom}}$ <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> $F_{zf} = \frac{bm g - (\ddot{x} - \dot{y}r)m h + h F_{xext} + b F_{zext} - M_{yext}}{a + b}$ $F_{zr} = \frac{am g + (\ddot{x} - \dot{y}r)m h - h F_{xext} + a F_{zext} + M_{yext}}{(a + b)}$ $F_{zfl} = F_{zf} + (m h (\ddot{y} + \dot{x}r) - h F_{yext} - M_{xext}) \frac{2}{w_f}$ $F_{zfr} = F_{zf} + (-m h (\ddot{y} + \dot{x}r) + h F_{yext} + M_{xext}) \frac{2}{w_f}$ $F_{zrl} = F_{zr} + (m h (\ddot{y} + \dot{x}r) - h F_{yext} - M_{xext}) \frac{2}{w_r}$ $F_{zrr} = F_{zr} + (-m h (\ddot{y} + \dot{x}r) + h F_{yext} + M_{xext}) \frac{2}{w_r}$

Calculation	Description
<p><i>Tire forces</i></p> <p>The block uses the ratio of the local and longitudinal and lateral velocities to determine the slip angles.</p> $\alpha_{fl} = \text{atan}\left(\frac{\dot{y} + ar}{\dot{x} + r\frac{w_f}{2}}\right) - \delta_{fl}$ $\alpha_{fr} = \text{atan}\left(\frac{\dot{y} + ar}{\dot{x} - r\frac{w_f}{2}}\right) - \delta_{fr}$ $\alpha_{rl} = \text{atan}\left(\frac{\dot{y} - ar}{\dot{x} + r\frac{w_r}{2}}\right) - \delta_{rl}$ $\alpha_{rr} = \text{atan}\left(\frac{\dot{y} - ar}{\dot{x} - r\frac{w_r}{2}}\right) - \delta_{rr}$ <p>To determine the slip angles, the block uses the longitudinal and lateral velocities, and the steering angles.</p> $\alpha_f = \text{atan}\left(\frac{\dot{y} + ar}{\dot{x}}\right) - \delta_f$ $\alpha_r = \text{atan}\left(\frac{\dot{y} - br}{\dot{x}}\right) - \delta_r$ <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 Axle forces 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>	

Calculation	Description
	$F_{xf} = F_{xft} = F_{xfinput}$ $F_{yf} = F_{yft} = F_{yfinput}$ $F_{xr} = F_{xrt} = F_{xrinput}$ $F_{yr} = F_{yrt} = F_{yrinput}$

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> $\bar{w} = \sqrt{(\dot{x}_b - w_x)^2 + (\dot{x}_y - w_y)^2 + (w_z)^2}$ $F_{dx} = -\frac{1}{2TR} C_d A_f P_{abs}(\bar{w})$ $F_{dy} = -\frac{1}{2TR} C_s A_f P_{abs}(\bar{w})$ $F_{dz} = -\frac{1}{2TR} C_l A_f P_{abs}(\bar{w})$

Calculation	Description
<i>Drag moments</i>	<p>Using the relative airspeed, the block determines the drag moments.</p> $M_{dr} = -\frac{1}{2TR}C_{rm}A_fP_{abs}(\bar{w}(a+b))$ $M_{dp} = -\frac{1}{2TR}C_{pm}A_fP_{abs}(\bar{w}(a+b))$ $M_{dy} = -\frac{1}{2TR}C_{ym}A_fP_{abs}(\bar{w}(a+b))$

Lateral Corner Stiffness and Relaxation Dynamics

Description	Implementation
<i>Constant values.</i>	The block uses constant stiffness values for C_{yf} and C_{yr} .
<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> $C_{yf} = f(\alpha_f, C_{yfdata})$ $C_{yr} = f(\alpha_r, C_{yrdata})$
<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. 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> $C_{yf} = f(\alpha_{f\sigma}, C_{yfdata})$ $C_{yr} = f(\alpha_{r\sigma}, C_{yrdata})$ $\alpha_{f\sigma} = \frac{1}{s} \left[\frac{(\alpha_f - \alpha_{f\sigma})v_{wf}}{\alpha_f} \right]$ $\alpha_{r\sigma} = \frac{1}{s} \left[\frac{(\alpha_r - \alpha_{r\sigma})v_{wr}}{\alpha_r} \right]$
<i>Slip angles include the relaxation length dynamic settings.</i>	

The equations use these variables.

x, \dot{x}, \ddot{x}	Vehicle CG displacement, velocity, and acceleration, along vehicle-fixed x -axis
y, \dot{y}, \ddot{y}	Vehicle CG displacement, velocity, and acceleration, along vehicle-fixed y -axis
ψ	Rotation of vehicle-fixed frame about 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 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 vehicle-fixed x -, y -, and z -axes
F_{dx}, F_{dy}, F_{dz}	Drag forces applied to vehicle CG, along vehicle-fixed x -, y -, and z -axes
$F_{xininput}, F_{yininput}, F_{zininput}$	Input forces applied to vehicle CG, along vehicle-fixed x -, y -, and z -axes
$M_{xext}, M_{yext}, M_{zext}$	External moment about vehicle CG, about vehicle-fixed x -, y -, and z -axes
M_{dx}, M_{dy}, M_{dz}	Drag moment about vehicle CG, about vehicle-fixed x -, y -, and z -axes
$M_{xininput}, M_{yininput}, M_{zininput}$	Input moment about vehicle CG, about 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 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 vehicle-fixed x -axis
F_{yfl}, F_{yfr}	Lateral force applied to front left and front right wheels, along vehicle-fixed y -axis
F_{xrl}, F_{xrr}	Longitudinal force applied to rear left and rear right wheels, along vehicle-fixed x -axis

F_{yrl}, F_{yrr}	Lateral force applied to rear left and rear right wheels, along vehicle-fixed y -axis
F_{xfl}, F_{xfr}	Longitudinal tire force applied to front left and front right wheels, along vehicle-fixed x -axis
F_{yfl}, F_{yfr}	Lateral force tire applied to front left and front right wheels, along vehicle-fixed y -axis
F_{xrl}, F_{xrr}	Longitudinal tire force applied to rear left and rear right wheels, along vehicle-fixed x -axis
F_{yrl}, F_{yrr}	Lateral force applied to rear left and rear right wheels, along vehicle-fixed y -axis
F_{zfl}, F_{zfr}	Normal force applied to front and rear wheels, along vehicle-fixed z -axis
F_{znom}	Nominal normal force applied to axles, along vehicle-fixed z -axis
F_{zfb}, 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
α_f, α_r	Front and rear wheel slip angles
α_{fl}, α_{fr}	Front left and right wheel slip angles
α_{rl}, α_{rr}	Rear left and right wheel slip angles
δ_f, δ_r	Front and rear wheel steering angles
δ_{rl}, δ_{rr}	Rear left and right wheel steering angles
δ_{fl}, δ_{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
σ_f, σ_r	Front and rear wheel relaxation length
α_{fo}, α_{ro}	Front and rear wheel slip angles that include relaxation length

v_{wf}, v_{wr}	Magnitude of front and rear wheel hardpoint velocity
μ_f, μ_r	Front and rear wheel friction coefficient
μ_{fl}, μ_{fr}	Front left and right wheel friction coefficient
μ_{rl}, μ_{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 vehicle-fixed x-axis
C_{pm}	Air drag pitch moment acting about 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 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, δ_F , in rad.

Vehicle Track Setting	Variable	Signal Dimension
Single (bicycle)	δ_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 create this port, on the **Input signals** pane, select **Front wheel steering**.

WhlAngR — Rear wheel steering angles

scalar | array

Rear wheel steering angles, δ_R , in rad.

Vehicle Track Setting	Variable	Signal Dimension
Single (bicycle)	δ_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 create this port, on the **Input signals** pane, select **Rear wheel steering**.

xdotin — Longitudinal velocity

scalar

Vehicle CG velocity along vehicle-fixed x-axis, in m/s.

Dependencies

To create 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 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

Vehicle Track Setting	Axle Forces Setting	Description	Variable	Signal Dimension
	External forces	Longitudinal and lateral forces on the front wheel	$FwF = [Fx_f \ Fy_f]$ or $\begin{bmatrix} Fx_f \\ Fy_f \end{bmatrix}$	Array - [1x2] or [2x1]
Dual	External longitudinal forces	Longitudinal force on the front wheels	$FwF = [Fx_{fl} \ Fx_{fr}]$ or $\begin{bmatrix} Fx_{fl} \\ Fx_{fr} \end{bmatrix}$	Array - [1x2] or [2x1]
	External forces	Longitudinal and lateral forces on the front wheels	$FwF = \begin{bmatrix} Fx_{fl} \ Fx_{fr} \\ Fy_{fl} \ Fy_{fr} \end{bmatrix}$	Array - [2x2]

Dependencies

To create 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, Fw_R , along 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	$FwR = Fx_r$	Scalar - 1

Vehicle Track Setting	Axle Forces Setting	Description	Variable	Signal Dimension
	External forces	Longitudinal and lateral forces on the rear wheel	$F_{wR} = [F_{xr} \ F_{yr}]$ or $\begin{bmatrix} F_{xr} \\ F_{yr} \end{bmatrix}$	Array - [1x2] or [2x1]
Dual	External longitudinal forces	Longitudinal force on the rear wheels	$F_{wR} = [F_{xrl} \ F_{xrr}]$ or $\begin{bmatrix} F_{xrl} \\ F_{xrr} \end{bmatrix}$	Array - [1x2] or [2x1]
	External forces	Longitudinal and lateral forces on the rear wheels	$F_{wR} = \begin{bmatrix} F_{xrl} \ F_{xrr} \\ F_{yrl} \ F_{yrr} \end{bmatrix}$	Array - [2x2]

Dependencies

To create 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 create 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 vehicle-fixed frame, in N·m. Signal vector dimensions are [1x3] or [3x1].

Dependencies

To create this port, on the **Input signals** pane, select **External 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 create this port, on the **Input signals** pane, select **External wind**.

Mu — Tire friction coefficient

scalar

Tire friction coefficient, μ , 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 create this port, on the **Input signals** pane, select **External friction**.

AirTemp — Ambient air temperature

scalar

Ambient air temperature, in K.

Dependencies

To create this port, on the **Input signals** pane, select **Air temperature**.

X_o — Initial longitudinal position

scalar

Initial vehicle CG displacement along earth-fixed X-axis, in m.

Dependencies

To create this port, on the **Input signals** pane, select **Initial longitudinal position**.

Y_o — Initial lateral position

scalar

Initial vehicle CG displacement along earth-fixed Y-axis, in m.

Dependencies

To create this port, on the **Input signals** pane, select **Initial lateral position**.

xdot_o — Initial longitudinal position

scalar

Initial vehicle CG velocity along vehicle-fixed x-axis, in m/s.

Dependencies

To create 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 vehicle-fixed y-axis, in m/s.

Dependencies

To create this port, on the **Input signals** pane, select **Initial lateral velocity**.

psi_o — Initial yaw angle

scalar

Rotation of vehicle-fixed frame about earth-fixed Z-axis (yaw), in rad.

Dependencies

To create 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 create 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
InertFr m	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

Signal				Description	Value	Units
FrntAx l	Ang	Zdot	Zdot	Vehicle CG velocity along earth-fixed Z-axis	Computed	m/s
			phi	Rotation of vehicle-fixed frame about earth-fixed X-axis (roll)	0	rad
			theta	Rotation of vehicle-fixed frame about earth-fixed Y-axis (pitch)	Computed	rad
			psi	Rotation of vehicle-fixed frame about earth-fixed Z-axis (yaw)	0	rad
	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	0	m
			Z	Front left wheel displacement along the earth-fixed Z-axis	Computed	m
	Vel	Xdot	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	0	m/s
			Zdot	Front left wheel velocity along the earth-fixed Z-axis	Computed	m/s

Signal					Description	Value	Units
Rght	Disp	X	Front right wheel displacement along the earth-fixed X-axis	Compute d	m		
			Y	Front right wheel displacement along the earth-fixed Y-axis	θ	m	
			Z	Front right wheel displacement along the earth-fixed Z-axis	Compute d	m	
	Vel	Xd _{ot}	Front right wheel velocity along the earth-fixed X-axis	Compute d	m/s		
		Yd _{ot}	Front right wheel velocity along the earth-fixed Y-axis	θ	m/s		
		Zd _{ot}	Front right wheel velocity along the earth-fixed Z-axis	Compute d	m/s		
RearAx l	Disp	X	Rear left wheel displacement along the earth-fixed X-axis	Compute d	m		
		Y	Rear left wheel displacement along the earth-fixed Y-axis	θ	m		
		Z	Rear left wheel displacement along the earth-fixed Z-axis	Compute d	m		
	Vel	Xd _{ot}	Rear left wheel velocity along the earth-fixed X-axis	Compute d	m/s		
		Yd _{ot}	Rear left wheel velocity along the earth-fixed Y-axis	θ	m/s		

Signal					Description	Value	Units		
				Zd ot	Rear left wheel velocity along the earth-fixed Z-axis	Computed	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	θ	m
						Z	Rear right wheel displacement along the earth-fixed Z-axis	Computed	m
				Vel	Xd ot		Rear right wheel velocity along the earth-fixed X-axis	Computed	m/s
					Yd ot		Rear right wheel velocity along the earth-fixed Y-axis	θ	m/s
					Zd ot		Rear right wheel 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		

Signal			Description		Value	Units
			Ydot	Vehicle chassis offset velocity along the earth-fixed Y-axis	Compute d	m/s
			Zdot	Vehicle chassis offset velocity along the earth-fixed Z-axis	Compute d	m/s
BdyFrm	Cg	Vel	xdot	Vehicle CG velocity along vehicle-fixed x-axis	Compute d	m/s
			ydot	Vehicle CG velocity along vehicle-fixed y-axis	θ	m/s
			zdot	Vehicle CG velocity along vehicle-fixed z-axis	Compute d	m/s
		AngVel	p	Vehicle angular velocity about the vehicle-fixed x-axis (roll rate)	θ	rad/s
			q	Vehicle angular velocity about the vehicle-fixed y-axis (pitch rate)	Compute d	rad/s
			r	Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate)	θ	rad/s
		Accel	ax	Vehicle CG acceleration along vehicle-fixed x-axis	Compute d	gn
			ay	Vehicle CG acceleration along vehicle-fixed y-axis	θ	gn

Signal				Description	Value	Units
Forces			az	Vehicle CG acceleration along vehicle-fixed z-axis	Computed	gn
			xddot	Vehicle CG acceleration along vehicle-fixed x-axis	Computed	m/s^2
			yddot	Vehicle CG acceleration along vehicle-fixed y-axis	0	m/s^2
			zddot	Vehicle CG acceleration along vehicle-fixed z-axis	Computed	m/s^2
	Body	Fx		Net force on vehicle CG along vehicle-fixed x-axis	Computed	N
		Fy		Net force on vehicle CG along vehicle-fixed y-axis	0	N
		Fz		Net force on vehicle CG along vehicle-fixed z-axis	Computed	N
	FrntAx l	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	0	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	
				Fy	Lateral force on right front wheel along the vehicle-fixed y-axis	0	N
				Fz	Normal force on right front wheel, along the vehicle-fixed z-axis	Compute d	N
	RearAx l	Lft	Fx	Fx	Longitudinal force on left rear wheel, along the vehicle-fixed x-axis	Compute d	N
				Fy	Lateral force on left rear wheel along the vehicle-fixed y-axis	0	N
				Fz	Normal force on left rear wheel, along the vehicle-fixed z-axis	Compute d	N
		Rght	Fx	Fx	Longitudinal force on right rear wheel, along the vehicle-fixed x-axis	Compute d	N
				Fy	Lateral force on right rear wheel along the vehicle-fixed y-axis	0	N
				Fz	Normal force on right rear wheel, along the vehicle-fixed z-axis	Compute d	N
	Tires	FrntTi res	L f t	Fx	Front left tire force, along vehicle-fixed x-axis	0	N
				Fy	Front left tire force, along vehicle-fixed y-axis	0	N
				Fz	Front left tire force, along vehicle-fixed z-axis	Compute d	N

Signal				Description			Value	Units
				R g h t	F x	Front right tire force, along vehicle-fixed x-axis	0	N
				R g h t	F y	Front right tire force, along vehicle-fixed y-axis	0	N
				R g h t	F z	Front right tire force, along vehicle-fixed z-axis	Computed	N
RearTires	Left	L f t	F x	Rear left tire force, along vehicle-fixed x-axis	0	N		
		L f t	F y	Rear left tire force, along vehicle-fixed y-axis	0	N		
		L f t	F z	Rear left tire force, along vehicle-fixed z-axis	Computed	N		
	Right	R g h t	F x	Rear right tire force, along vehicle-fixed x-axis	0	N		
		R g h t	F y	Rear right tire force, along vehicle-fixed y-axis	0	N		
		R g h t	F z	Rear right tire force, along vehicle-fixed z-axis	Computed	N		
Drag	Fx		Drag force on vehicle CG along vehicle-fixed x-axis			Computed	N	
	Fy		Drag force on vehicle CG along vehicle-fixed y-axis			Computed	N	

Signal				Description	Value	Units
Signal	Grvty	Fx	Fz	Drag force on vehicle CG along vehicle-fixed z-axis	Computed	N
			Fx	Gravity force on vehicle CG along vehicle-fixed x-axis	Computed	N
			Fy	Gravity force on vehicle CG along vehicle-fixed y-axis	0	N
			Fz	Gravity force on vehicle CG along vehicle-fixed z-axis	Computed	N
	Momen ts	Body	Mx	Body moment on vehicle CG about vehicle-fixed x-axis	0	N·m
			My	Body moment on vehicle CG about vehicle-fixed y-axis	Computed	N·m
			Mz	Body moment on vehicle CG about vehicle-fixed z-axis	0	N·m
	Drag	Drag	Mx	Drag moment on vehicle CG about vehicle-fixed x-axis	0	N·m
			My	Drag moment on vehicle CG about vehicle-fixed y-axis	Computed	N·m
			Mz	Drag moment on vehicle CG about vehicle-fixed z-axis	0	N·m
	FrntAx l	Lft	Disp	Front left wheel displacement along the vehicle-fixed x-axis	Computed	m

Signal					Description	Value	Units	
				y	Front left wheel displacement along the vehicle-fixed y-axis	0	m	
					Front left wheel displacement along the vehicle-fixed z-axis	Compute d	m	
				Vel	Front left wheel velocity along the vehicle-fixed x-axis	Compute d	m/s	
					Front left wheel velocity along the vehicle-fixed y-axis	0	m/s	
					Front left wheel velocity along the vehicle-fixed z-axis	Compute d	m/s	
			Rght	Disp	Front right wheel displacement along the vehicle-fixed x-axis	Compute d	m	
					Front right wheel displacement along the vehicle-fixed y-axis	0	m	
					Front right wheel displacement along the vehicle-fixed z-axis	Compute d	m	
			Vel	xd ot	Front right wheel velocity along the vehicle-fixed x-axis	Compute d	m/s	
					Front left wheel steering angle	Compute d	rad	
			Steer	WhlAngFR		Front right wheel steering angle	Compute d	rad
				Lft		Rear left wheel displacement along the vehicle-fixed x-axis	Compute d	m

Signal				Description	Value	Units	
Rear Left Wheel				y	Rear left wheel displacement along the vehicle-fixed y-axis	0	m
				z	Rear left wheel displacement along the vehicle-fixed z-axis	Compute d	m
	Vel	xd ot	x	Rear left wheel velocity along the vehicle-fixed x-axis	Compute d	m/s	
			y	Rear left wheel velocity along the vehicle-fixed y-axis	0	m/s	
			z	Rear left wheel velocity along the vehicle-fixed z-axis	Compute d	m/s	
		Rght	Disp	Rear right wheel displacement along the vehicle-fixed x-axis	Compute d	m	
			y	Rear right wheel displacement along the vehicle-fixed y-axis	0	m	
			z	Rear right wheel displacement along the vehicle-fixed z-axis	Compute d	m	
	Vel	xd ot	x	Rear right wheel velocity along the vehicle-fixed x-axis	Compute d	m/s	
			y	Rear right wheel velocity along the vehicle-fixed y-axis	0	m/s	
			z	Rear right wheel velocity along the vehicle-fixed z-axis	Compute d	m/s	

Signal				Description	Value	Units
		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
	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	Computed	m/s
	Beta	Beta	Body slip angle, β $\beta = \frac{V_y}{V_x}$		Computed	rad

xdot — Vehicle longitudinal velocity
scalar

Vehicle CG velocity along vehicle-fixed x -axis, in m/s.

ydot — Vehicle lateral velocity

scalar

Vehicle CG velocity along vehicle-fixed y -axis, in m/s.

psi — Yaw

scalar

Rotation of 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.

FzF — Normal force on front wheels

scalar | array

Normal force on front wheels, Fz_F , along 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 front wheels	$FzF = [Fz_{fl} \ Fz_{fr}]$	Array - [1x2]

FzR — Normal force on rear wheels

scalar | array

Normal force on rear wheels, Fz_R , along 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 rear wheels	$FzR = [Fz_{rl} \ Fz_{rr}]$	Array - [1x2]

Parameters

Options

Vehicle track — Type

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
Vehicle Body 3DOF Single Track	Single (bicycle)	<ul style="list-style-type: none"> Forces act along the center line at the front and rear axles. No lateral load transfer.
Vehicle Body 3DOF Dual Track	Dual	Forces act at the four vehicle corners or <i>hard points</i> .

Axle forces — Type

External longitudinal velocity | External longitudinal force | 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"> Block assumes that the external longitudinal velocity is quasi-steady state so the longitudinal acceleration is approximately zero. Since the motion is quasi-steady, the block calculates lateral forces using the tire slip angles and linear cornering stiffness. Consider this setting when you want to: <ul style="list-style-type: none"> Generate virtual sensor signal data. Conduct high-level software studies that are not impacted by driveline or nonlinear tire responses.
External longitudinal force	<ul style="list-style-type: none"> Block uses the external longitudinal force to accelerate or brake the vehicle. Block calculates lateral forces using the tire slip angles and linear cornering stiffness. Consider this setting when you want to: <ul style="list-style-type: none"> Account for changes in the longitudinal velocity on the lateral and yaw motion. Specify the external longitudinal motion through a force instead of an external longitudinal velocity. Connect the block to tractive actuators, wheels, and brakes.
External forces	<ul style="list-style-type: none"> Block uses the external lateral and longitudinal forces to steer, accelerate, or brake the vehicle. Block does not use the steering input to calculate vehicle motion. Consider this setting when you need more accurate nonlinear combined lateral and longitudinal slip tire models.

Input Signals

Front wheel steering – WhlAngF input port
 off (default) | on

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.

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.

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, `NF` – Front wheel count
scalar

Number of wheels on front axle, N_F , dimensionless.

Number of wheels on rear axle, `NR` – Rear wheel count
scalar

Number of wheels on rear axle, N_R , dimensionless.

Vehicle mass, `m` – Vehicle mass
scalar

Vehicle mass, m , in kg.

Longitudinal distance from center of mass to front axle, `a` – Front axle distance
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
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
scalar

Height of vehicle CG above the axles, h , in m.

Initial inertial frame longitudinal position, x_o — Position scalar

Initial vehicle CG displacement along earth-fixed X-axis, in m.

Initial longitudinal velocity, $xdot_o$ — Velocity 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, Cy_f — Stiffness scalar

Front tire corner stiffness, Cy_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, Cy_r — Stiffness scalar

Rear tire corner stiffness, Cy_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
scalar

Initial vehicle CG displacement along earth-fixed Y-axis, in m.

Initial lateral velocity, ydot_o — Velocity
scalar

Initial vehicle CG velocity along vehicle-fixed y-axis, in m/s.

Mapped Lateral Stiffness

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

Track width — Width
scalar

Track width, w , in m.

Dependencies

To enable this parameter, set **Vehicle track** to Dual.

Front tire(s) relaxation length, sigma_f — Relaxation length scalar

Front tire relaxation length, σ_f , in m.

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**.
- 3 Select **Include relaxation length dynamics**.

Rear tire(s) relaxation length, sigma_f — Relaxation length scalar

Rear tire relaxation length, σ_r , in m.

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**.
- 3 Select **Include relaxation length dynamics**.

Front axle slip angle breakpoints, alpha_f_brk — Breakpoints vector

Front axle slip angle breakpoints, α_{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 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 vector

Rear axle slip angle breakpoints, α_{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 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, Izz – Inertia
scalar

Yaw polar inertia, in $\text{kg} \cdot \text{m}^2$.

Initial yaw angle, psi_o – Psi
scalar

Rotation of vehicle-fixed frame about earth-fixed Z-axis (yaw), in rad.

Initial yaw rate, r_o – Yaw rate
scalar

Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate), in rad/s.

Aerodynamic

Longitudinal drag area, Af – Area
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
scalar

Air drag coefficient, C_d , dimensionless.

Longitudinal lift coefficient, Cl – Lift
scalar

Air lift coefficient, C_l , dimensionless.

Longitudinal drag pitch moment, Cpm – Pitch drag
scalar

Longitudinal drag pitch moment coefficient, C_{pm} , dimensionless.

Relative wind angle vector, beta_w — Wind angle vector

Relative wind angle vector, β_w , in rad.

Side force coefficient vector, Cs — Side force drag vector

Side force coefficient vector coefficient, C_s , dimensionless.

Yaw moment coefficient vector, Cym — Yaw moment drag vector

Yaw moment coefficient vector coefficient, C_{ym} , dimensionless.

Environment

Absolute air pressure, Pabs — Pressure scalar

Environmental absolute pressure, P_{abs} , in Pa.

Air temperature, Tair — Temperature scalar

Environmental absolute temperature, T , in K.

Dependencies

To enable this parameter, clear **Air temperature**.

Gravitational acceleration, g — Gravity scalar

Gravitational acceleration, g , in m/s².

Nominal friction scaling factor, mu — Friction scale factor scalar

Nominal friction scale factor, μ , 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
scalar

Longitudinal velocity tolerance, in m/s.

Nominal normal force, Fznom — Normal force
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
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
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 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

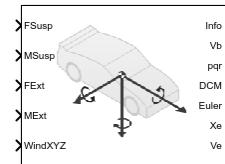
“Coordinate Systems in Vehicle Dynamics Blockset”

Introduced in R2018a

Vehicle Body 6DOF

6DOF rigid vehicle body to calculate 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.

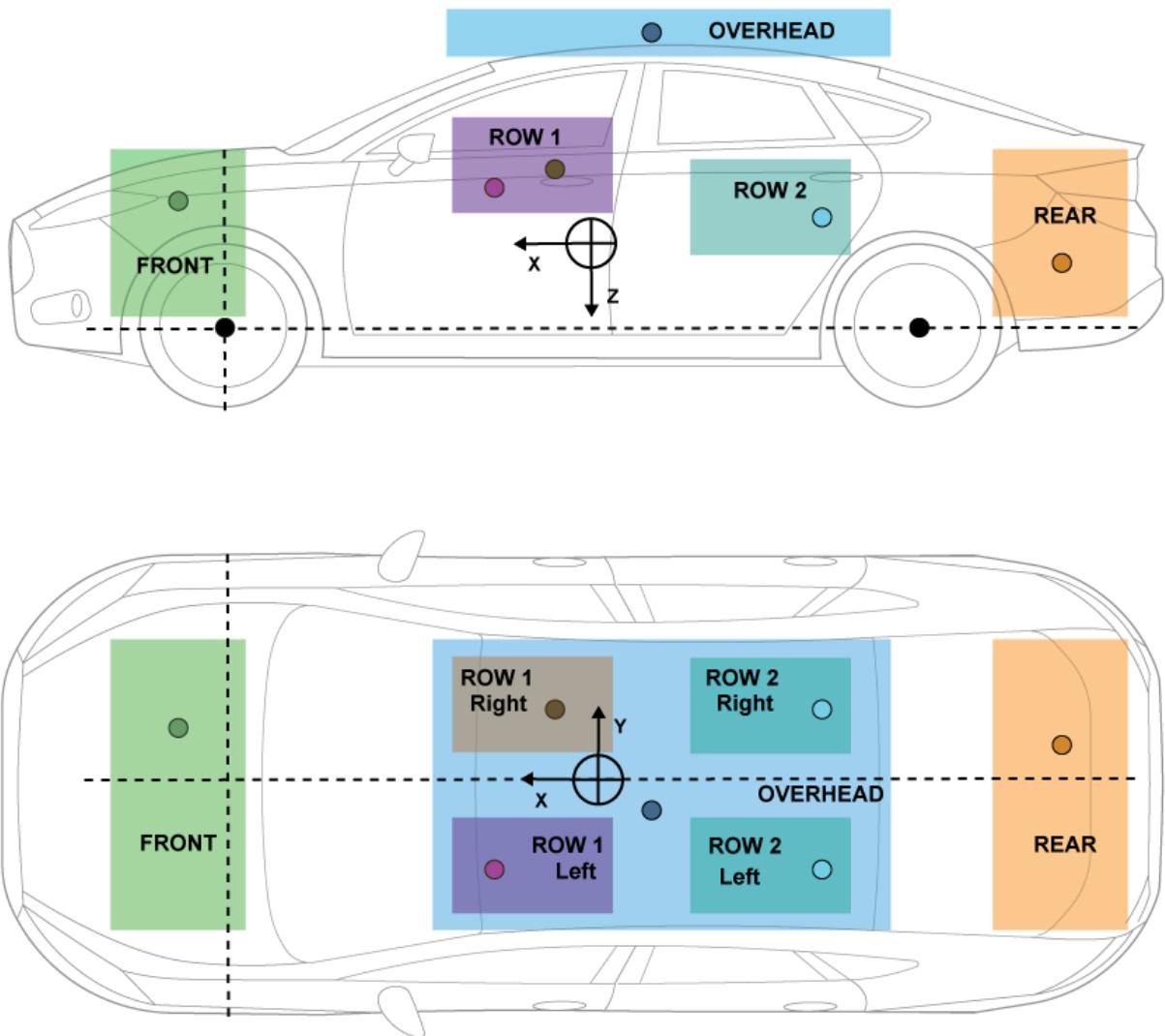
Inertial Loads

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 dots in this illustration indicate example load locations. 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 vehicle-fixed x-axis
- Vehicle centerline to load, along vehicle-fixed y-axis

- Front suspension hardpoint to load, along vehicle-fixed z -axis

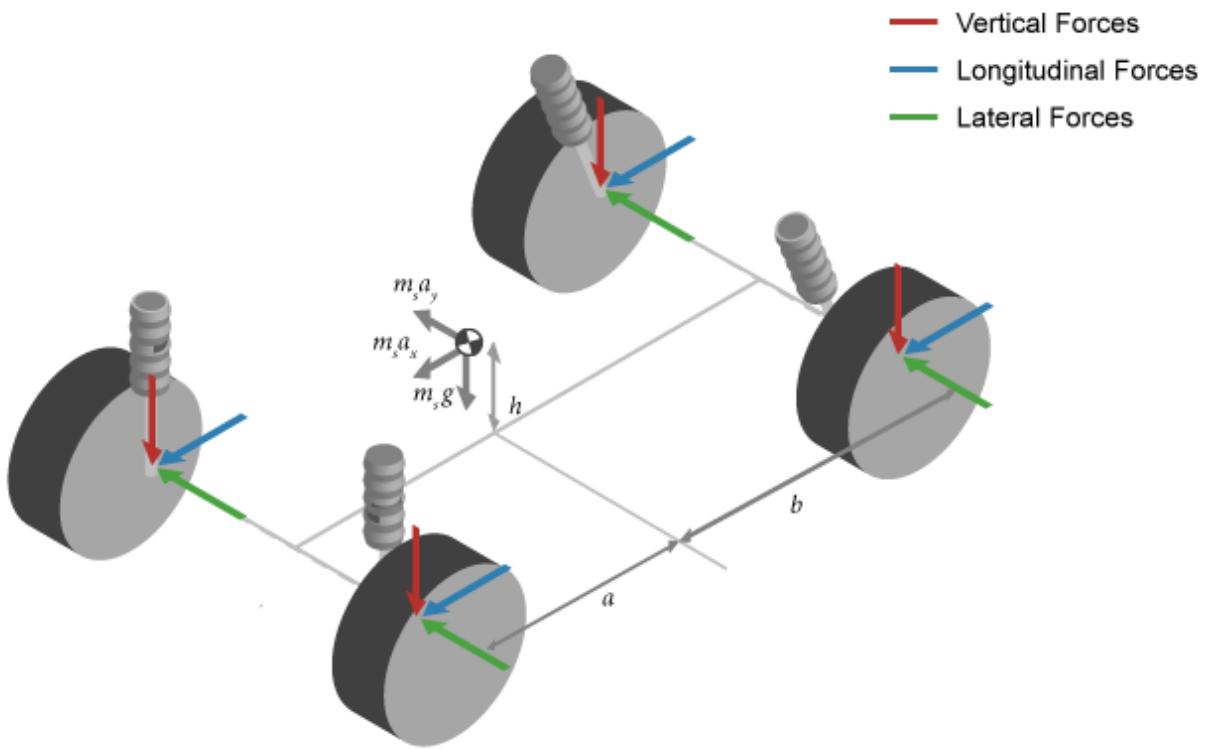
Load	Parameter	Example Location
Front	Distance vector from front axle, $z1R$	<ul style="list-style-type: none"> $z1R(1,1)<0$ — Forward of the front axle $z1R(1,2)>0$ — Right of the vehicle centerline $z1R(1,3)>0$ — Above the front axle suspension hardpoint
Overhead	Distance vector from front axle, $z2R$	<ul style="list-style-type: none"> $z2R(1,1)>0$ — Rear of the front axle $z2R(1,2)<0$ — Left of the vehicle centerline $z2R(1,3)>0$ — Above the front axle suspension hardpoint
Row 1, left side	Distance vector from front axle, $z3R$	<ul style="list-style-type: none"> $z3R(1,1)>0$ — Rear of the front axle $z3R(1,2)<0$ — Left of the vehicle centerline $z3R(1,3)>0$ — Above the front axle suspension hardpoint
Row 1, right side	Distance vector from front axle, $z4R$	<ul style="list-style-type: none"> $z4R(1,1)>0$ — Rear of the front axle $z4R(1,2)>0$ — Right of the vehicle centerline $z4R(1,3)>0$ — Above the front axle suspension hardpoint
Row 2, left side	Distance vector from front axle, $z5R$	<ul style="list-style-type: none"> $z5R(1,1)>0$ — Rear of the front axle $z5R(1,2)<0$ — Left of the vehicle centerline $z5R(1,3)>0$ — Above the front axle suspension hardpoint
Row 2, right side	Distance vector from front axle, $z6R$	<ul style="list-style-type: none"> $z6R(1,1)>0$ — Rear of the front axle $z6R(1,2)>0$ — Right of the vehicle centerline $z6R(1,3)>0$ — Above the front axle suspension hardpoint

Load	Parameter	Example Location
Rear	Distance vector from front axle, z7R	<ul style="list-style-type: none"> • $z7R(1,1)>0$ — Rear of the front axle • $z7R(1,2)>0$ — Right of the vehicle centerline • $z7R(1,3)>0$ — Above the front axle suspension hardpoint

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
<i>Load masses and inertias</i>	Block uses parallel axis theorem to resolve the individual load masses and inertias with the vehicle mass and inertia. $J_{ij} = I_{ij} + m(R ^2\delta_{ij} - R_i R_j)$
<i>Gravitational forces, F_g</i>	Block uses direction cosine matrix (DCM) to transform the gravitational vector in the inertial-fixed frame to the body-fixed frame.

Calculation	Implementation
<i>Drag forces, F_d, and moments, M_d</i>	<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> $\bar{w} = \sqrt{(\dot{x}_b - w_x)^2 + (\dot{x}_y - w_x)^2 + (w_z)^2}$ $F_{dx} = -\frac{1}{2TR} C_d A_f P_{abs}(\bar{w})$ $F_{dy} = -\frac{1}{2TR} C_s A_f P_{abs}(\bar{w})$ $F_{dz} = -\frac{1}{2TR} C_l A_f P_{abs}(\bar{w})$ <p>Using the relative airspeed, the block determines the drag moments.</p> $M_{dr} = -\frac{1}{2TR} C_{rm} A_f P_{abs}(\bar{w})(a + b)$ $M_{dp} = -\frac{1}{2TR} C_{pm} A_f P_{abs}(\bar{w})(a + b)$ $M_{dy} = -\frac{1}{2TR} C_{ym} A_f P_{abs}(\bar{w})(a + b)$
<i>External forces, F_{in}, and moments, M_{in}</i>	External forces and moments are input via ports FExt and MExt.
<i>Suspension forces and moments</i>	<p>Block assumes that the suspension forces and moments act on these hardpoint locations:</p> <ul style="list-style-type: none"> • F_{FL}, M_{FL} — Front left • F_{FR}, M_{FR} — Front right • F_{RL}, M_{RL} — Rear left • F_{RR}, M_{RR} — Rear right

The equations use these variables.

x, \dot{x}, \ddot{x}

Vehicle CM displacement, velocity, and acceleration along vehicle-fixed x-axis

y, \dot{y}, \ddot{y}	Vehicle CM displacement, velocity, and acceleration along vehicle-fixed y -axis
z, \dot{z}, \ddot{z}	Vehicle CM displacement, velocity, and acceleration along vehicle-fixed z -axis
φ	Rotation of vehicle-fixed frame about earth-fixed X -axis (roll)
θ	Rotation of vehicle-fixed frame about earth-fixed Y -axis (pitch)
ψ	Rotation of vehicle-fixed frame about earth-fixed Z -axis (yaw)
$F_{FLx}, F_{FLy}, F_{FLz}$	Suspension forces applied to front left hardpoint along vehicle-fixed x -, y -, and z -axes
$F_{FRx}, F_{FRy}, F_{FRz}$	Suspension forces applied to front right hardpoint along vehicle-fixed x -, y -, and z -axes
$F_{RLx}, F_{RLy}, F_{RLz}$	Suspension forces applied to rear left hardpoint along vehicle-fixed x -, y -, and z -axes
$F_{RRx}, F_{RRy}, F_{RRz}$	Suspension forces applied to rear right hardpoint along vehicle-fixed x -, y -, and z -axes
M_{Fx}, F_{Fy}, F_{Fz}	Suspension moments applied to vehicle CM about vehicle-fixed x -, y -, and z -axes
$F_{extx}, F_{exty}, F_{extz}$	External forces applied to vehicle CM along vehicle-fixed x -, y -, and z -axes
F_{dx}, F_{dy}, F_{dz}	Drag forces applied to vehicle CM along vehicle-fixed x -, y -, and z -axes
$M_{extx}, M_{exty}, M_{extz}$	External moment about vehicle CM about vehicle-fixed x -, y -, and z -axes
M_{dx}, M_{dy}, M_{dz}	Drag moment about vehicle CM about 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
h	Height of vehicle CM above the axle plane
w_F, w_R	Front and rear track widths
γ	Road grade angle
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 vehicle-fixed x -axis
C_{pm}	Air drag pitch moment acting about 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 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].

$$FSusp = \begin{bmatrix} F_{xFL} & F_{xFR} & F_{xRL} & F_{xRR} \\ F_{yFL} & F_{yFR} & F_{yRL} & F_{yRR} \\ F_{zFL} & F_{zFR} & F_{zRL} & F_{zRR} \end{bmatrix}$$

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)

Array Element	Axle	Track	Force Axis
FSusp(2, 2)	Front	Right	Vehicle-fixed z -axis (vertical)
FSusp(2, 3)	Rear	Left	
FSusp(2, 4)	Rear	Right	
FSusp(3, 1)	Front	Left	
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. Signal dimensions are [3x4].

$$MSusp = \begin{bmatrix} M_{xFL} & M_{xFR} & M_{xRL} & M_{xRR} \\ M_{yFL} & M_{yFR} & M_{yRL} & M_{yRR} \\ M_{zFL} & M_{zFR} & M_{zRL} & M_{zRR} \end{bmatrix}$$

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	

Array Element	Axle	Track	Moment Axis
MSusp(3,4)	Rear	Right	

FExt — External forces acting on vehicle vector

External forces on vehicle, in N. Signal vector dimensions are [1x3] or [3x1].

$$\mathbf{FExt} = F_{ext} = [F_{ext_x} \ F_{ext_y} \ F_{ext_z}] \text{ or } \begin{bmatrix} F_{ext_x} \\ F_{ext_y} \\ F_{ext_z} \end{bmatrix}$$

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 vehicle, in N·m. Signal vector dimensions are [1x3] or [3x1].

$$\mathbf{MExt} = M_{ext} = [M_{ext_x} \ M_{ext_y} \ M_{ext_z}] \text{ or } \begin{bmatrix} M_{ext_x} \\ M_{ext_y} \\ M_{ext_z} \end{bmatrix}$$

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)

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].

AirTemp — Ambient air temperature

scalar

Ambient air temperature, T_{air} , in K.

Dependencies

To create this port, on the **Environment** pane, select **Air temperature**.

Output Arguments

Info — Bus signal

bus

Bus signal containing these block values.

