ASM Brake Hydraulics

# Reference

For ASM Brake Hydraulics Blockset 2.1.5 and ASM Brake Hydraulics Operator Blockset 2.1.5

Release 2021-A – May 2021

dSPACE

## How to Contact dSPACE


| | |
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## How to Contact dSPACE Support

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- For countries not listed, contact dSPACE GmbH in Paderborn, Germany.
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You can also use the support request form: http://www.dspace.com/go/supportrequest. If you are logged on to mydSPACE, you are automatically identified and do not need to add your contact details manually.

If possible, always provide the relevant dSPACE License ID or the serial number of the CmContainer in your support request.

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dSPACE strongly recommends that you download and install the most recent patches for your current dSPACE installation. Visit http://www.dspace.com/go/patches for software updates and patches.

## Important Notice

# Contents

# About This Reference

**Content**

This reference introduces you to the features provided by the dSPACE ASM Brake Hydraulics Model. It describes the model structure and parts of the model, its physical background, and the data required for parameterization.

**Symbols**

dSPACE user documentation uses the following symbols:

| Symbol | Description |
|---|---|
| ⚠ DANGER | Indicates a hazardous situation that, if not avoided, will result in death or serious injury. |
| ⚠ WARNING | Indicates a hazardous situation that, if not avoided, could result in death or serious injury. |
| ⚠ CAUTION | Indicates a hazardous situation that, if not avoided, could result in minor or moderate injury. |
| NOTICE | Indicates a hazard that, if not avoided, could result in property damage. |
| Note | Indicates important information that you should take into account to avoid malfunctions. |
| Tip | Indicates tips that can make your work easier. |
| | Indicates a link that refers to a definition in the glossary, which you can find at the end of the document unless stated otherwise. |
| | Precedes the document title in a link that refers to another document. |

**Naming conventions**

dSPACE user documentation uses the following naming conventions:

**%name%** Names enclosed in percent signs refer to environment variables for file and path names.

< > Angle brackets contain wildcard characters or placeholders for variable file and path names, etc.

**Special folders**

Some software products use the following special folders:

**Common Program Data folder** A standard folder for application-specific configuration data that is used by all users.

%PROGRAMDATA%\dSPACE\<InstallationGUID>\<ProductName>

or

%PROGRAMDATA%\dSPACE\<ProductName>\<VersionNumber>

**Documents folder** A standard folder for user-specific documents.

%USERPROFILE%\Documents\dSPACE\<ProductName>\
<VersionNumber>

**Local Program Data folder** A standard folder for application-specific configuration data that is used by the current, non-roaming user.

%USERPROFILE%\AppData\Local\dSPACE\<InstallationGUID>\
<ProductName>

**Accessing dSPACE Help and PDF Files**

After you install and decrypt dSPACE software, the documentation for the installed products is available in dSPACE Help and as PDF files.

**dSPACE Help (local)** You can open your local installation of dSPACE Help:

- On its home page via Windows Start Menu
- On specific content using context-sensitive help via **F1**

**dSPACE Help (Web)** You can access the Web version of dSPACE Help at www.dspace.com/go/help.

To access the Web version, you must have a *mydSPACE* account.

**PDF files** You can access PDF files via the icon in dSPACE Help. The PDF opens on the first page.

# Overview of the Brake Hydraulics Library

## Brake Hydraulics Library

**Introduction**

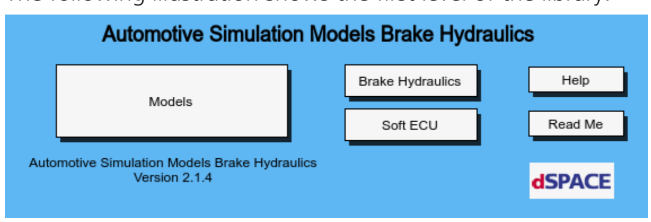
This topic gives you an overview of the ASM Brake Hydraulics Library.

**Opening the library**

You can open the library in MATLAB/Simulink. Refer to How to Open an ASM Library (ASM Vehicle Dynamics Model Description 📖).

**Contents**

The following illustration shows the first level of the library.




The library has three main subsystems.

**Brake Hydraulics** The Brake Hydraulics subsystem contains all the Simulink blocks necessary to model a brake hydraulics system. Refer to Brake Hydraulics on page 11.

**Soft ECU** The Soft ECU subsystem contains all the subsystems that allows you to use the model offline or if a real ECU is not available. Refer to Soft ECU on page 53.

**Models** The ASM Brake Hydraulics Library contains two brake hydraulics models (basic and advanced) and two soft ECU brake models (basic and advanced). Refer to Models on page 75.

**Related topics**

Basics



References

# Brake Hydraulics

**Where to go from here**

Information in this section

# Valves

**Where to go from here**

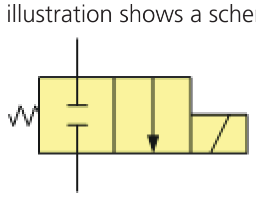
Information in this section



## Precharge Valve

**Description**

The precharge valve delivers brake fluid from the master brake cylinder to the pump intake. This is necessary if the braking pressure must be increased without brake pedal actuation (for example, during ESP or ASR intervention). Therefore, the valve is normally closed and only opened during ECU interventions. The flow is possible in only one direction in the open state [Bos98]. The following illustration shows a schematic of the valve.

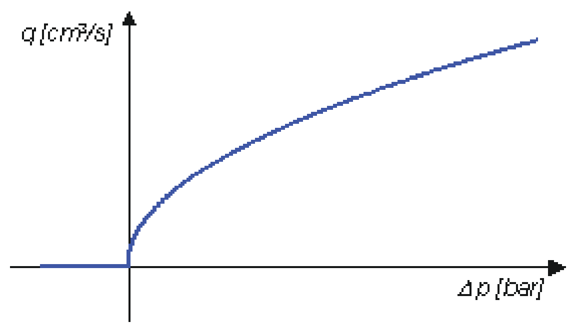


For a low flow resistance, the orifice should be as large as possible. However, a large orifice area needs a high force to open the valve, if there is a high pressure difference between the inlet and outlet pipes. Therefore, the opening path of the valve is designed as a two-stage aperture with a large cross section if the intake pressure is low (for example, during an ASR intervention) and a small cross section for high intake pressure (for example, when the driver performs partial braking during an ESP intervention) [Zan04].