Signal				Description	Value	Units
InertFr m	Cg	Disp	X	Vehicle CM displacement along earth-fixed X-axis	Computed	m
			Y	Vehicle CM displacement along earth-fixed Y-axis	Computed	m
			Z	Vehicle CM displacement along earth-fixed Z-axis	Computed	m
	Vel		Xdot	Vehicle CM velocity along earth-fixed X-axis	Computed	m/s
			Ydot	Vehicle CM velocity along earth-fixed Y-axis	Computed	m/s

Signal				Description	Value	Units
FrntAx l	Ang	Zdot		Vehicle CM velocity along earth-fixed Z-axis	Computed	m/s
			phi	Rotation of vehicle-fixed frame about earth-fixed X-axis (roll)	Computed	rad
			theta	Rotation of vehicle-fixed frame about earth-fixed Y-axis (pitch)	Computed	rad
			psi	Rotation of vehicle-fixed frame about earth-fixed Z-axis (yaw)	Computed	rad
	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
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	Xd _{ot}	Front right axle velocity along the earth-fixed X-axis	Computed	m/s	
			Yd _{ot}	Front right axle velocity along the earth-fixed Y-axis	Computed	m/s	
			Zd _{ot}	Front right axle velocity along the earth-fixed Z-axis	Computed	m/s	
RearAx l	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	Xd _{ot}	Rear left axle velocity along the earth-fixed X-axis	Computed	m/s	
			Yd _{ot}	Rear left axle velocity along the earth-fixed Y-axis	Computed	m/s	

Signal					Description	Value	Units		
				Zd ot	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
						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	Xd ot		Rear right axle velocity along the earth-fixed X-axis	Computed	m/s
					Yd ot		Rear right axle velocity along the earth-fixed Y-axis	Computed	m/s
					Zd ot		Rear right axle 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

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 vehicle-fixed x-axis	Computed	m/s
			ydot	Vehicle CM velocity along vehicle-fixed y-axis	Computed	m/s
			zdot	Vehicle CM velocity along 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 vehicle-fixed x-axis	Computed	gn
			ay	Vehicle CM acceleration along vehicle-fixed y-axis	Computed	gn

Signal				Description	Value	Units
			az	Vehicle CM acceleration along vehicle-fixed z-axis	Computed	gn
			xddot	Vehicle CM acceleration along vehicle-fixed x-axis	Computed	m/s^2
			yddot	Vehicle CM acceleration along vehicle-fixed y-axis	Computed	m/s^2
			zddot	Vehicle CM acceleration along vehicle-fixed z-axis	Computed	m/s^2
		DCM	Direction cosine matrix		Computed	rad
	Forces	Body	Fx	Net force on vehicle CM along vehicle-fixed x-axis	Computed	N
			Fy	Net force on vehicle CM along vehicle-fixed y-axis	Computed	N
			Fz	Net force on vehicle CM along vehicle-fixed z-axis	Computed	N
		FrntAx_l	Lft	Fx	Longitudinal force on front left axle along the vehicle-fixed x-axis	Computed
					Compute d	N
					Computed	N

Signal					Description	Value	Units
		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
	RearAx l	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
Tires	FrntTi res	L f t	F x		Front left tire force along vehicle-fixed x-axis	Computed	N
			F y		Front left tire force along vehicle-fixed y-axis	Computed	N

Signal				Description	Value	Units
Front Tires	Front	z	F	Front left tire force along vehicle-fixed z-axis	Computed	N
			R	Front right tire force along vehicle-fixed x-axis	Computed	N
			g	Front right tire force along vehicle-fixed y-axis	Computed	N
			h	Front right tire force along vehicle-fixed z-axis	Computed	N
	Rear Tires	Left	F	Rear left tire force along vehicle-fixed x-axis	Computed	N
			x	Rear left tire force along vehicle-fixed y-axis	Computed	N
			f	Rear left tire force along vehicle-fixed z-axis	Computed	N
		Right	F	Rear right tire force along vehicle-fixed x-axis	Computed	N
			g	Rear right tire force along vehicle-fixed y-axis	Computed	N
			h	Rear right tire force along vehicle-fixed z-axis	Computed	N
	Drag	Fx		Drag force on vehicle CM along vehicle-fixed x-axis	Computed	N

Signal			Description	Value	Units	
Signal	Grvty	Fy	Drag force on vehicle CM along vehicle-fixed y-axis	Computed	N	
		Fz	Drag force on vehicle CM along vehicle-fixed z-axis	Computed	N	
	Grvty	Fx	Gravity force on vehicle CM along vehicle-fixed x-axis	Computed	N	
		Fy	Gravity force on vehicle CM along vehicle-fixed y-axis	Computed	N	
		Fz	Gravity force on vehicle CM along vehicle-fixed z-axis	Computed	N	
	Momen ts	Body	Mx	Body moment on vehicle CM about vehicle-fixed x-axis	Computed	N·m
		My	Body moment on vehicle CM about vehicle-fixed y-axis	Computed	N·m	
		Mz	Body moment on vehicle CM about vehicle-fixed z-axis	Computed	N·m	
	Drag	Mx	Drag moment on vehicle CM about vehicle-fixed x-axis	Computed	N·m	
		My	Drag moment on vehicle CM about vehicle-fixed y-axis	Computed	N·m	
		Mz	Drag moment on vehicle CM about vehicle-fixed z-axis	Computed	N·m	

Signal					Description	Value	Units
FrntAx l	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	xd ot	Front left axle velocity along the vehicle-fixed x-axis	Computed	m/s	
			yd ot	Front left axle velocity along the vehicle-fixed y-axis	Computed	m/s	
			zd ot	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	xd ot	Front right axle velocity along the vehicle-fixed x-axis	Computed	m/s	
			yd ot	Front right axle velocity along the vehicle-fixed y-axis	Computed	m/s	

Signal					Description	Value	Units
RearAxle	Lft	Disp	x	zd _{ot}	Front right axle velocity along the vehicle-fixed z-axis	Computed	m/s
				y	Rear left axle displacement along the vehicle-fixed x-axis	Computed	m
				z	Rear left axle displacement along the vehicle-fixed y-axis	Computed	m
		Vel	xd _{ot}	Rear left axle velocity along the vehicle-fixed z-axis	Computed	m/s	
			yd _{ot}	Rear left axle velocity along the vehicle-fixed y-axis	Computed	m/s	
			zd _{ot}	Rear left axle velocity along the vehicle-fixed x-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	xd _{ot}	Rear right axle velocity along the vehicle-fixed x-axis	Computed	m/s	

Signal					Description	Value	Units	
				yd ot	Rear right axle velocity along the vehicle-fixed y-axis	Computed	m/s	
				zd ot	Rear right axle 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 earth-fixed z-axis	Input	m	
	Vel		xd ot		Vehicle chassis offset velocity along the vehicle-fixed x-axis	Computed	m/s	
			yd ot		Vehicle chassis offset velocity along the vehicle-fixed y-axis	Computed	m/s	
			zd ot		Vehicle chassis offset velocity along the vehicle-fixed z-axis	Computed	m/s	
	Ang		Beta	Body slip angle, β $\beta = \frac{V_y}{V_x}$		Computed	rad	

Vb — Vehicle velocity along vehicle-fixed frame

vector

Vehicle CM velocity along vehicle-fixed x -, y -, z - axes, respectively, in m/s.

pqr — Vehicle angular velocity about vehicle-fixed frame

vector

Vehicle CM angular velocity about vehicle-fixed x (roll rate)-, y (pitch rate)-, z (yaw rate)-axes, respectively, in rad/s.

DCM — Direction cosine matrix

array

Direction cosine matrix, in rad.

Euler — Euler angles

array

Euler angles, φ , θ , and ψ , respectively, in rad.

Xe — Vehicle position in inertial reference frame

vector

Vehicle CM position along inertial-fixed X -, Y -, Z - axes, respectively, in m.

Ve — Vehicle velocity in inertial reference frame

vector

Vehicle CM velocity along inertial-fixed X -, Y -, Z - axes, respectively, in m/s.

Parameters

Chassis

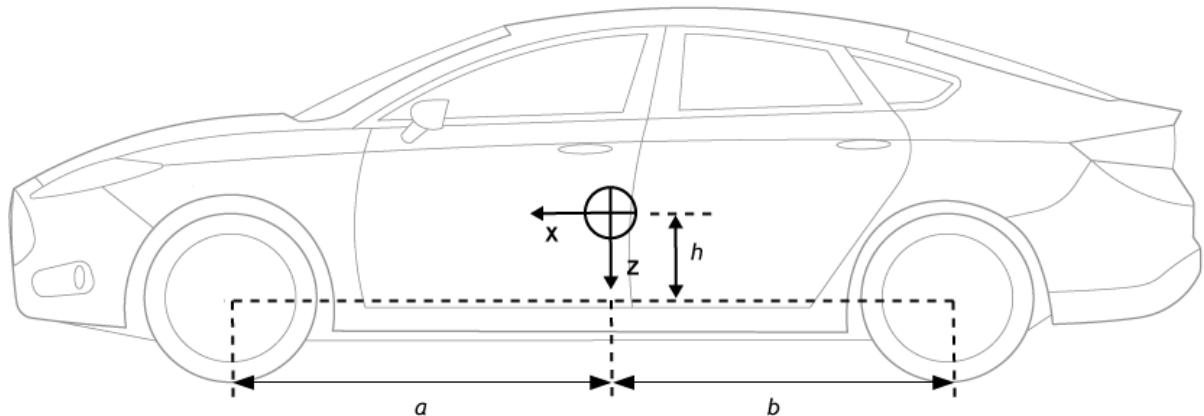
Vehicle mass, m — Mass

scalar

Vehicle mass, m , in kg.

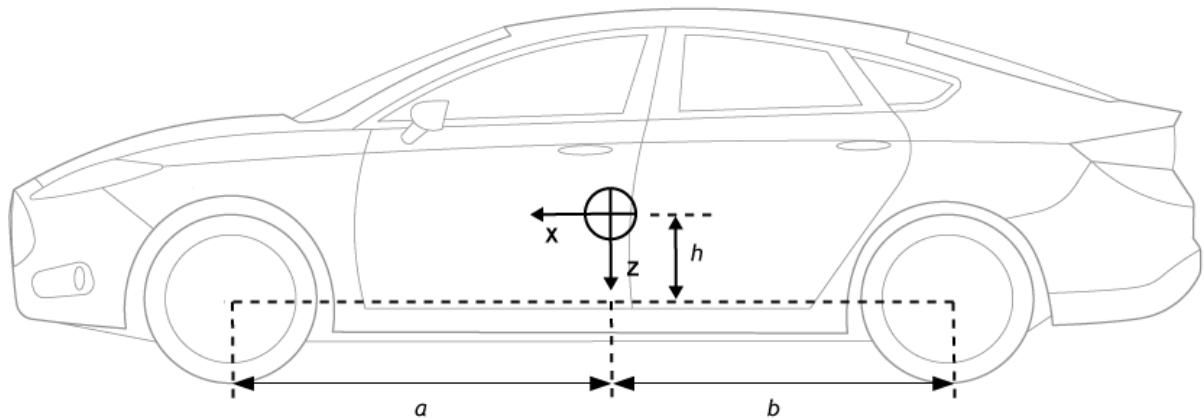
Longitudinal distance from center of mass to front axle, a — Distance scalar

Distance from vehicle CM to front axle, a , in m.



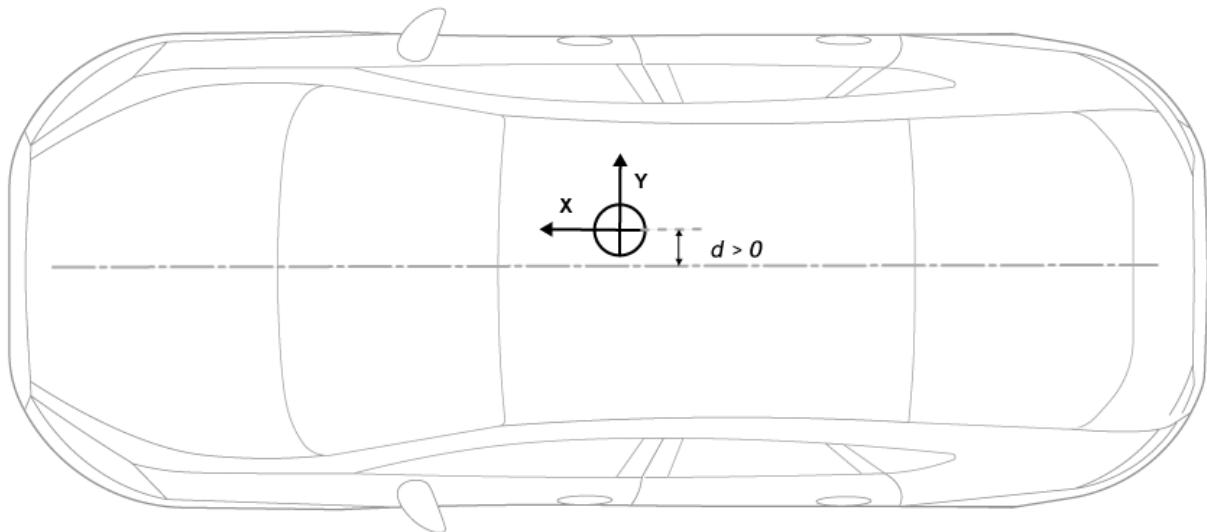
Longitudinal distance from center of mass to rear axle, b — Distance scalar

Distance from vehicle CM to front axle, b , in m.



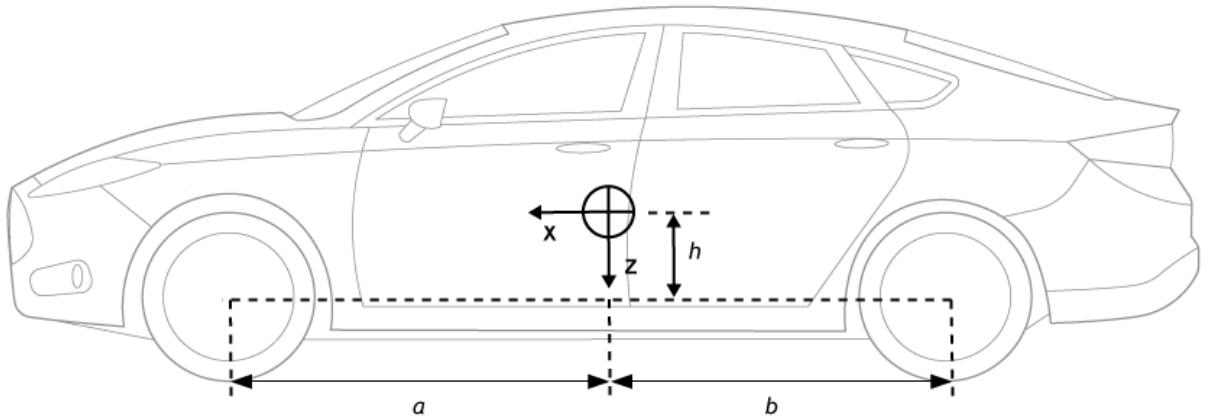
Lateral distance from geometric centerline to center of mass, d — Distance scalar

Lateral distance from geometric centerline to center of mass, d , in m, along 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 scalar

Vertical distance from vehicle CM to axle plane, h , in m.



Initial position in inertial frame [X_{e_o},Y_{e_o},Z_{e_o}], X_{e_o} — Position vector

Initial position of vehicle in inertial frame, X_{e_o} , in m.

Initial longitudinal velocity [x_{dot_o},y_{dot_o},z_{dot_o}], x_{bdot_o} — Velocity vector

Initial longitudinal velocity, in m/s.

Initial Euler orientation [roll, pitch, yaw], eul_{_o} — Rotation vector

Euler angle orientation of vehicle, in rad.

Initial body rotation rates [p,q,r], p_{_o} — Rotation rate vector

Euler angle rotation rate, in rad/s.

Chassis inertia tensor, I_{veh} — Inertia array

Vehicle inertia tensor, I_{veh} , in kg*m^2. Dimensions are [3-by-3].

Track widths [front,rear], w — Widths
vector

Front and rear track width, in m. Dimensions are [2-by-1].

Inertial Loads

Front

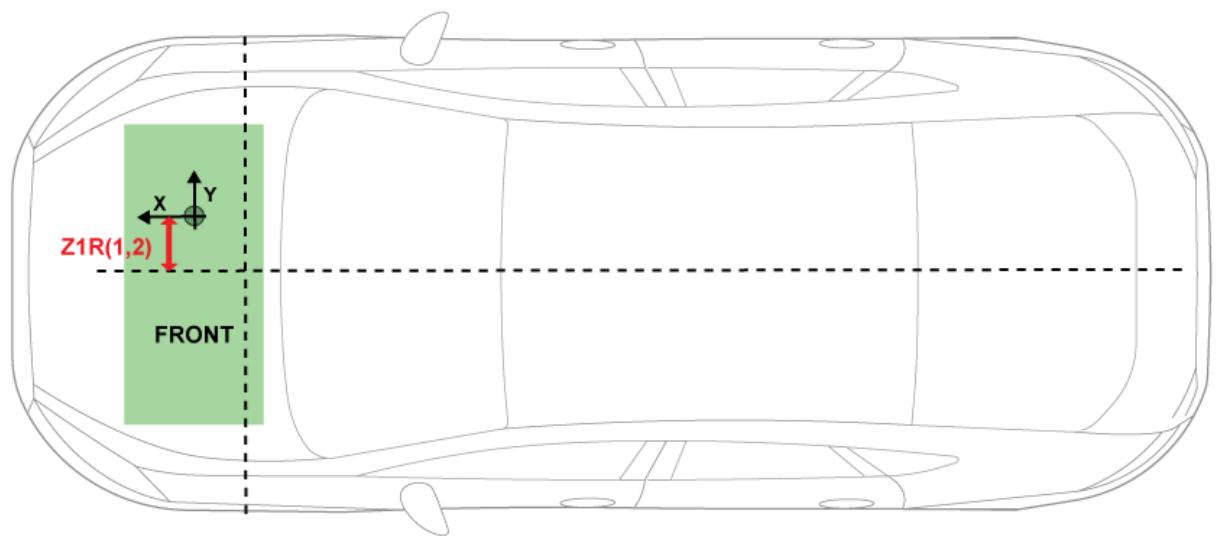
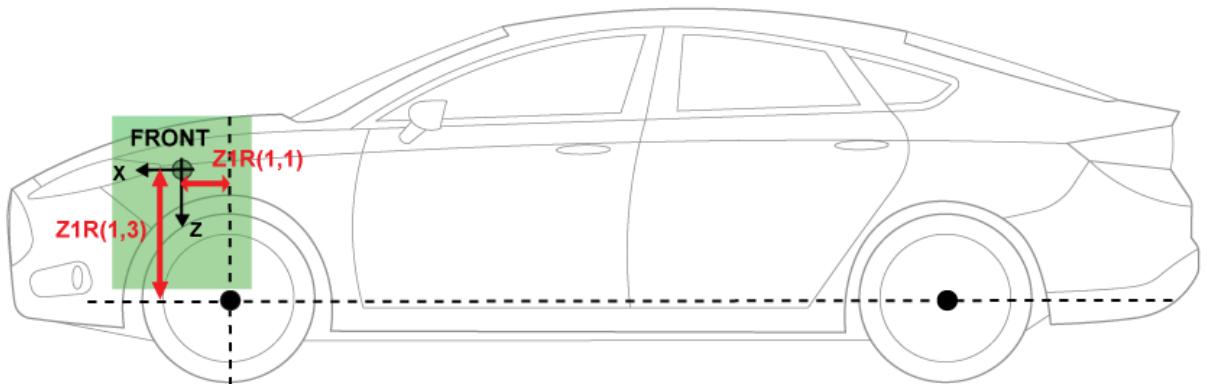
Mass, z1m — Mass
scalar

Mass, $z1m$, in kg.

Distance vector from front axle, z1R — Distance
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 indicated by the dots.

Example Location	Sign
<ul style="list-style-type: none">Forward of the front axleRight of the vehicle centerlineAbove the front axle suspension hardpoint	<ul style="list-style-type: none">$z1R(1,1) < 0$$z1R(1,2) > 0$$z1R(1,3) > 0$

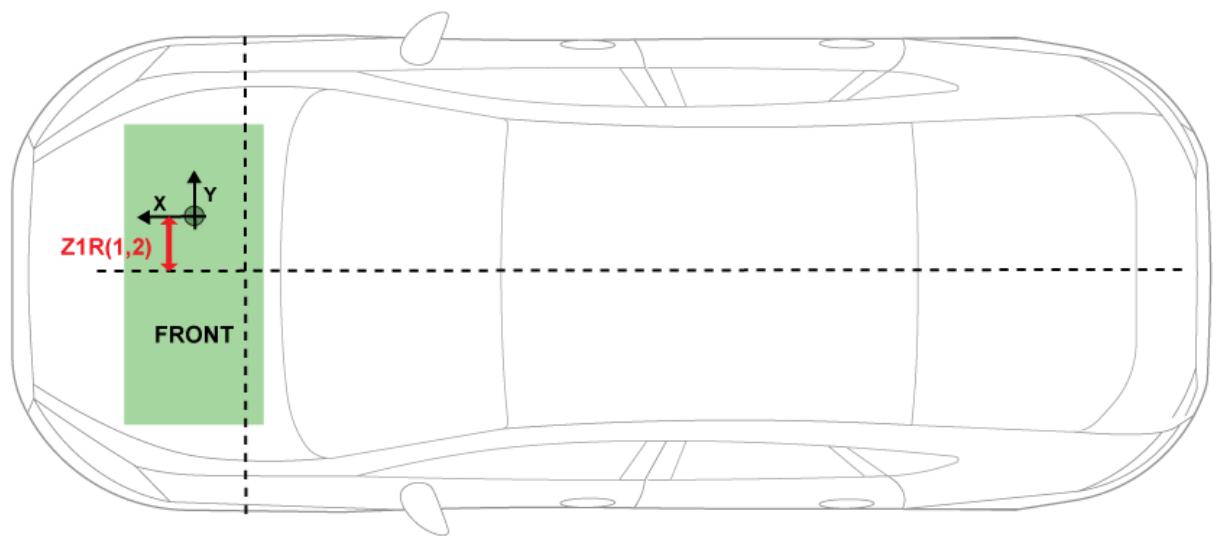
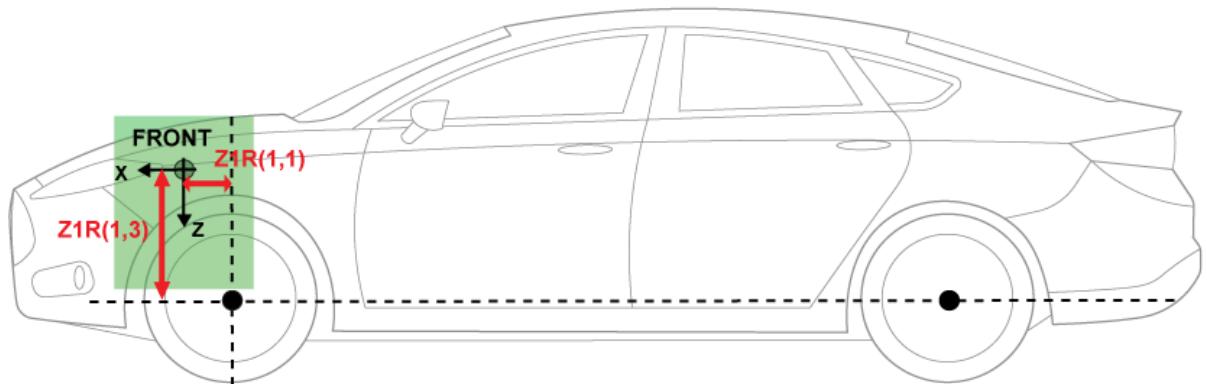
Inertia tensor, z1I — Inertia array

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 vehicle-fixed x -axis
- y -axis along vehicle-fixed y -axis
- z -axis along vehicle-fixed z -axis



Overhead

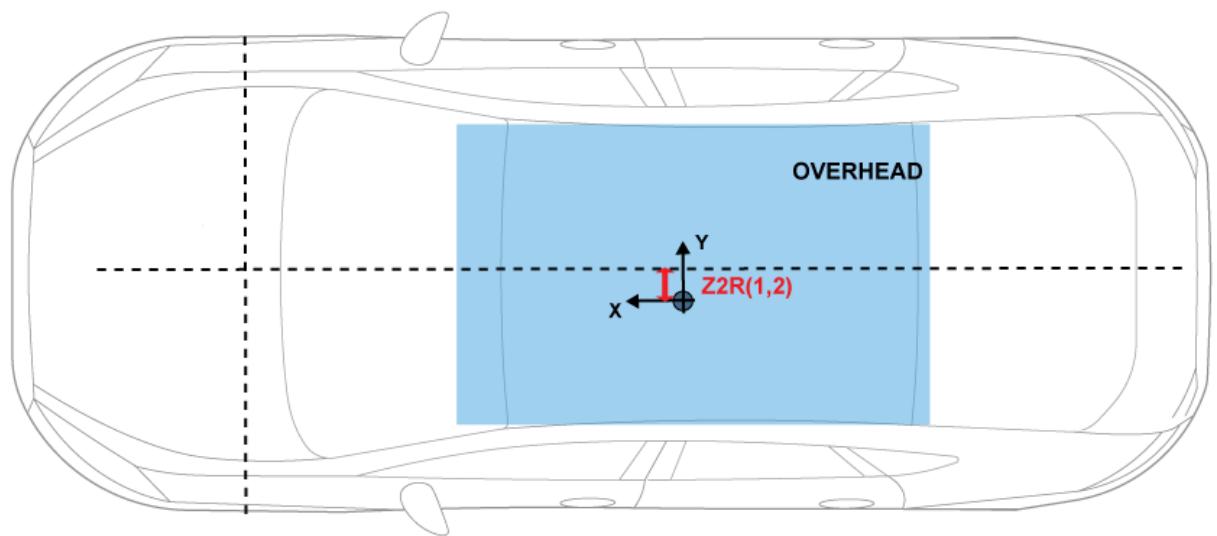
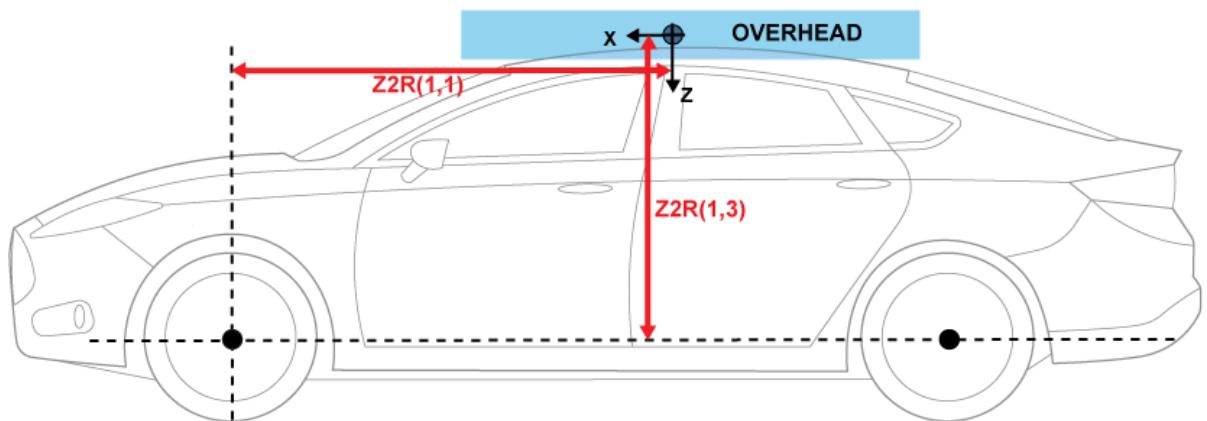
Mass, $z2m$ — Mass scalar

Mass, $z2m$, in kg.

Distance vector from front axle, z2R — Distance 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 indicated by the dot.

Example Location	Sign
<ul style="list-style-type: none">• Rear of the front axle• Left of the vehicle centerline• Above the front axle suspension hardpoint	<ul style="list-style-type: none">• $z2R(1,1) > 0$• $z2R(1,2) < 0$• $z2R(1,3) > 0$

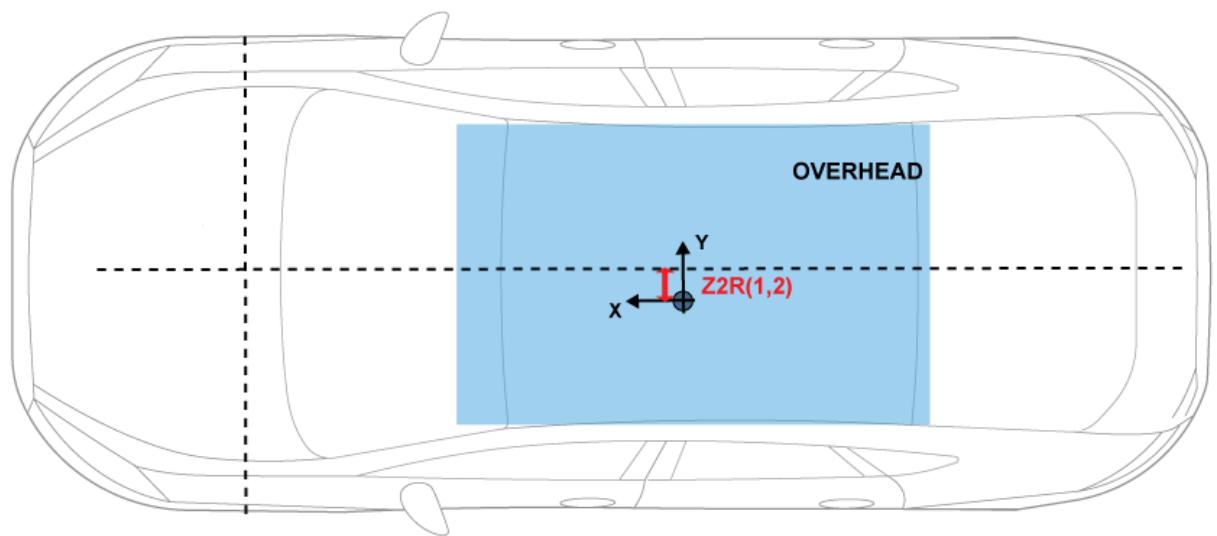
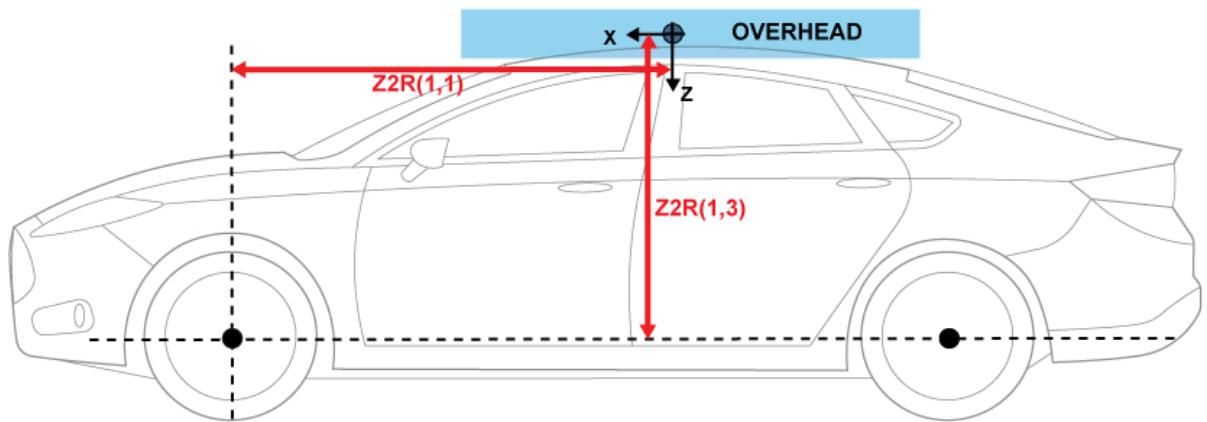
Inertia tensor, z2I — Inertia array

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 vehicle-fixed x -axis
- y -axis along vehicle-fixed y -axis
- z -axis along vehicle-fixed z -axis

**Row 1, left side**

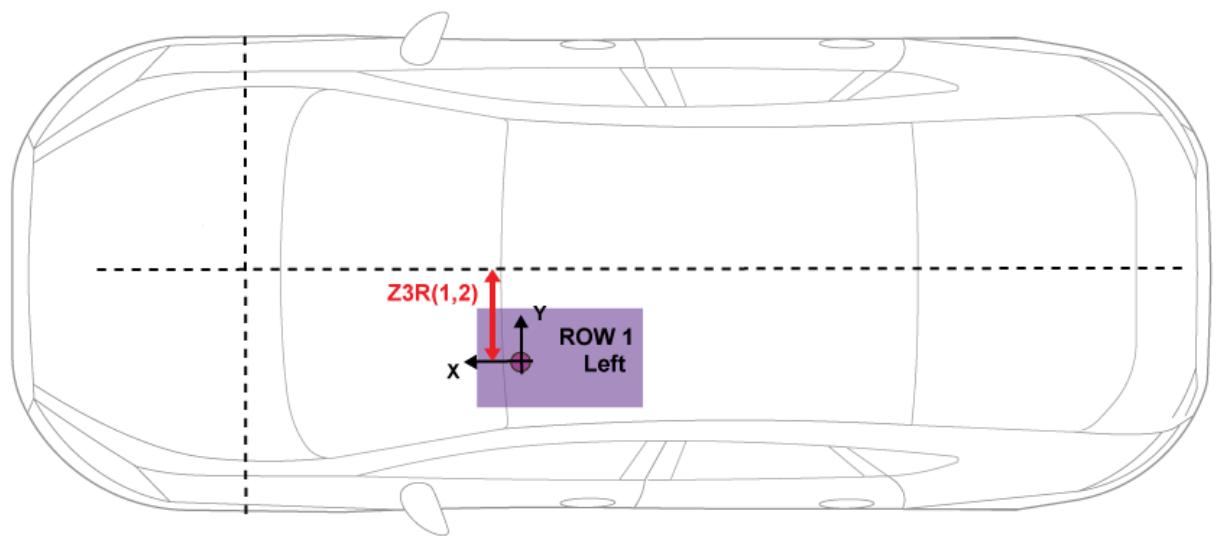
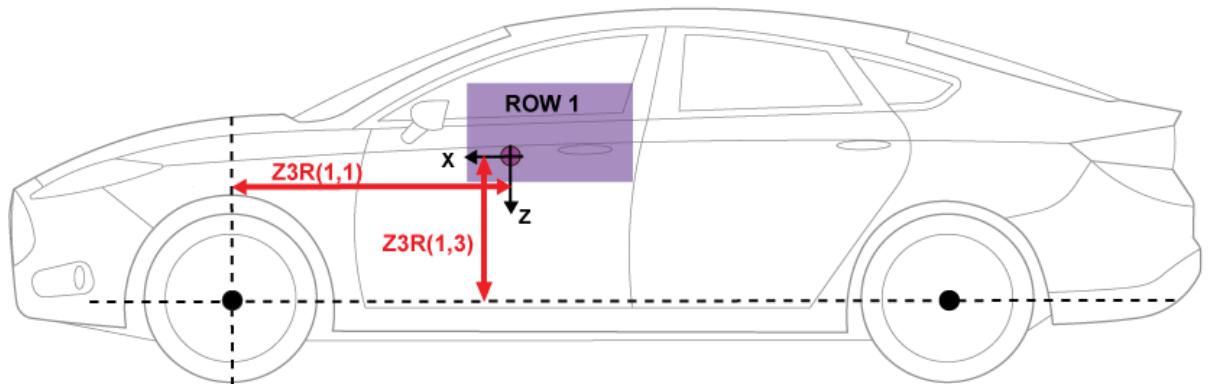
Mass, $z3m$ — Mass scalar

Mass, $z3m$, in kg.

Distance vector from front axle, z3R — Distance 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 indicated by the dot.

Example Location	Sign
<ul style="list-style-type: none">• Rear of the front axle• Left of the vehicle centerline• Above the front axle suspension hardpoint	<ul style="list-style-type: none">• $z3R(1,1) > 0$• $z3R(1,2) < 0$• $z3R(1,3) > 0$

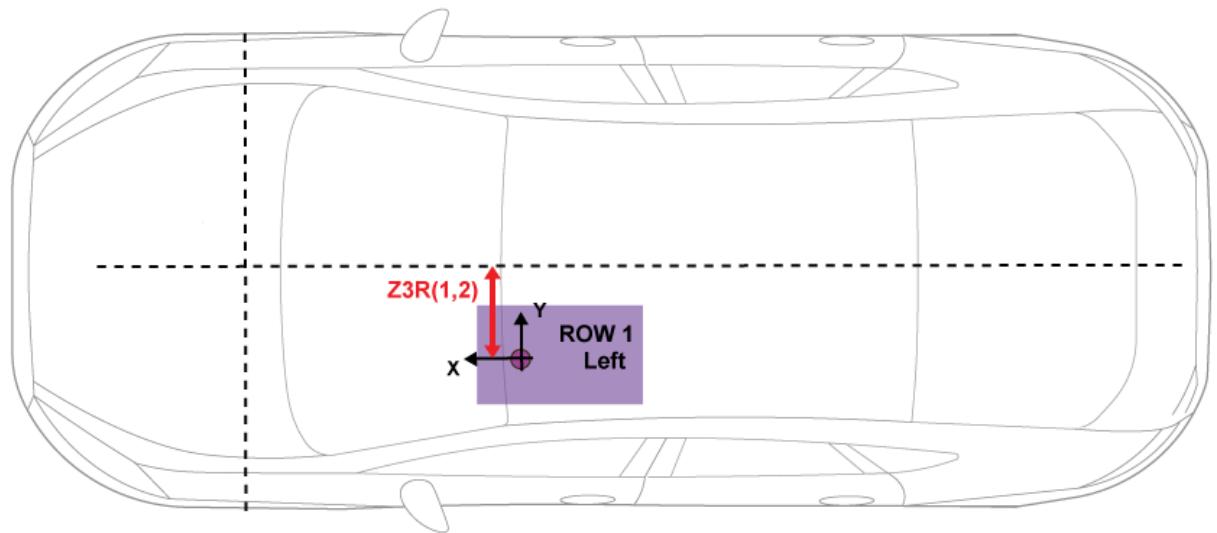
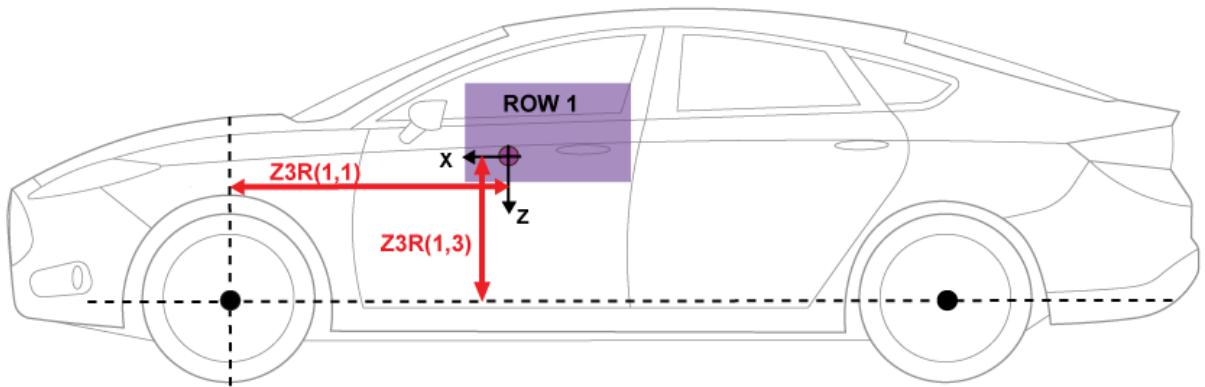
Inertia tensor, z3I — Inertia array

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 vehicle-fixed x -axis
- y -axis along vehicle-fixed y -axis
- z -axis along vehicle-fixed z -axis

**Row 1, right side**

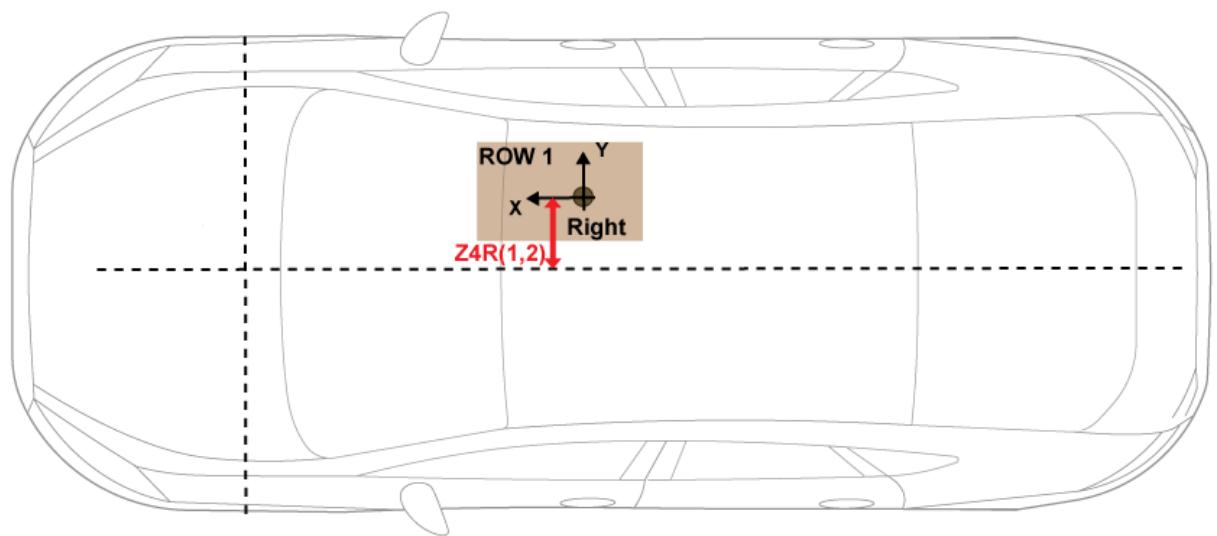
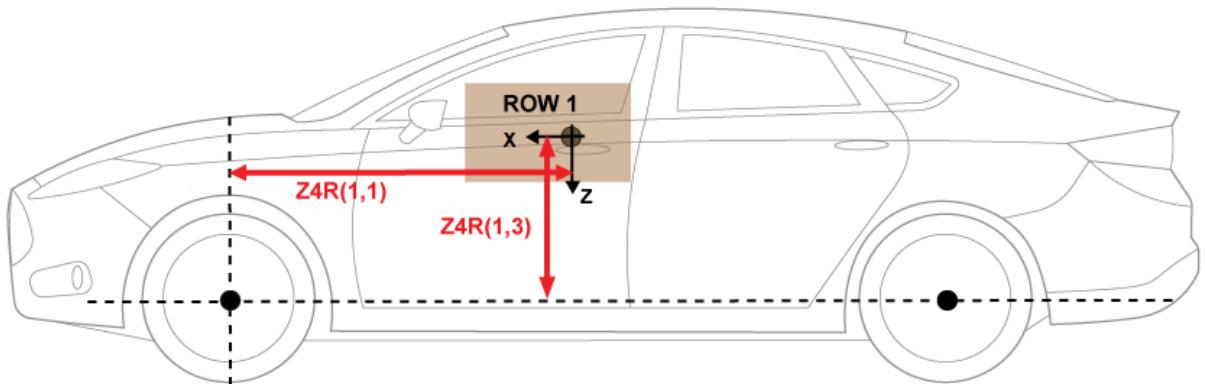
**Mass, $z4m$ — Mass
scalar**

Mass, $z4m$, in kg.

Distance vector from front axle, z4R — Distance 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 indicated by the dot.

Example Location	Sign
<ul style="list-style-type: none"> • Rear of the front axle • Right of the vehicle centerline • Above the front axle suspension hardpoint 	<ul style="list-style-type: none"> • $z4R(1,1) > 0$ • $z4R(1,2) > 0$ • $z4R(1,3) > 0$

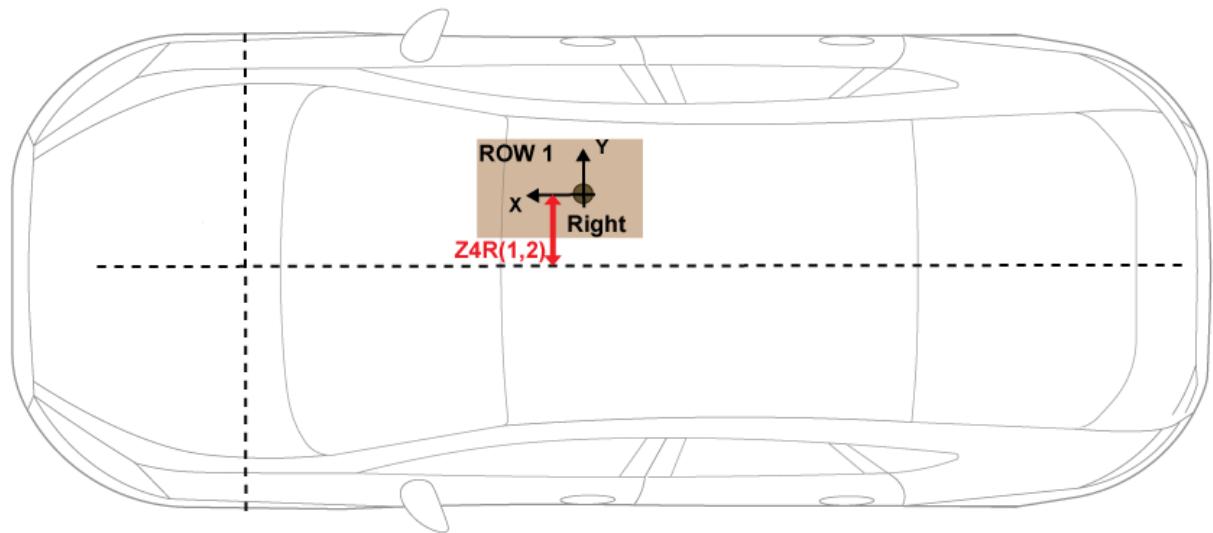
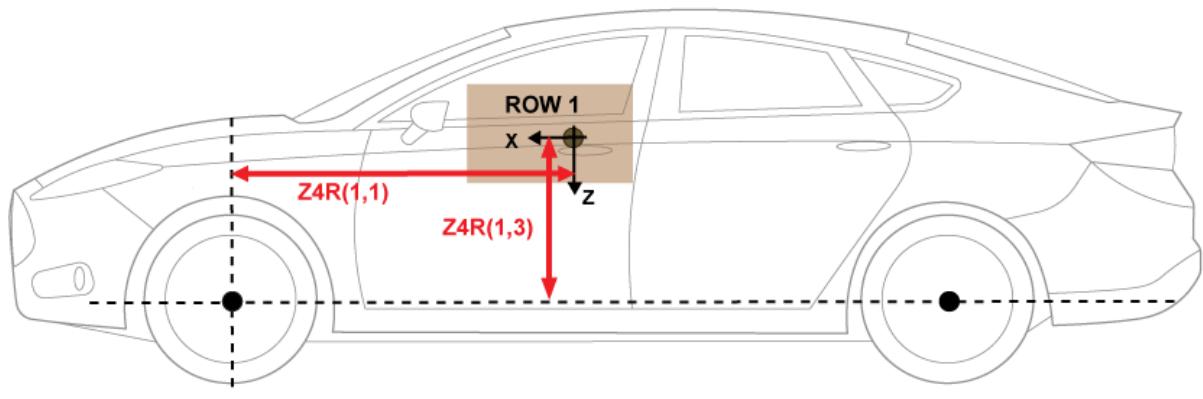
Inertia tensor, $z4I$ — Inertia array

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 vehicle-fixed x -axis
- y -axis along vehicle-fixed y -axis
- z -axis along vehicle-fixed z -axis

**Row 2, left side**

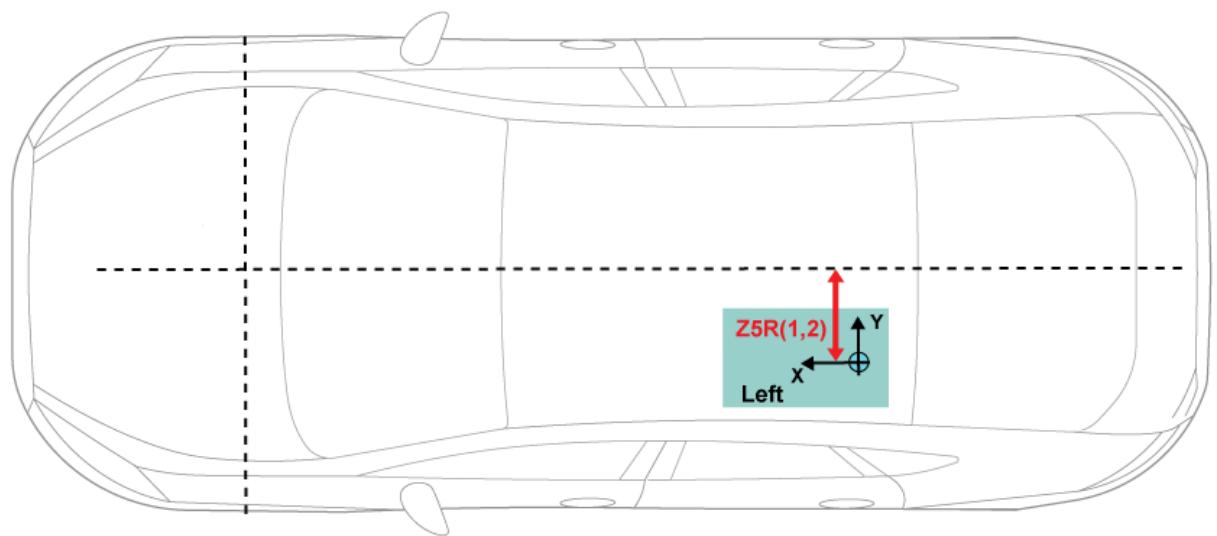
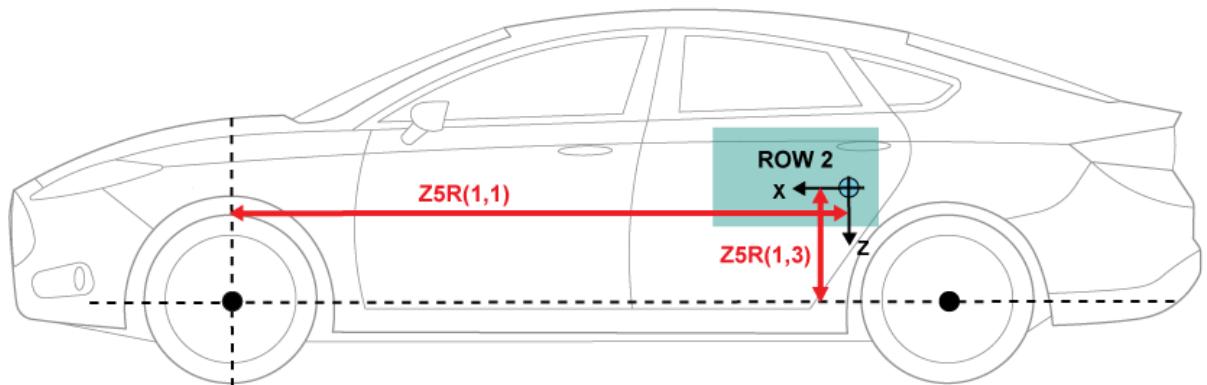
**Mass, $z5m$ — Mass
scalar**

Mass, $z5m$, in kg.

Distance vector from front axle, z5R — Distance 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 indicated by the dot.

Example Location	Sign
<ul style="list-style-type: none">• Rear of the front axle• Left of the vehicle centerline• Above the front axle suspension hardpoint	<ul style="list-style-type: none">• $z5R(1,1) > 0$• $z5R(1,2) < 0$• $z5R(1,3) > 0$

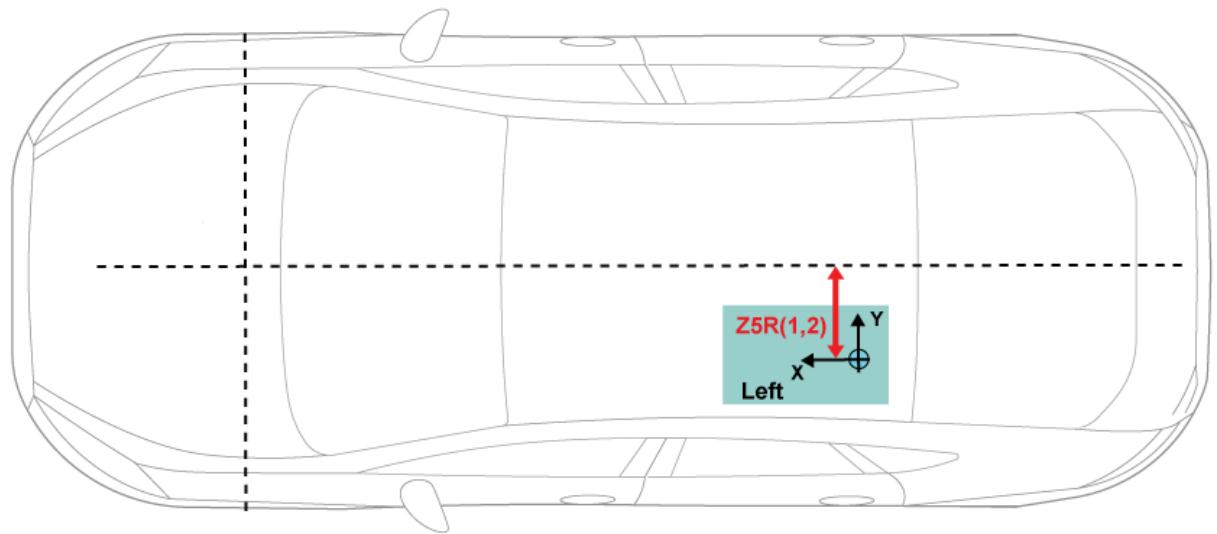
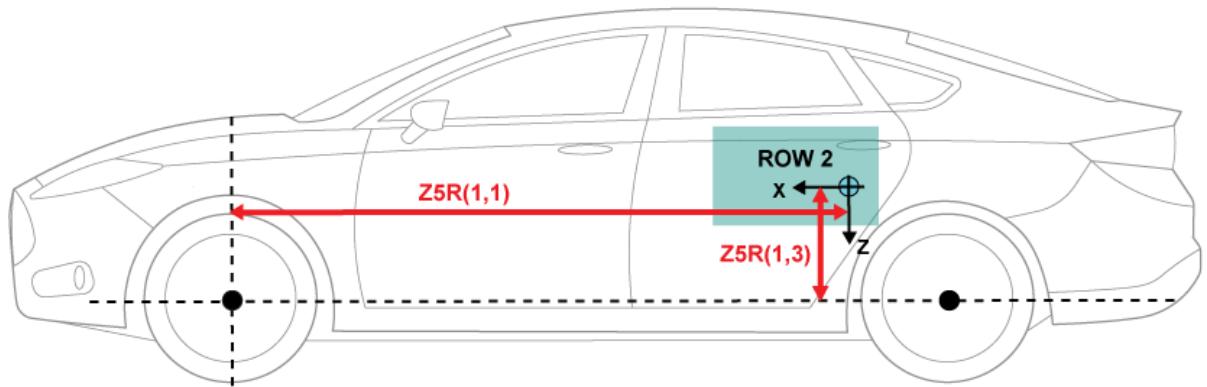
Inertia tensor, $z5I$ — Inertia array

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 vehicle-fixed x -axis
- y -axis along vehicle-fixed y -axis
- z -axis along vehicle-fixed z -axis

**Row 2, right side**

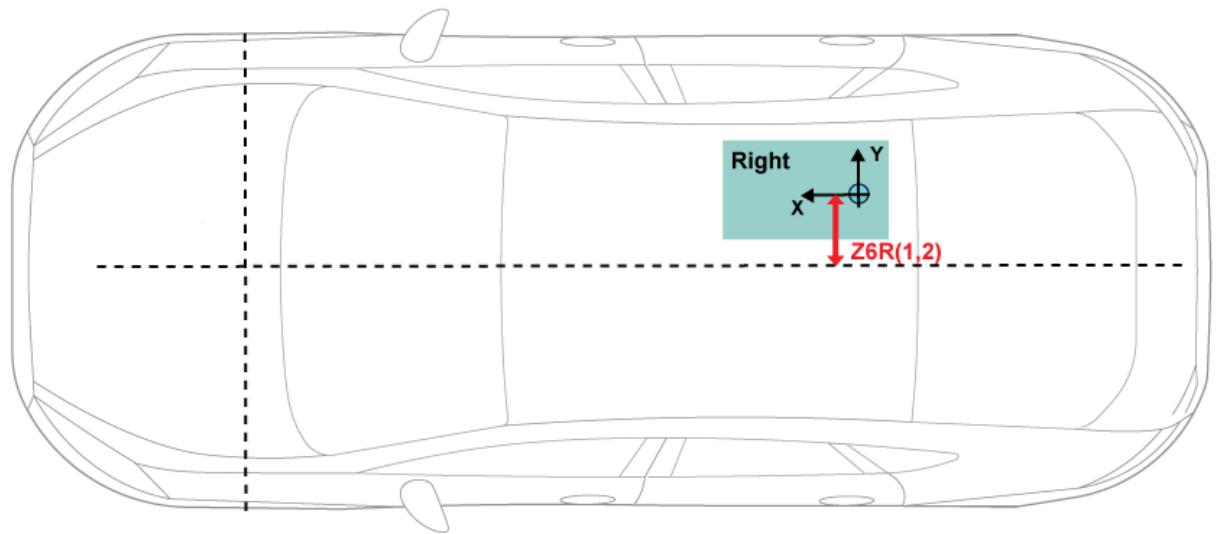
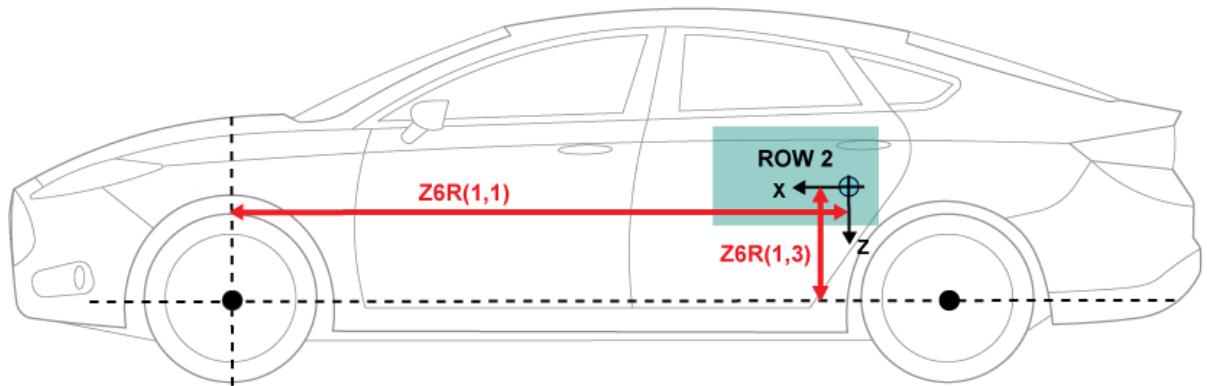
Mass, $z6m$ — Mass scalar

Mass, $z6m$, in kg.

Distance vector from front axle, z6R — Distance 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 indicated by the dot.

Example Location	Sign
<ul style="list-style-type: none">• Rear of the front axle• Right of the vehicle centerline• Above the front axle suspension hardpoint	<ul style="list-style-type: none">• $z6R(1,1) > 0$• $z6R(1,2) > 0$• $z6R(1,3) > 0$

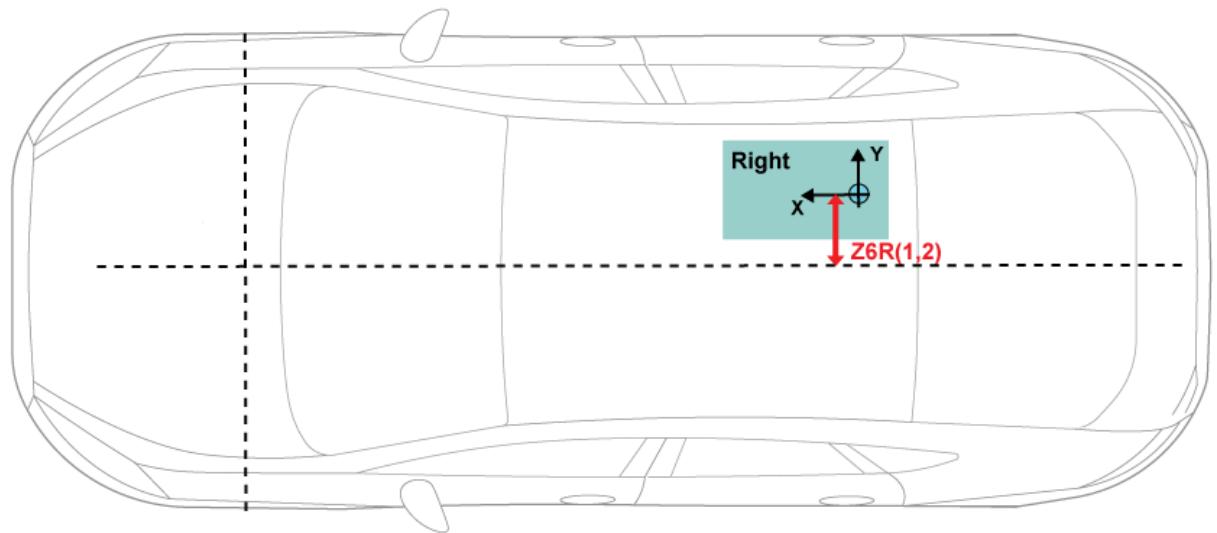
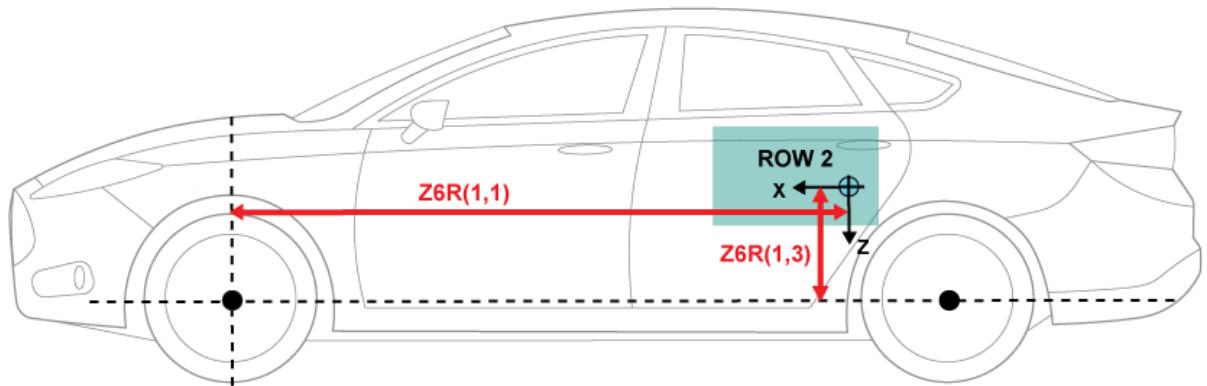
Inertia tensor, $z6I$ — Inertia array

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 vehicle-fixed x -axis
- y -axis along vehicle-fixed y -axis
- z -axis along vehicle-fixed z -axis



Rear

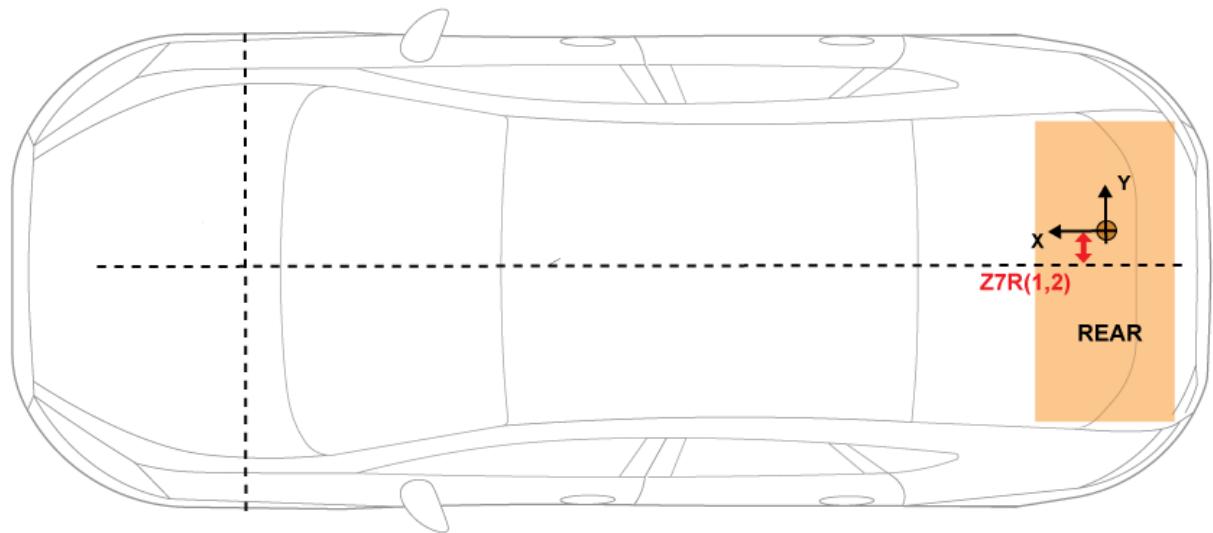
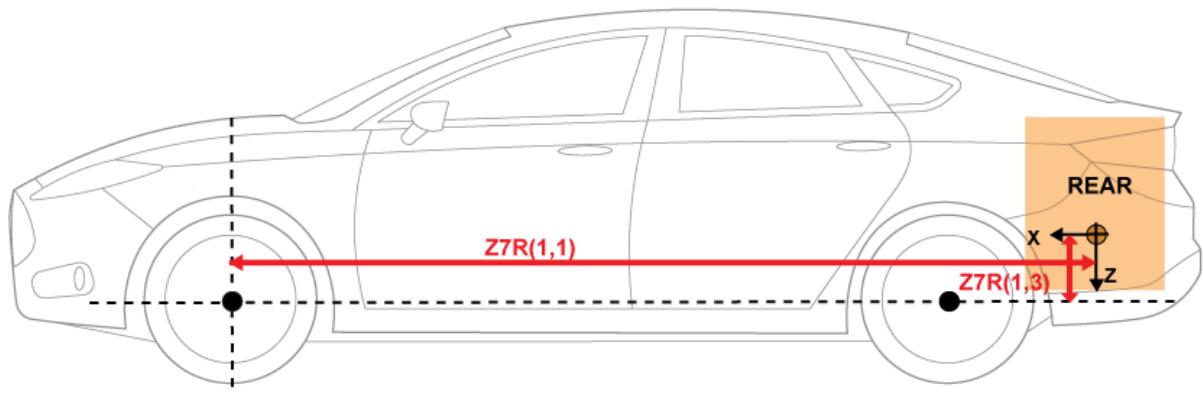
Mass, $z7m$ — Mass scalar

Mass, $z7m$, in kg.

Distance vector from front axle, z7R — Distance 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 indicated by the dot.

Example Location	Sign
<ul style="list-style-type: none">• Rear of the front axle• Right of the vehicle centerline• Above the front axle suspension hardpoint	<ul style="list-style-type: none">• $z7R(1,1) > 0$• $z7R(1,2) > 0$• $z7R(1,3) > 0$

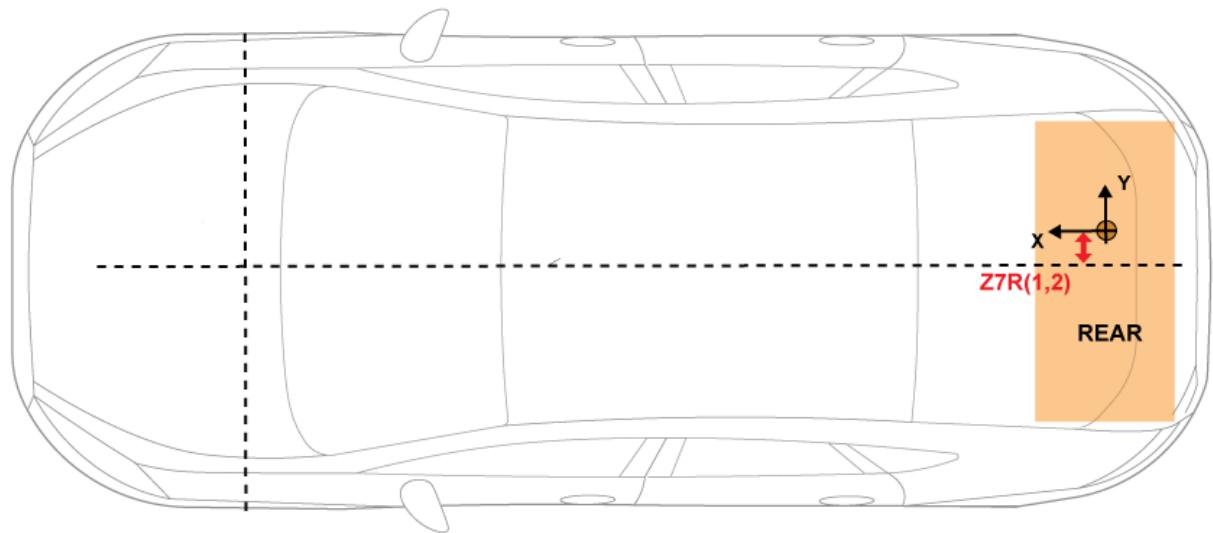
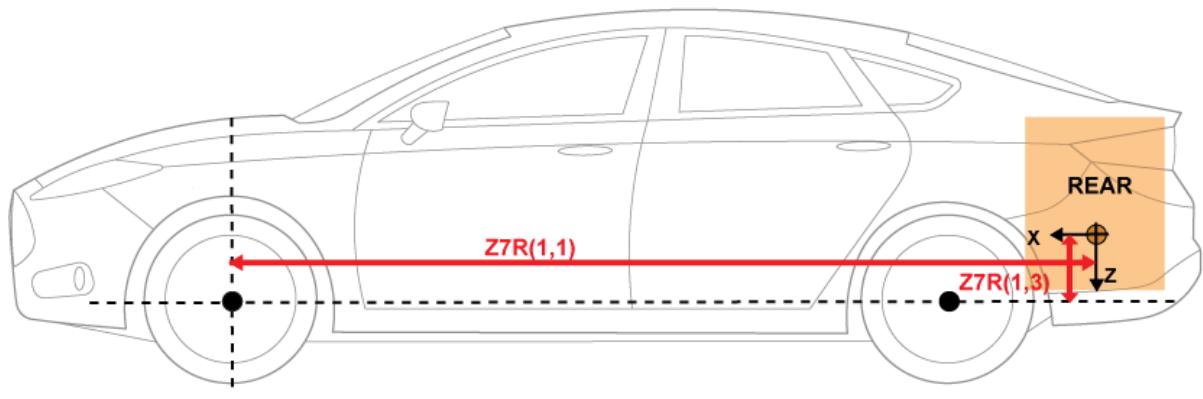
Inertia tensor, $z7I$ — Inertia array

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 vehicle-fixed x -axis
- y -axis along vehicle-fixed y -axis
- z -axis along vehicle-fixed z -axis



Aerodynamic

Longitudinal drag area, A_f — Area 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 scalar

Air drag coefficient, C_d , dimensionless.

Longitudinal lift coefficient, Cl — Lift scalar

Air lift coefficient, C_l , dimensionless.

Longitudinal drag pitch moment, Cpm — Pitch drag scalar

Longitudinal drag pitch moment coefficient, C_{pm} , dimensionless.

Relative wind angle vector, beta_w — Wind angle vector

Relative wind angle vector, β_w , in rad.

Side force coefficient vector, Cs — Side force drag vector

Side force coefficient vector coefficient, C_s , dimensionless.

Yaw moment coefficient vector, Cym — Yaw moment drag vector

Yaw moment coefficient vector coefficient, C_{ym} , dimensionless.

Environment

Absolute air pressure, Pabs — Pressure scalar

Environmental air absolute pressure, P_{abs} , in Pa.

Air temperature, Tair — Ambient air temperature scalar

Ambient air temperature, T_{air} , in K.

Dependencies

To enable this parameter, clear **Air temperature**.

Gravitational acceleration, g — Gravity scalar

Gravitational acceleration, g , in m/s².

Simulation

Longitudinal velocity tolerance, xdot_tol — Tolerance scalar

Longitudinal velocity tolerance, $xdot_{tol}$, in m/s.

Geometric longitudinal offset from axle plane, longOff — Longitudinal offset 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 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 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”](#)

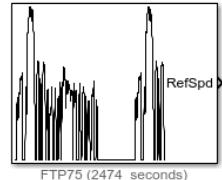
Introduced in R2018a

Vehicle Scenario Blocks – Alphabetical List

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.

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 Repeat cyclically .
Output the acceleration, as calculated by Savitzky-Golay differentiation.	Select Output acceleration .
Specify a sample period for discrete applications.	Specify a Output sample period (0 for continuous) , dt parameter.
Update the simulation run time so that it equals the length of the drive cycle.	Click Update simulation time . If a model configuration reference exists, the block does not enable this option.
Plot the drive cycle in a MATLAB® figure.	Click Plot drive cycle .
Specify the drive cycle using a workspace variable.	<p>Click Specify variable. The block:</p> <ul style="list-style-type: none"> • Sets the Drive cycle source parameter to Workspace variable. • Enables the From workspace parameter. <p>Specify the workspace variable so that it contains time, velocity, and, optionally, the gear shift schedule.</p>
Specify the drive cycle using a file.	<p>Click Select file. The block:</p> <ul style="list-style-type: none"> • Sets the Drive cycle source parameter to .mat, .xls, .xlsx or .txt file. • Enables the Drive cycle source file parameter. <p>Specify a file that contains time, velocity, and, optionally, the gear shift schedule.</p>

Goal	Action
Output drive cycle gear.	<p>Specify a drive cycle that contains a gear shift schedule. You can use:</p> <ul style="list-style-type: none">• 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. <p>Click Output gear shift data.</p>
Install additional drive cycles from a support package.	Click Install additional drive cycles . The block enables the parameter if you can install additional drive cycles from a support package.

Ports

Output

Speed — Vehicle reference speed

scalar

Vehicle reference speed, in units that you specify. To specify the units, use the **Output velocity units** parameter.

Acceleration — 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 create 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

Drive Cycle

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, t_wot1 Initial reference speed, xdot_woto Nominal reference speed, xdot_wot1 Time to start deceleration, wot2 Final reference speed, xdot_wot2 WOT simulation time, t_wotend 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

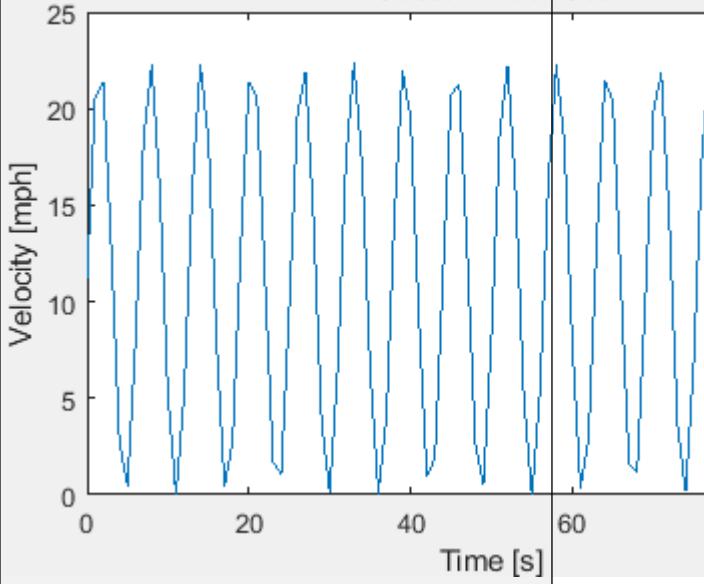
From workspace — Workspace variable

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.

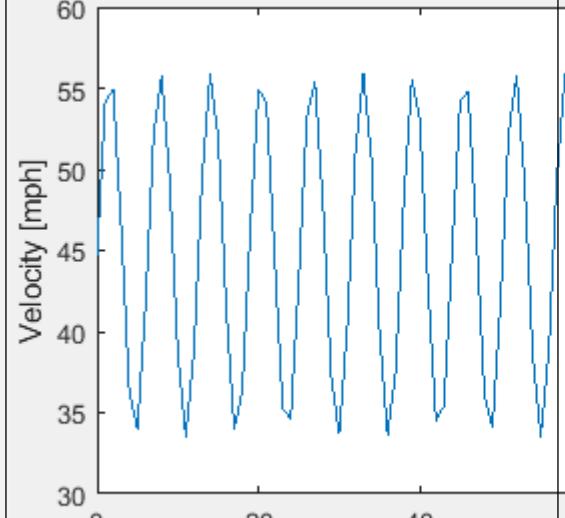
A valid point must exist for each corresponding time value. You cannot specify `inf`, `empty`, or `NaN`.

Workspace Variable	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot
<p>Structure without a gear shift schedule. From workspace 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 style="text-align: center;">Custom Data Set</p> <p>The plot displays a velocity profile over time, characterized by a series of sharp, high-frequency oscillations between approximately 12 mph and 33 mph. The signal starts at 12 mph, rises to a peak of about 33 mph, falls to a minimum of about 12 mph, and then repeats this cycle every 10 seconds. This pattern continues for the entire 60-second duration shown on the x-axis.</p>

Workspace Variable	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot																
Structure with a gear shift schedule. From workspace set to myCycleS. <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	<p style="text-align: center;">Custom Data Set</p> <table border="1"> <caption>Data points estimated from the Custom Data Set plot</caption> <thead> <tr> <th>Time [s]</th> <th>Velocity [mph]</th> </tr> </thead> <tbody> <tr><td>0.0</td><td>0.0</td></tr> <tr><td>1.0</td><td>10.0</td></tr> <tr><td>2.0</td><td>20.0</td></tr> <tr><td>3.0</td><td>30.0</td></tr> <tr><td>4.0</td><td>40.0</td></tr> <tr><td>4.5</td><td>65.0</td></tr> <tr><td>6.0</td><td>70.0</td></tr> </tbody> </table>	Time [s]	Velocity [mph]	0.0	0.0	1.0	10.0	2.0	20.0	3.0	30.0	4.0	40.0	4.5	65.0	6.0	70.0
Time [s]	Velocity [mph]																		
0.0	0.0																		
1.0	10.0																		
2.0	20.0																		
3.0	30.0																		
4.0	40.0																		
4.5	65.0																		
6.0	70.0																		

Workspace Variable	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot
2-D array without a gear shift schedule. From workspace set to myCycleA. <code>t = 0:1:100; xdot = 5.*sin(t)+5; myCycleA = [t',xdot'];</code>	m/s	mph	<p style="text-align: center;">Custom Data Set</p> 

Workspace Variable	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot																		
<p>2-D array with a gear shift schedule. From workspace set to myCycleA.</p> <pre> gears=[0, 1, 2, 3, 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	<p style="text-align: center;">Custom Data Set</p> <table border="1"> <caption>Data points estimated from the Custom Data Set plot</caption> <thead> <tr> <th>Time [s]</th> <th>Velocity [mph]</th> </tr> </thead> <tbody> <tr><td>0</td><td>0</td></tr> <tr><td>1</td><td>10</td></tr> <tr><td>2</td><td>20</td></tr> <tr><td>3</td><td>30</td></tr> <tr><td>4</td><td>40</td></tr> <tr><td>5</td><td>50</td></tr> <tr><td>6</td><td>60</td></tr> <tr><td>7</td><td>60</td></tr> </tbody> </table>	Time [s]	Velocity [mph]	0	0	1	10	2	20	3	30	4	40	5	50	6	60	7	60
Time [s]	Velocity [mph]																				
0	0																				
1	10																				
2	20																				
3	30																				
4	40																				
5	50																				
6	60																				
7	60																				

Workspace Variable	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot
<p>Time series object without a gear shift schedule. From workspace 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>Custom Data Set 1</p>  <p>The plot displays a periodic, triangular waveform representing velocity over time. The y-axis is labeled "Velocity [mph]" and ranges from 30 to 60 with major ticks every 5 units. The x-axis is labeled "Time [s]" and ranges from 0 to 60 with major ticks every 20 units. The waveform starts at approximately 55 mph at 0 seconds, drops to about 35 mph at 5 seconds, rises to 55 mph again at 10 seconds, and then repeats this cycle throughout the 60-second duration.</p>

Workspace Variable	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot										
<p>Time series object without a gear shift schedule. From workspace set to <code>myCycleT</code>.</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	<p>Custom Data Set 1</p> <table border="1"> <caption>Data points estimated from the Drive Cycle Plot</caption> <thead> <tr> <th>Time [s]</th> <th>Velocity [mph]</th> </tr> </thead> <tbody> <tr><td>0.0</td><td>0.0</td></tr> <tr><td>2.5</td><td>30.0</td></tr> <tr><td>3.5</td><td>30.0</td></tr> <tr><td>6.0</td><td>55.0</td></tr> </tbody> </table>	Time [s]	Velocity [mph]	0.0	0.0	2.5	30.0	3.5	30.0	6.0	55.0
Time [s]	Velocity [mph]												
0.0	0.0												
2.5	30.0												
3.5	30.0												
6.0	55.0												

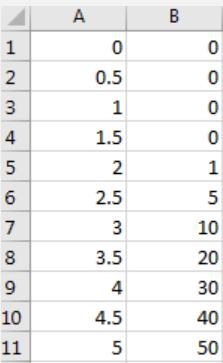
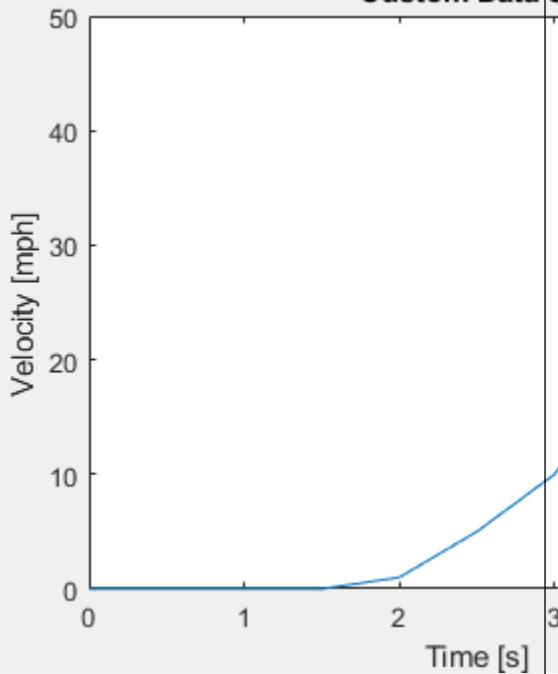
Dependencies

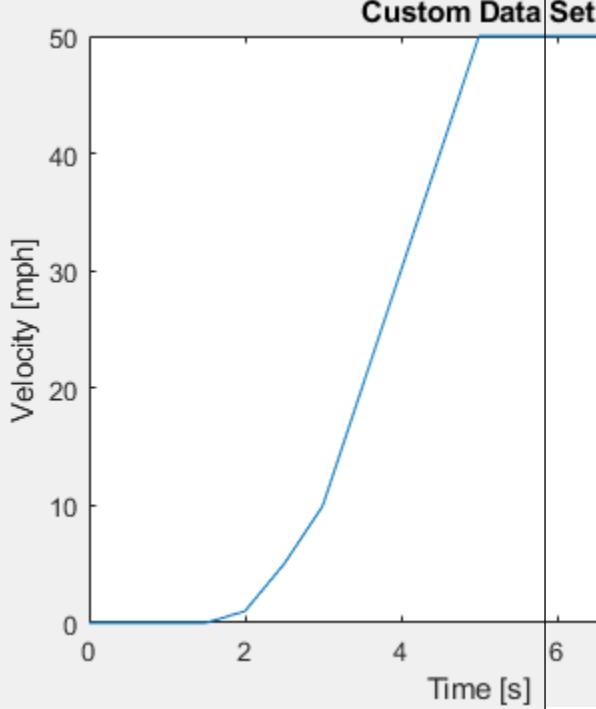
To enable this parameter, select **Workspace variable** from **Drive cycle source**.

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																																				
An .xls or .xlsx file with time in column A and velocity in column B.  <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	Custom Data Set 
	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																																					

File	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot																																																				
An .xls or .xlsx file with time in column A, velocity in column B, and gear in column C. The block: <ul style="list-style-type: none"> • Ignores the units in the file. • Converts the gear information to integers: <ul style="list-style-type: none"> • N to 0 • D to 2 <table border="1"> <thead> <tr> <th></th> <th>A</th> <th>B</th> <th>C</th> </tr> <tr> <th>1</th> <th>sec</th> <th>mph</th> <th>gear</th> </tr> </thead> <tbody> <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	
	A	B	C																																																				
1	sec	mph	gear																																																				
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9	3.5	20	D																																																				
10	4	30	D																																																				
11	4.5	40	D																																																				
12	5	50	D																																																				

File	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot
A .txt with time in column 1 and velocity in column 2. The block ignores the header and units information. <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	<p style="text-align: center;">Custom Data Set</p> <p>The plot shows a piecewise linear function representing the drive cycle. It is zero for the first 4 seconds, increases linearly from 4 to 8 seconds, and then follows a curve that increases more slowly, reaching a final velocity of 60 mph at 15 seconds.</p>

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

Gear	Integer
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)

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)

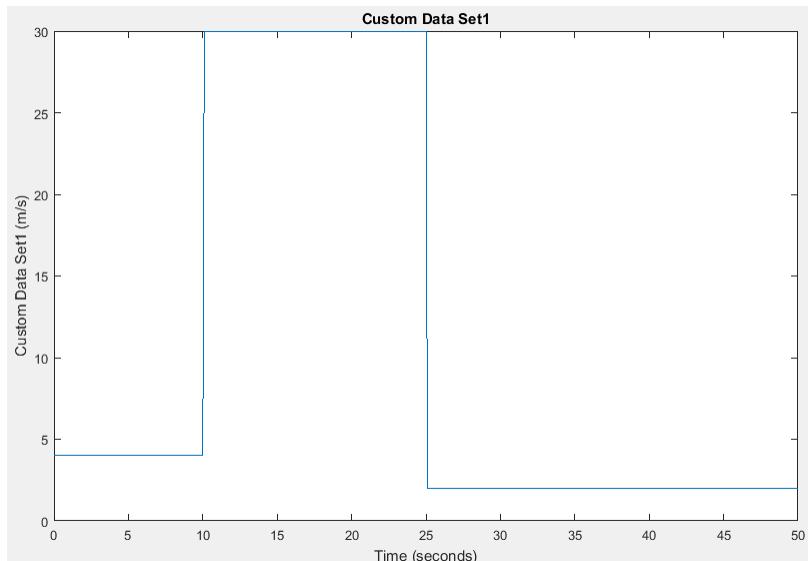
Dependencies

- 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
scalar

Drive cycle start time, in s. For example, this plot shows a drive cycle with a start time of 10 s.

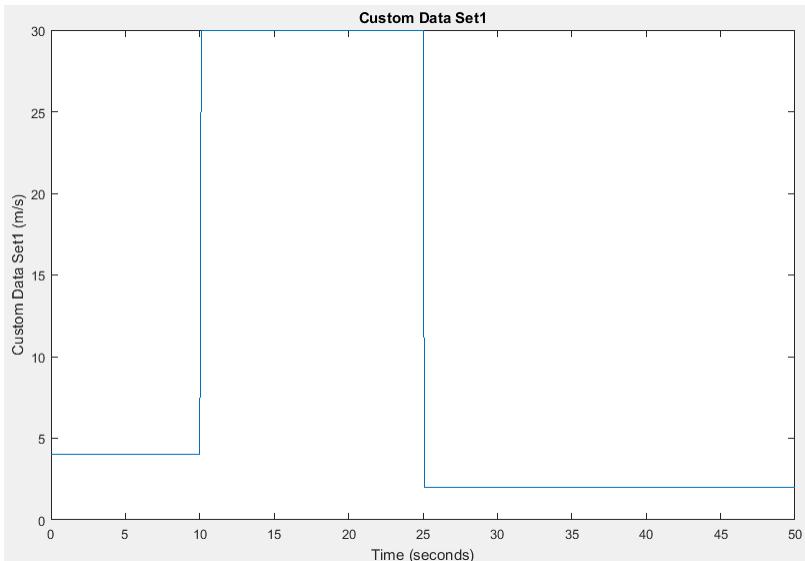


Dependencies

To enable this parameter, select the **Drive cycle source** parameter **Wide Open Throttle (WOT)**.