The valve is modeled as an orifice with a continuously controllable cross section. The flow depends on the orifice cross section A, the flow coefficient α, the fluid density ρ, and the pressure difference Δp between the inlet and outlet areas of the valve. The equation (Bernoulli equation) to calculate the valve flow can be written as [Bea99]

$$q = A(Ctrl\_Valve)\alpha\sqrt{\frac{2}{\rho}(p_{in} - p_{out})}$$

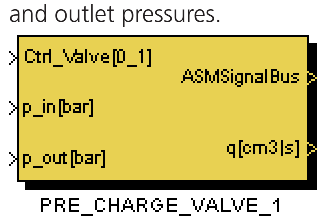
The following illustration shows the characteristic curve of the precharge valve:




**Note**

The effect of temperature on the hydraulic fluid is ignored.

The following illustration shows the Simulink representation of the precharge valve. It calculates the flow rate as a function of the control signal and the inlet and outlet pressures.




## Inports

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| Ctrl_Valve | [0_1] | Control signal, range 0 … 1 (0 fully closed, 1 fully open) |
| p_in | [bar] | Inlet pressure |
| p_out | [bar] | Outlet pressure |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 📖). |
| q | [$cm^3/s$] | Flow rate |

**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Const_diam_max_LowPressure | [mm] | Maximum effective flow diameter at low pressure difference |
| Const_diam_max_HighPressure | [mm] | Maximum effective flow diameter at high pressure difference |
| Const_FlowCoeff | [] | Flow coefficient |
| Const_p_threshold | [bar] | Pressure threshold to switch between the two diameters |
| Sw_FlowDirection | [0\|1] | Flow direction<br>▪ 0: One-way<br>▪ 1: Two-way |
| Sw_nom_state | [0\|1] | Nominal open state<br>▪ 0: Normally closed<br>▪ 1: Normally opened |

**Processing information**

The flow coefficient $\alpha$ depends on the orifice dimension and the Reynolds number. For standard dynamic procedures, a flow coefficient of $\alpha \approx 0{,}7$ can be assumed [Bea99].

**Related topics**

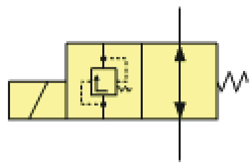
References

Braking Circuit 1 (ModelDesk Parameterizing 📖)
Braking Circuit 2 (ModelDesk Parameterizing 📖)
History of the PRE_CHARGE_VALVE_x Block.......................................................................107

# Change-over Valve

**Description**

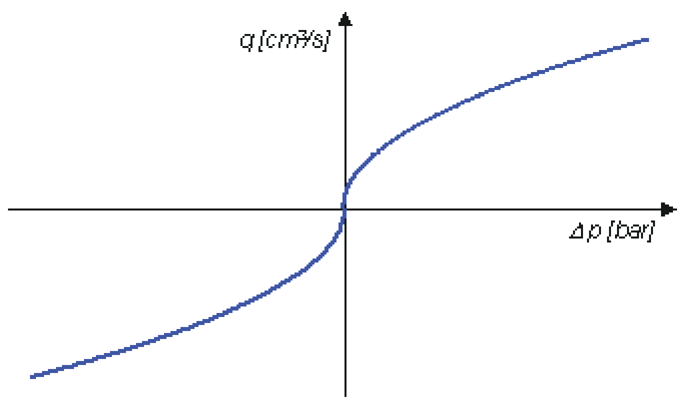
The change-over valve delivers brake fluid from the master brake cylinder to the inlet valves. The valve is normally open to enable the standard braking procedure. Flow is possible in both directions in the open state. When the pump is switched on to increase the braking pressure without driver brake intervention (for example, during ESP or ASR intervention), the change-over valve is closed. In the closed state, the valve functions as a pressure relieve valve. Thus, it normally prevents the brake fluid from being pumped back to the master brake cylinder. However, if the pump delivers more fluid than required, the pressure relief function allows the brake fluid to return to the master brake cylinder [Bos98].



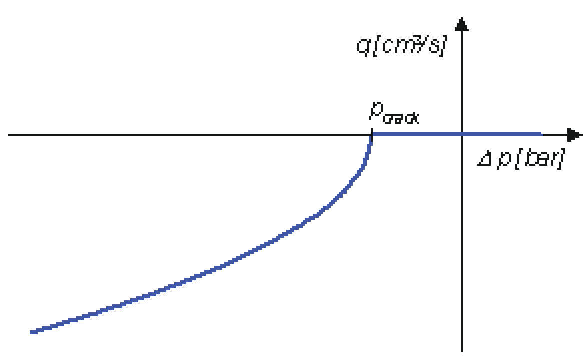
The valve is modeled as an orifice with a continuously controllable cross section. The flow depends on the orifice cross section A, the flow coefficient $\alpha$, the fluid density $\rho$, and the pressure difference $\Delta p = p_{in} - p_{out}$ between the inlet and outlet of the valve. The equation (Bernoulli equation) to calculate the valve flow can be written as [Bea99]

$$q = A(Ctrl\_Valve)\alpha\sqrt{\frac{2}{\rho}(p_{in} - p_{out})}$$

The following illustration shows the characteristic curve of the change-over valve in the open state:



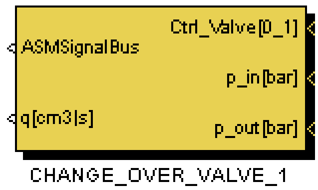

The following illustration shows the characteristic curve of the pressure relief function (close state):



**Note**

The effect of temperature on the hydraulic fluid is ignored.

The following illustration shows the Simulink representation of the change-over valve. It calculates the flow rate as a function of the control signal and the inlet and outlet pressures.




## Inports

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| Ctrl_Valve | [0_1] | Control signal, range 0 … 1 (0 fully open, 1 fully closed) |
| p_in | [bar] | Inlet pressure |
| p_out | [bar] | Outlet pressure |

## Outports

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide). |
| q | [$cm^3$/s] | Flow rate |

## Parameters

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Const_diam_max | [mm] | Maximum effective flow diameter |
| Const_diam_max_pLimit | [mm] | Maximum effective flow diameter, pressure limiter |
| Const_FlowCoeff | [] | Flow coefficient |
| Const_FlowCoeff_pLimit | [] | Flow coefficient pressure limiter |
| Const_p_crack_pLimt | [bar] | Crack pressure of pressure limiter |
| Sw_FlowDirection | [0\|1] | Flow direction<br>▪ 0: One-way<br>▪ 1: Two-way |
| Sw_nom_state | [0\|1] | Nominal open state<br>▪ 0: Normally closed<br>▪ 1: Normally opened |

**Processing information**

The flow coefficient α depends on the orifice dimension and the Reynolds number. For standard dynamic procedures, a flow coefficient of $\alpha \approx 0.7$ can be assumed [Bea99].