Initial reference speed, xdot_woto — Speed
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.

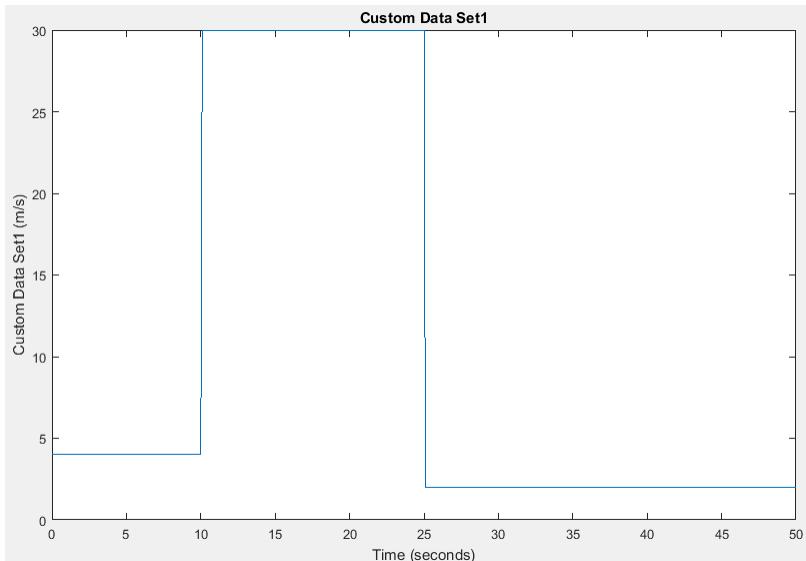


Dependencies

To enable this parameter, select the **Drive cycle source** parameter **Wide Open Throttle (WOT)**.

Nominal reference speed, `xdot_wot1` – Speed 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.

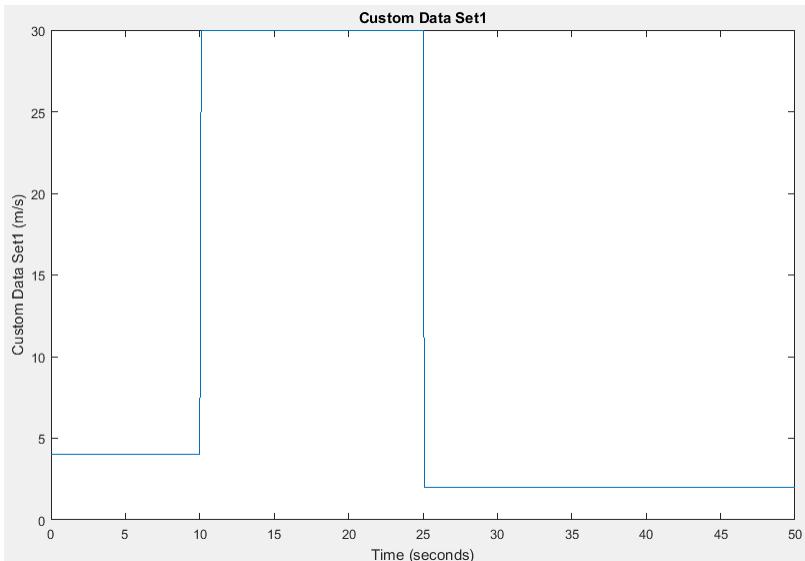


Dependencies

To enable this parameter, select the **Drive cycle source** parameter **Wide Open Throttle (WOT)**.

Time to start deceleration, wot2 — Time scalar

Time to start vehicle deceleration, in s. For example, this plot shows a drive cycle with vehicle deceleration starting at 25 s.

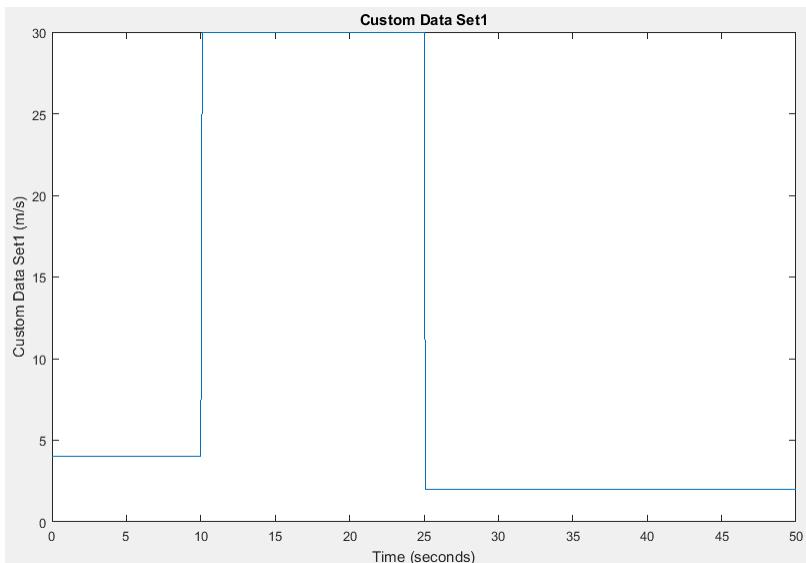


Dependencies

To enable this parameter, select the **Drive cycle source** parameter **Wide Open Throttle (WOT)**.

Final reference speed, `xdot_wot2` — Speed
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.

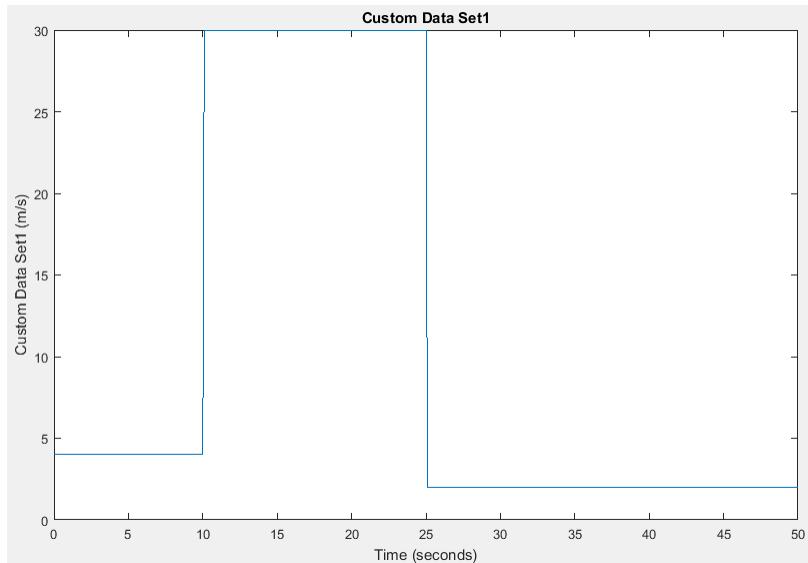


Dependencies

To enable this parameter, select the **Drive cycle source** parameter **Wide Open Throttle (WOT)**.

WOT simulation time, t_wotend — Time 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/s² (default)

Specify the output acceleration units.

Dependencies

To enable this parameter, select **Output acceleration**.

Output sample period (0) for continuous – Sample rate scalar

Sample rate. Set to 0 for continuous sample period. For a discrete period, specify a non-zero rate.

Extended Capabilities

C/C++ Code Generation

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

See Also

Lateral Driver | Longitudinal Driver | Predictive Driver

Topics

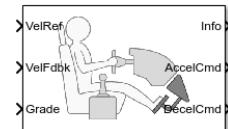
“Time Series Objects” (MATLAB)

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

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.

Setting	Block Implementation
Predictive	<p>Optimal single-point preview (look ahead) control model developed by C. C. MacAdam^{1, 2, 3}. 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"> 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

Shift

Use the **Shift type**, **shiftType** 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® 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"> • Initial gear • Upshift and downshift accelerator pedal positions • Upshift and downshift velocity • Timing for shifting and engaging forward and reverse from neutral <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>

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	$y = \frac{K_{ff}}{v_{nom}}v_{ref} + \frac{K_p}{v_{nom}}e_{ref} + \left(\frac{K_i}{v_{nom}} + K_{aw}e_{out} \right) \int e_{ref} dt + K_g\theta$
Scheduled PI	$y = \frac{K_{ff}(v)}{v_{nom}}v_{ref} + \frac{K_p(v)e_{ref}}{v_{nom}} + \left(\frac{K_i}{v_{nom}}(v) + K_{aw}e_{out} \right) \int e_{ref} dt + K_g(v)\theta$

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 feed-forward gain
θ	Grade angle
τ_{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^{1, 2, 3}. 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.

$$\begin{aligned} x_1 &= v \\ \dot{x} = x_2 &= \frac{K_{pt}}{m} - g\sin(\theta) + F_r x_1 \end{aligned}$$

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^*, \mathbf{b}^*	Driver prediction scalar and vector gain, respectively
\mathbf{x}	Predicted vehicle state vector
v	Longitudinal velocity
\mathbf{F}	System matrix
K_{pt}	Tractive force and brake limit
\mathbf{g}	Control coefficient vector
g	Gravitational constant
T^*	Preview time window
$f(t+T^*)$	Previewed path input T^* seconds ahead
U	Forward vehicle velocity
\mathbf{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, $(t, t+T)$.

$$J = \frac{1}{T} \int^{t+T} [f(\eta) - y(\eta)]^2 d\eta$$

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^{1, 2, 3}.

$$u^o(t) = u(t) + \frac{e(t + T^*)}{a^*}$$

The equations use these variables.

$f(t+T^*)$	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
J	Performance index

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.

τ	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.

VelFdbk — Longitudinal vehicle velocity

scalar

Longitudinal vehicle velocity, U , in vehicle-fixed frame, in m/s.

Grade — Road grade angle

scalar

Road grade angle, θ , in deg.

ExtGear — Gear

scalar

Gear	Integer
Park	80
Reverse	-1
Neutral	0
Drive	1
Gear	Gear number

Dependencies

To create this port, set **Shift type**, **shftType** to External.

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

Signal	Variable	Description
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

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.**Gear — Commanded vehicle gear**

scalar

Integer value of commanded vehicle gear.

Gear	Integer
Park	80
Reverse	-1
Neutral	0
Drive	1
Gear	Gear number

DependenciesTo create this port, select **Output gear signal**.

Parameters

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 ^{1, 2, 3} . 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">Represents the dynamics as a linear single track (bicycle) vehicleMinimizes the previewed error signal at a single point T^* seconds ahead in timeAccounts for the driver lag deriving from perceptual and neuromuscular mechanisms

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"> • Initial gear • Upshift and downshift accelerator pedal positions • Upshift and downshift velocity • Timing for shifting and engaging forward and reverse from neutral <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
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**

Control**Longitudinal Nominal Gains****Proportional gain, Kp — Gain**
scalarProportional gain, K_p , dimensionless.**Dependencies**To create this parameter, set **Control type** to PI.**Integral gain, Ki — Gain**
scalar

Proportional gain, K_i , dimensionless.

Dependencies

To create this parameter, set **Control type** to PI.

Velocity feed-forward, Kff — Gain

scalar

Velocity feed-forward gain, K_{ff} , dimensionless.

Dependencies

To create this parameter, set **Control type** to PI.

Grade feed-forward, Kg — Gain

scalar

Grade feed-forward gain, K_g , in 1/deg.

Dependencies

To create this parameter, set **Control type** to PI.

Velocity gain breakpoints, VehVelVec — Breakpoints

array

Velocity gain breakpoints, $VehVelVec$, dimensionless.

Dependencies

To create this parameter, set **Control type** to Scheduled PI.

Velocity feed-forward gain values, KffVec — Gain

array

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

array

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 array**

Integral gain values, $KiVec$, as a function of vehicle velocity, dimensionless.

Dependencies

To create this parameter, set **Control type** to Scheduled PI.

Grade feed-forward values, **KgVec — Grade gain array**

Grade 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 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 scalar**

Anti-windup gain, K_{aw} , dimensionless.

Dependencies

To create this parameter, set **Control type** to PI or Scheduled PI.

Error filter time constant, **tauerr — Filter scalar**

Error filter time constant, τ_{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
scalar

Vehicle mass, m , in kg.

Dependencies

To create this parameter, set **Longitudinal control type, cntrlType** to Predictive.

Effective vehicle total tractive force, Kp — Tractive force
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
scalar

Driver response time, τ , in s.

Dependencies

To create this parameter, set **Longitudinal control type, cntrlType** to Predictive.

Preview distance, L — Distance
scalar

Driver preview distance, L , in m.

Dependencies

To create this parameter, set **Longitudinal control type, cntrlType** to Predictive.

Rolling resistance coefficient, aR — Resistance
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, bR — Resistance 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 scalar

Aerodynamic drag coefficient, c_R , in N·s²/m². 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 scalar

Gravitational constant, g , in m/s².

Dependencies

To create this parameter, set **Longitudinal control type**, **cntrlType** to Predictive.

Shift

Reverse, Neutral, Drive

Initial gear, GearInit — Initial gear 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 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 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

Gear	Integer
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

[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 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 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 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

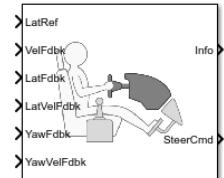
[Drive Cycle Source](#) | [Lateral Driver](#) | [Predictive Driver](#)

Introduced in R2017a

Lateral Driver

Lateral path-tracking controller

Library: Vehicle Dynamics Blockset / Vehicle Scenarios /
Driver



Description

The Lateral Driver block implements an optimal single point preview (look ahead) 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 Predictive Driver block output to steering block inputs.

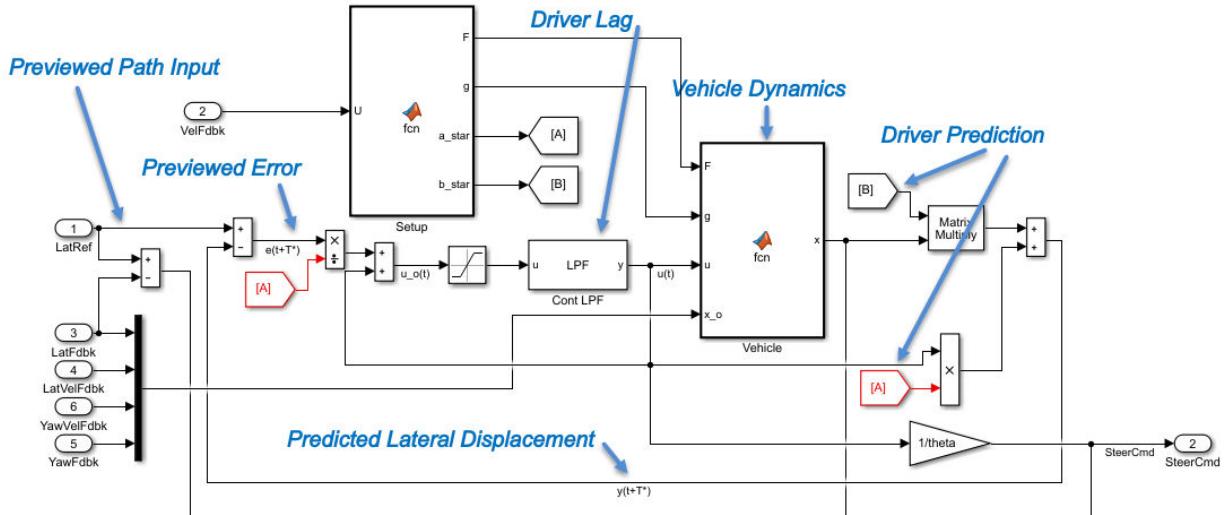
Also, you can specify a tire wheel angle saturation limit using the **Tire wheel angle limit, theta** parameter.

Lateral Path-Tracking Controller

The Lateral Driver block implements an optimal single-point preview (look ahead) control model developed by C. C. MacAdam^{1, 2, 3}. 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:

$$x = \begin{bmatrix} y \\ v \\ r \\ \psi \end{bmatrix}$$

$$F = \begin{bmatrix} 0 & 1 & 0 & U \\ 0 & -2\frac{C_{\alpha F} + C_{\alpha R}}{mU} & 2\frac{bC_{\alpha R} - aC_{\alpha F}}{mU} - U & 0 \\ 0 & \frac{bC_{\alpha R} - aC_{\alpha F}}{IU} & -2\frac{a^2C_{\alpha F} + b^2C_{\alpha R}}{IU} & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$$x = \begin{bmatrix} 0 \\ \frac{2C_{\alpha F}}{m} \\ \frac{2aC_{\alpha F}}{I} \\ 0 \end{bmatrix}$$

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_{aF}	Front tire cornering coefficient
C_{aR}	Rear tire cornering coefficient
a^*, \mathbf{b}^*	Driver prediction scalar and vector gain, respectively
\mathbf{x}	Predicted vehicle state vector
v	Lateral velocity
r	Yaw rate
Ψ	Front wheel heading angle
y	Lateral displacement
\mathbf{F}	System matrix
δ	Steer angle
\mathbf{g}	Control coefficient vector
U	Forward vehicle velocity
T^*	Preview time window
$f(t+T^*)$	Previewed path input T^* seconds ahead
U	Forward vehicle velocity
\mathbf{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, $(t, t+T)$.

$$J = \frac{1}{T} \int^{t+T} [f(\eta) - y(\eta)]^2 d\eta$$

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^{1, 2, 3}.

$$u^o(t) = u(t) + \frac{e(t + T^*)}{a^*}$$

The equations use these variables.

$f(t+T^*)$	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
J	Performance index

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.

τ	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

LatRef — Lateral displacement reference
scalar

Lateral center of mass (CM) displacement reference, in the inertial reference frame, in m.

VelFdbk — Longitudinal vehicle velocity

scalar

Longitudinal vehicle velocity, U , in the vehicle-fixed frame, in m/s.**LatFdbk — Lateral displacement**

scalar

Lateral CM displacement, y_o , in the inertial reference frame, in m.**LatVelFdbk — Lateral vehicle velocity**

scalar

Lateral vehicle velocity, v_o , in the vehicle-fixed frame, in m/s.**YawFdbk — Vehicle yaw angle**

scalar

Vehicle yaw angle, Ψ_o , in the inertial reference frame, in rad.**YawVelFdbk — Yaw rate**

scalar

Yaw rate, r_o , in the vehicle-fixed frame, in rad/s.

Output

Info — Bus signal

bus

Bus signal containing these block calculations.

Signal	Variable	Description
Predicted	y	Predicted lateral displacement, in vehicle-fixed frame.
	ydot	Predicted lateral velocity, in vehicle-fixed frame.
	psi	Predicted front wheel heading angle.
	r	Predicted yaw rate, in vehicle-fixed frame.

Signal	Variable	Description
SteerCmd	δ_F	Commanded steer angle, normalized from 0 through 1.
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.

SteerCmd — Normalized steer angle command
scalar

Commanded steer angle, δ_F , normalized from -1 through 1. The block uses the tire wheel angle saturation limit **Tire wheel angle limit, theta** parameter to normalize the command.

Parameters

Forward location of tire, a — Along vehicle longitudinal axis
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
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
scalar

Vehicle mass, m , in kg.

Vehicle rotational inertia, I — Inertia about yaw axis
scalar

Vehicle rotational inertia, I , about the vehicle yaw axis, in N·m·s².

Front tire cornering coefficient, Cy_f — Coefficient
scalar

Cornering stiffness coefficient, $C_{\alpha F}$, in N/rad.

Rear tire cornering coefficient, Cy_r — Coefficient
scalar

Cornering stiffness coefficient, $C_{\alpha R}$, in N/rad.

Tire wheel angle limit, theta — Angle limit
scalar

Tire wheel angle limit, θ , in rad.

Driver response time, tau — Response time
scalar

Driver response time, τ , in s.

Preview distance, L — Distance
scalar

Driver preview distance, L , in m.

References

- [1] MacAdam, C. C. "An Optimal Preview Control for Linear Systems". *Journal of Dynamic Systems, Measurement, and Control*. 102(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*. Volume 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. The University of Michigan Transportation Research Institute. December, 1988.

Extended Capabilities

C/C++ Code Generation

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

See Also

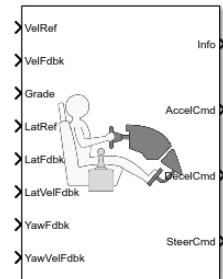
[Longitudinal Driver](#) | [Predictive Driver](#)

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

Controller

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.

Setting	Block Implementation
Predictive	<p>Optimal single-point preview (look ahead) control model developed by C. C. MacAdam^{1, 2, 3}. 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"> 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

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 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"> • Initial gear • Upshift and downshift accelerator pedal positions • Upshift and downshift velocity • Timing for shifting and engaging forward and reverse from neutral <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>

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	$y = \frac{K_{ff}}{v_{nom}}v_{ref} + \frac{K_p}{v_{nom}}e_{ref} + \left(\frac{K_i}{v_{nom}} + K_{aw}e_{out} \right) \int e_{ref} dt + K_g\theta$
Scheduled PI	$y = \frac{K_{ff}(v)}{v_{nom}}v_{ref} + \frac{K_p(v)e_{ref}}{v_{nom}} + \left(\frac{K_i}{v_{nom}}(v) + K_{aw}e_{out} \right) \int e_{ref} dt + K_g(v)\theta$

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 feed-forward gain
θ	Grade angle
τ_{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 to **Predictive**, the block implements an optimal single-point preview (look ahead) control model developed by C. C. MacAdam^{1, 2, 3}. 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:

$$x = \begin{bmatrix} x_1 \\ x_2 \\ y \\ v \\ r \\ \psi \end{bmatrix}$$

$$F = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ \frac{Fr}{m} & 0 & 0 & 0 & v & 0 \\ 0 & 0 & 0 & 1 & 0 & U \\ 0 & 0 & 0 & -\frac{2(C_{\alpha F} + C_{\alpha R})}{mU} & \frac{2(bC_{\alpha R} - aC_{\alpha F})}{mU} - U & 0 \\ 0 & 0 & 0 & \frac{2(bC_{\alpha R} - aC_{\alpha F})}{IU} & -\frac{2(a^2C_{\alpha F} + b^2C_{\alpha R})}{IU} & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

$$g = \begin{bmatrix} 0 & 0 \\ \frac{K_{pt}}{m} & 0 \\ 0 & 0 \\ 0 & \frac{2C_{\alpha F}}{m} \\ 0 & \frac{2aC_{\alpha F}}{I} \\ 0 & 0 \end{bmatrix}$$

$$u = \begin{bmatrix} \bar{u} \\ \delta_F \end{bmatrix}$$

$$\bar{u} = u - \frac{m^2}{K_{pt}} g \sin(\gamma)$$

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.

$$a^* = (T^*)m^T[I + \sum_{n=1}^{\infty} \frac{F^n(T^*)^n}{(n+1)!}]g$$

$$b^* = m^T[I + \sum_{n=1}^{\infty} \frac{F^n(T^*)^n}{n!}]$$

$$m^T = [1 \ 1 \ 1 \ 0 \ 0 \ 0]$$

The equations use these variables.

a, b	Forward and rearward tire location, respectively
m	Vehicle mass
I	Vehicle rotational inertia
C_{aF}	Front tire cornering coefficient
C_{aR}	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
Ψ	Front wheel heading angle
y	Lateral displacement
\mathbf{F}	System matrix
δ	Steer angle
\mathbf{g}	Control coefficient vector
U	Forward vehicle velocity
T^*	Preview time window
$f(t+T^*)$	Previewed path input T^* seconds ahead
U	Forward vehicle velocity
\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, $(t, t+T)$.

$$J = \frac{1}{T} \int^{t+T} [f(\eta) - y(\eta)]^2 d\eta$$

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^{1, 2, 3}.

$$u^o(t) = u(t) + \frac{e(t+T^*)}{a^*}$$

The equations use these variables.

$f(t+T^*)$	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
J	Performance index

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.

τ	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.

Grade — Road grade angle
scalar

Road grade angle, θ , in deg.

ExtGear — Gear
scalar

Gear	Integer
Park	80
Reverse	-1
Neutral	0
Drive	1
Gear	Gear number

Dependencies

To create this port, set **Shift type**, **shftType** to External.

LatRef — Lateral displacement reference

scalar

Lateral center of mass (CM) displacement reference, in the inertial reference frame, in m.

VelFdbk — Longitudinal vehicle velocity

scalar

Longitudinal vehicle velocity, U , in the vehicle-fixed frame, in m/s.

LatFdbk — Lateral displacement

scalar

Lateral CM displacement, y_o , in the inertial reference frame, in m.

LatVelFdbk — Lateral vehicle velocity

scalar

Lateral vehicle velocity, v_o , in the vehicle-fixed frame, in m/s.

YawFdbk — Vehicle yaw angle

scalar

Vehicle yaw angle, Ψ_o , in the inertial reference frame, in rad.

YawVelFdbk — Yaw rate

scalar

Yaw rate, r_o , in the vehicle-fixed frame, in rad/s.

Output

Info — Bus signal

bus

Bus signal containing these block calculations.

Signal	Variable	Description
Steer	δ_F	Commanded steer angle, normalized from 0 through 1

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	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.
Err	LngErr	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

SteerCmd — Normalized steer angle command

scalar

Commanded steer angle, δ_F , normalized from -1 through 1. The block uses the tire wheel angle saturation limit **Tire wheel angle limit, theta** parameter to normalize the 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.

Gear — Commanded vehicle gear

scalar

Integer value of commanded vehicle gear.

Gear	Integer
Park	80
Reverse	-1
Neutral	0
Drive	1
Gear	Gear number

Dependencies

To create this port, select **Output gear signal**.

Parameters

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.

Setting	Block Implementation
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^{1, 2, 3}. 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"> 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

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"> • Initial gear • Upshift and downshift accelerator pedal positions • Upshift and downshift velocity • Timing for shifting and engaging forward and reverse from neutral <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
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**

Reference Control**Longitudinal Nominal Gains****Proportional gain, Kp – Gain**
scalarProportional gain, K_p , dimensionless.**Dependencies**To create this parameter, set **Control type** to PI.**Integral gain, Ki – Gain**
scalar

Proportional gain, K_i , dimensionless.

Dependencies

To create this parameter, set **Control type** to PI.

Velocity feed-forward, Kff — Gain
scalar

Velocity feed-forward gain, K_{ff} , dimensionless.

Dependencies

To create this parameter, set **Control type** to PI.

Grade feed-forward, Kg — Gain
scalar

Grade feed-forward gain, K_g , in 1/deg.

Dependencies

To create this parameter, set **Control type** to PI.

Velocity gain breakpoints, VehVelVec — Breakpoints
array

Velocity gain breakpoints, $VehVelVec$, dimensionless.

Dependencies

To create this parameter, set **Control type** to Scheduled PI.

Velocity feed-forward gain values, KffVec — Gain
array

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
array

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 array

Integral gain values, $KiVec$, as a function of vehicle velocity, dimensionless.

Dependencies

To create this parameter, set **Control type** to Scheduled PI.

Grade feed-forward values, *KgVec* — Grade gain array

Grade 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 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 scalar

Anti-windup gain, K_{aw} , dimensionless.

Dependencies

To create this parameter, set **Control type** to PI or Scheduled PI.

Error filter time constant, *tauerr* — Filter scalar

Error filter time constant, τ_{err} , in s. To disable the filter, enter 0.

Dependencies

To create this parameter, set **Control type** to PI or Scheduled PI.

Forward location of tire, a — Along vehicle longitudinal axis
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
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
scalar

Vehicle mass, m , in kg.

Vehicle rotational inertia, I — Inertia about yaw axis
scalar

Vehicle rotational inertia, I , about the vehicle yaw axis, in N·m·s².

Front tire cornering coefficient, Cy_f — Coefficient
scalar

Cornering stiffness coefficient, $C_{\alpha F}$, in N/rad.

Rear tire cornering coefficient, Cy_r — Coefficient
scalar

Cornering stiffness coefficient, $C_{\alpha R}$, in N/rad.

Tire wheel angle limit, theta — Angle limit
scalar

Tire wheel angle limit, θ , in rad.

Driver response time, tau — Response time
scalar

Driver response time, τ , in s.

Preview distance, L — Distance
scalar

Driver preview distance, L , in m.

Effective vehicle total tractive force, K_p — Tractive force
scalar

Effective vehicle total tractive force, K_p , in N.

Dependencies

To create this parameter, set **Longitudinal control type, cntrlType** to Predictive.

Rolling resistance coefficient, a_R — Resistance
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
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, c_R — Drag
scalar

Aerodynamic drag coefficient, c_R , in N·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
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
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
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
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

[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
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
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
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

Lateral Driver | Longitudinal Driver

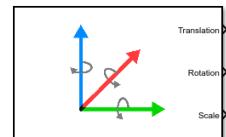
Introduced in R2018a

3D Simulation Blocks – Alphabetical List

Simulation 3D Actor Transform Get

Get actor translation, rotation, scale

Library: Vehicle Dynamics Blockset / Vehicle Scenarios / Sim3D / Sim3D Core



Description

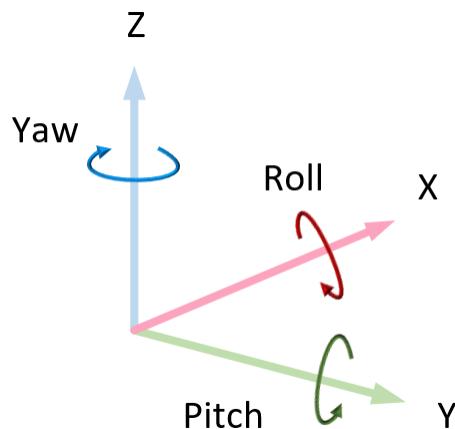
The Simulation 3D Actor Transform Get block provides the actor translation, rotation, and scale for the Simulink simulation environment.

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.

Use **Actor type** to select Passenger vehicle or Camera. The Passenger vehicle actor includes components for a vehicle body with four wheels.

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

3D Visualization

When you run simulations with the 3D engine enabled, you can view scene information in the `VehicleSimulation` window.

To change the camera views in the `VehicleSimulation` window, 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

Ports

Output

Translation — Component translation

array

Component translation. Array dimensions are number of components 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, along world X-, Y, and Z- axes, respectively.

For example, consider a vehicle with four wheels. If the vehicle body and wheels are components, the `Translation` signal:

- Dimensions are [5x3].
- Contains translation information according to the axle and wheel locations, relative to vehicle.

$$\text{Translation} = \begin{bmatrix} X_v & Y_v & Z_v \\ X_{FL} & Y_{FL} & Z_{FL} \\ X_{FR} & Y_{FR} & Z_{FR} \\ X_{RL} & Y_{RL} & Z_{RL} \\ X_{RR} & Y_{RR} & Z_{RR} \end{bmatrix}$$

Translation	Array Element	Translation Axis
Vehicle, X_v	Translation(1, 1)	World X-axis
Vehicle, Y_v	Translation(1, 2)	World Y-axis
Vehicle, Z_v	Translation(1, 3)	World Z-axis
Front left wheel, X_{FL}	Translation(2, 1)	World X-axis
Front left wheel, Y_{FL}	Translation(2, 2)	World Y-axis
Front left wheel, Z_{FL}	Translation(2, 3)	World Z-axis
Front right wheel, X_{FR}	Translation(3, 1)	World X-axis
Front right wheel, Y_{FR}	Translation(3, 2)	World Y-axis
Front right wheel, Z_{FR}	Translation(3, 3)	World Z-axis
Rear left wheel, X_{RL}	Translation(4, 1)	World X-axis
Rear left wheel, Y_{RL}	Translation(4, 2)	World Y-axis

Translation	Array Element	Translation Axis
Rear left wheel, Z_{RL}	Translation(4, 3)	World Z-axis
Rear right wheel, X_{RR}	Translation(5, 1)	World X-axis
Rear right wheel, Y_{RR}	Translation(5, 2)	World Y-axis
Rear right wheel, Z_{RR}	Translation(5, 3)	World Z-axis

Rotation — Component rotation

array

Component rotation. Array dimensions are number of components by 3.

- `Rotation(1,1)`, `Rotation(1,2)`, and `Rotation(1,3)` — Vehicle rotation about world coordinate system X-, Y, and Z- axes, respectively.
- `Rotation(...,1)`, `Rotation(...,2)`, and `Rotation(...,3)` — Actor rotation about world coordinate system X-, Y, and Z- axes, respectively.

For example, consider a vehicle with four wheels. If the vehicle body and wheels are components, the `Rotation` signal:

- Dimensions are [5x3].
- 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, $Roll_v$	<code>Rotation(1,1)</code>	World X-axis
Vehicle, $Pitch_v$	<code>Rotation(1,2)</code>	World Y-axis

Rotation	Array Element	Rotation Axis
Vehicle, Yaw_v	<code>Rotation(1, 3)</code>	World Z-axis
Front left wheel, $Roll_{FL}$	<code>Rotation(2, 1)</code>	World X-axis
Front left wheel, $Pitch_{FL}$	<code>Rotation(2, 2)</code>	World Y-axis
Front left wheel, Yaw_{FL}	<code>Rotation(2, 3)</code>	World Z-axis
Front right wheel, $Roll_{FR}$	<code>Rotation(3, 1)</code>	World X-axis
Front right wheel, $Pitch_{FR}$	<code>Rotation(3, 2)</code>	World Y-axis
Front right wheel, Yaw_{FR}	<code>Rotation(3, 3)</code>	World Z-axis
Rear left wheel, $Roll_{RL}$	<code>Rotation(4, 1)</code>	World X-axis
Rear left wheel, $Pitch_{RL}$	<code>Rotation(4, 2)</code>	World Y-axis
Rear left wheel, Yaw_{RL}	<code>Rotation(4, 3)</code>	World Z-axis
Rear right wheel, $Roll_{RR}$	<code>Rotation(5, 1)</code>	World X-axis
Rear right wheel, $Pitch_{RR}$	<code>Rotation(5, 2)</code>	World Y-axis
Rear right wheel, Yaw_{RR}	<code>Rotation(5, 3)</code>	World Z-axis

Scale — Component scale

array

Component scale. Array dimensions are number of components 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 with four wheels. If the vehicle body and wheels are components, the `Scale` signal:

- Dimensions are [5x3].
- 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, $X_{v_{scale}}$	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
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

Dependencies

Setting **Actor type** to Custom or Passenger vehicle creates the Scale port.

Parameters

Tag for actor in 3D scene, ActorTag — Name
SimulinkActor1 (default)

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.

Actor type — Selection

Passenger vehicle (default) | Camera

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 Passenger vehicle actor includes components for a vehicle body with four wheels.

Dependencies

Actor Type Setting	Creates Port
Passenger vehicle	Scale
Camera	<i>None</i>

Sample time, Ts — Sample time

-1 (default)

Sample time, T_s . The graphics frame rate is the inverse of the sample time.

See Also

[Simulation 3D Config](#) | [Simulation 3D Actor Transform Set](#) | [Simulation 3D Camera Get](#) | [Vehicle Terrain Sensor](#)

Topics

“Vehicle Dynamics Blockset Communication with 3D Visualization Software”

“Scene Interrogation”

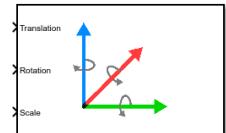
“3D Visualization Engine Requirements”

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.

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.

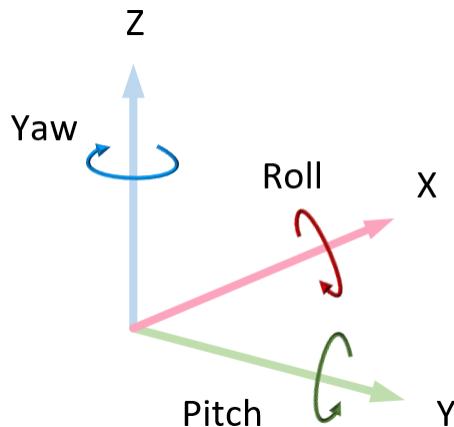
Use **Actor type** to select Passenger vehicle or Camera. The Passenger vehicle actor includes components for a vehicle body with four wheels.

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	Muscle Car
Sedan	Sedan
Sport utility vehicle	Sport Utility Vehicle
Small pickup truck	Small Pickup Truck
Hatchback	Hatchback

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

3D Visualization

When you run simulations with the 3D engine enabled, you can view scene information in the `VehicleSimulation` window.

To change the camera views in the `VehicleSimulation` window, 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

Ports

Input

Translation – Component translation array

Component translation. Array dimensions are number of components 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, along world X-, Y, and Z- axes, respectively.

For example, consider a vehicle with four wheels. If the vehicle body and wheels are components, 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	Translation Axis
Vehicle, X_v	Translation(1, 1)	World X-axis
Vehicle, Y_v	Translation(1, 2)	World Y-axis
Vehicle, Z_v	Translation(1, 3)	World Z-axis
Front left wheel, X_{FL}	Translation(2, 1)	World X-axis
Front left wheel, Y_{FL}	Translation(2, 2)	World Y-axis
Front left wheel, Z_{FL}	Translation(2, 3)	World Z-axis
Front right wheel, X_{FR}	Translation(3, 1)	World X-axis
Front right wheel, Y_{FR}	Translation(3, 2)	World Y-axis
Front right wheel, Z_{FR}	Translation(3, 3)	World Z-axis
Rear left wheel, X_{RL}	Translation(4, 1)	World X-axis
Rear left wheel, Y_{RL}	Translation(4, 2)	World Y-axis

Translation	Array Element	Translation Axis
Rear left wheel, Z_{RL}	Translation(4, 3)	World Z-axis
Rear right wheel, X_{RR}	Translation(5, 1)	World X-axis
Rear right wheel, Y_{RR}	Translation(5, 2)	World Y-axis
Rear right wheel, Z_{RR}	Translation(5, 3)	World Z-axis

Rotation — Component rotation

array

Component rotation. Array dimensions are number of components by 3.

- `Rotation(1,1)`, `Rotation(1,2)`, and `Rotation(1,3)` — Vehicle rotation about world coordinate system X-, Y, and Z- axes, respectively.
- `Rotation(...,1)`, `Rotation(...,2)`, and `Rotation(...,3)` — Actor rotation about world coordinate system X-, Y, and Z- axes, respectively.

For example, consider a vehicle with four wheels. If the vehicle body and wheels are components, the `Rotation` signal:

- Dimensions are [5x3].
- Contains rotation information according to the axle and wheel locations.

$$\text{Rotation} = \begin{bmatrix} Roll_v & Pitch_v & Yaw_v \\ Roll_{FL} & Pitch_{FL} & Yaw_{FL} \\ Roll_{FR} & Pitch_{FR} & Yaw_{FR} \\ Roll_{RL} & Pitch_{RL} & Yaw_{RL} \\ Roll_{RR} & Pitch_{RR} & Yaw_{RR} \end{bmatrix}$$

Rotation	Array Element	Rotation Axis
Vehicle, $Roll_v$	<code>Rotation(1,1)</code>	World X-axis
Vehicle, $Pitch_v$	<code>Rotation(1,2)</code>	World Y-axis

Rotation	Array Element	Rotation Axis
Vehicle, Yaw_v	<code>Rotation(1,3)</code>	World Z-axis
Front left wheel, $Roll_{FL}$	<code>Rotation(2,1)</code>	World X-axis
Front left wheel, $Pitch_{FL}$	<code>Rotation(2,2)</code>	World Y-axis
Front left wheel, Yaw_{FL}	<code>Rotation(2,3)</code>	World Z-axis
Front right wheel, $Roll_{FR}$	<code>Rotation(3,1)</code>	World X-axis
Front right wheel, $Pitch_{FR}$	<code>Rotation(3,2)</code>	World Y-axis
Front right wheel, Yaw_{FR}	<code>Rotation(3,3)</code>	World Z-axis
Rear left wheel, $Roll_{RL}$	<code>Rotation(4,1)</code>	World X-axis
Rear left wheel, $Pitch_{RL}$	<code>Rotation(4,2)</code>	World Y-axis
Rear left wheel, Yaw_{RL}	<code>Rotation(4,3)</code>	World Z-axis
Rear right wheel, $Roll_{RR}$	<code>Rotation(5,1)</code>	World X-axis
Rear right wheel, $Pitch_{RR}$	<code>Rotation(5,2)</code>	World Y-axis
Rear right wheel, Yaw_{RR}	<code>Rotation(5,3)</code>	World Z-axis

Scale — Component scale

array

Component scale. Array dimensions are number of components 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 with four wheels. If the vehicle body and wheels are components, the `Scale` signal:

- Dimensions are [5x3].
- 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)	World X-axis
Vehicle, Y_{Vscale}	Scale(1,2)	World Y-axis
Vehicle, Z_{Vscale}	Scale(1,3)	World Z-axis
Front left wheel, $X_{FLscale}$	Scale(2,1)	World X-axis
Front left wheel, $Y_{FLscale}$	Scale(2,2)	World Y-axis
Front left wheel, $Z_{FLscale}$	Scale(2,3)	World Z-axis
Front right wheel, $X_{FRscale}$	Scale(3,1)	World X-axis
Front right wheel, $Y_{FRscale}$	Scale(3,2)	World Y-axis
Front right wheel, $Z_{FRscale}$	Scale(3,3)	World Z-axis
Rear left wheel, $X_{RLscale}$	Scale(4,1)	World X-axis
Rear left wheel, $Y_{RLscale}$	Scale(4,2)	World Y-axis
Rear left wheel, $Z_{RLscale}$	Scale(4,3)	World Z-axis
Rear right wheel, $X_{RRscale}$	Scale(5,1)	World X-axis
Rear right wheel, $Y_{RRscale}$	Scale(5,2)	World Y-axis
Rear right wheel, $Z_{RRscale}$	Scale(5,3)	World Z-axis

Dependencies

Setting **Actor type** to Custom or Passenger vehicle creates the Scale port.

Parameters

Actor Setup

Actor type — Selection

Passenger vehicle (default) | Camera | Custom

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 Passenger vehicle actor includes components for a vehicle body with four wheels.

Only select Custom if you are developing custom scenes using the Unreal Engine® editor.

Dependencies

Actor Type Setting	Creates Parameters	Creates Port
Custom	Number of parts per actor to set, NumberOfParts	Scale
Passenger vehicle	Vehicle type Paint color	

Vehicle type — Type

Muscle car (default) | Sedan | Sport utility vehicle | Small pickup truck | Hatchback

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	Muscle Car
Sedan	Sedan
Sport utility vehicle	Sport Utility Vehicle
Small pickup truck	Small Pickup Truck
Hatchback	Hatchback

Paint color – Vehicle

Red (default) | Orange | Yellow | Green | Blue | Black | White | Silver

Dependencies

Actor Type Setting	Creates Parameters
Passenger vehicle	Vehicle type Paint color

Initial Values

Initial array values to translate actor per part, Translation – Initial position array

Initial actor position, along world X-, Y-, and Z- axes

Initial array values to rotate actor per part, Rotation – Initial rotation array

Initial actor rotation, about world X-, Y-, and Z- axes

Initial array values to scale actor per part, Scale – Initial scale array

Initial actor scale.