**Related topics**

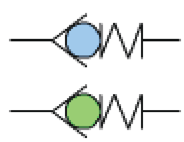
References



# Non-Return Valve (at Reservoir)

**Description**

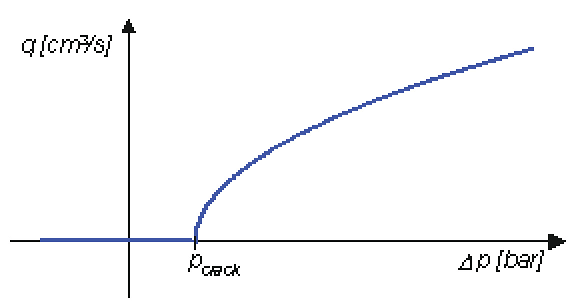
The non-return valve allows a flow in one direction only. The valve is closed with a prestressed spring. If the pressure difference across the valve is greater than the force of the prestressed spring, the valve opens. In the open state, the valve behaves like a flow valve.



The valve is modeled as an orifice with a fixed cross-section. The flow depends on the orifice cross-section A, the flow coefficient $\alpha$, the fluid density $\rho$, and the pressure difference $\Delta p = p_{in} - p_{out}$ between the inlet and outlet areas of the valve. The flow is zero if the pressure difference across the valve is lower than the crack pressure. The equation (Bernoulli equation) to calculate the valve flow can be written as [Bea99].

$$q = A\alpha\sqrt{\frac{2}{\rho}(p_{in} - p_{out})}$$

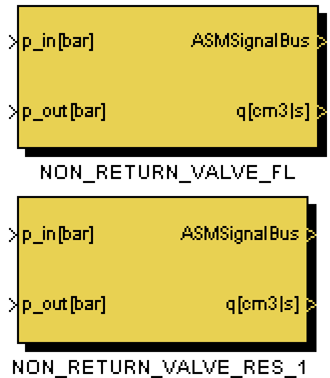
The following illustration shows the characteristic curve of the non-return valve.



**Note**

The effect of temperature on the hydraulic fluid is not considered.

The following illustration shows the Simulink representation of the non-return valve. It calculates the flow rate as a function of the inlet and outlet pressures.




**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| p_in | [bar] | Inlet pressure |
| p_out | [bar] | Outlet pressure |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide). |
| q | [$cm^3$/s] | Flow rate |

**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Const_diam_max | [mm] | Maximum effective flow diameter |
| Const_FlowCoeff | [] | Flow coefficient |
| Const_p_crack | [bar] | Crack pressure |

**Processing information**

The flow coefficient $\alpha$ depends on the orifice dimension and the Reynolds number. For standard dynamic procedures, a flow coefficient of $\alpha \approx 0{,}7$ can be assumed [Bea99].

**Related topics**

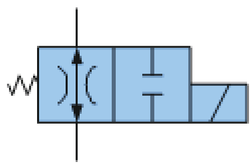
References



# Inlet Valve

**Description**

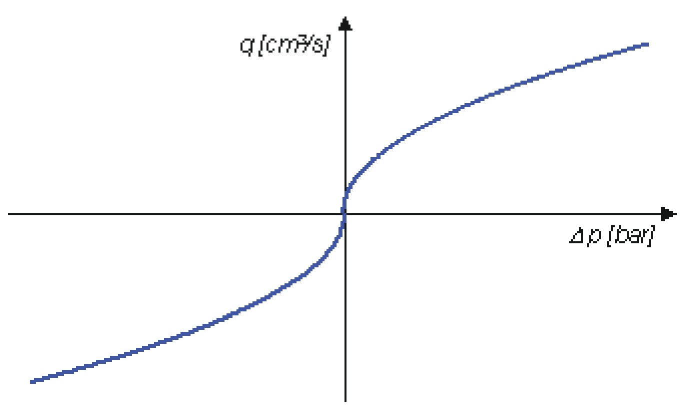
The inlet valve delivers brake fluid to the wheel brake cylinder. The valve is normally open to perform the standard braking procedure. In the open state, flow is possible in both directions. During an ABS (anti-lock braking system), ESP (electronic stability program), or TCS (traction control system) intervention, the valve can be closed to hold or decrease the braking pressure in the wheel brake cylinder.



The valve is modeled as an orifice with a continuously controllable cross-section. The flow rate depends on the orifice cross-section A, the flow coefficient $\alpha$, the fluid density $\rho$ and the pressure difference $\Delta p = p_{in} - p_{out}$ between the inlet and outlet areas of the valve. The equation (Bernoulli equation) to calculate the valve flow can be written as [Bea99]

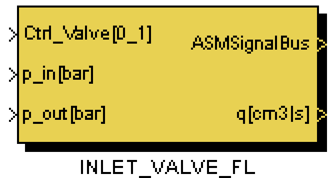
$$q = A(Ctrl\_Valve)\alpha\sqrt{\frac{2}{\rho}(p_{in} - p_{out})}$$

The following illustration shows the characteristic curve of the change-over valve in the open state:



> **Note**
>
> The effect of temperature on the hydraulic fluid is ignored.

The following illustration shows the Simulink representation of the inlet valve. It calculates the flow rate as a function of the control signal and the inlet and outlet pressures.




**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| Ctrl_Valve | [0_1] | Control signal, range 0 … 1 (0 fully open, 1 fully closed) |
| p_in | [bar] | Inlet pressure |
| p_out | [bar] | Outlet pressure |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide). |
| q | [$cm^3$/s] | Flow rate |

**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Const_diam_max | [mm] | Maximum effective flow diameter |
| Const_FlowCoeff | [] | Flow coefficient |
| Sw_FlowDirection | [0\|1] | Flow direction<br>▪ 0: One-way<br>▪ 1: Two-way |
| Sw_nom_state | [0\|1] | Nominal open state<br>▪ 0: Normally closed<br>▪ 1: Normally opened |

**Processing information**

The flow coefficient $\alpha$ depends on the orifice dimension and the Reynolds number. For standard dynamic procedures, a flow coefficient of $\alpha \approx 0{,}7$ can be assumed [Bea99].