Sample time, Ts – Sample time

-1 (default)

Sample time, T_s . The graphics frame rate is the inverse of the sample time.**See Also**

[Simulation 3D Config](#) | [Simulation 3D Actor Transform Get](#) | [Simulation 3D Camera Get](#) | [Vehicle Terrain Sensor](#)

Topics

[“Vehicle Dynamics Blockset Communication with 3D Visualization Software”](#)

“Scene Interrogation”

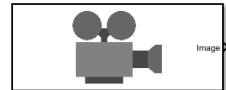
“3D Visualization Engine Requirements”

Introduced in R2018a

Simulation 3D Camera Get

Camera image

Library: Vehicle Dynamics Blockset / Vehicle Scenarios / Sim3D / Sim3D Core



Description

The 3D Scene Camera block gets the image feedback from a camera actor in the 3D visualization environment. The feedback is a red, green, and blue (RGB) array.

Ports

Output

Image — Resolution
array

Red, green, and blue (RGB) image resolution, in pixels. Signal dimensions are vertical resolution by horizontal resolution by 3.

Parameters

Actor Setup

Tag for actor in 3D scene, ActorTag — Name
SimulinkActor1 (default)

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.

Configuration

Horizontal resolution, HorizontalResolution — Pixels
uint32(1920) (default) | scalar

Horizontal image resolution, in pixels.

Vertical resolution, VerticalResolution — Pixels
uint32(1080) (default) | scalar

Vertical image resolution, in pixels.

Horizontal field of view, HorizontalFOV — Field of view
single(90) (default) | scalar

Horizontal field of view (FOV), in deg.

Camera enabled — Selection
on (default) | off

Enable camera to provide the image feedback.

Sample time, Ts — Sample time
-1 (default)

Sample time, T_s . The graphics frame rate is the inverse of the sample time.

See Also

[Simulation 3D Config](#) | [Simulation 3D Actor Transform Get](#) | [Simulation 3D Actor Transform Set](#) | [Vehicle Terrain Sensor](#)

Topics

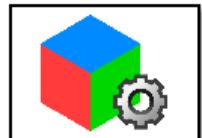
“Vehicle Dynamics Blockset Communication with 3D Visualization Software”
“Scene Interrogation”
“3D Visualization Engine Requirements”

Introduced in R2018a

Simulation 3D Config

Scene configuration

Library: Vehicle Dynamics Blockset / Vehicle Scenarios / Sim3D / Sim3D Core



Description

The Simulation 3D Config 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 specify the type of co-simulation, use the **Co-simulation format** parameter.

Setting	Implementation
Executable	<p>(Recommended) The block uses an executable program to implement the 3D visualization environment. By default, the block sets these parameters:</p> <ul style="list-style-type: none"> • Project name to <code>VehicleSimulation.exe</code>. The 3D visualization executable <code>VehicleSimulation.exe</code> contains two scene actors: <ul style="list-style-type: none"> • Camera with actor tag <code>Camera0</code>. • Passenger vehicle with actor tag <code>SimulinkVehicle1</code>. The passenger vehicle actor has five components: <ul style="list-style-type: none"> • Vehicle body • Two front and two rear wheels • Scene description to <code>Straight road</code>. Additional scenes include <code>Curved road</code>, <code>Parking lot</code>, and <code>Open surface</code>.

Setting	Implementation
Editor	Only use this option if you are developing custom scenes using the Unreal Engine editor.

Ports

Output

State — Visualization engine state

0 | 1 | 2 | 3 | 4 | 8

State of the visualization engine.

Value	Visualization Engine
0	Stopped
1	Initializing
2	Running
3	Paused
4	Terminating
8	Error

Dependencies

To create the State and Ts ports, select **Show state and sample time**.

Ts — Sample time

- 1 (default)

Sample time, T_s . The graphics frame rate is the inverse of the sample time.

Dependencies

To create the State and Ts ports, select **Show state and sample time**.

Parameters

Co-simulation format — Type

Executable (default) | Editor

To specify the type of co-simulation, use the **Co-simulation format** parameter.

Setting	Implementation
Executable	<p>(Recommended) The block uses an executable program to implement the 3D visualization environment. By default, the block sets these parameters:</p> <ul style="list-style-type: none">• Project name to <code>VehicleSimulation.exe</code>. The 3D visualization executable <code>VehicleSimulation.exe</code> contains two scene actors:<ul style="list-style-type: none">• Camera with actor tag <code>Camera0</code>.• Passenger vehicle with actor tag <code>SimulinkVehicle1</code>. The passenger vehicle actor has five components:<ul style="list-style-type: none">• Vehicle body• Two front and two rear wheels• Scene description to Straight road. Additional scenes include Curved road, Parking lot, and Open surface.
Editor	Only use this option if you are developing custom scenes using the Unreal Engine editor.

Project name — Executable 3D visualization environment program

`VehicleSimulation.exe` (default)

Specify the name of the executable 3D visualization environment program.

The 3D visualization executable `VehicleSimulation.exe` contains two scene actors:

- Camera with actor tag `Camera0`.
- Passenger vehicle with actor tag `SimulinkVehicle1`. The passenger vehicle actor has five components:

- Vehicle body
- Two front and two rear wheels

Dependencies

To create this parameter, set **Co-simulation format** to Executable.

Scene description — 3D scene

Straight road (default) | Curved road | Parking lot | Double lane change | Open surface | Custom

Specify the name of the 3D scene.

Only select Custom if you are developing custom scenes using the Unreal Engine editor.

Dependencies

To create this parameter, set **Co-simulation format** to Executable.

Show state and sample time — Create output ports

off (default) | on

Dependencies

To create the State and Ts ports, select **Show state and sample time**.

Sample time, Ts — Sample time

- 1 (default)

Sample time, T_s . The graphics frame rate is the inverse of the sample time.

See Also

Curved Road | Double Lane Change | Open Surface | Parking Lot | Straight Road | Vehicle Terrain Sensor

Topics

“Vehicle Dynamics Blockset Communication with 3D Visualization Software”

“Scene Interrogation”

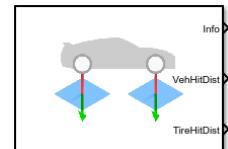
“3D Visualization Engine Requirements”

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.

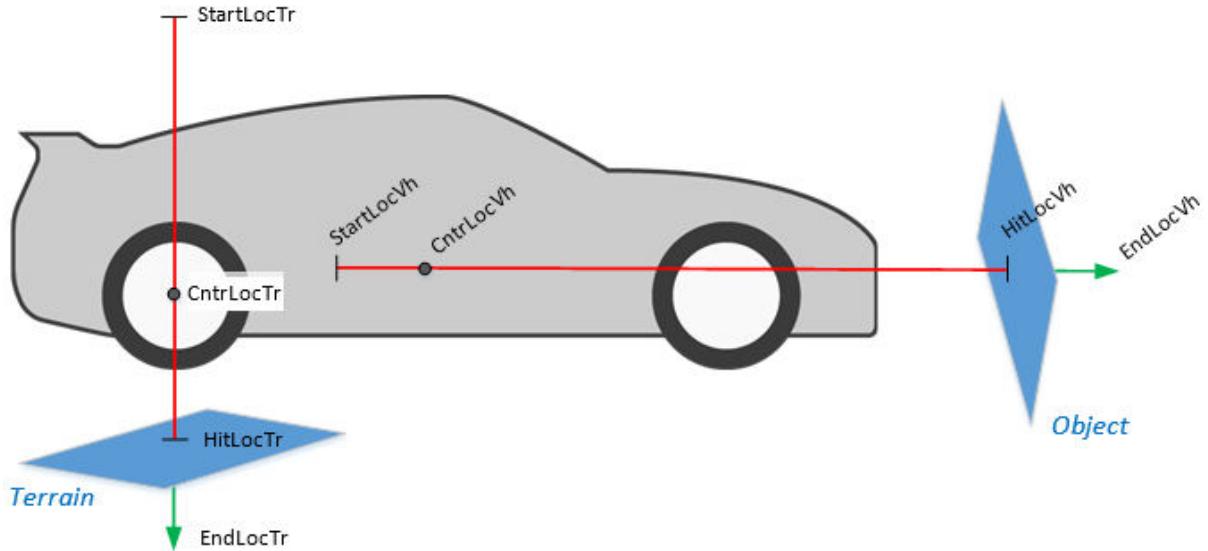
- Vehicle body
- Left front wheel
- Right front wheel
- Left rear wheel
- Right rear wheel

Note 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>	$\text{DistToHitTr} = \text{GetLength}(\text{CntrLocTr}, \text{HitLocTr})$ $\text{DistToHitTrAdjust} = \text{DistToHitTr} - \text{TireRadiiVal}$ $\text{EndLocTr} = \text{CntrLocTr} + \text{LengthTr} - \text{OffsetTr}$ $\text{OffsetTr} = \text{CntrLocTr} - \text{StartLocTr}$ $\text{LengthTr} = \text{StartLocTr} - \text{EndLocTr}$



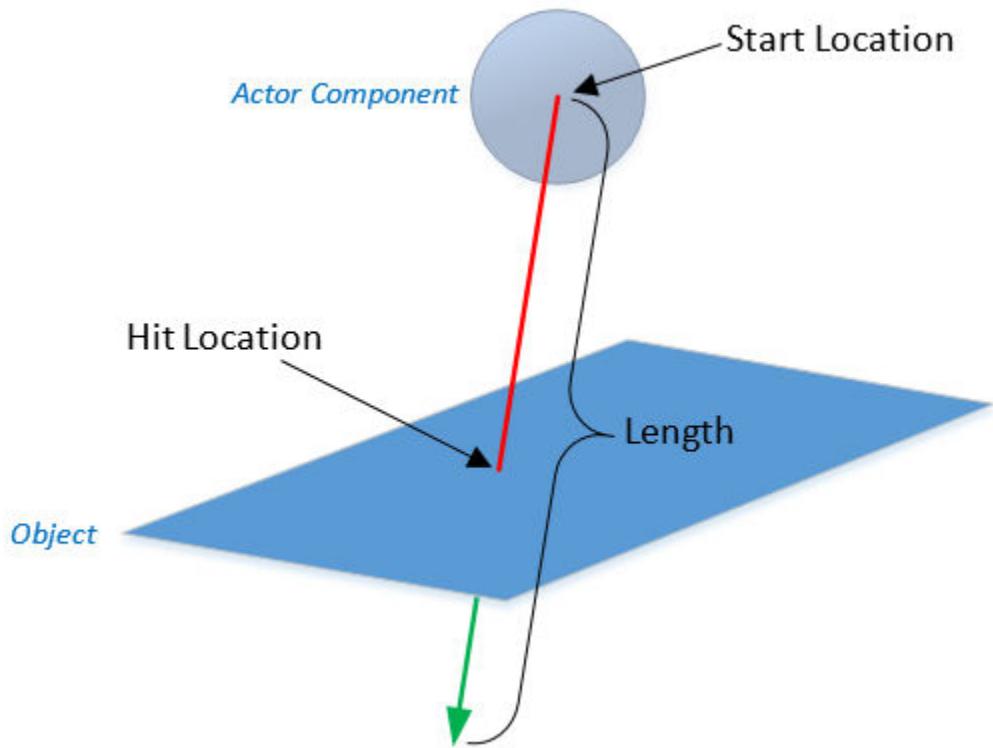
This illustration and equations use these variables.

<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>VehRayLength</i>	Vehicle trace length
<i>VehCntrLengthVal</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
<i>LengthTr</i>	Tire trace length
<i>TireRadiusVal</i>	Tire radius

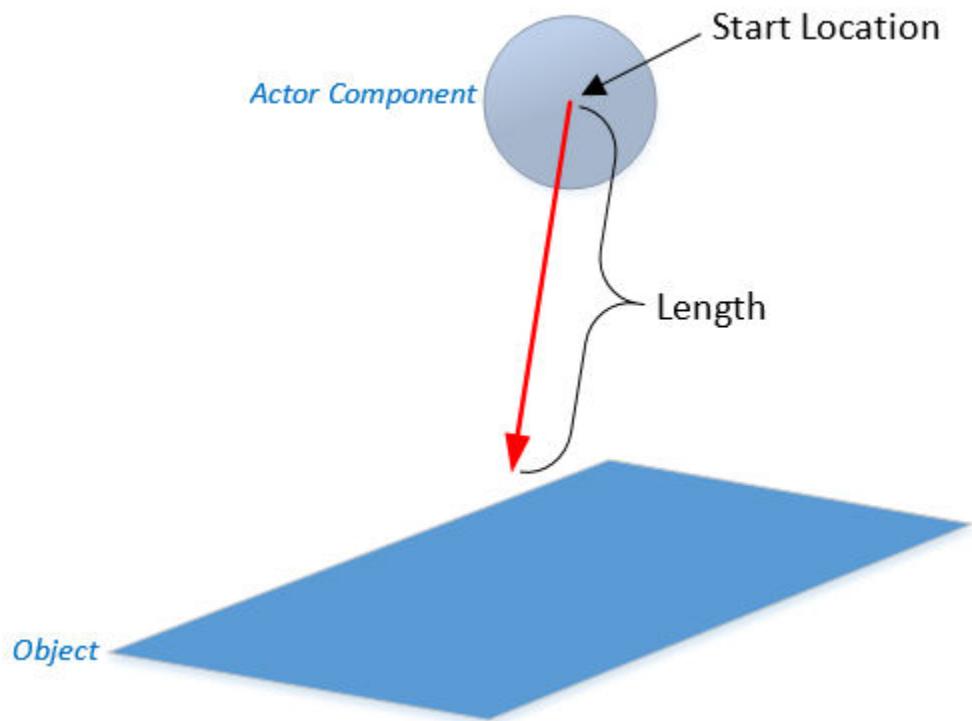
Hit Event

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	Distance from vehicle center to front, VehCntrLngthVal
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	Distance from tire center to ground, TireRadiiVal
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"> • Hit an object - 1 • Miss an object - 0 	$\begin{bmatrix} Vehicle \\ FrontLeft \\ FrontRight \\ RearLeft \\ RearRight \end{bmatrix}$	NA

Signal	Description	Variable	Units
HitLoc	Vehicle, <i>HitLocVh</i> , and tire, <i>HitLocTr</i> , hit locations, in world coordinate system X-, Y, and Z- axes, respectively	<i>VehicleX</i> <i>VehicleY</i> <i>VehicleZ</i> <i>FrontLeftX</i> <i>FrontLeftY</i> <i>FrontLeftZ</i> <i>FrontRightX</i> <i>FrontRightY</i> <i>FrontRightZ</i> <i>RearLeftX</i> <i>RearLeftY</i> <i>RearLeftZ</i>	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	<i>RearRearX</i> <i>RearRearY</i> <i>RearRearZ</i>	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.

$$\text{DistToHitTrAdjust} = [\text{FrontLeft } \text{FrontRight } \text{RearLeft } \text{RearRight}]$$

Parameters

Actor Setup**Tag for actor in 3D scene, ActorTag — Name**

SimulinkActor1 (default)

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	Distance from vehicle center to front, VehCntrLnghVal
External input	VehCntr	<i>None</i>

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	Distance from tire center to ground, TireRadiiVal
External input	TireRadii	<i>None</i>

Distance from vehicle center to front, VehCntrLnghVal — Vehicle center scalar

Distance from the vehicle center to front, *VehCntrLnghVal*, in m.

Dependencies

Distance to vehicle center	Creates Port	Creates Parameter
Constant	None	Distance from vehicle center to front, VehCntrLnghVal

Distance to vehicle center	Creates Port	Creates Parameter
External input	VehCntr	<i>None</i>

Distance from tire center to ground, TireRadiiVal — Tire radii scalar

Tire radius, *TireRadiiVal*, in m.

Dependencies

Distance to tire center Setting	Creates Port	Creates Parameter
Constant	None	Distance from tire center to ground, TireRadiiVal
External input	TireRadii	None

Trace Lengths

Vehicle body x-axis trace length, VehRayLngth — Trace length scalar

Vehicle body trace length, *VehRayLngth*, in m.

Left front wheel z-axis trace length, LfRayLngth — Trace length scalar

Left front wheel trace length, *LfRayLngth* and *LengthTr*, in m.

Right front wheel z-axis trace length, RfRayLngth — Trace length scalar

Right front wheel trace length, *RfRayLngth* and *LengthTr*, in m.

Left rear wheel z-axis trace length, LrRayLngth — Trace length scalar

Left rear wheel trace length, *LrRayLngth* and *LengthTr*, in m.

Right rear wheel z-axis trace length, RrRayLngth — Trace length scalar

Right rear wheel trace length, *RrRayLength* and *LengthTr*, in m.

Starting Point Offsets

Vehicle body x-axis trace offset, VehRayOffset — Offset the vehicle ray trace
scalar

Vehicle body trace offset, *OffsetVh*, in m.

Left front wheel z-axis trace offset, LfRayOffset — Offset the left front wheel ray trace
scalar

Left front wheel trace offset, *LfRayOffset* and *OffsetTr*, in m.

Right front wheel z-axis trace offset, RfRayOffset — Offset the right front wheel ray trace
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
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
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, Ts — Sample time
-1 (default)

Sample time, T_s . The graphics frame rate is the inverse of the sample time.

See Also

[Simulation 3D Config](#) | [Simulation 3D Actor Transform Get](#) | [Simulation 3D Actor Transform Set](#) | [Simulation 3D Camera Get](#)

Topics

“Scene Interrogation”

External Websites

Unreal Engine

Introduced in R2018a

Shipping Scenes – Alphabetical List

Straight Road

Straight road 3D environment

Description

The scene contains a straight road, camera, and two vehicles.

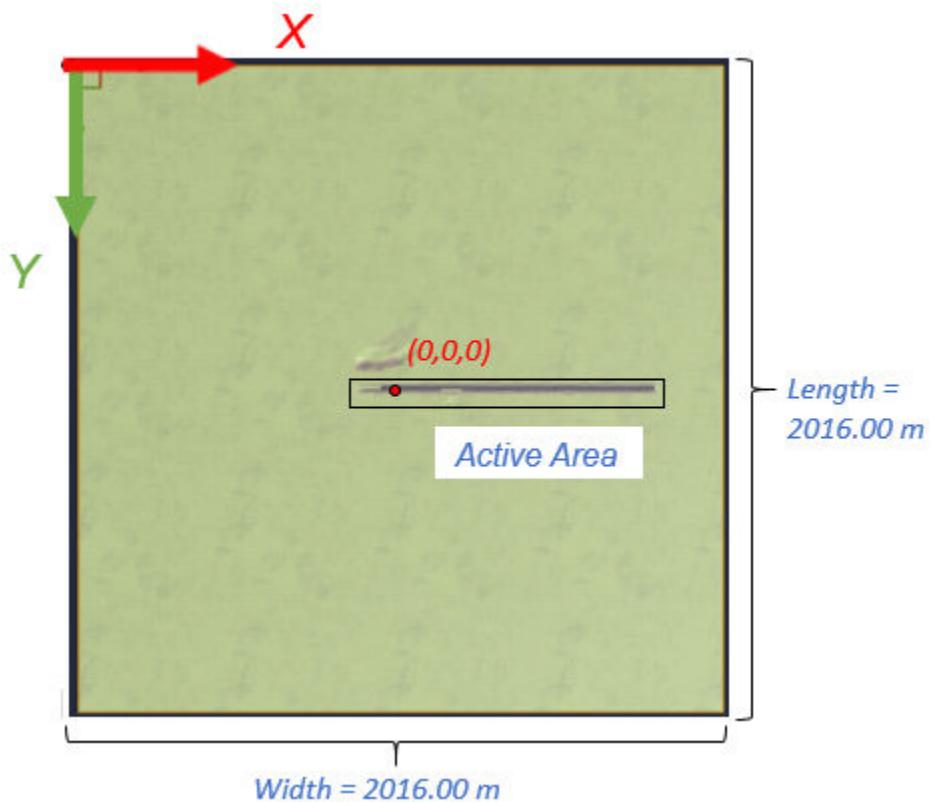


To simulate a driving maneuver in a straight road 3D environment, in the Simulink window, open the Simulation 3D Config block. Use either of these parameter setting configurations.

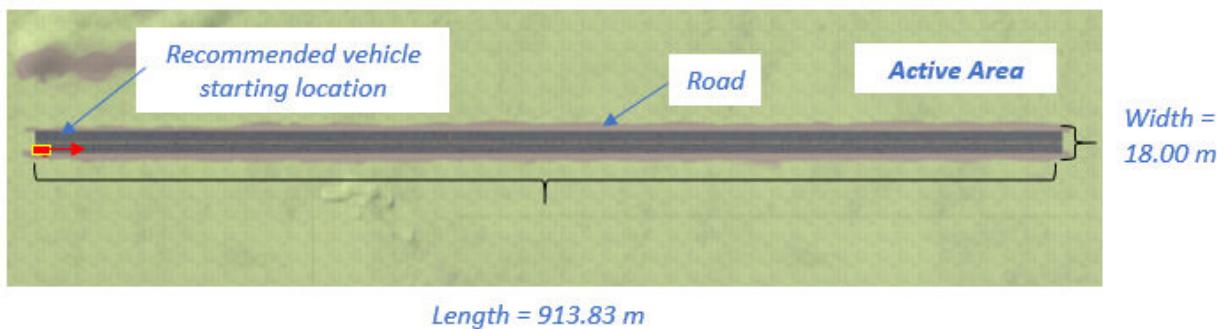
- Set **Scene description** to Straight road.
- Set **Scene description** to Custom and **Project name** to VehicleSimulation.exe /Game/Maps/HwStrght.

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	-1080	-1080	0
Scene — Bottom right	1080	1080	0
Active area — Bottom left	-122.19	6.00	0

Recommended Starting Locations

This table provides the names and recommended starting locations in the world coordinate system. Dimensions are in m.

Tag Name	Unreal Engine Editor Name	Recommended Starting Location					
		X	Y	Z	Roll	Pitch	Yaw
Simulink Vehicle1	Sim3dPas sVeh1	-118	3.125	0	0	0	0
Simulink Vehicle2	Sim3dPas sVeh2	-118	3.125	0	0	0	0

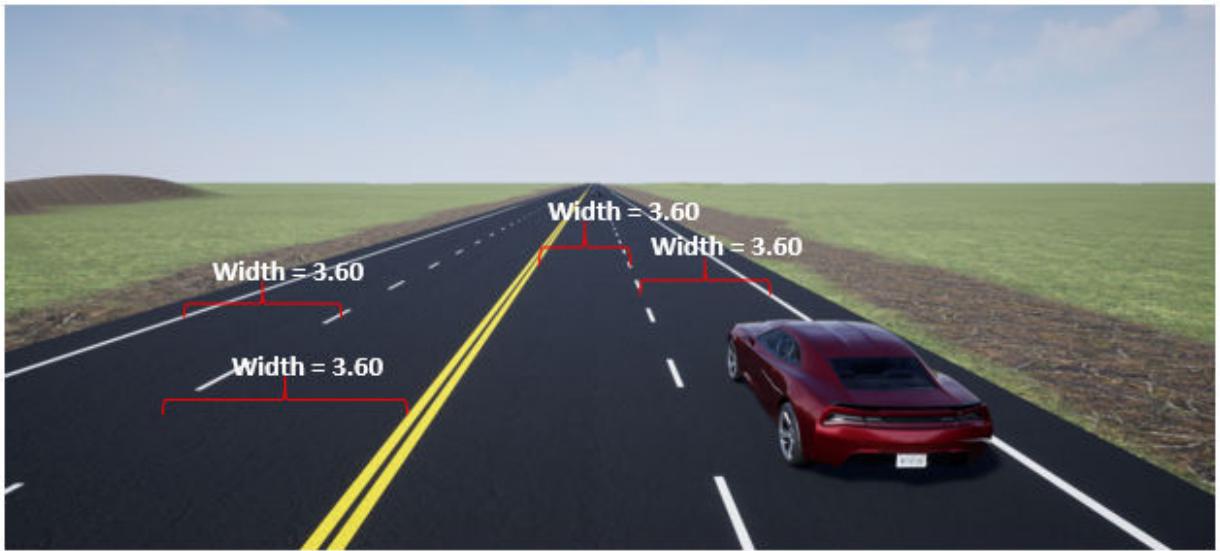
Camera

This table provides the scene capture camera name and Unreal Engine editor parent. The parent is the object to which the camera is attached.

Tag Name	Unreal Engine Editor Name	Unreal Engine Editor Parent
Camera0	Sim3dSceneCap1	World (root)

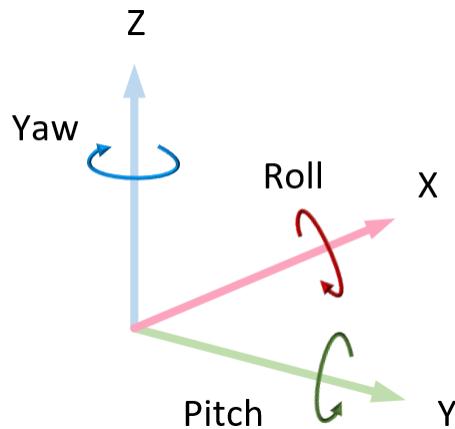
Lane Dimensions

This figure shows the lane 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

See Also

[Curved Road](#) | [Double Lane Change](#) | [Large Parking Lot](#) | [Open Surface](#) | [Parking Lot](#) | Simulation 3D Config | [US City Block](#) | [US Highway](#) | [Virtual Mcity](#)

Topics

“3D Visualization Engine Requirements”
“Vehicle Dynamics Blockset Communication with 3D Visualization Software”
“Support Package for Customizing Scenes”

Curved Road

Curved road 3D environment

Description

The scene contains a curved road, camera, and two vehicles.

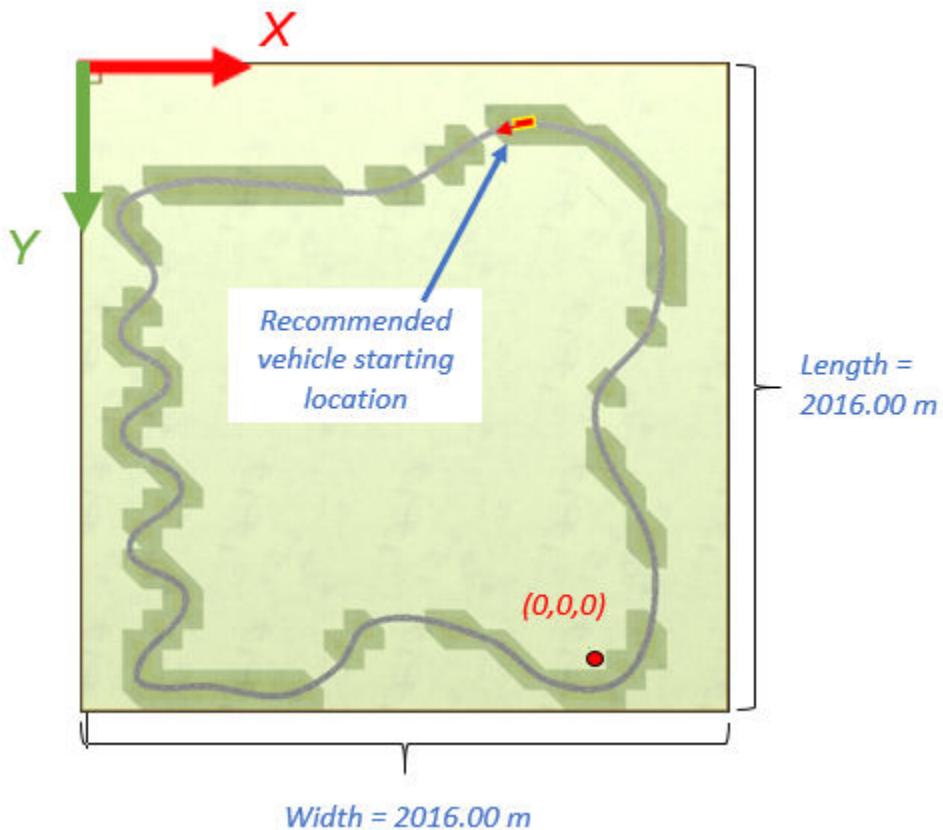


To simulate a driving maneuver in a curved road 3D environment, in the Simulink window, open the Simulation 3D Config block. Use either of these parameter setting configurations.

- Set **Scene description** to Curved road.
- Set **Scene description** to Custom and **Project name** to VehicleSimulation.exe /Game/Maps/HwCurve.

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	-1587.75	195.39	0
Scene — Top right	428.26	-1820.60	0

Recommended Starting Locations

This table provides the names and recommended starting locations in the world coordinate system. Dimensions are in m.

Tag Name	Unreal Engine Editor Name	Recommended Starting Location					
		X	Y	Z	Roll	Pitch	Yaw
Simulink Vehicle1	Sim3dPas sVeh1	0.2	-1605.00	0	0	0	-156°
Simulink Vehicle2	Sim3dPas sVeh2	0.2	-1605.00	0	0	0	-156°

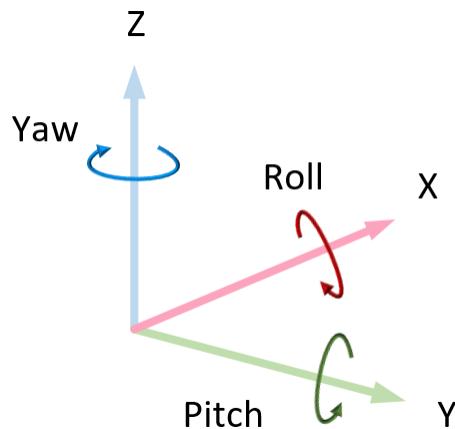
Camera

This table provides the scene capture camera name and Unreal Engine editor parent. The parent is the object to which the camera is attached.

Tag Name	Unreal Engine Editor Name	Unreal Engine Editor Parent
Camera0	Sim3dSceneCap1	World (root)

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

See Also

[Double Lane Change](#) | [Large Parking Lot](#) | [Open Surface](#) | [Parking Lot](#) | Simulation 3D Config | [Straight Road](#) | [US City Block](#) | [US Highway](#) | [Virtual Mcity](#)

Topics

“3D Visualization Engine Requirements”
“Vehicle Dynamics Blockset Communication with 3D Visualization Software”
“Support Package for Customizing Scenes”

Parking Lot

Parking lot 3D environment

Description

The scene contains a parking lot, camera, and two vehicles.

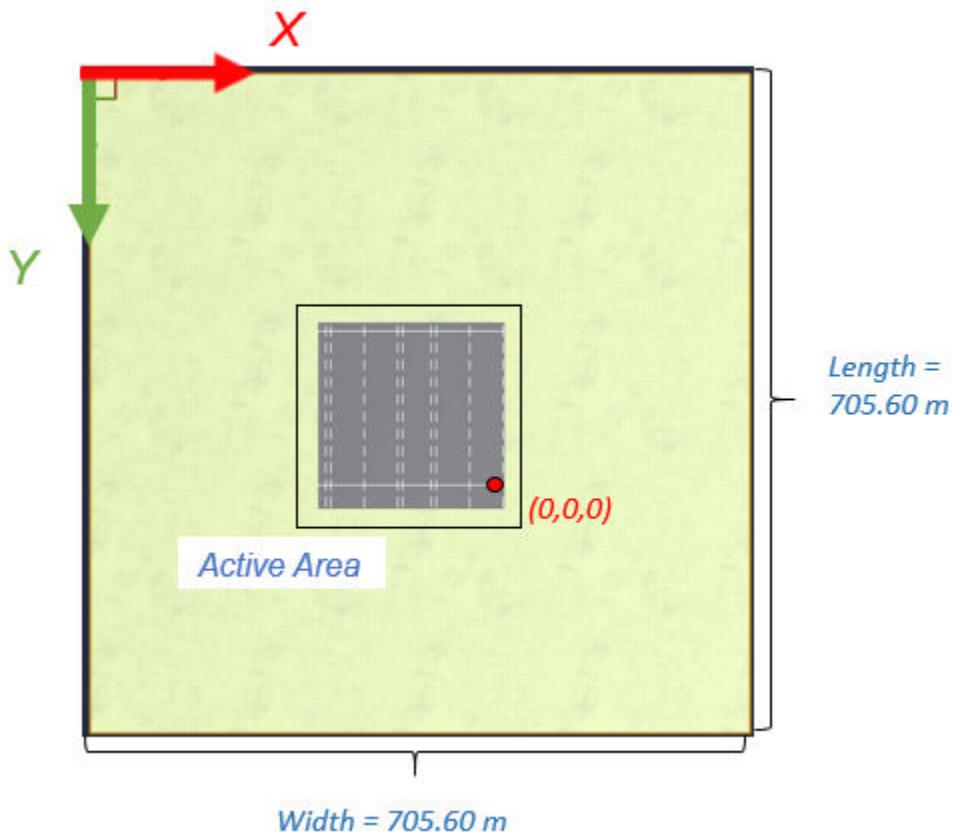


To simulate a driving maneuver in a parking lot 3D environment, in the Simulink window, open the Simulation 3D Config block. Use either of these parameter setting configurations.

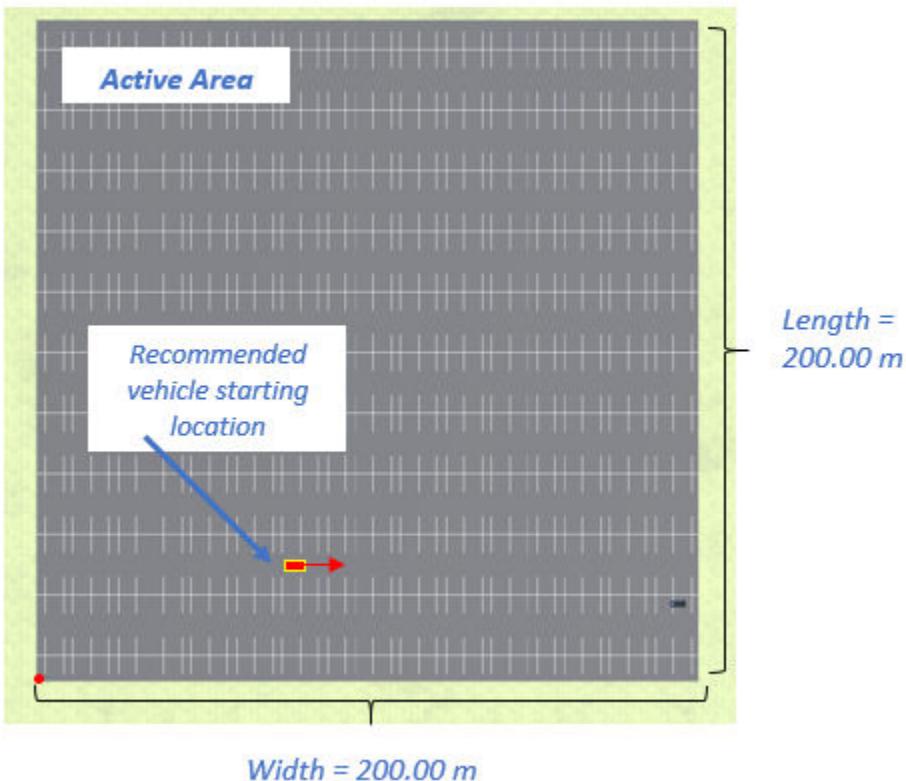
- Set **Scene description** to **Parking lot**.
- Set **Scene description** to **Custom** and **Project name** to **VehicleSimulation.exe /Game/Maps/SimpleLot**.

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	Y	Z
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 Locations

This table provides the names and recommended starting locations in the world coordinate system. Dimensions are in m.

Tag Name	Unreal Engine Editor Name	Recommended Starting Location					
		X	Y	Z	Roll	Pitch	Yaw
Simulink Vehicle1	Sim3dPas sVeh1	-104.0	-9.7	0	0	0	0
Simulink Vehicle2	Sim3dPas sVeh2	-104.0	-9.7	0	0	0	0

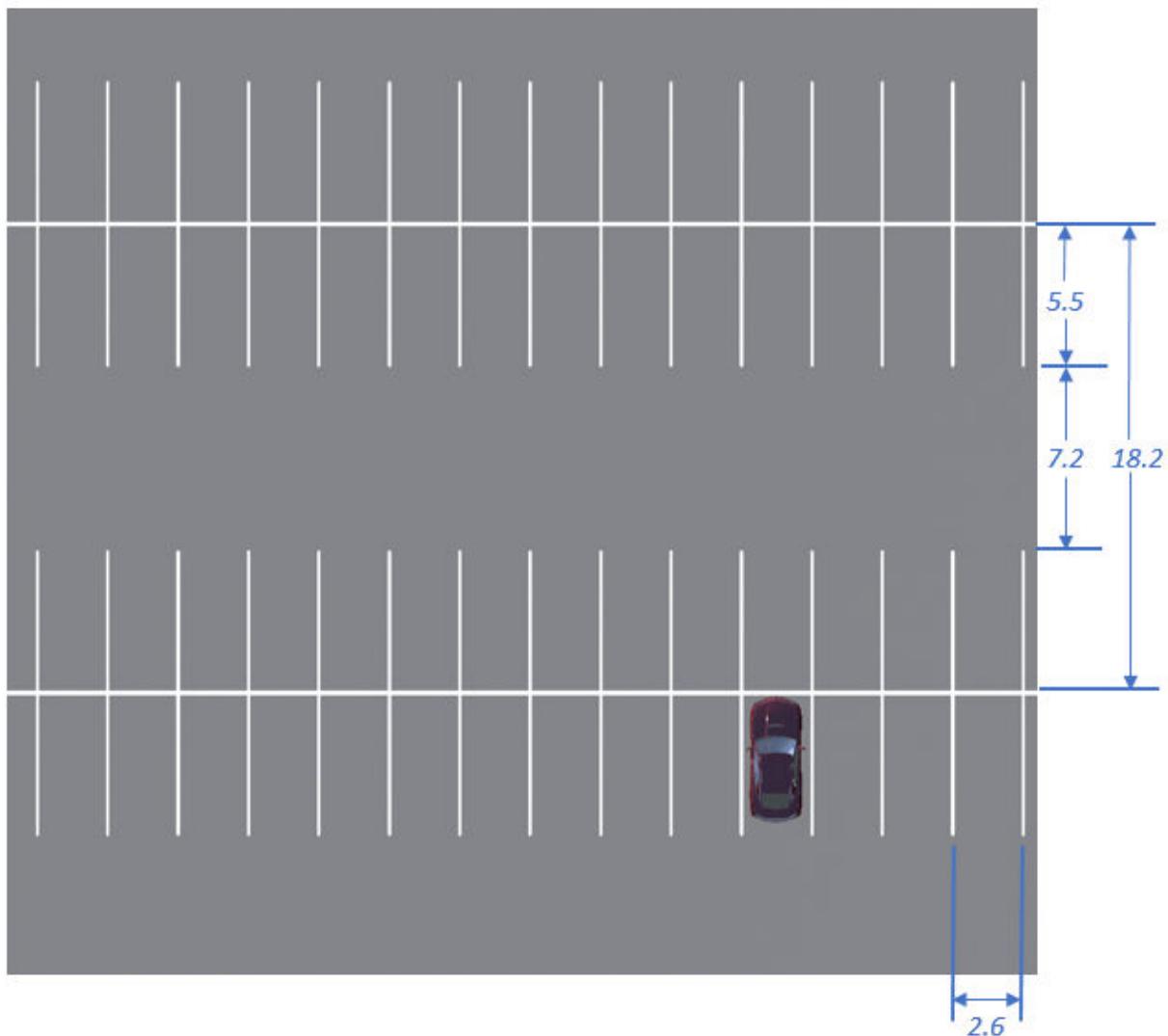
Camera

This table provides the scene capture camera name and Unreal Engine editor parent. The parent is the object to which the camera is attached.

Tag Name	Unreal Engine Editor Name	Unreal Engine Editor Parent
Camera0	Sim3dSceneCap1	World (root)

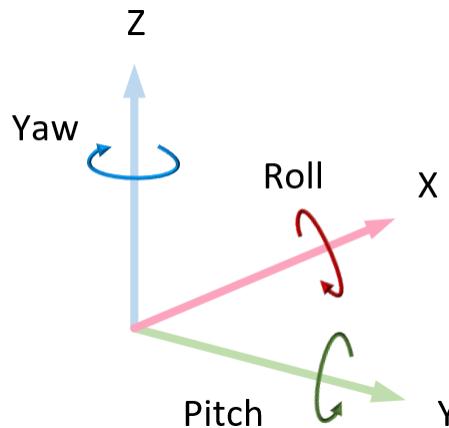
Parking Space Dimensions

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

See Also

[Curved Road](#) | [Double Lane Change](#) | [Large Parking Lot](#) | [Open Surface](#) | Simulation
3D Config | [Straight Road](#) | [US City Block](#) | [US Highway](#) | [Virtual Mcity](#)

Topics

“3D Visualization Engine Requirements”

"Vehicle Dynamics Blockset Communication with 3D Visualization Software"
"Support Package for Customizing Scenes"

Large Parking Lot

Large parking lot 3D environment

Setup

The scene contains a large parking lot 3D environment, a camera, vehicles, cones, curbs, and traffic signs.



To simulate a driving maneuver in a curved road 3D environment, in the Simulink window, open the Simulation 3D Config block. Use either of these parameter setting configurations.

- Set **Scene description** to Large parking lot.
- Set **Scene description** to Custom and **Project name** to VehicleSimulation.exe /Game/Maps/LargeParkingLot.