**Related topics**

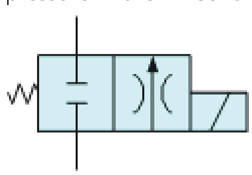
References



# Outlet Valve

**Description**

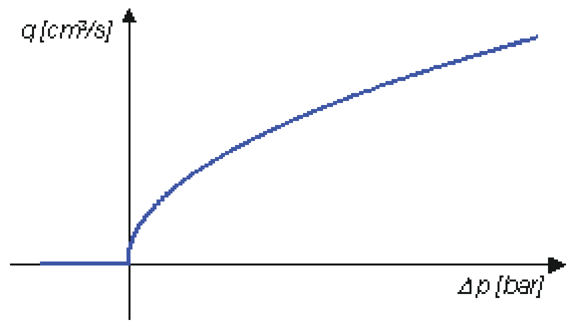
The outlet valve delivers brake fluid from the wheel brake cylinder to the reservoir. The valve is normally closed to perform the standard braking procedure. Flow is possible in only one direction in the open state. During an ABS, ESP, or ASR intervention, the valve can be opened to decrease the braking pressure in the wheel brake cylinder.



The valve is modeled as an orifice with a continuously controllable cross-section. The flow depends on the orifice cross-section A, the flow coefficient $\alpha$, the fluid density $\rho$ and the pressure difference $\Delta p = p_{in} - p_{out}$ between the inlet and outlet areas of the valve. The equation (Bernoulli equation) to calculate the valve flow rate can be written as [Bea99]

$$q = A(Ctrl\_Valve)\alpha\sqrt{\frac{2}{\rho}(p_{in} - p_{out})}$$

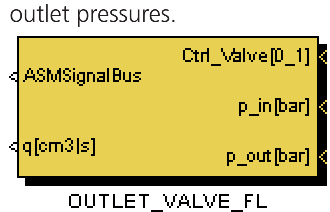
The following illustration shows the characteristic curve of the change-over valve in the open state:




**Note**

The effect of temperature on the hydraulic fluid is not considered.

The following illustration shows the Simulink representation of the outlet valve. It calculates the flow rate as a function of the control signal and the inlet and outlet pressures.




**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| Ctrl_Valve | [0_1] | Control signal, range 0 … 1 (0 fully closed, 1 fully open) |
| p_in | [bar] | Inlet pressure |
| p_out | [bar] | Outlet pressure |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 📖). |
| q | [$cm^3/s$] | Flow rate |

**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Const_diam_max | [mm] | Maximum effective flow diameter |
| Const_FlowCoeff | [] | Flow coefficient |
| Sw_FlowDirection | [0\|1] | Flow direction<br>▪ 0: One-way<br>▪ 1: Two-way |
| Sw_nom_state | [0\|1] | Nominal open state<br>▪ 0: Normally closed<br>▪ 1: Normally opened |

**Processing information**

The flow coefficient $\alpha$ depends on the orifice dimension and the Reynolds number. For standard dynamic procedures, a flow coefficient of $\alpha \approx 0{,}7$ can be assumed [Bea99].

**Related topics**

References

Braking Circuit 1 (ModelDesk Parameterizing 📖)
Braking Circuit 2 (ModelDesk Parameterizing 📖)
History of the OUTLET_VALVE_x Block........................................................................ 106

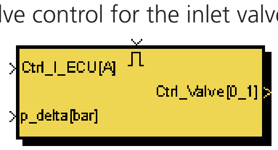
# Continuous Valve Control

**Description**

In some cases, valves are continuously controlled by an ECU via a control current. The flow area of these valves depends on the valve control current and the pressure difference. The modeled system is based on a look-up-table that calculates the valve control signal from the valve control current and the pressure difference.

The continuous valve control function is available for the inlet, outlet, precharge, and change-over valves. Whether these valves are calculated as digitally or continuously controlled valves is defined via the valve control switches model block. For details, refer to Valve Control Switches on page 49.

The following illustration shows the Simulink representation of the continuous valve control for the inlet valve front left:




CONTINUOUS_CTRL_INLET_VALVE_FL

**Inports**

The following table shows the inports.

| Name | Unit | Description |
|---|---|---|
| Ctrl_I_ECU | [A] | Valve control current |
| p_delta | [bar] | Pressure difference between valve inport and outport |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| Ctrl_Valve | [0_1] | Control signal, range 0 … 1 |

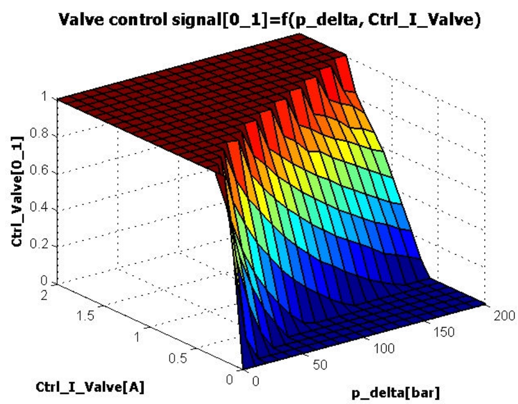
**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Map_ContinuousValveControl | [0_1] | Valve control signal = f(p_delta, Ctrl_I_ECU) |

**Processing information**

The following illustration shows an example of a valve control look-up table:




**Related topics**

References

History of the CONTINUOUS_CTRL_INLET_VALVE_x Block .......... 101
Valve Control Switches .......... 49

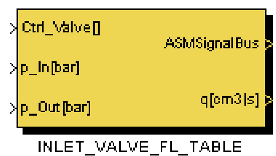
# Table-Based Valves

**Description**

The modeled valve is based on a look-up-table that calculates the valve flow from a control signal, for example, the valve control current, and the pressure difference. This model approach can be useful if the fluid flow was measured with a test bench or if it is available from a data sheet.

Table-based valve models are available for the inlet, outlet, precharge, and change-over valves.

The following illustration shows the Simulink representation of the table-based inlet valve front left:




**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| Ctrl_Valve | [] | Valve control signal, for example, valve control current |
| p_In | [bar] | Valve input pressure |
| p_Out | [bar] | Valve output pressure |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 📖). |
| q | [$cm^3$/s] | Fluid quantity |

**Parameters**

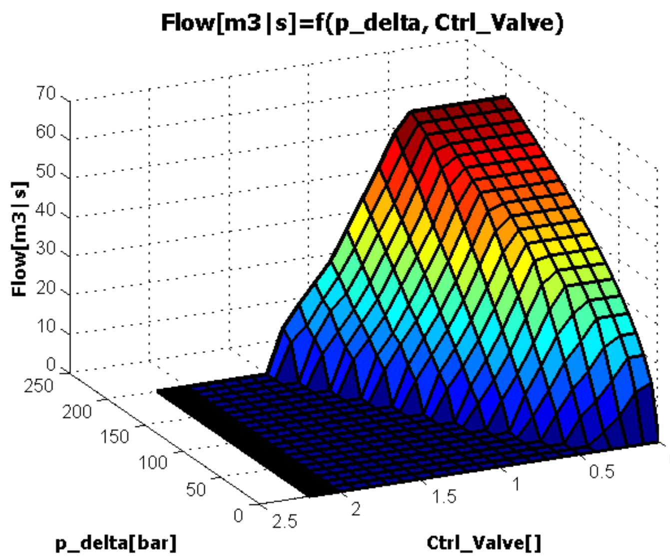
The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Map_Flow | [$cm^3$/s] | Valve flow[$cm^3$/s] = f(p_delta, Ctrl_Valve) |
| Sw_FlowDirection_TableValve | [0\|1] | Flow direction<br>▪ 0: One-way, flow values for negative delta pressure are set to zero<br>▪ 1: Two-way, flow values for positive and negative delta pressure are taken from table data |

| Name | Unit | Description |
|---|---|---|
| Sw_Mirror_TableValve | [0\|1] | Mirror look-up table<br>▪ 0: Off, flow values for positive and negative delta pressure are taken from table data<br>▪ 1: On, flow values for negative delta pressure are mirrored from table data of the positive delta pressure |

**Processing information**

The following illustration shows an example of a valve look-up table that describes the valve fluid flow:




**Related topics**

References


Braking Circuit 1 (ModelDesk Parameterizing 🕮)
Braking Circuit 2 (ModelDesk Parameterizing 🕮)
History of the INLET_VALVE_x_TABLE Block........ 104

# Chambers

**Where to go from here**

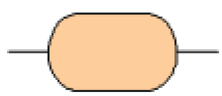
Information in this section



## Damper Chamber

**Description**

The damper chamber levels the pressure pulses generated by the hydraulic pump. It also decreases the noise during an ABS, ESP, or ASR intervention [Bos98].

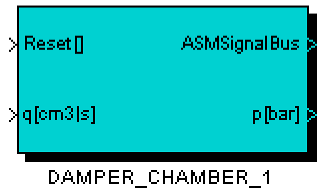


The chamber is simulated as a fixed volume that is filled with a compressible fluid. It describes the pressure state as a function of the flow quantity into and out of the chamber. Based on the continuity law, the differential equation for the chamber pressure $p$ of this system can be written as [Bor03]

$$\dot{p} = \frac{E}{V_0}\Sigma_i q_i$$

where E is the bulk module, $V_0$ the volume of the chamber, and $q$ the flow into and out of the chamber. The factor $\frac{E}{V_0}$ is also known as the inverse of the hydraulic capacity.

The following illustration shows the Simulink representation of the damper chamber. It calculates the pressure as a function of the fluid quantity that flows into and out of the damper chamber:




## Inports

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| q | [$cm^3$/s] | Flow quantity |
| Reset | [] | Resets all integrators in the block to their initial conditions |

## Outports

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide). |
| p | [bar] | Chamber pressure |

## Parameters

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Const_p_Init | [bar] | Initial pressure |
| Const_V | [$cm^3$] | Chamber volume |

## Processing information

The bulk module E of the hydraulic fluid is parameterized in the common fluid parameter block. Refer to Common Fluid Parameters on page 48.

**Note**

The hydraulic fluid bulk module E has a relatively high value. The inverse hydraulic capacity E / $V_0$ is therefore very large for low chamber volumes, which leads to a stiff differential equation that might become a numerically instable system if the sampling rate is too low. To avoid numerical instability, it is recommended to use a value for the volume parameter that is 10-20 times greater than the actual chamber size. Increasing the volume to this extent has only a minimal effect on the accuracy of the simulation result.

**Related topics**

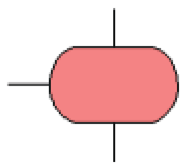
References



# Connection Chamber

**Description**

The connection chamber is required as a connecting element between the precharge valve, the non-return valve, and the pump. The physical representation of this chamber is the volume of the hydraulic pipe.

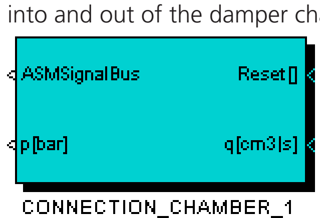


The chamber is simulated as a fixed volume that is filled with a compressible fluid. It describes the pressure state as a function of the flow quantity into and out of the chamber. Based on the continuity law, the differential equation for the chamber pressure $p$ of this system can be written as [Bor03]

$$\dot{p} = \frac{E}{V_0}\sum_i q_i$$

where E is the bulk module, $V_0$ the volume, and $q$ the flow into respectively out of the chamber. The factor $\frac{E}{V_0}$ is also known as the inverse of the hydraulic capacity.

The following illustration shows the Simulink representation of the damper chamber. It calculates the pressure as a function of the fluid quantity that flows into and out of the damper chamber:




**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| q | [cm$^3$/s] | Flow quantity |
| Reset | [] | Resets all integrators in the block to their initial conditions |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 📖). |
| p | [bar] | Chamber pressure |

**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Const_p_Init | [bar] | Initial pressure |
| Const_V | [$cm^3$] | Chamber volume |

**Processing information**

The bulk module E of the hydraulic fluid is parameterized in the common fluid parameter block. Refer to Common Fluid Parameters on page 48.

**Note**

The hydraulic fluid bulk module E has a relatively high value. The inverse hydraulic capacity $E / V_0$ is therefore very large for low chamber volumes, which leads to a stiff differential equation which might become a numerically instable system if the sampling rate is too low. To avoid numerical instability, it is recommended to use a value for the volume parameter that is 10-20 times greater than the actual chamber size. Increasing the volume to this extent has only a minimal effect on the accuracy of the simulation result.

**Related topics**

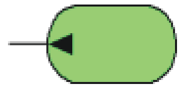
References

Braking Circuit 1 (ModelDesk Parameterizing 📖)
Braking Circuit 2 (ModelDesk Parameterizing 📖)
History of the CONNECTION_CHAMBER Block........................................................................ 101

# Reservoir

**Description**

The reservoir takes the exhaust brake fluid from the outlet valve during an ABS, ESP, or ASR intervention. The hydraulic pump ensures that the fluid is returned from the reservoir to the main brake cylinder [Bos98].