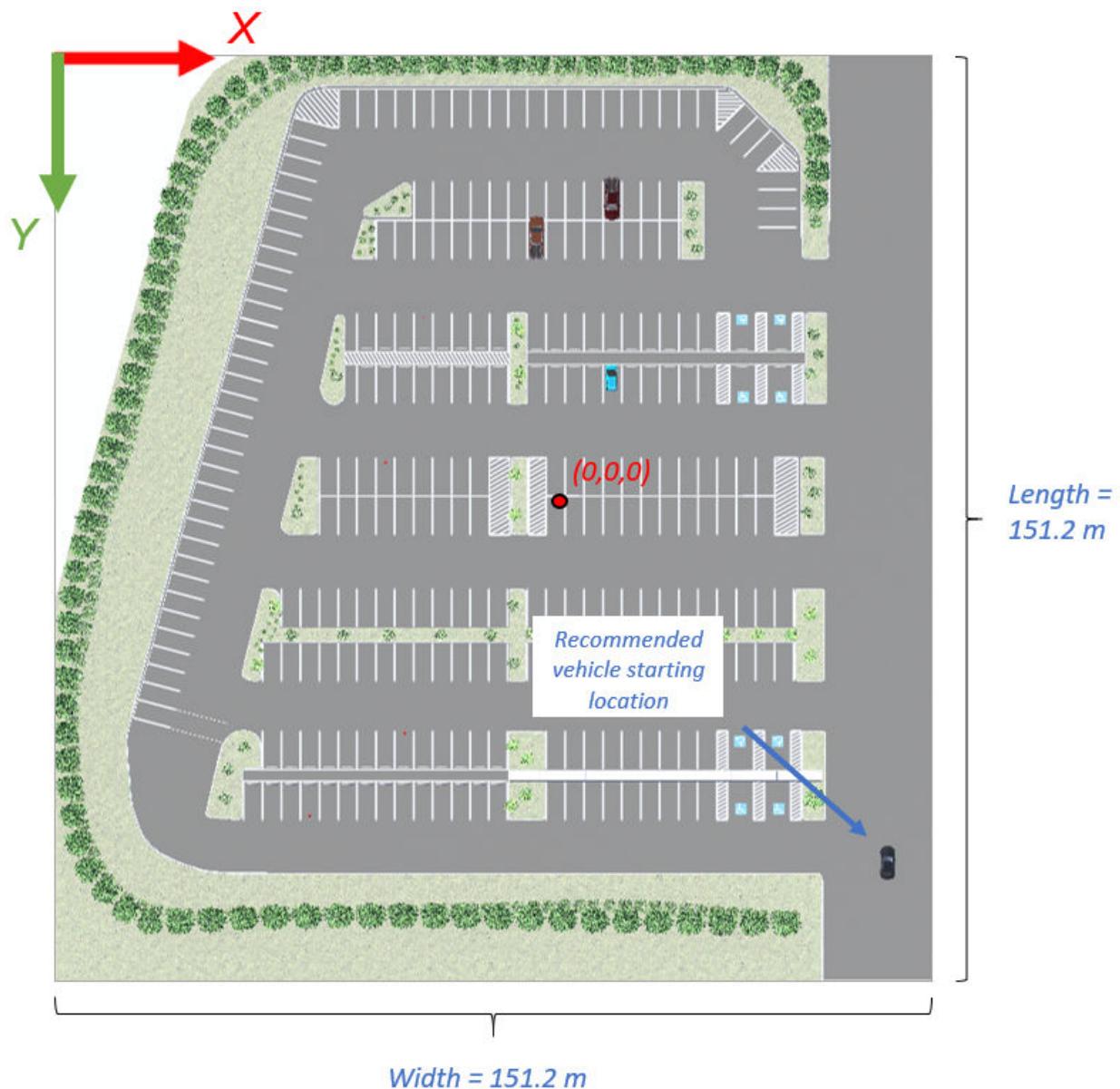
Description

The scene contains the large parking lot 3D environment, a camera, vehicles, cones, curbs, and traffic signs.

Scene Layout

The scene uses the world coordinate system to locate objects.

8 Shipping Scenes — Alphabetical List



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 name and recommended starting locations in the world coordinate system. Dimensions are in m and deg. When the scene opens, the vehicle is in the recommended starting location.

Tag Name	Unreal Engine Editor Name	Recommended Starting Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
Simulink Vehicle1	Sim3dPas sVeh1	45.0	54.7	0	0	0	-90
Simulink Vehicle2	Sim3dPas sVeh2	45.0	54.7	0	0	0	-90

Parking Space Dimensions

This figure shows the parking space dimensions, in m.

8 Shipping Scenes — Alphabetical List



Camera

This table provides the scene capture camera name and Unreal Engine editor parent. The parent is the object to which the camera is attached.

Tag Name	Unreal Engine Editor Name	Unreal Engine Editor Parent
Camera0	Sim3dSceneCap1	World (root)

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	5.48	-14.75	0.05	0	0	-90
	SM_Pickup Truck2	5.59	-40.40	0.05	0	0	90
	SM_Pickup Truck	-5.255	-34.87	0.05	0	0	-90

Cones

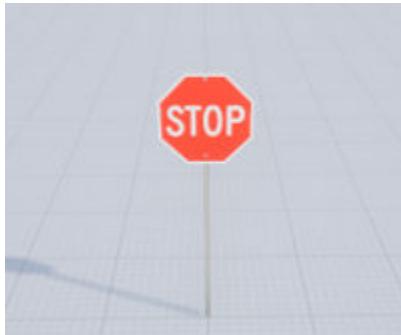


8 Shipping Scenes — Alphabetical List

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



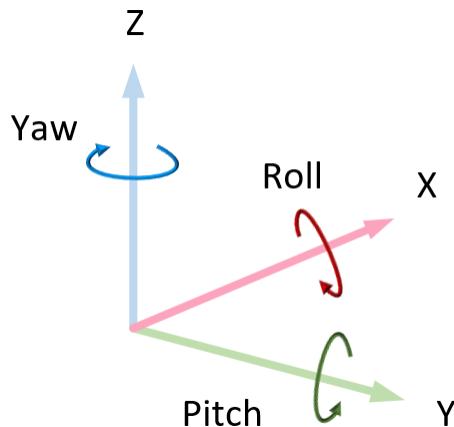
This table provides the object names and locations in the world coordinate system. Dimensions are in m and deg.

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

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
SM_StopSign3	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_DisabilitySi gn1	23.81	42.71	0.11	0	0	0
	SM_DisabilitySi gn2	29.21	42.71	0.11	0	0	0
	SM_DisabilitySi gn3	23.81	41.71	0.11	0	0	180
	SM_DisabilitySi gn4	29.21	41.71	0.11	0	0	180
	SM_DisabilitySi gn5	24.25	-17.01	0.11	0	0	0
	SM_DisabilitySi gn6	29.69	-17.01	0.11	0	0	0
	SM_DisabilitySi gn7	25.25	-18.31	0.11	0	0	180
	SM_DisabilitySi gn8	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

See Also

[Curved Road](#) | [Double Lane Change](#) | [Open Surface](#) | [Parking Lot](#) | [Simulation 3D Config](#) | [Straight Road](#) | [US City Block](#) | [US Highway](#) | [Virtual Mcity](#)

Topics

“3D Visualization Engine Requirements”
“Vehicle Dynamics Blockset Communication with 3D Visualization Software”
“Support Package for Customizing Scenes”

Open Surface

Open surface 3D environment

Description

The scene contains a black lake, camera, and two vehicles.

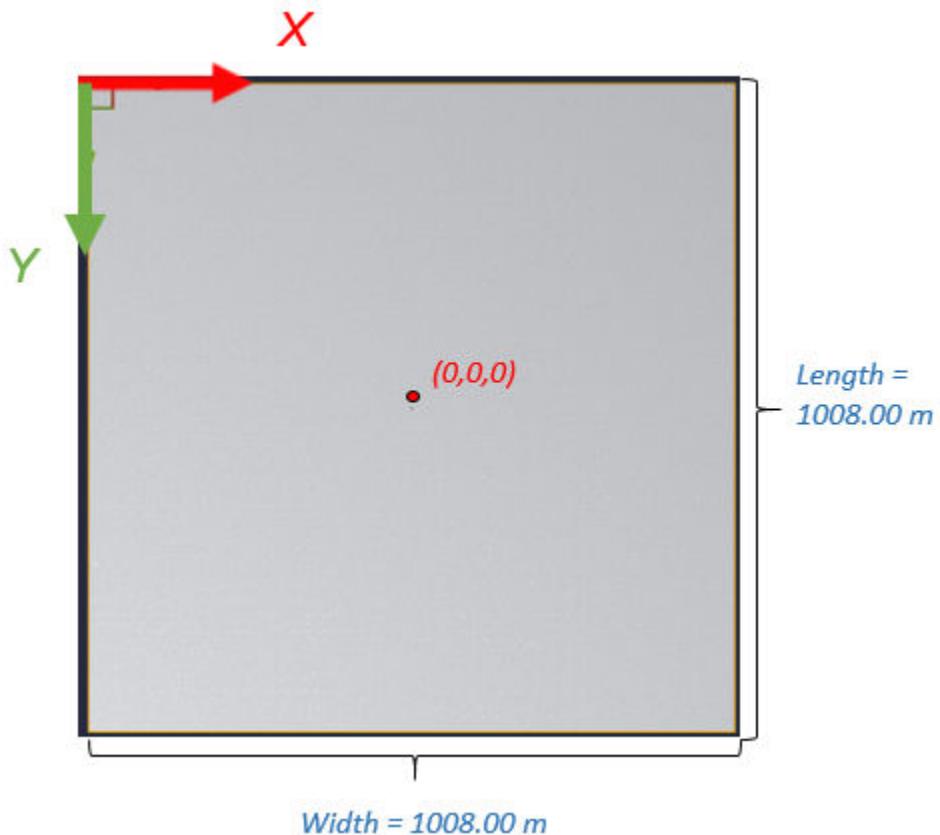


To simulate a driving maneuver in an open surface 3D environment, in the Simulink window, open the Simulation 3D Config block. Use either of these parameter setting configurations.

- Set **Scene description** to Open surface.
- Set **Scene description** to Custom and **Project name** to VehicleSimulation.exe /Game/Maps/BlackLake.

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 Locations

This table provides the names and recommended starting locations in the world coordinate system. Dimensions are in m.

Tag Name	Unreal Engine Editor Name	Recommended Starting Location					
		X	Y	Z	Roll	Pitch	Yaw
Simulink Vehicle1	Sim3dPas sVeh1	0	0	0	0	0	0
Simulink Vehicle2	Sim3dPas sVeh2	0	0	0	0	0	0

Initial Vehicle Locations

This table provides the names and initial locations in the world coordinate system. Dimensions are in m.

Tag Name	Unreal Engine Editor Name	Initial Location					
		X	Y	Z	Roll	Pitch	Yaw
Simulin kVehicel el	Sim3dPas sVeh1	0	0	0	0	0	0
Simulin kVehicel e2	Sim3dPas sVeh2						

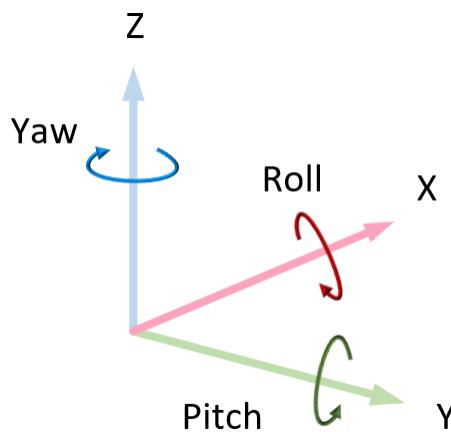
Camera

This table provides the scene capture camera name and Unreal Engine editor parent. The parent is the object to which the camera is attached.

Tag Name	Unreal Engine Editor Name	Unreal Engine Editor Parent
Camera0	Sim3dSceneCap1	World (root)

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

See Also

**Curved Road | Double Lane Change | Large Parking Lot | Parking Lot | Simulation
3D Config | Straight Road | US City Block | US Highway | Virtual Mcity**

Topics

“3D Visualization Engine Requirements”
“Vehicle Dynamics Blockset Communication with 3D Visualization Software”
“Support Package for Customizing Scenes”

Double Lane Change

Double lane change 3D environment

Description

The scene contains a straight road, camera, two vehicles, cones, barrels, and traffic signs.

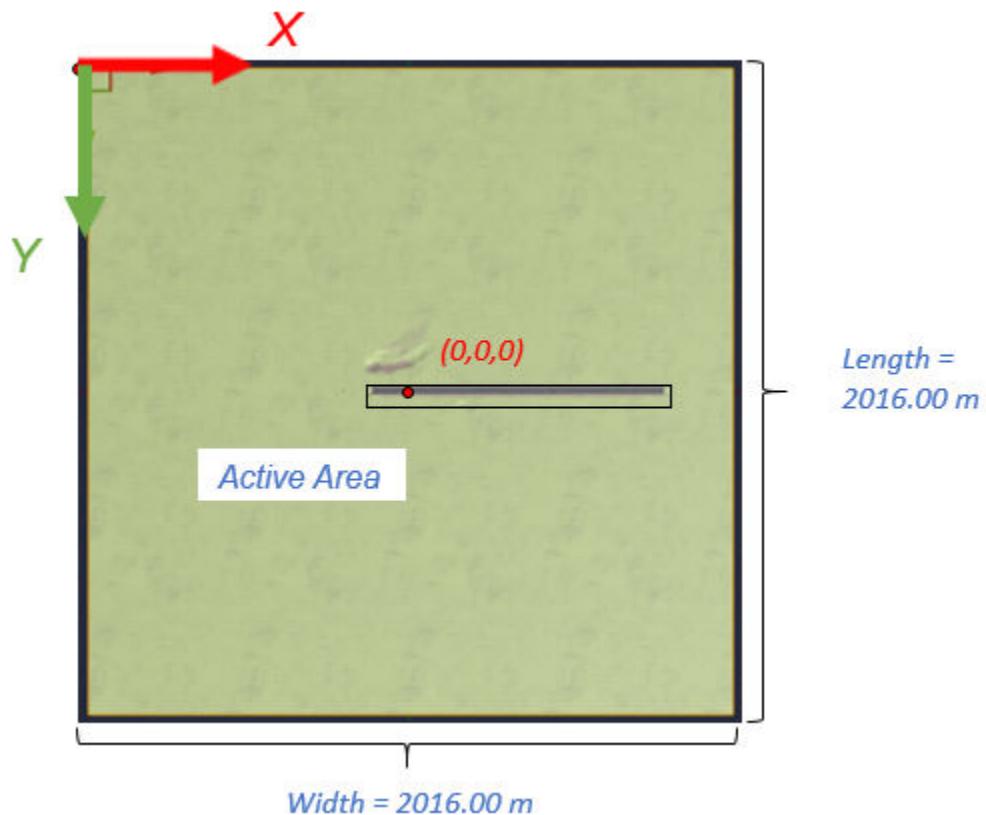


To simulate a driving maneuver in a double lane change 3D environment, in the Simulink window, open the Simulation 3D Config block. Use either of these parameter setting configurations.

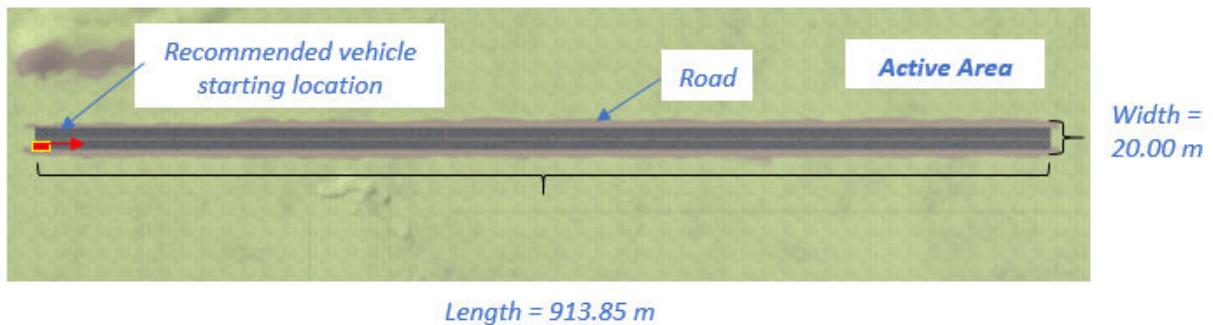
- Set **Scene description** to Double lane change.
- Set **Scene description** to Custom and **Project name** to VehicleSimulation.exe /Game/Maps/DblLnChng.

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 Locations

This table provides the names and recommended starting locations in the world coordinate system. Dimensions are in m.

Tag Name	Unreal Engine Editor Name	Recommended Starting Location					
		X	Y	Z	Roll	Pitch	Yaw
Simulink Vehicle1	Sim3dPas sVeh1	0	3.125	0	0	0	0
Simulink Vehicle2	Sim3dPas sVeh2	0	3.125	0	0	0	0

Camera

This table provides the scene capture camera name and Unreal Engine editor parent. The parent is the object to which the camera is attached.

Tag Name	Unreal Engine Editor Name	Unreal Engine Editor Parent
Camera0	Sim3dSceneCap1	World (root)

Cones



This table provides the object names and locations in the world coordinate system. Dimensions are in m.

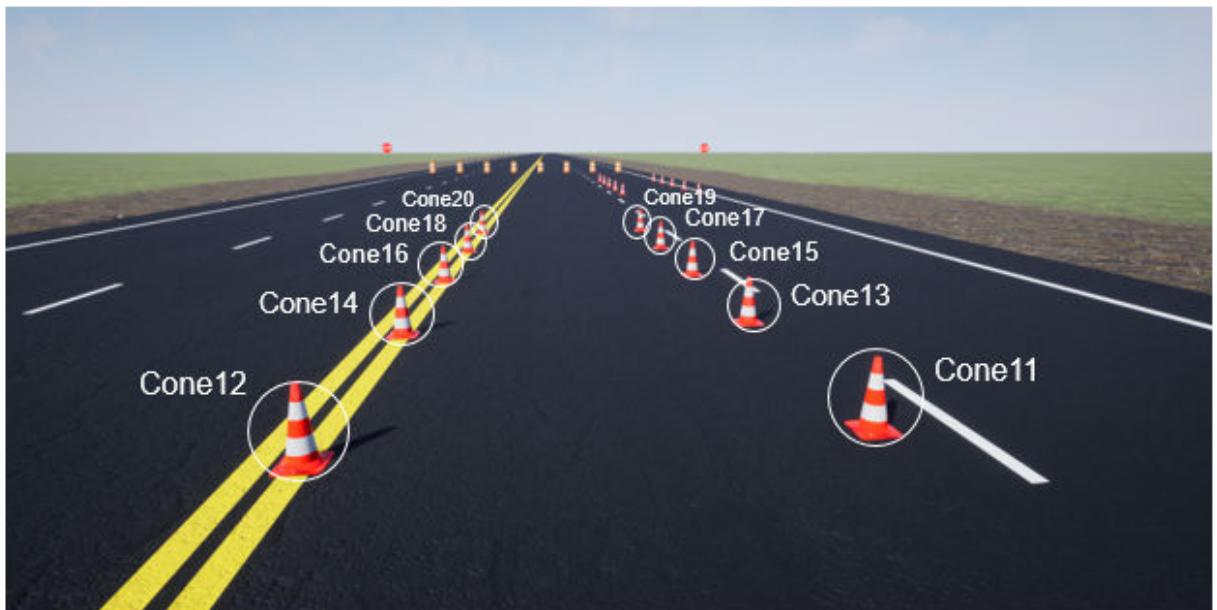
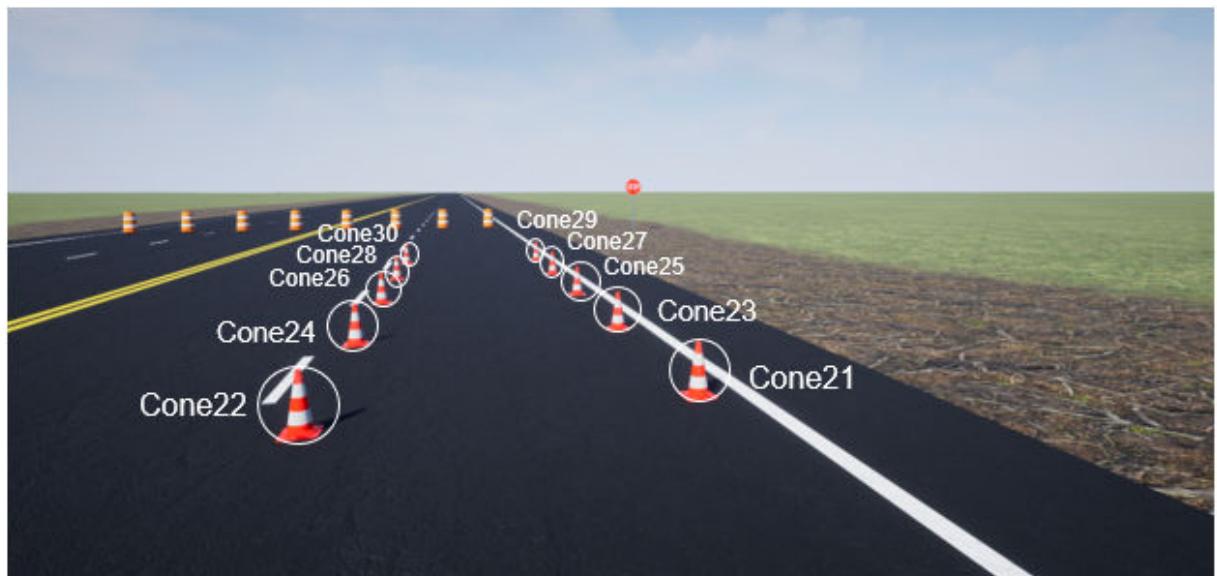
Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
Cone	SM_Cone10	175.90	4.73	.009	0	0	0
	SM_Cone05	175.90	1.70	.009			
	SM_Cone09	178.90	4.73	.009			
	SM_Cone04	178.90	1.70	.009			

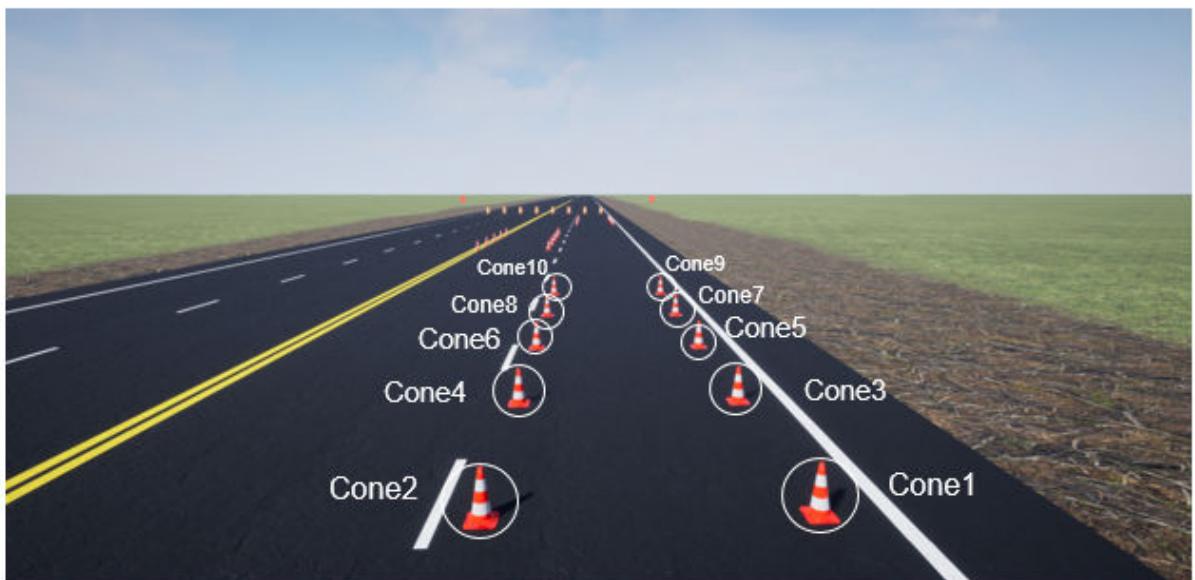
8 Shipping Scenes — Alphabetical List

Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
	SM_Cone08	181.90	4.73	.009			
	SM_Cone03	181.90	1.70	.009			
	SM_Cone07	184.90	4.73	.009			
	SM_Cone02	184.90	1.70	.009			
	SM_Cone06	187.90	4.73	.009			
	SM_Cone01	187.90	1.70	.009			
	SM_Cone20	201.40	0.69	.009			
	SM_Cone15	201.40	-2.86	.009			
	SM_Cone19	204.15	0.69	.009			
	SM_Cone14	204.15	-2.86	.009			
	SM_Cone18	206.90	0.69	.009			
	SM_Cone13	206.90	-2.86	.009			
	SM_Cone17	209.65	0.69	.009			
	SM_Cone12	209.65	-2.86	.009			
	SM_Cone16	212.40	0.69	.009			

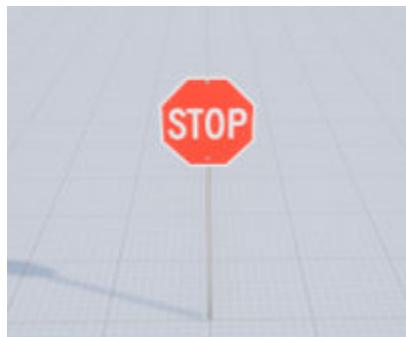
Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
	SM_Cone1 1	212.40	-2.86	.009			
	SM_Cone3 0	224.90	4.95	.009			
	SM_Cone2 5	224.90	1.70	.009			
	SM_Cone2 9	227.90	4.95	.009			
	SM_Cone2 4	227.90	1.70	.009			
	SM_Cone2 8	230.90	4.95	.009			
	SM_Cone2 3	230.90	1.70	.009			
	SM_Cone2 7	233.90	4.95	.009			
	SM_Cone2 2	236.90	1.70	.009			
	SM_Cone2 6	236.90	4.95	.009			
	SM_Cone2 1	236.90	1.70	.009			

8 Shipping Scenes — Alphabetical List





Traffic Signs



This table provides the object names locations in the world coordinate system.
Dimensions are in m.

Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
Traffic sign	SM_StopSign	248.80	-13.10	0	0	0	0
	SM_StopSign2	248.80	10.90	0			

Barrels



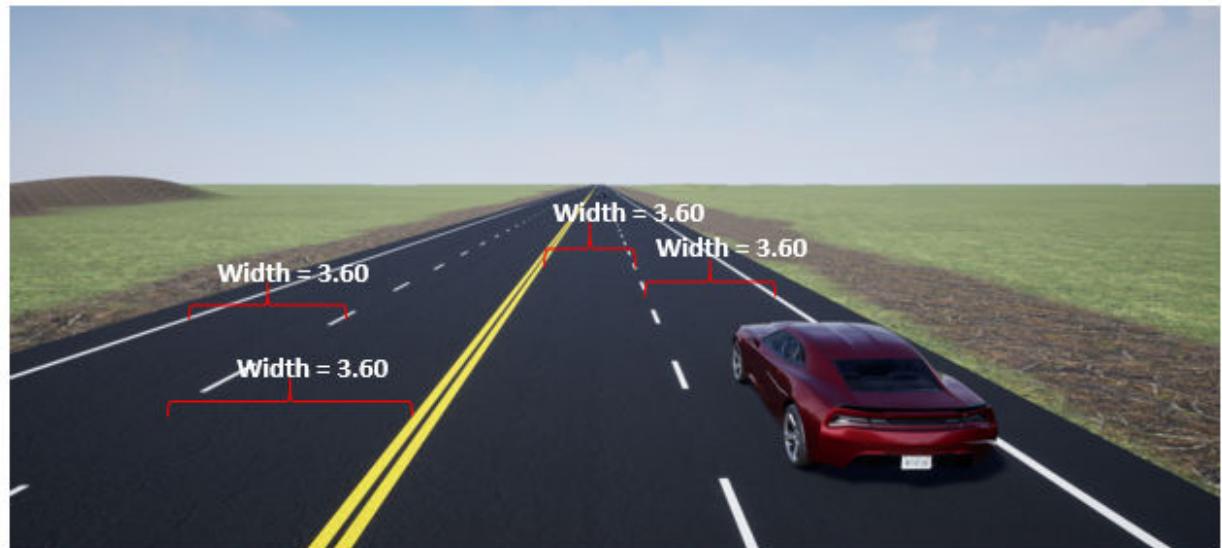
This table provides the object names and locations in the world coordinate system.
Dimensions are in m.

Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
Barrels	SM_TrafficBarrel1	252.70	4.50	0	0	0	180.00°
	SM_TrafficBarrel2	252.70	2.35	0	0	0	0
	SM_TrafficBarrel3	252.70	.20	0	0	0	0

Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
	SM_TrafficBarrel4	252.70	-1.95	0	0	0	0
	SM_TrafficBarrel5	252.70	-4.10	0	0	0	0
	SM_TrafficBarrel6	252.70	-6.25	0	0	0	0
	SM_TrafficBarrel7	252.70	-8.40	0	0	0	0
	SM_TrafficBarrel8	252.70	-10.55	0	0	0	0

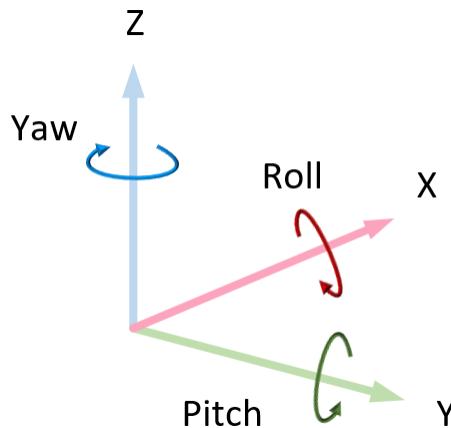
Lane Dimensions

This figure shows the lane 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

See Also

[Curved Road](#) | [Large Parking Lot](#) | [Open Surface](#) | [Parking Lot](#) | [Simulation 3D Config](#) | [Straight Road](#) | [US City Block](#) | [US Highway](#) | [Virtual Mcity](#)

Topics

“3D Visualization Engine Requirements”

"Vehicle Dynamics Blockset Communication with 3D Visualization Software"
"Support Package for Customizing Scenes"

US City Block

US city block 3D environment

Setup

The scene contains a US city block with 15 intersections, a camera, and two vehicles.



To simulate a driving maneuver in a curved road 3D environment, in the Simulink window, open the Simulation 3D Config block. Use either of these parameter setting configurations.

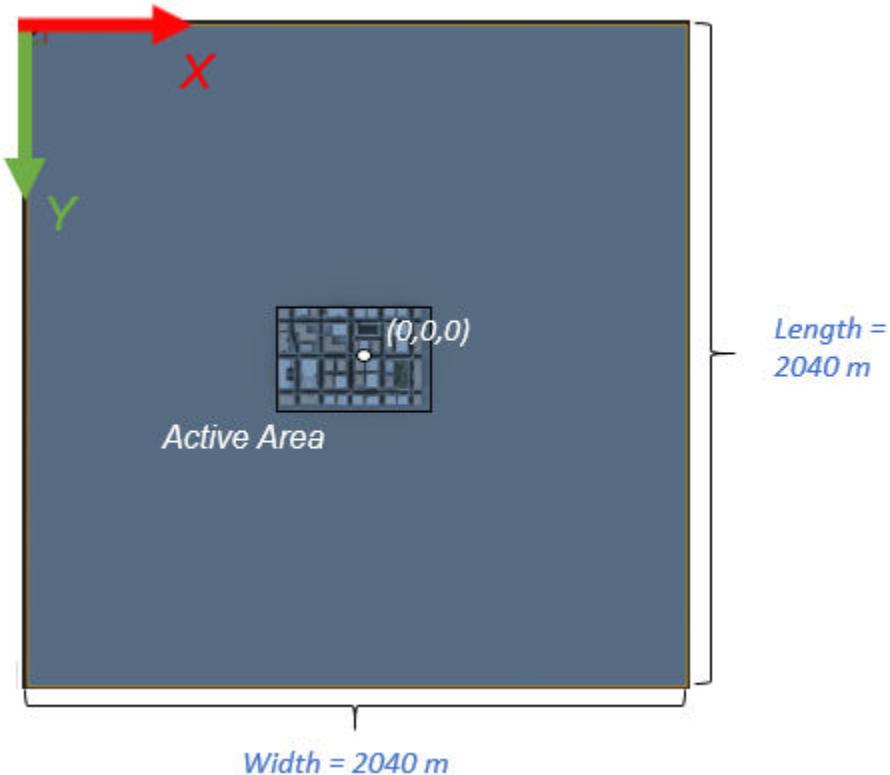
- Set **Scene description** to **US city block**.
- Set **Scene description** to **Custom** and **Project name** to **VehicleSimulation.exe /Game/Maps/USCityBlock**.

Description

The scene contains a US city block with 15 intersections, a camera, and two vehicles.

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.

Locations	X	Y	Z
Scene — Top left	-1020	-1020	0
Scene — Bottom right	1020	1020	0
Active area — Bottom left	-240.77	151.67	0

Recommended Starting Locations

This table provides the names and recommended starting locations in the world coordinate system. Dimensions are in m.

Tag Name	Unreal Engine Editor Name	Recommended Starting Location					
		X	Y	Z	Roll	Pitch	Yaw
Simulink Vehicle1	Sim3dPas sVeh1	-125.19	1.65	-0.04	0	0	0
Simulink Vehicle2	Sim3dPas sVeh2	-125.19	1.65	-0.04	0	0	0

Camera

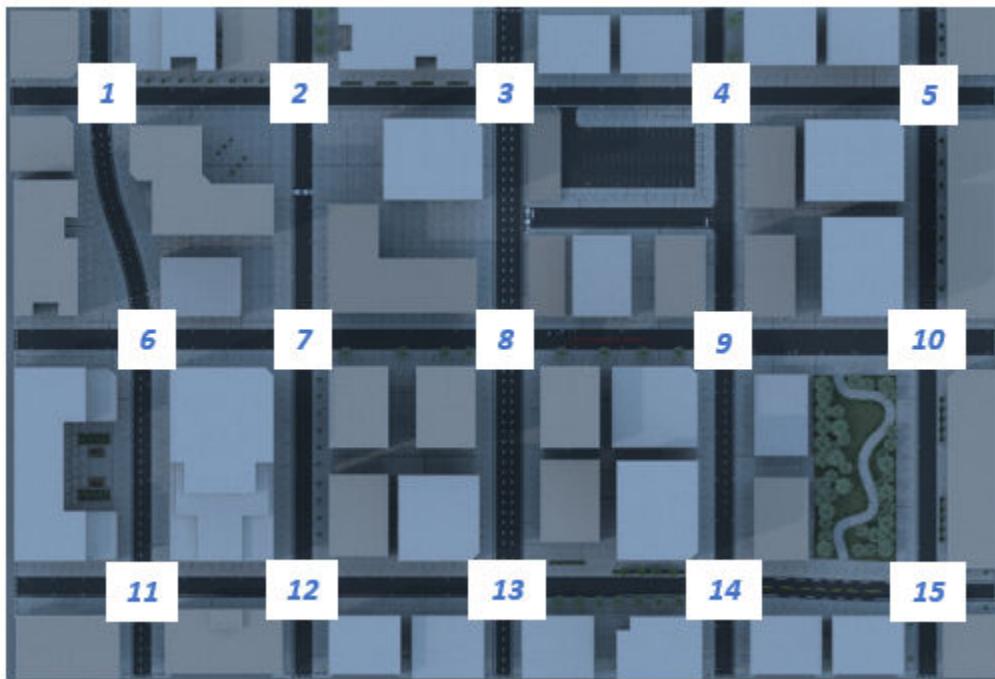
This table provides the scene capture camera name and Unreal Engine editor parent. The parent is the object to which the camera is attached.

Tag Name	Unreal Engine Editor Name	Unreal Engine Editor Parent
Camera0	Sim3dSceneCap1	World (root)

Intersections

The US city block scene has 15 intersections, as indicated in this diagram.

8 Shipping Scenes — Alphabetical List

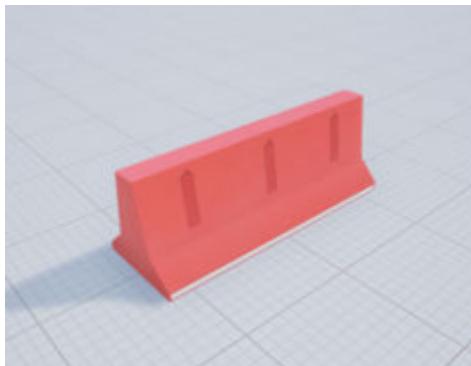


This table provides the intersection locations in the world coordinate system. Dimensions are in m.

Intersection	Center Location		
	X	Y	Z
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

Intersection	Center Location		
	X	Y	Z
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
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°

8 Shipping Scenes — Alphabetical List

Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
	SM_Barrie_r2	166.35	-146.95	0	0	0	90°
	SM_Barrie_r3	169.2	-146.95	0	0	0	90°
	SM_Barrie_r7	163.5	150.15	0	0	0	90°
	SM_Barrie_r8	166.35	150.15	0	0	0	90°
	SM_Barrie_r9	169.2	150.15	0	0	0	90°
	SM_Barrie_r11	197.05	109.65	0	0	0	-180°
	SM_Barrie_r13	197.05	112.5	0	0	0	-180°
	SM_Barrie_r14	197.05	115.34	0	0	0	-180°
	SM_Barrie_r18	197.05	-2.9	0	0	0	-180°
	SM_Barrie_r19	197.05	-0.05	0	0	0	-180°
	SM_Barrie_r20	197.05	2.8	0	0	0	-180°
	SM_Barrie_r21	-240.5	107.65	0	0	0	-180°
	SM_Barrie_r22	197.05	-110.9	0	0	0	-180°
	SM_Barrie_r24	197.05	5.6	0	0	0	-180°
	SM_Barrie_r27	197.05	-108.05	0	0	0	-180°

Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
SM_Barrie r28	SM_Barrie r28	197.05	-105.25	0	0	0	-180°
	SM_Barrie r31	-240.5	110.5	0	0	0	-180°
	SM_Barrie r32	-240.5	113.35	0	0	0	-180°
	SM_Barrie r36	-240.1	-2.9	0	0	0	-180°
	SM_Barrie r37	-240.1	-0.05	0	0	0	-180°
	SM_Barrie r38	-240.1	2.8	0	0	0	-180°
	SM_Barrie r43	-242.15	110.9	0	0	0	-180°
	SM_Barrie r44	-242.15	-108.05	0	0	0	-180°
	SM_Barrie r45	-242.15	-105.25	0	0	0	-180°
	SM_Barrie r48	73.4	150.15	0	0	0	90°
	SM_Barrie r49	76.25	150.15	0	0	0	90°
	SM_Barrie r50	79.1	150.15	0	0	0	90°
	SM_Barrie r54	-25.55	150.15	0	0	0	90°
	SM_Barrie r55	-22.7	150.15	0	0	0	90°
	SM_Barrie r56	-19.85	150.15	0	0	0	90°

8 Shipping Scenes — Alphabetical List

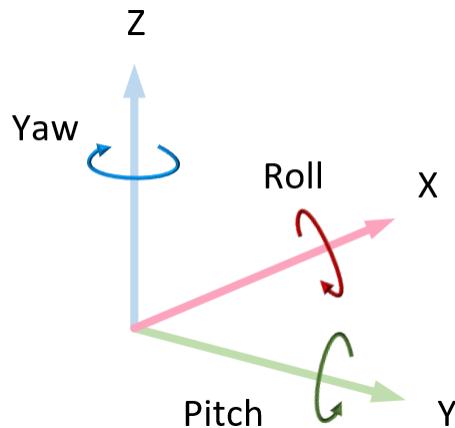
Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
SM_Barrie r59	SM_Barrie r59	-115.3	150.15	0	0	0	90°
	SM_Barrie r60	-112.45	150.15	0	0	0	90°
	SM_Barrie r61	-109.6	150.15	0	0	0	90°
	SM_Barrie r66	69.25	-147.35	0	0	0	90°
	SM_Barrie r68	75.45	-147.5	0.15	0	0	90°
	SM_Barrie r69	72.45	-147.5	0.15	0	0	90°
	SM_Barrie r70	-25.55	-146.45	0	0	0	90°
	SM_Barrie r71	-22.15	-146.45	0	0	0	90°
	SM_Barrie r72	-18.65	-146.45	0	0	0	90°
	SM_Barrie r75	-115.3	-147.6	0	0	0	90°
	SM_Barrie r76	-112.45	-147.6	0	0	0	90°
	SM_Barrie r77	-109.6	-147.6	0	0	0	90°
	SM_Barrie r84	-15.45	-146.45	0	0	0	90°
	SM_Barrie r88	-187.5	150.15	0	0	0	90°
	SM_Barrie r89	-184.65	150.15	0	0	0	90°

Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
SM_Barrie	r90	-181.8	150.15	0	0	0	90°
	r94	-205.6	-147.4	0	0	0	90°
	r95	-202.75	-147.4	0	0	0	90°
	r96	-199.9	-147.4	0	0	0	90°
	r101	44.15	3.05	0	0	0	-50°
	r102	39.15	0.55	0	0	0	-90°
	r103	41.95	1.3	0	0	0	-50°
	r104	36.5	.55	0	0	0	-90°
	r105	33.85	.55	0	0	0	-90°
	r106	31.2	.55	0	0	0	-90°
	r107	28.45	.55	0	0	0	-90°
	r108	25.8	.55	0	0	0	-90°
	r109	23.15	.55	0	0	0	-90°
	r110	20.5	.55	0	0	0	-90°
	r111	17.95	.55	0	0	0	-90°

Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
	SM_Barrie_r112	15.3	.55	0	0	0	-90°
	SM_Barrie_r113	12.65	.55	0	0	0	-90°
	SM_Barrie_r114	10.0	.55	0	0	0	-90°
	SM_Barrie_r115	7.01	1.38	0	0	0	-125°
	SM_Barrie_r116	4.75	3.05	0	0	0	-125°

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

See Also

[Curved Road](#) | [Double Lane Change](#) | [Large Parking Lot](#) | [Open Surface](#) | [Parking Lot](#) | [Simulation 3D Config](#) | [Straight Road](#) | [US Highway](#) | [Virtual Mcity](#)

Topics

“3D Visualization Engine Requirements”

“Vehicle Dynamics Blockset Communication with 3D Visualization Software”

“Support Package for Customizing Scenes”

US Highway

US highway 3D environment

Setup

The scene contains a US highway, a camera, cones, traffic signs, and two vehicles.



To simulate a driving maneuver in a highway 3D environment, in the Simulink window, open the Simulation 3D Config block. Use either of these parameter setting configurations.

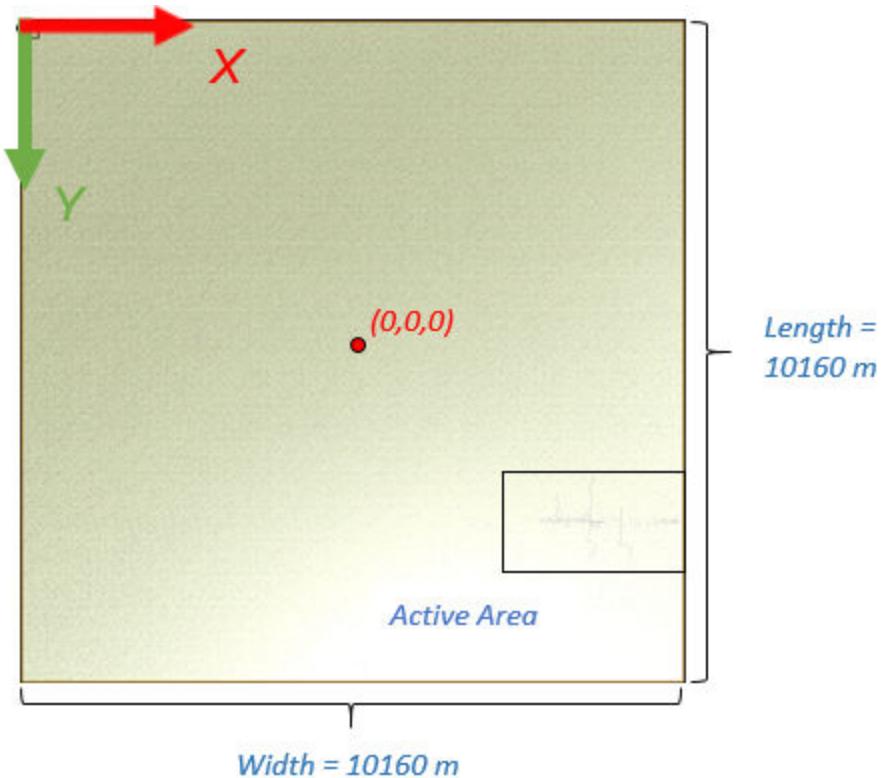
- Set **Scene description** to US highway.
- Set **Scene description** to Custom and **Project name** to VehicleSimulation.exe /Game/Maps/USHighway.