The reservoir is simulated as a hydropneumatic accumulator, for example, a bubble accumulator or membrane accumulator. The accumulator contains a gas bubble that has greater compressibility than the hydraulic fluid. The accumulator is therefore able to absorb and deliver a relatively high quantity of hydraulic fluid. The capacity of the accumulator depends on the charging pressure (gas pressure of the empty accumulator).

Based on the Poisson equation, the nonlinear differential equation for the accumulator pressure p of this system can be written as [Bac94]

$$\dot{p} = \frac{q\chi p}{V_0}\left(\frac{p}{p_0}\right)^{\frac{1}{\chi}}$$

where $\chi$ is the polytropic gas index, $V_0$ the volume of the reservoir, $p_0$ the charging pressure and $q$ the flow rate into and out of the accumulator.

The following illustration shows the Simulink representation of the reservoir. It calculates the pressure depending on the fuel quantity that flows into and out of the accumulator.


**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| q | [cm$^3$/s] | Flow quantity |
| Reset | [] | Resets all integrators in the block to their initial conditions |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide). |
| p | [bar] | Accumulator pressure |

**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Const_GasIndex | [] | Polytropic gas index |
| Const_p_Init | [bar] | Initial charging pressure |
| Const_V_Init | [$cm^3$] | Initial volume |

**Processing information**

The polytropic gas index for oxygen, air, and azote is 1.4 [Her92].

**Related topics**

References

Braking Circuit 1 (ModelDesk Parameterizing 📖)
Braking Circuit 2 (ModelDesk Parameterizing 📖)
History of the RESERVOIR Block........ 109

# Brake Cylinders

**Where to go from here**

Information in this section



## Master Brake Cylinder

**Description**

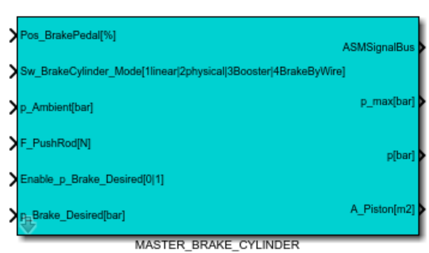
The master brake cylinder is modeled with the following different approaches:

- Linear type
- Physical, nonlinear type, with or without brake booster support
- Brake-by-wire type

With the Sw_MasterBrakeCylinderType inport you can switch between the model types.

In some vehicle configurations, you must be able to decelerate the vehicle without a driver brake pedal action. This brake intervention is controlled by a real or soft ECU (refer to Desired Brake Pressure on page 54), for example an ACC ECU. If the enable inport flag Enable_p_Brake_Desired is set, the block outputs the master brake cylinder pressure or the desired external pressure, whichever is greater. If the enable flag is not set, the block outport pressure is the master brake cylinder pressure. An exception is the brake-by-wire mode, where the master brake cylinder pressure is zero if the enable flag is not set.

The following illustration shows the Simulink representation of the master brake cylinder. It calculates the pressure as a function of the brake pedal position.



**Linear type**

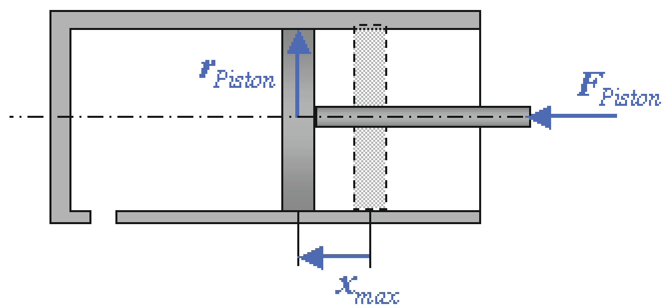
The linear master brake cylinder simulation converts only the brake pedal position to cylinder pressure between zero and a given maximum pressure in a linear way.

$$p_{MasterCylinder} = \frac{Pos_{BrakePedal} \, p_{max}}{100\%}$$

For example, this linear model type can be used if a brake pedal position of 70% must produce exactly 70% of the maximum braking pressure.

**Physical type**

The brake cylinder is simulated as a massless piston that can move in longitudinal direction in the cylinder body. Losses and leakage are neglected. The following illustration shows the simulated system.




The equations of the system can be written as

$$x = \frac{Pos_{BrakePedal} \, x_{Max}}{100}$$

$$F_{Piston} = f(x)$$

$$p_{MasterCylinder} = \frac{F_{Piston}}{\pi r^2_{Piston}}$$

For example, this physical model type can be used to obtain a more realistic behavior if measured data on the brake pedal position is to be fed to the simulation. If the brake booster support is used, the piston force is taken from the F_PushRod inport.

**Brake-by-wire type**

For battery electric and hybrid applications, you must be able to decouple the mechanical connection between brake pedal and master brake cylinder. In this applications, the brake intervention is controlled by a real or soft ECU (refer to Desired Brake Pressure on page 54), for example.

If the enable inport flag is set, the block outport pressure is set to the value of the desired external pressure.

If the enable flag is not set, the block outport pressure is set to zero. The brake pedal position inport value then has no effect on the brake pressure outport value.

**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| Enable_p_Brake_Desired | [0\|1] | Enable the desired brake pressure as block output pressure:<br>▪ 0: Disable<br>▪ 1: Enable |
| F_PushRod | [N] | Push rod (piston) force, used for brake booster support |
| p_ambient | [bar] | Ambient pressure |
| Pos_BrakePedal | [%] | Brake pedal position |
| p_Brake_Desired | [bar] | Desired brake pressure that is set as block output pressure if the enable flag is set |
| Sw_MasterBrakeCylinderType | [1\|2\|3\|4] | Switch to select the master brake cylinder type:<br>▪ 1: Linear<br>▪ 2: Physical<br>▪ 3: Physical with brake booster<br>▪ 4: Brake-by-wire |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 📖). |
| A_Piston | [$m^2$] | Piston area of physical brake cylinder |
| p | [bar] | Pressure in master brake cylinder |
| p_max | [bar] | Maximum pressure in master brake cylinder |

**Parameters**

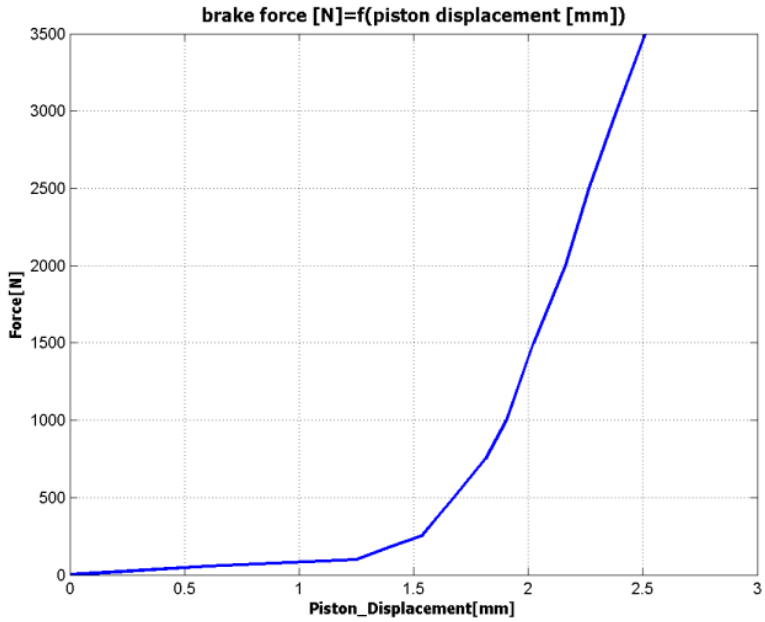
The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Const_displ_max_piston | [mm] | Maximum piston displacement |
| Const_p_ambient | [bar] | Ambient pressure |
| Const_p_max | [bar] | Maximum master cylinder pressure |
| Const_r_piston | [mm] | Piston radius |
| Map_BrakeForce | [N] | Brake pedal force = f(piston displacement) |

**Processing information**

The `Const_p_max` parameter parameterizes the linear model. All the other parameters parameterize the physical model. This means if the linear model type is used, only the `Const_p_max` parameter must have a correct value, and for the physical model type, all the other parameters must be set.

The braking force [N] is calculated from a look-up table with the piston displacement [mm] input. The following illustration shows an example [Yam01].




**Related topics**

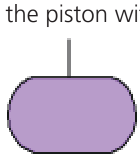
References



# Wheel Brake Cylinder

**Description**

The wheel brake cylinder consists of a cylinder with a piston. If the brake pedal is pressed, hydraulic fluid flows into the cylinder, increases the pressure, and pushes the piston with the friction pads onto the brake disc.



**Note**

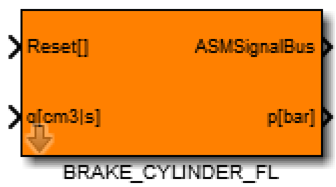
The friction pad and brake disc model is not part of the brake hydraulics library.

The modeled system is based on a look-up table that calculates the cylinder pressure from the cylinder volume. The brake fluid quantity that flows into and out of the cylinder is integrated into the current fluid volume in the cylinder. The pressure can be calculated from the volume by means of the look-up table [See97].

$$V = \int q \, dt$$

$$p = f(V)$$

The following illustration shows the Simulink representation of the wheel brake cylinder. It calculates the pressure depending on the fluid quantity that flows into and out of the brake cylinder.




## Inports

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| q | [$cm^3$/s] | Flow quantity |
| Reset | [] | Resets all integrators in the block to their initial conditions |

## Outports

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide). |
| p | [bar] | Wheel brake cylinder pressure |

## Parameters

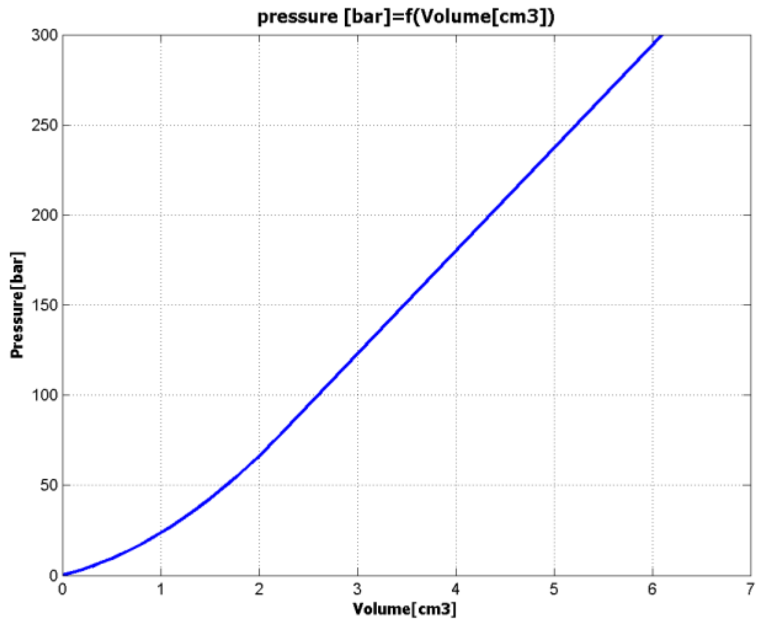
The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Const_V_Init | [$cm^3$] | Initial volume |
| Map_BrakePressure | [bar] | Cylinder pressure = f(cylinder volume) |

## Processing information

The initial volume should be set so that the pressure look-up table delivers a pressure value near the ambient pressure, for example, 1 bar.

The brake cylinder pressure [bar] is calculated from a look-up table with the fluid volume in the cylinder [cm$^3$] input. The following illustration shows an example [See97]:




**Related topics**

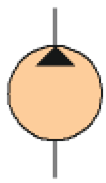
References

# Pumps

## Pump

**Description**

The hydraulic pump transports brake fluid back from the accumulator to the master brake cylinder. Its second function is to deliver brake fluid to the inlet valves during active braking without driver intervention. This is necessary for ESP and ASR functionalities [Bos98].



The modeled system is based on a look-up table that calculates the delivered fluid quantity from the pressure difference between the inlet and outlet areas ($\Delta p = p_{in} - p_{out}$) [Bor03].

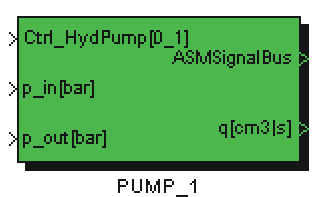
> **Note**
>
> The sinusoidal pulsation of the delivered flow quantity is neglected.

The flow rate calculated from the look-up table is delivered only if the intake pressure of the pump is greater than a defined pressure. Below this minimum input pressure $p_{min}$ the flow is decreased linearly to zero. This anticipates that the pump assumes no mass flow if the input pressure is too low.

The equation of the system can be written as

$$q = \begin{cases} f(p_{in} - p_{out}) & p_{in} \geq p_{min} \\ f(p_{in} - p_{out})\dfrac{p_{in}}{p_{min}} & p_{in} < p_{min} \end{cases}$$

The following illustration shows the Simulink representation of the wheel brake cylinder. It calculates the flow quantity as a function of the pump intake and outlet pressures.