Description

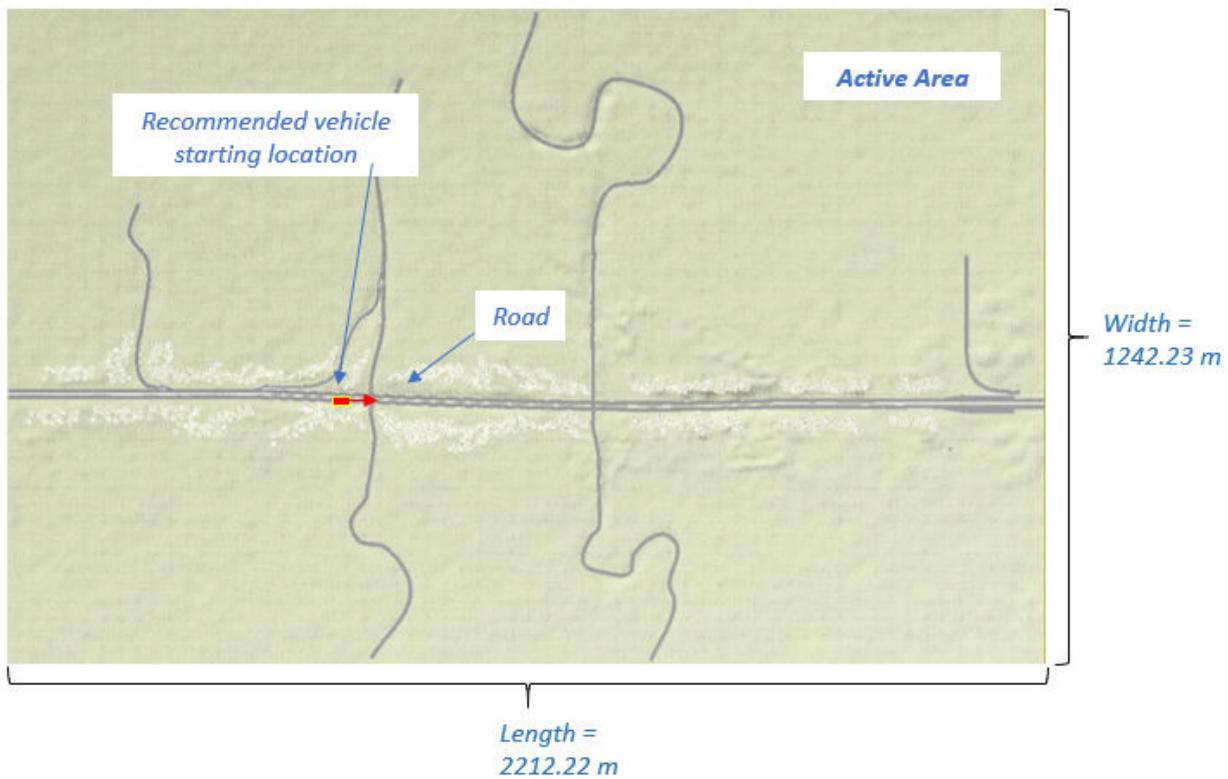
The scene contains a US highway, a camera, cones, traffic signs, and two vehicles.

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	-5080	-5080	1
Scene — Bottom right	5080	5080	1
Active area — Bottom left	2867.41	3169.93	1

Recommended Starting Locations

This table provides the names and recommended starting locations in the world coordinate system. Dimensions are in m.

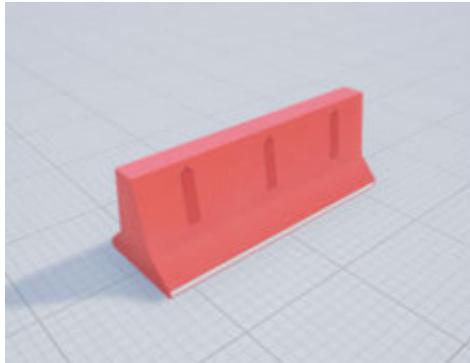
Tag Name	Unreal Engine Editor Name	Recommended Starting Location					
		X	Y	Z	Roll	Pitch	Yaw
Simulin kVehicel1	Sim3dPass Veh1	3592.00	2617.00	-1	0	0	0
Simulin kVehicel2	Sim3dPass Veh2	3592.00	2617.00	-1	0	0	0

Camera

This table provides the scene capture camera name and Unreal Engine editor parent. The parent is the object to which the camera is attached.

Tag Name	Unreal Engine Editor Name	Unreal Engine Editor Parent
Camera0	Sim3dSceneCap1	World (root)

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_Barrie_r26	2866.45	2612.1	1	0	0	0
	SM_Barrie_r27	2866.45	2609.35	1			
	SM_Barrie_r28	2866.45	2606.6	1			
	SM_Barrie_r29	2866.45	2603.95	1			
	SM_Barrie_r30	2866.45	2599.7	1			
	SM_Barrie_r31	2866.45	2596.95	1			
	SM_Barrie_r32	2866.45	2594.2	1			
	SM_Barrie_r33	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	Y	Z	Roll	Pitch	Yaw
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

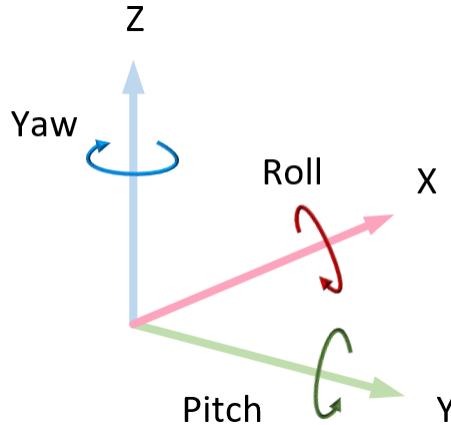


This table provides the traffic sign tag names and locations in the world coordinate system. Dimensions are in m.

Object	Unreal Engine Editor Name	Location					
		X	Y	Z	Roll	Pitch	Yaw
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°
	ChevronAlignmentSign_2	3149.10	2579.45	1	0	0	-85°
	ChevronAlignmentSign_3	3144.15	2571.95	1	0	0	-85°
	ChevronAlignmentSign_4	3139.45	2562.60	1	0	0	-85°

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

See Also

[Curved Road](#) | [Double Lane Change](#) | [Large Parking Lot](#) | [Open Surface](#) | [Parking Lot](#) | [Simulation 3D Config](#) | [Straight Road](#) | [US City Block](#) | [Virtual Mcity](#)

Topics

“3D Visualization Engine Requirements”
 “Vehicle Dynamics Blockset Communication with 3D Visualization Software”
 “Support Package for Customizing Scenes”

Virtual Mcity

Virtual Mcity 3D environment

Setup

The scene contains the virtual Mcity® 3D environment, a camera, vehicles, cones, barriers, an animal, traffic lights, and traffic signs.



To simulate a driving maneuver in a curved road 3D environment, in the Simulink window, open the Simulation 3D Config block. Use either of these parameter setting configurations.

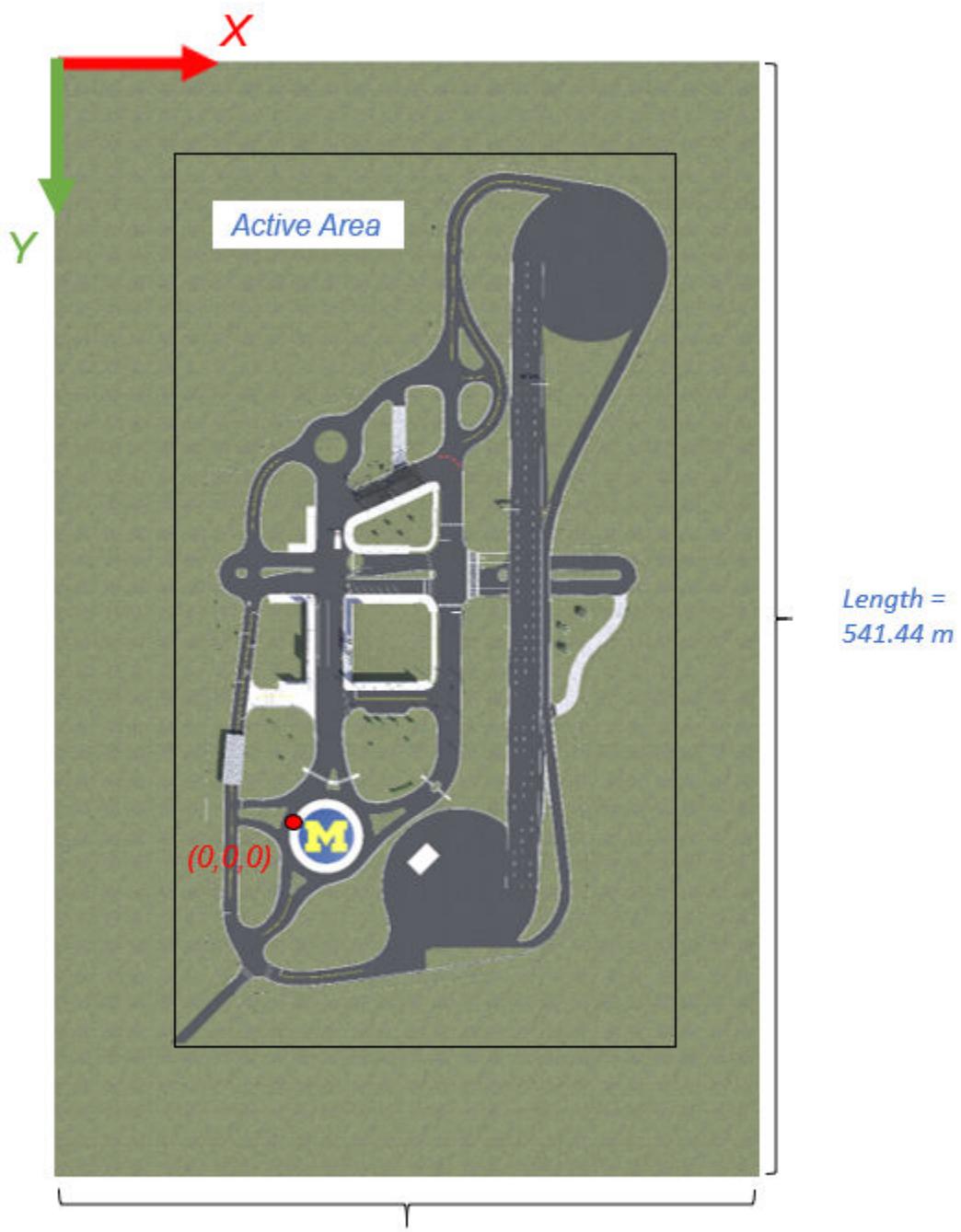
- Set **Scene description** to Virtual Mcity.
- Set **Scene description** to Custom and **Project name** to VehicleSimulation.exe /Game/Maps/VirtualMCity.

Description

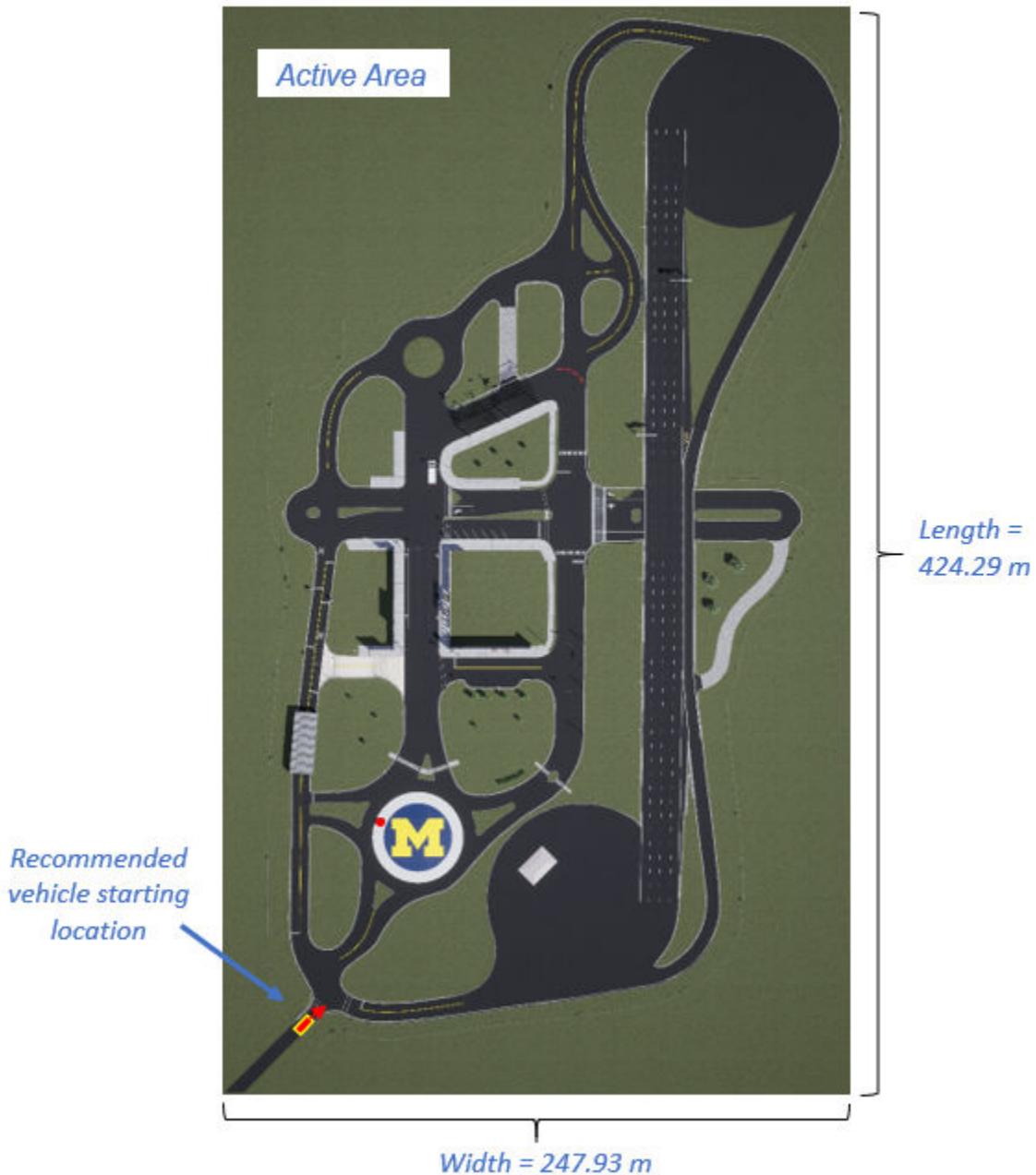
The scene contains the virtual Mcity 3D environment, a camera, vehicles, cones, barriers, an animal, traffic lights, and traffic signs.

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 names and recommended starting locations in the world coordinate system. Dimensions are in m and deg.

Tag Name	Unreal Engine Editor Name	Recommended Starting Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
Simulink Vehicle1	Sim3dPas sVeh1	-26.00	76.0	0	0	0	-40
Simulink Vehicle2	Sim3dPas sVeh2	-26.00	76.0	0	0	0	-40

Camera

This table provides the scene capture camera name and Unreal Engine editor parent. The parent is the object to which the camera is attached.

Tag Name	Unreal Engine Editor Name	Unreal Engine Editor Parent
Camera0	Sim3dSceneCap1	World (root)

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.

8 Shipping Scenes — Alphabetical List

Object	Unreal Engine Editor Name	Locations					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (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

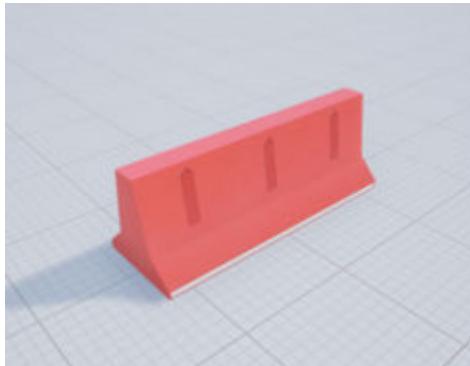


This table provides the object names and locations in the world coordinate system. Dimensions are in m and deg.

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

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
	SM_Cone 3	20.03	-131.51	0	0	0	0
	SM_Cone 4	18.93	-131.51	0	0	0	0

Barrier



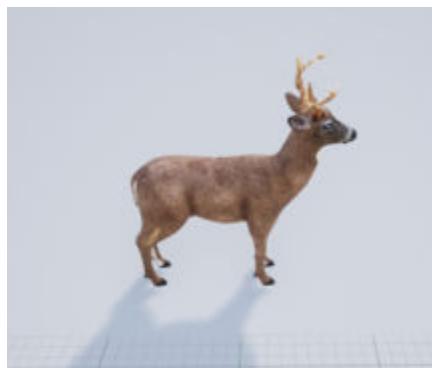
This table provides the object names and locations in the world coordinate system. Dimensions are in m and deg.

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

8 Shipping Scenes — Alphabetical List

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
	SM_Barri er16	71.18	-177.64	0	0	0	-95

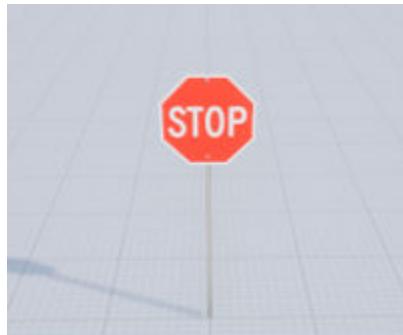
Animals



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
	LargeDoubleArrowSign4	-35.19	-4.39	0	0	0	-90
	LargeDoubleArrowSign	-31.01	-60.55	0	0	0	-80
	Railroad Sign2	-27.06	-88.67	0	0	0	5
	Railroad Sign	-17.79	-89.77	0	0	0	-170

8 Shipping Scenes — Alphabetical List

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
	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

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
	SM_Large_Exit_Sign2	101.79	-151.66	0	0	0	180
	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
	SchoolBusesOnlySign	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_CrossSignals5	72.42	-12.06	0	0	0	40

8 Shipping Scenes — Alphabetical List

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
	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

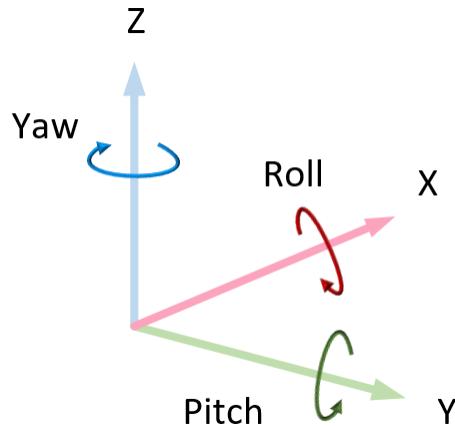
8 Shipping Scenes — Alphabetical List

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
	SM_TrafficLights_SideOnly5	9.24	-67.70	.16	0	0	85
	SM_TrafficLights_SideOnly6	24.50	-67.82	.16	0	0	85
	SM_TrafficLights_3	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
	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

Object	Unreal Engine Editor Name	Location					
		X (m)	Y (m)	Z (m)	Roll (deg)	Pitch (deg)	Yaw (deg)
	SM_HangingTrafficLightSingle7	75.07	-51.25	7.95	0	0	-180
	SM_HangingTrafficLight	-24.78	-61.49	6.71	0	0	100
	SM_RailroadCrossing4	-18.21	-86.63	.01	0	0	8
	SM_RailroadCrossing5	-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

See Also

[Curved Road](#) | [Double Lane Change](#) | [Large Parking Lot](#) | [Open Surface](#) | [Parking Lot](#) | Simulation 3D Config | [Straight Road](#) | [US City Block](#) | [US Highway](#)

Topics

“3D Visualization Engine Requirements”
“Vehicle Dynamics Blockset Communication with 3D Visualization Software”
“Support Package for Customizing Scenes”

External Websites

Mcity Test Facility

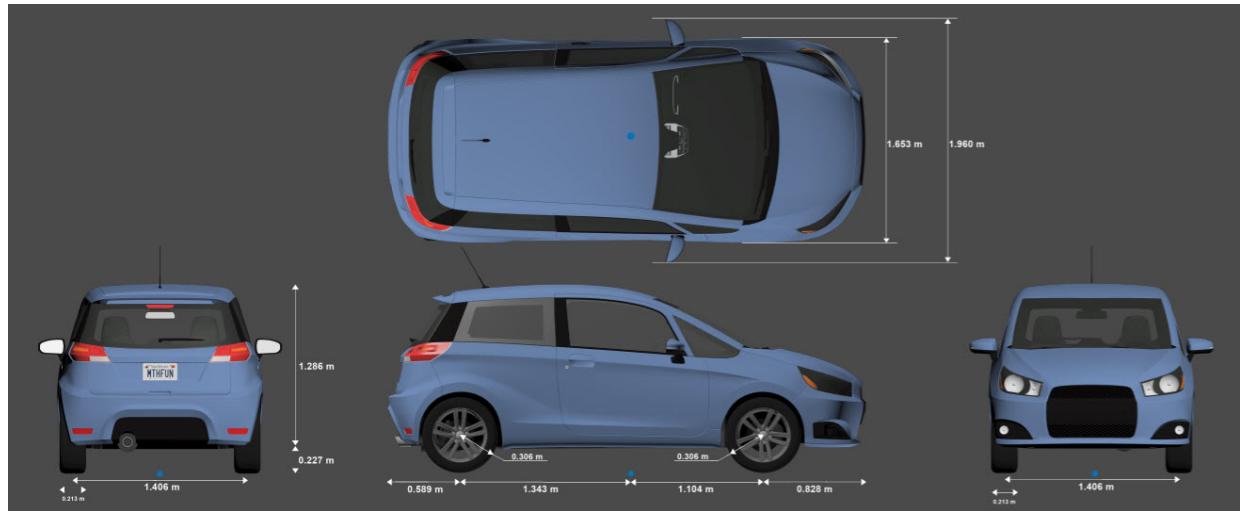
Vehicle Dimensions

Hatchback

Hatchback vehicle dimensions

Description

The diagram provides the vehicle dimensions and the origin of the vehicle dimension coordinate system.



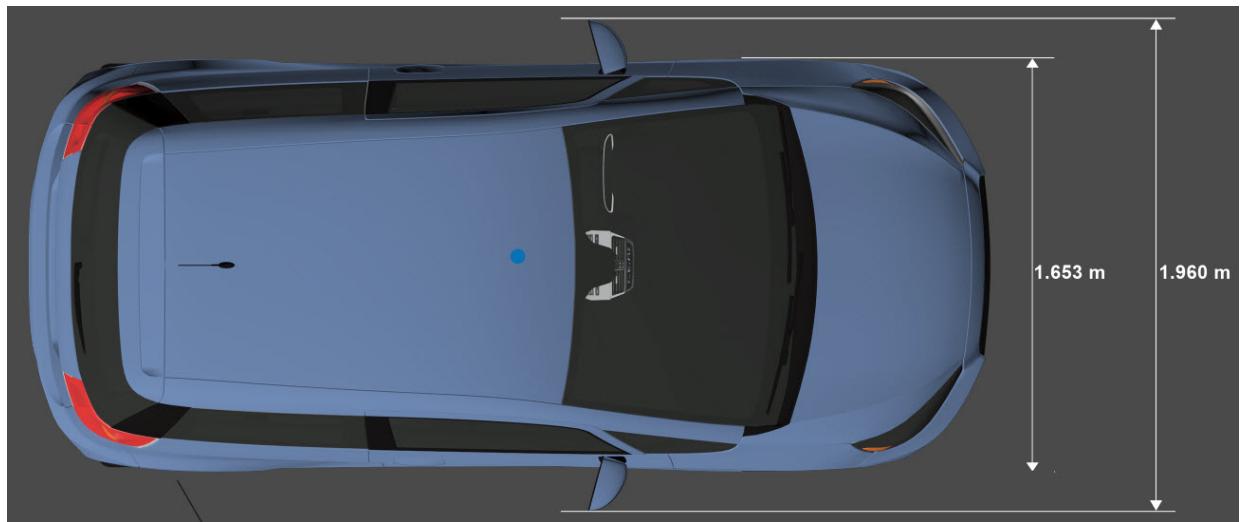
- Reference for vertical dimensions — Vehicle ground plane
- Reference for length and width dimensions — Approximate geometric center

To configure the 3D environment to use the hatchback vehicle, set these Simulation 3D Actor Transform Set block parameters:

- **Actor type** to Passenger vehicle
- **Vehicle type** to Hatchback

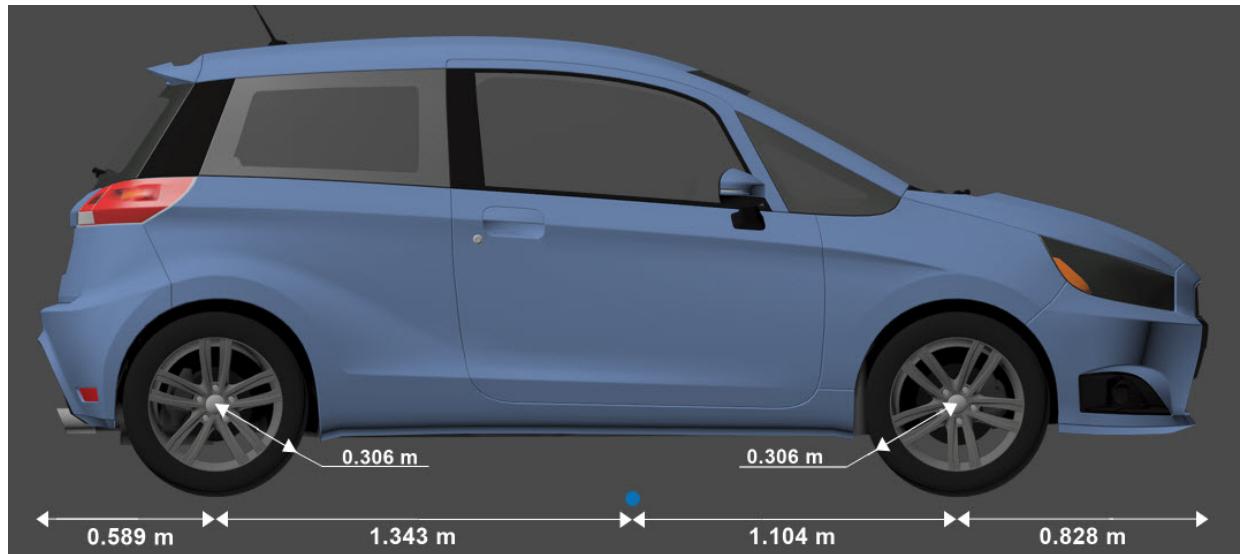
Dimensions

Top — Dimensions
scalar

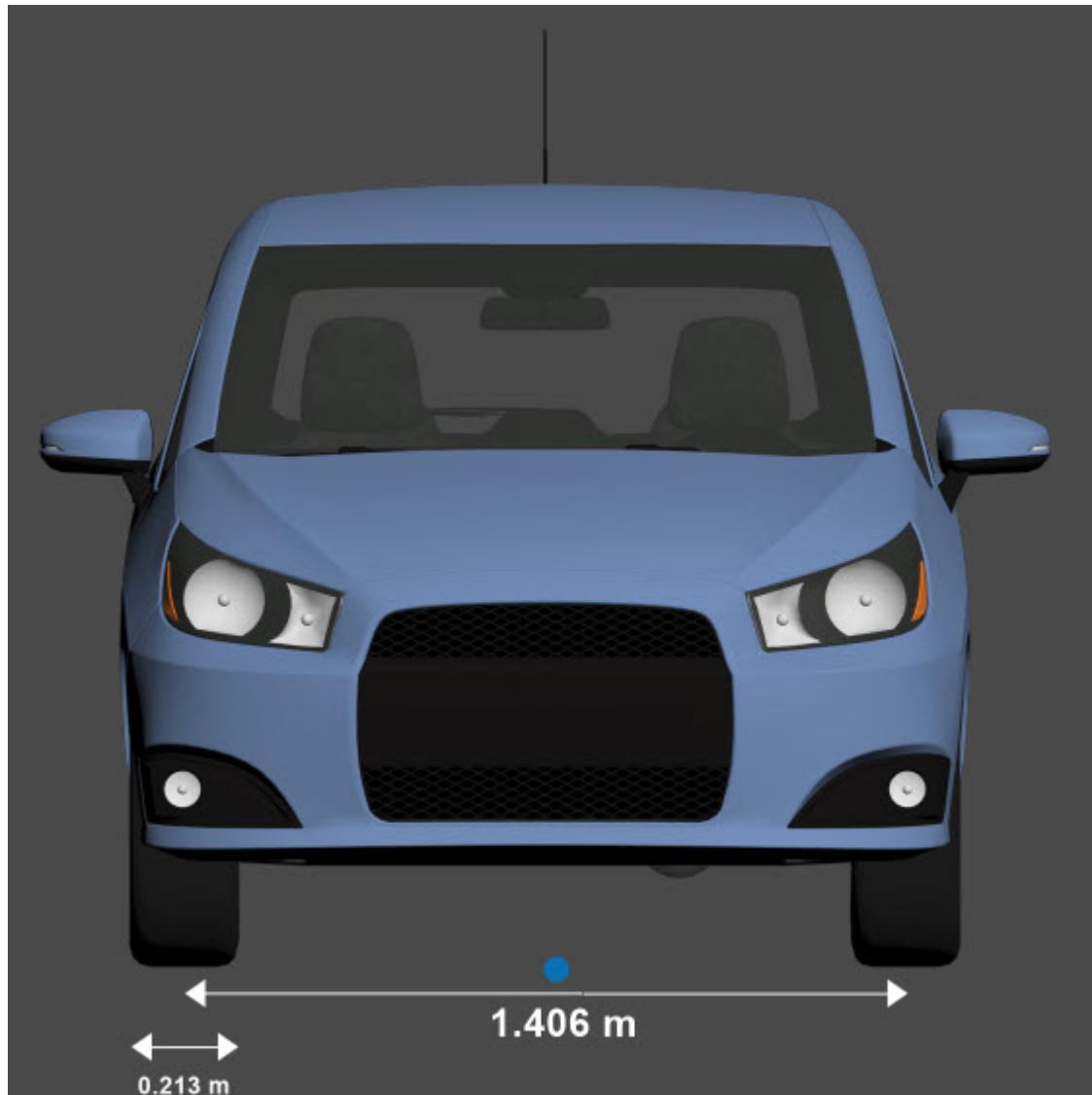


Side — Dimensions
scalar

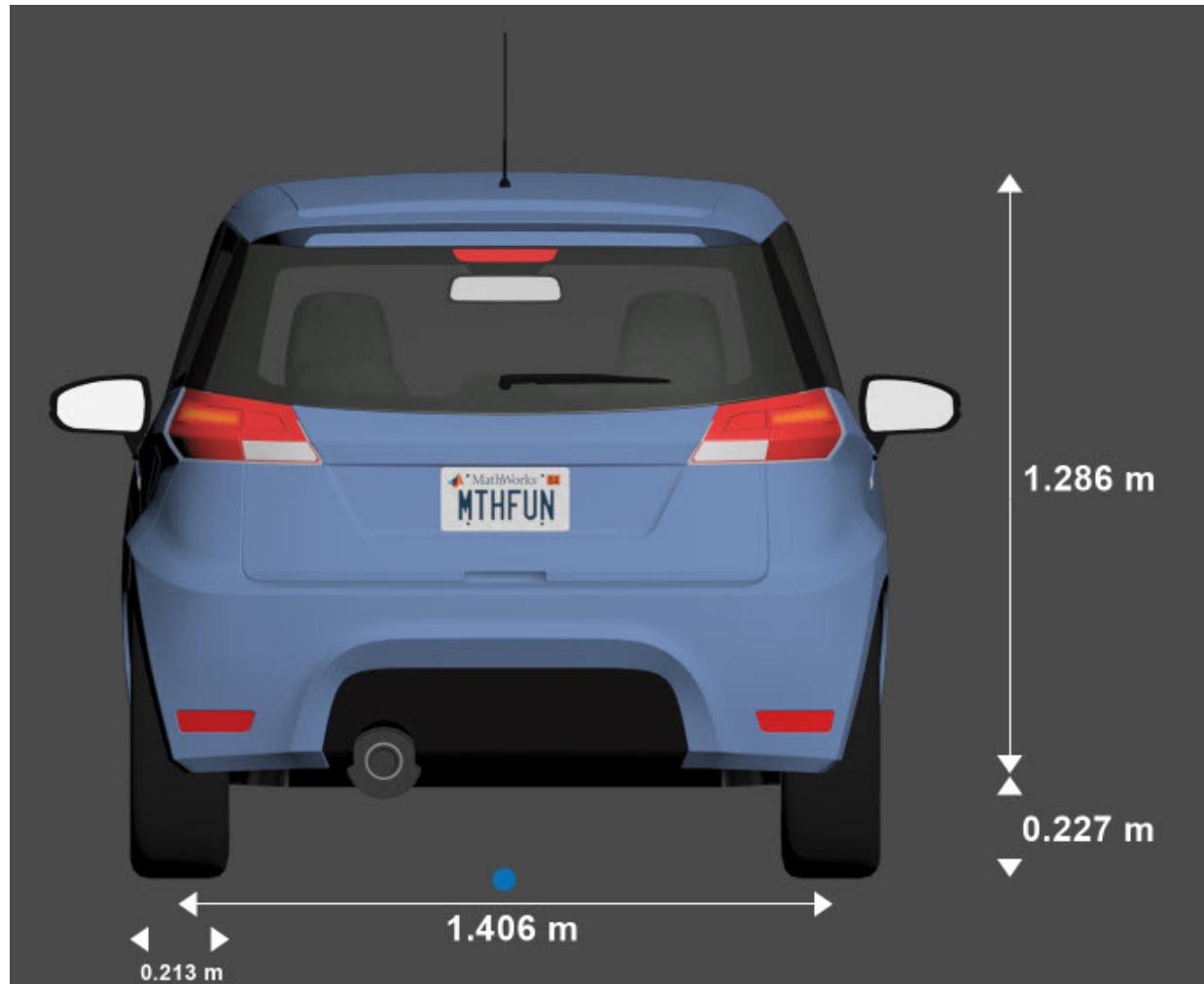
9 Vehicle Dimensions



Front — Dimensions
scalar



Rear — Dimensions
scalar



See Also

[Simulation 3D Actor Transform Set](#) | [Simulation 3D Config](#)

Topics

["Coordinate Systems in Vehicle Dynamics Blockset"](#)

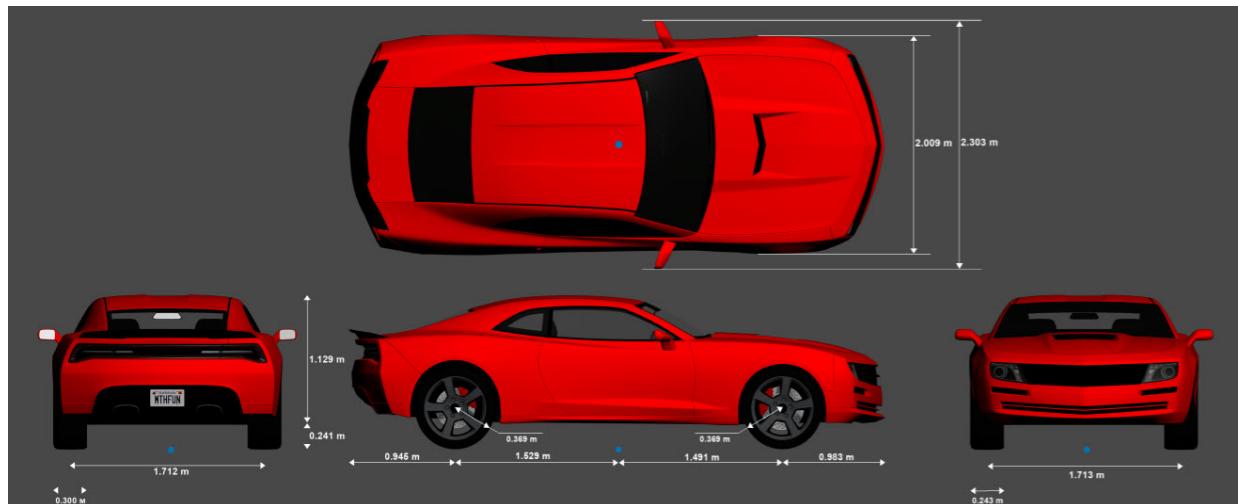
"Vehicle Dynamics Blockset Communication with 3D Visualization Software"

Muscle Car

Muscle car vehicle dimensions

Description

The diagram provides the vehicle dimensions and the origin of the vehicle dimension coordinate system.



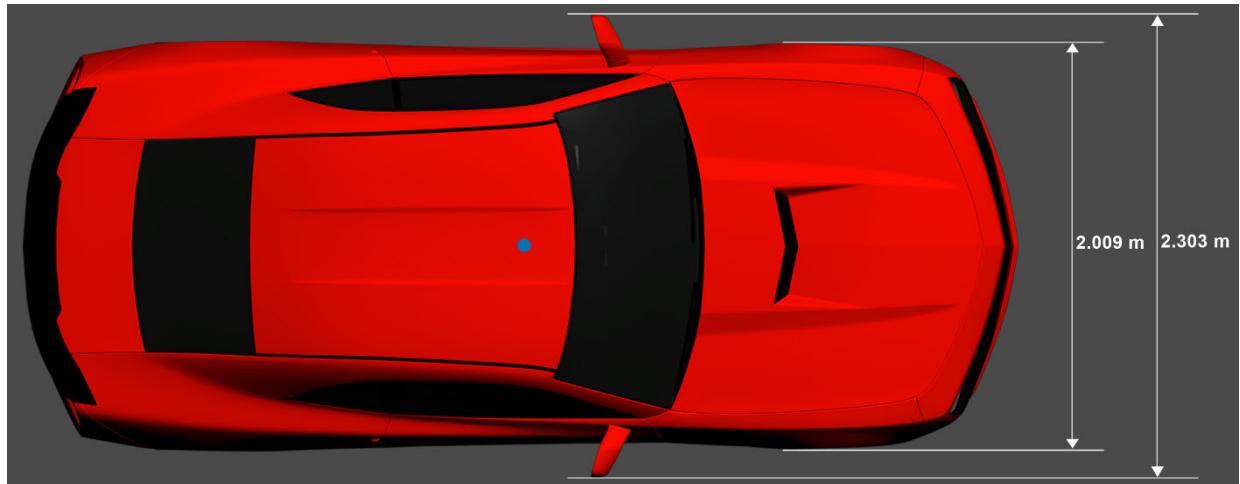
- Reference for vertical dimensions — Vehicle ground plane
- Reference for length and width dimensions — Approximate geometric center

To configure the 3D environment to use the muscle car vehicle, set these Simulation 3D Actor Transform Set block parameters:

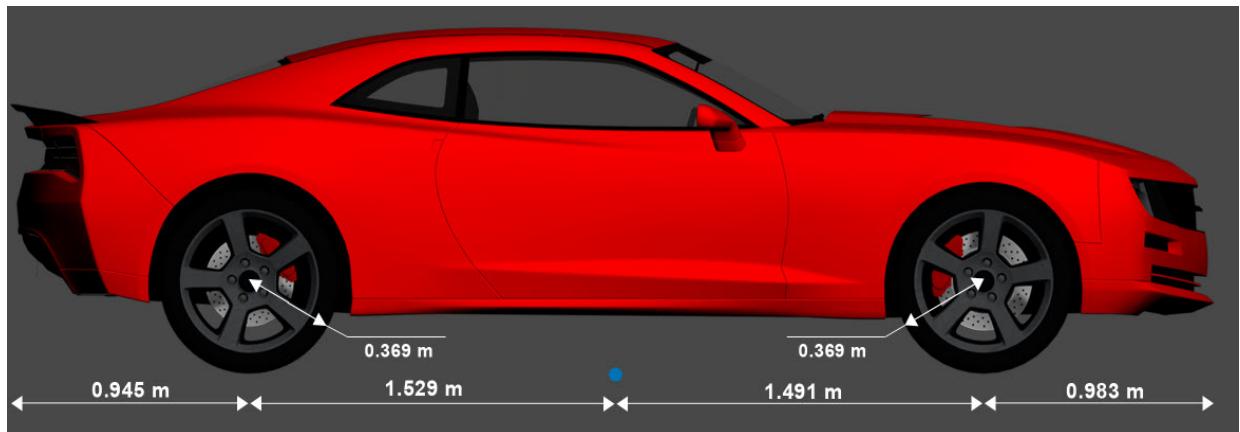
- **Actor type** to Passenger vehicle
- **Vehicle type** to Muscle car

Dimensions

Top — Dimensions
scalar



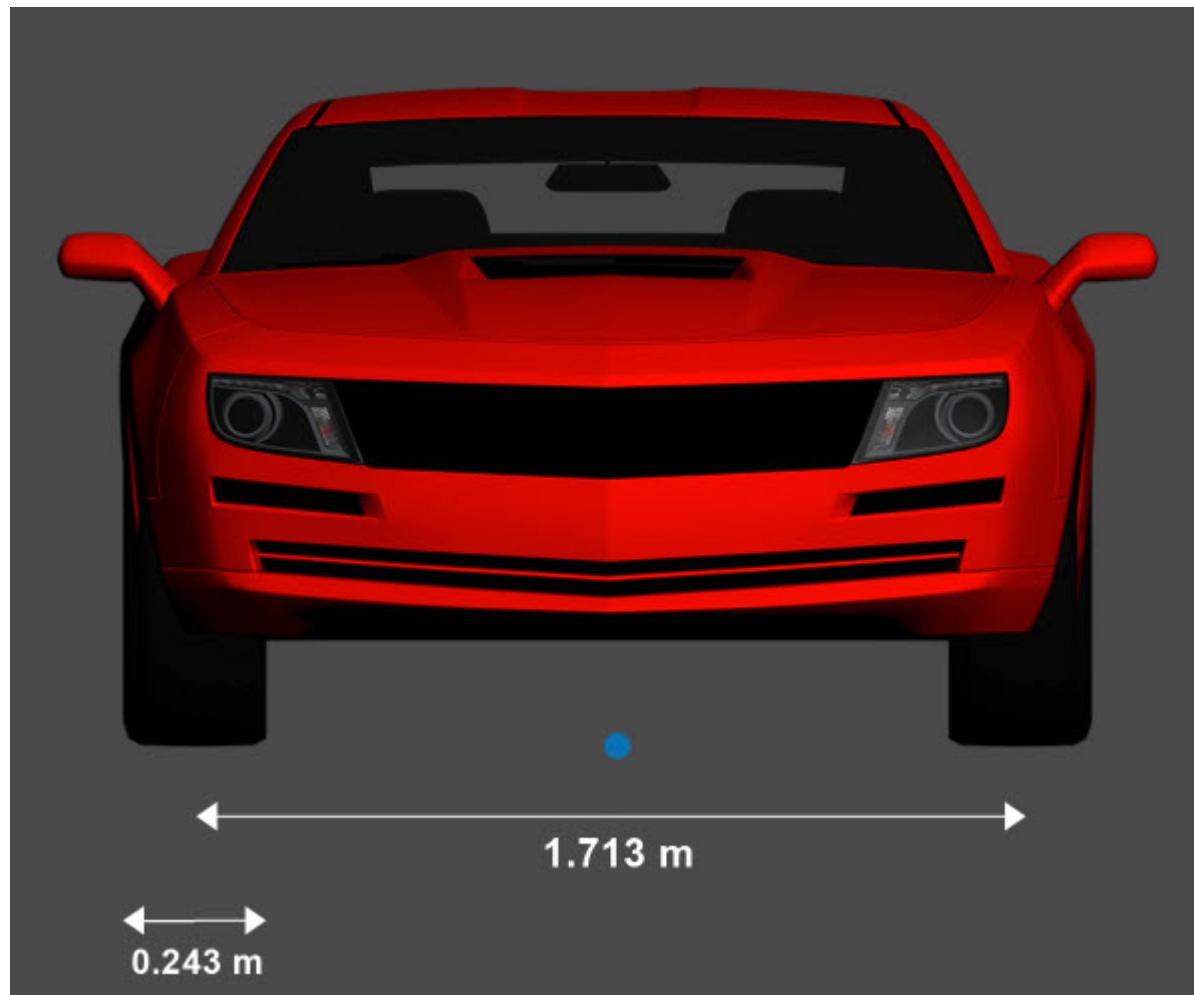
Side — Dimensions
scalar



9 Vehicle Dimensions

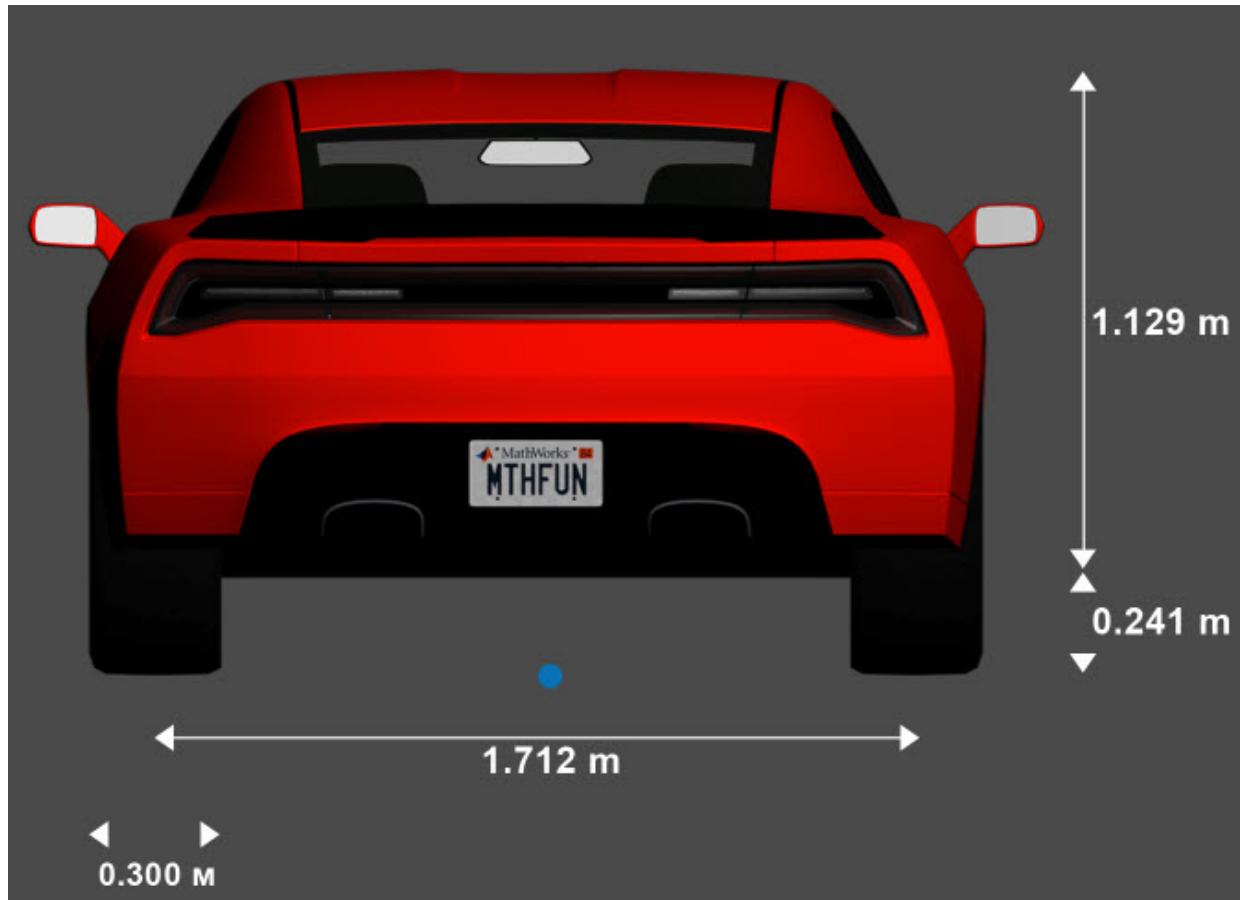
Front — Dimensions

scalar



Rear — Dimensions

scalar



See Also

[Simulation 3D Actor Transform Set](#) | [Simulation 3D Config](#)

Topics

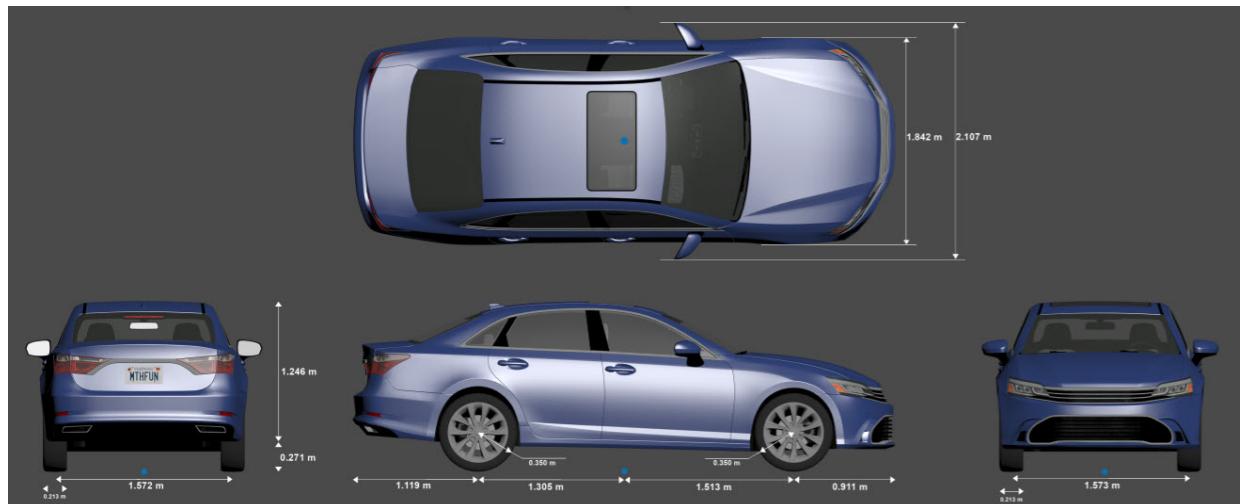
["Coordinate Systems in Vehicle Dynamics Blockset"](#)
["Vehicle Dynamics Blockset Communication with 3D Visualization Software"](#)

Sedan

Sedan vehicle dimensions

Description

The diagram provides the vehicle dimensions and the origin of the vehicle dimension coordinate system.



- Reference for vertical dimensions — Vehicle ground plane
- Reference for length and width dimensions — Approximate geometric center

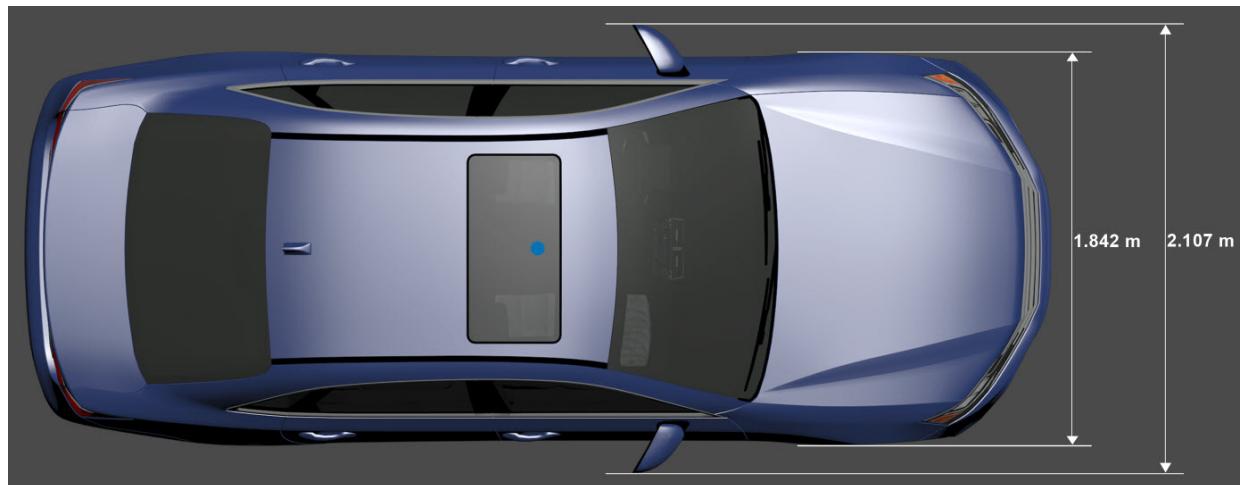
To configure the 3D environment to use the sedan vehicle, set these Simulation 3D Actor Transform Set block parameters:

- **Actor type** to Passenger vehicle
- **Vehicle type** to Sedan

Dimensions

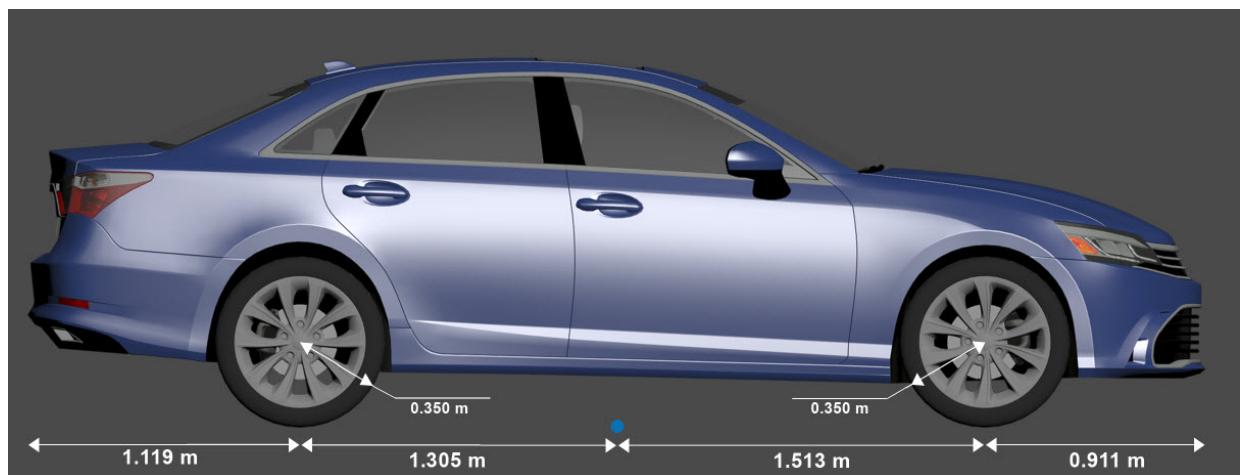
Top — Dimensions

scalar



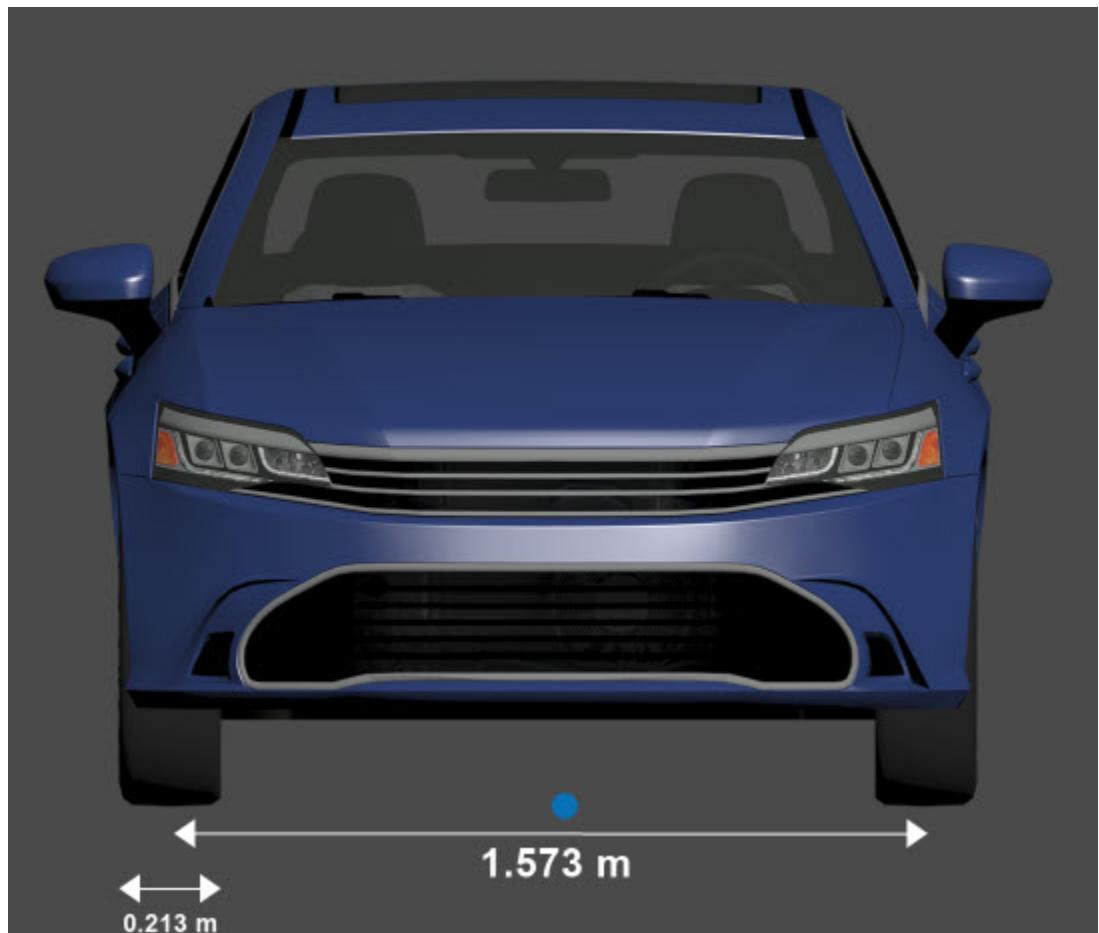
Side — Dimensions

scalar



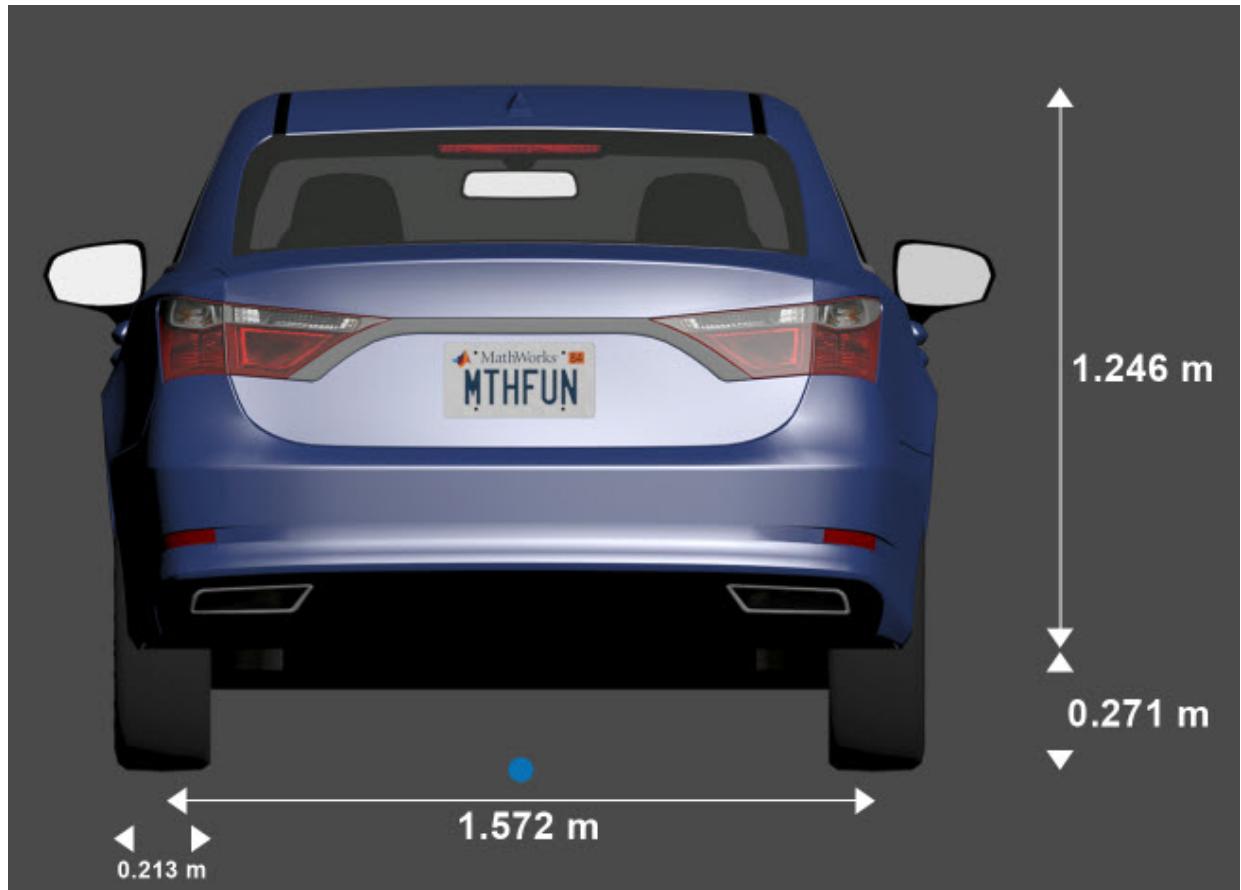
Front — Dimensions

scalar



Rear — Dimensions

scalar



See Also

[Simulation 3D Actor Transform Set](#) | [Simulation 3D Config](#)

Topics

["Coordinate Systems in Vehicle Dynamics Blockset"](#)
["Vehicle Dynamics Blockset Communication with 3D Visualization Software"](#)

Sport Utility Vehicle

Sport utility vehicle dimensions

Description

The diagram provides the vehicle dimensions and the origin of the vehicle dimension coordinate system.



- Reference for vertical dimensions — Vehicle ground plane
- Reference for length and width dimensions — Approximate geometric center

To configure the 3D environment to use the sport utility vehicle (SUV), set these Simulation 3D Actor Transform Set block parameters:

- **Actor type** to Passenger vehicle
- **Vehicle type** to Sport utility vehicle

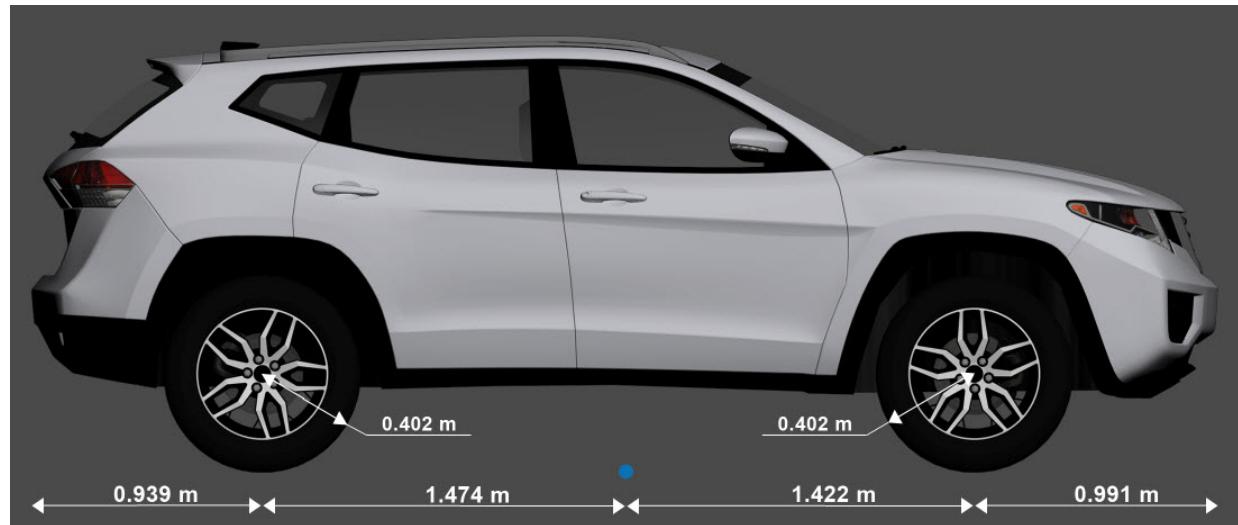
Dimensions

Top — Dimensions
scalar

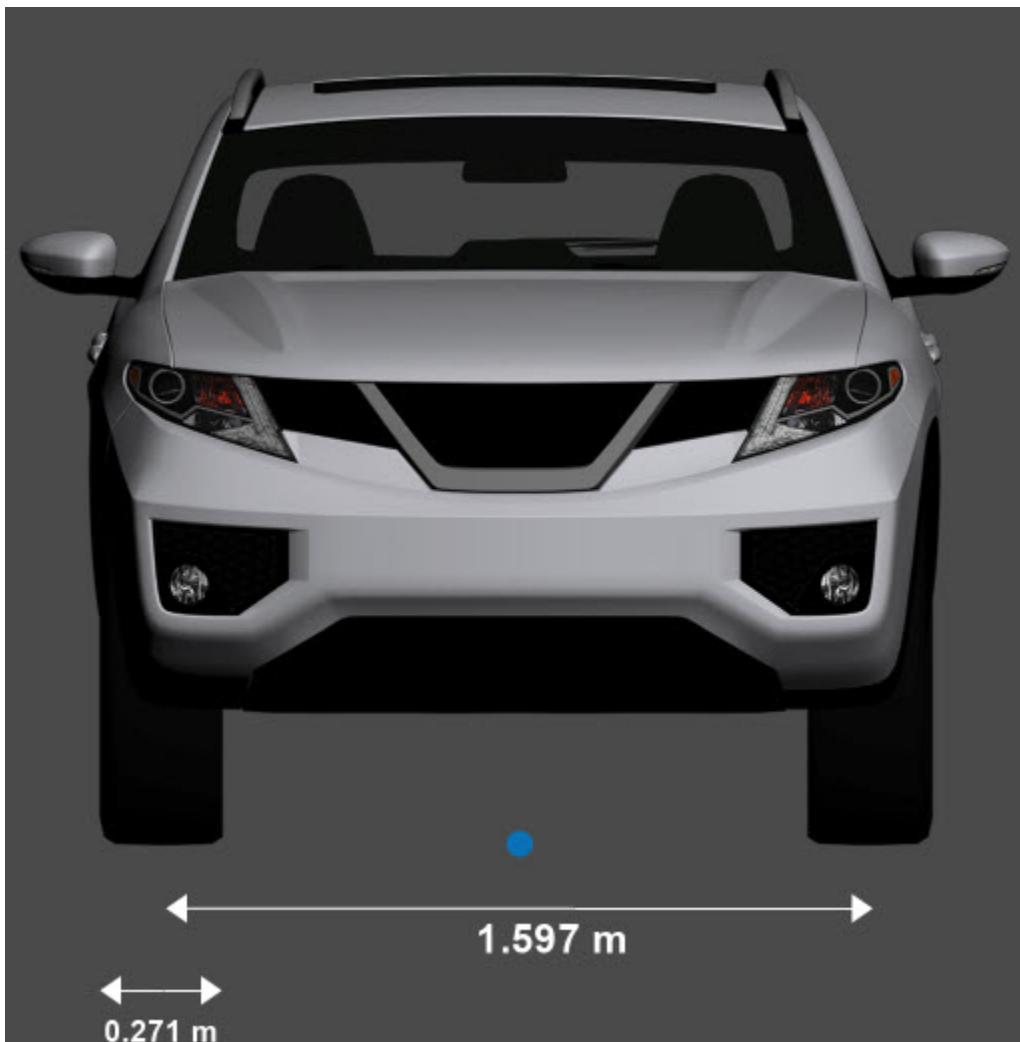


Side — Dimensions
scalar

9 Vehicle Dimensions

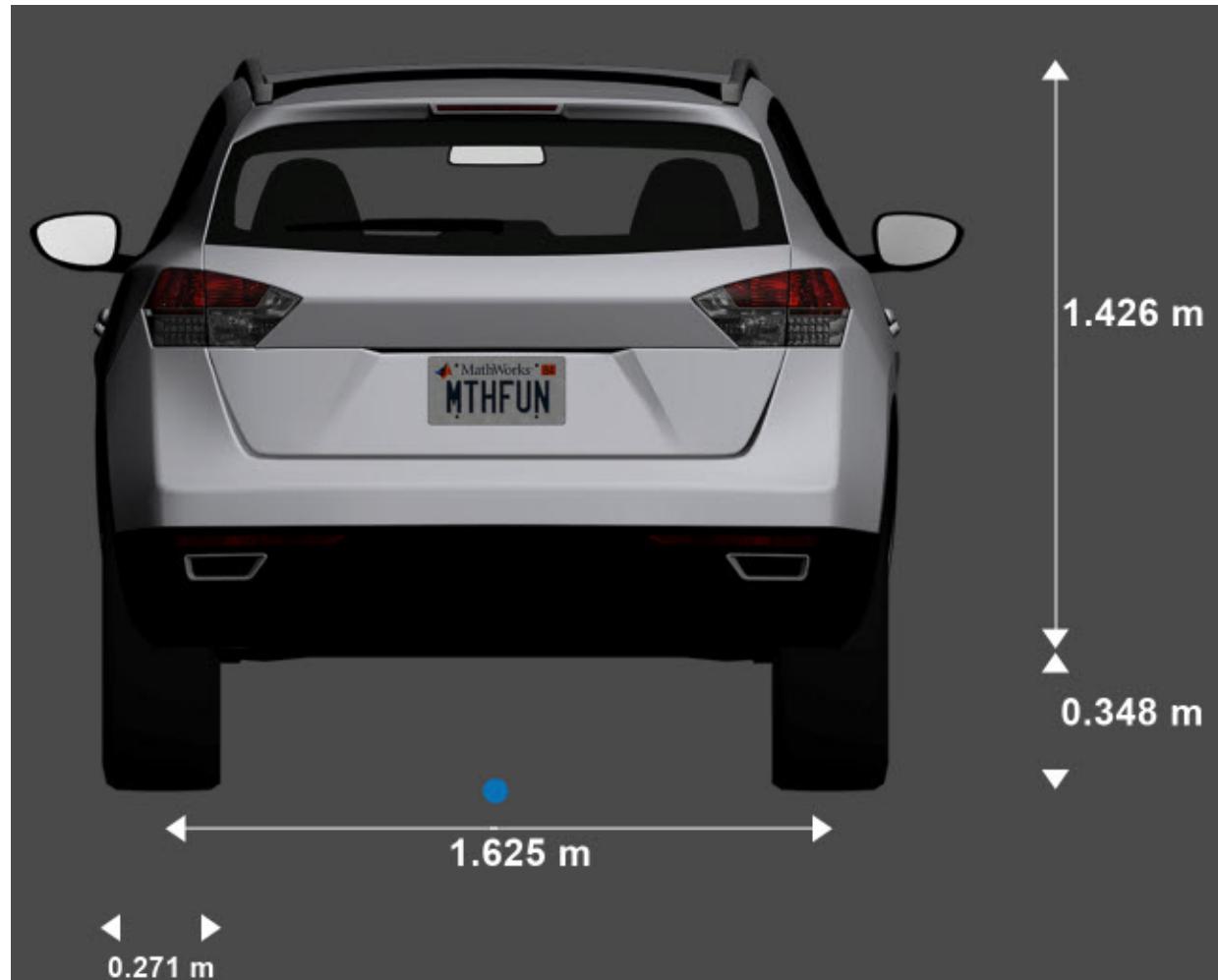


Front — Dimensions
scalar



Rear — Dimensions

scalar



See Also

[Simulation 3D Actor Transform Set](#) | [Simulation 3D Config](#)

Topics

["Coordinate Systems in Vehicle Dynamics Blockset"](#)

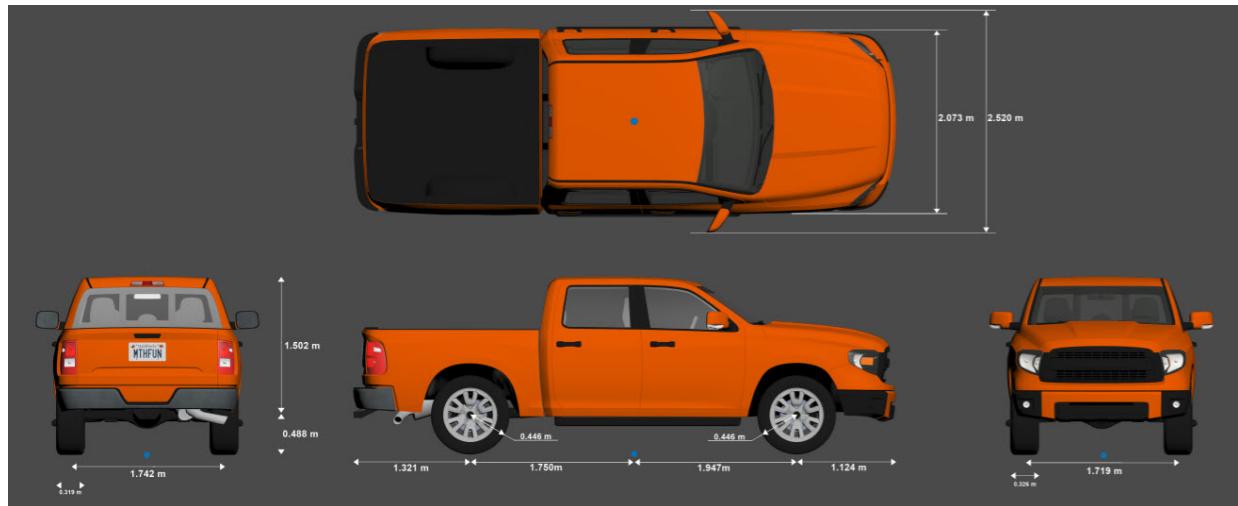
"Vehicle Dynamics Blockset Communication with 3D Visualization Software"

Small Pickup Truck

Small pickup truck vehicle dimensions

Description

The diagram provides the vehicle dimensions.



- Reference for vertical dimensions — Vehicle ground plane
- Reference for length and width dimensions — Approximate geometric center

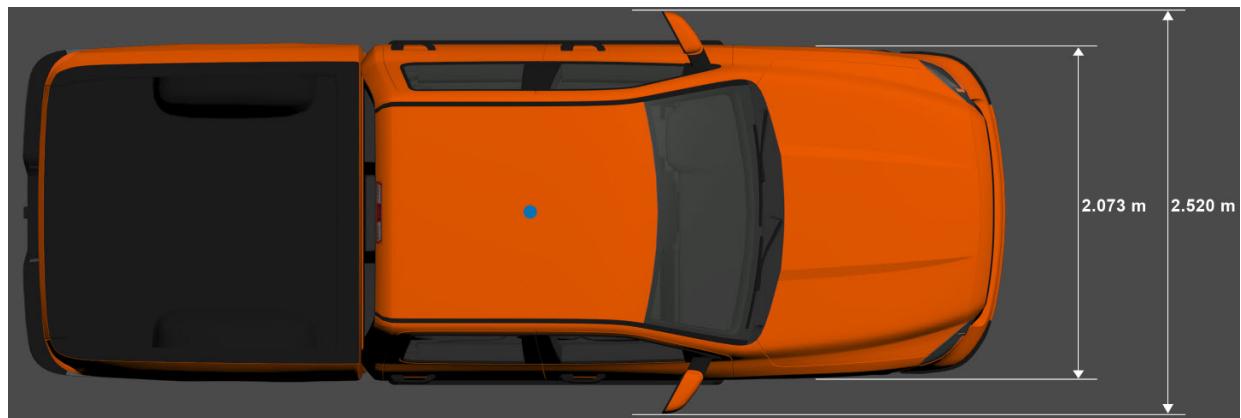
To configure the 3D environment to use the truck vehicle, set these Simulation 3D Actor Transform Set block parameters:

- **Actor type** to Passenger vehicle
- **Vehicle type** to Small pickup truck

Dimensions

Top — Dimensions

scalar



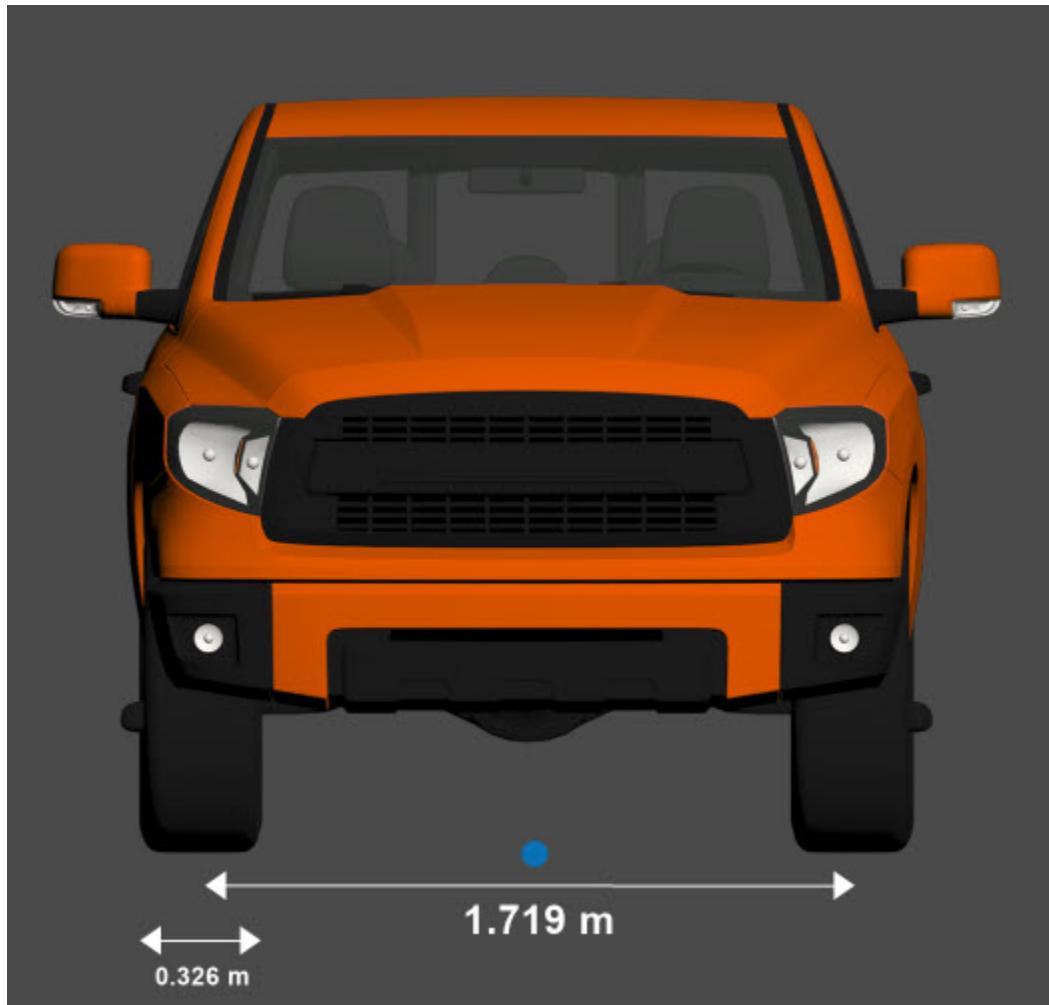
Side — Dimensions

scalar

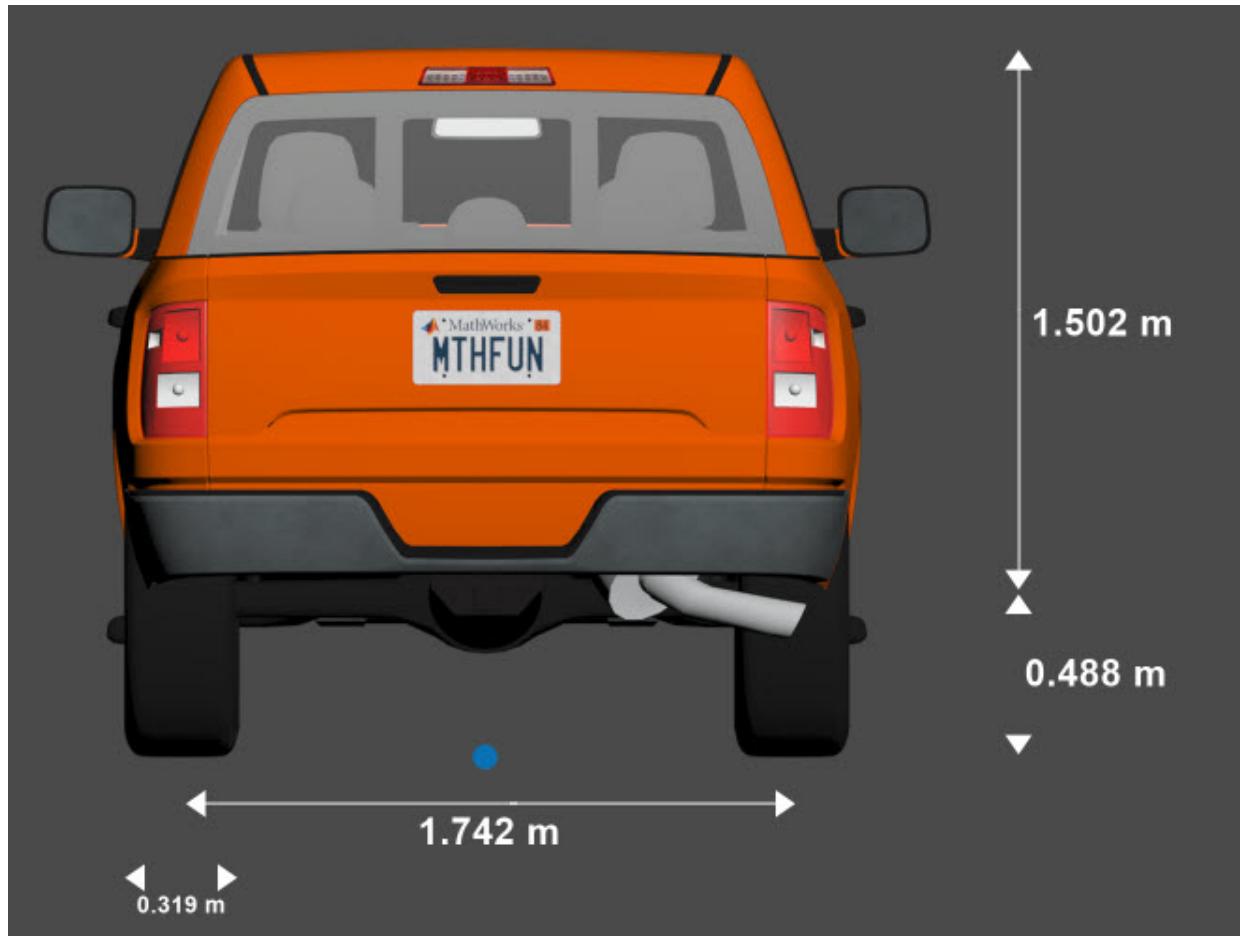


Front — Dimensions

scalar



Rear — Dimensions
scalar



See Also

[Simulation 3D Actor Transform Set](#) | [Simulation 3D Config](#)

Topics

["Coordinate Systems in Vehicle Dynamics Blockset"](#)

["Vehicle Dynamics Blockset Communication with 3D Visualization Software"](#)

Blocks in Reference Applications – Alphabetical List

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** Select **Apply** to modify the initial vehicle position parameters.
- 3** 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 | Custom

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 earth-fixed X-axis, in m.

Initial lateral position, Y_o — Initial lateral position

off (default) | on

Initial vehicle CG position along earth-fixed Y-axis, in m.

Initial vertical position, Z_o — Initial vertical position

off (default) | on

Initial vehicle CG position along earth-fixed Z-axis, in m.

Initial roll angle, phi_o – Roll
off (default) | on

Rotation of vehicle-fixed frame about earth-fixed X-axis (roll), in rad.

Initial pitch angle, theta_o – Pitch
off (default) | on

Rotation of vehicle-fixed frame about earth-fixed Y-axis (pitch), in rad.

Initial yaw angle, psi_o – Yaw
off (default) | on

Rotation of vehicle-fixed frame about 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”
“Vehicle Dynamics Blockset Communication with 3D Visualization Software”
“3D Visualization Engine Requirements”

External Websites

Unreal Engine

Introduced in R2019a

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">• Vehicle width — Lane signals for the Visualization subsystem; used for the left and right lane boundaries• Lateral reference data — Lateral reference trajectory as a function of the longitudinal distance• Distance after target speed to begin reference — Start the maneuver at specified distance after the vehicle reaches the target speed

Maneuver Setting	Implementation
Increasing Steer	"Slowly Increasing Steering Maneuver" <ul style="list-style-type: none">• Handwheel rate — Linear rate to increase steering wheel angle• Maximum handwheel angle — Maximum steering wheel angle
Swept Sine	"Swept-Sine Steering Maneuver" <ul style="list-style-type: none">• Steering amplitude — Sinusoidal wave amplitude• Final frequency — Cut off frequency to stop the maneuver
Sine with Dwell	In the test, the vehicle: <ul style="list-style-type: none">• Accelerates until it hits a target velocity.• Maintains the target velocity.• Responds to a sinusoidal with dwell steering command.• Steer frequency — Sinusoidal wave frequency• Steer amplitude — Sinusoidal wave amplitude• Dwell time — Dwell time
Constant Radius	"Constant Radius Maneuver" <ul style="list-style-type: none">• Radius value — Turn radius

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”. 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 Select **Apply** to modify the initial vehicle position parameters.
- 3 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 | Custom

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 earth-fixed X-axis, in m.

Initial lateral position, Y_o — Initial lateral position
off (default) | on

Initial vehicle CG position along earth-fixed Y-axis, in m.

Initial vertical position, Z_o — Initial vertical position
off (default) | on

Initial vehicle CG position along earth-fixed Z-axis, in m.

Initial roll angle, phi_o — Roll
off (default) | on

Rotation of vehicle-fixed frame about earth-fixed X-axis (roll), in rad.

Initial pitch angle, theta_o — Pitch
off (default) | on

Rotation of vehicle-fixed frame about earth-fixed Y-axis (pitch), in rad.

Initial yaw angle, psi_o — Yaw
off (default) | on

Rotation of vehicle-fixed frame about 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”
“Vehicle Dynamics Blockset Communication with 3D Visualization Software”
“3D Visualization Engine Requirements”

External Websites

Unreal Engine

Introduced in R2019a