**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| Ctrl_HydPump | [0_1] | Control signal in the range 0 .. 1 (0 completely deactivated, 1 completely activated) |
| p_in | [bar] | Intake pressure |
| p_out | [bar] | Outlet pressure |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 📖). |
| q | [cm³/s] | Fluid quantity |

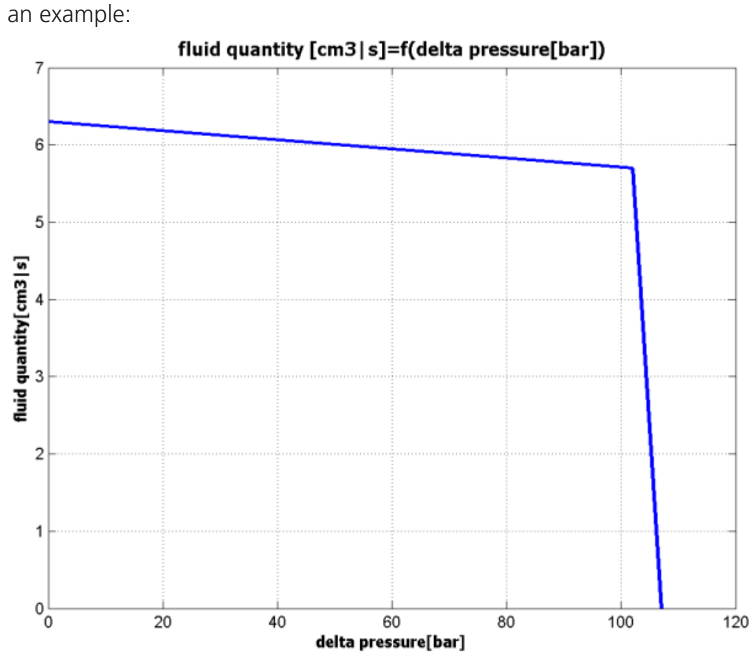
**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Const_p_in_Min | [bar] | Minimum pump input pressure |
| Map_FluidQuantity | [cm³/s] | Fluid quantity = f(pressure difference) |

**Processing information**

The delivered flow rate [cm³/s] is calculated from a look-up table with the pressure difference [bar] ($\Delta p = p_{in} - p_{out}$) input. The following illustration shows an example:



**Related topics**

References

Braking Circuit 1 (ModelDesk Parameterizing 📖)
Braking Circuit 2 (ModelDesk Parameterizing 📖)

# Braking Circuit Basic

**Where to go from here**

Information in this section



## Braking Circuit Basic Controlled

**Description**

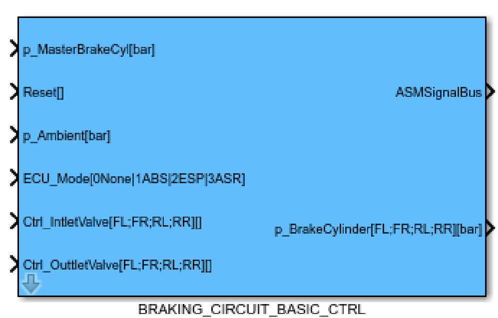
The BRAKING_CIRCUIT_BASIC_CTRL block simulates the wheel brake cylinder pressure of each wheel depending on the inlet and outlet valve control signals, and the master brake cylinder pressure. The brake pressure dynamics are based on a first-order time delay model approach.

Depending on the ECU mode, different input pressures are used for the wheel brake cylinders:

- For the ECU modes *ESP* and *ASR*, the hydraulic pump pressure Const_p_Pump parameter of the BRAKING_CIRCUIT_BASIC_CTRL block is used.
- For the ECU modes *None* and *ABS*, the master brake cylinder pressure of the p_MasterBrakeCyl[bar] inport is used.

As output pressure of the wheel brake cylinders the ambient pressure is set.

The following illustration shows the Simulink representation of the model.



**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| Ctrl_IntletValve | [0_1] | Control signal for the inlet valve (normally open) of each wheel. The signal value must be between 0 and 1.<br>▪ 0: Inlet valve fully open<br>▪ 1: Inlet valve fully closed |
| Ctrl_OutletValve | [0_1] | Control signal for the outlet valve (normally closed) of each wheel. The signal value must be between 0 and 1.<br>▪ 0: Outlet valve fully open<br>▪ 1: Outlet valve fully closed |
| ECU_Mode | [0\|1\|2\|3] | ECU mode that indicates if an ECU intervention is active:<br>▪ 0: None<br>▪ 1: ABS<br>▪ 2: ESP<br>▪ 3: ASR |
| p_Ambient | [bar] | Ambient pressure |
| p_MasterBrakeCyl | [bar] | Master brake cylinder pressure |
| Reset | [] | Reset |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 🕮). |
| p_BrakeCylinder | [bar] | Wheel brake cylinder pressure of each wheel |

**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Const_p_init | [bar] | Initial wheel brake cylinder pressure |
| Const_p_Pump | [bar] | Hydraulic pump pressure |
| Const_TimeConst_In_Front | [s] | Time constant of inlet pressure at front |
| Const_TimeConst_In_Rear | [s] | Time constant of inlet pressure at rear |
| Const_TimeConst_Out_Front | [s] | Time constant of outlet pressure at front |
| Const_TimeConst_Out_Rear | [s] | Time constant of outlet pressure at rear |
| Step size | [s] | Simulation step size |

**Related topics**

References



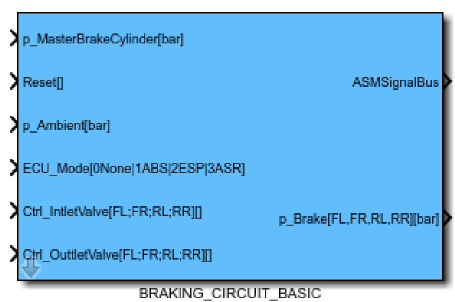
# Braking Circuit Basic

**Description**

The BRAKING_CIRCUIT_BASIC block simulates the dynamics of the brake hydraulics via a first-order time delay function.

The illustration shows the Simulink representation of the braking circuit. It delays the pressure signal via a first-order time delay function and distributes the pressure of each wheel brake cylinder.

The inlet and outlet valve control signal inputs from the vehicle stability control system have no function in the BRAKING_CIRCUIT_BASIC model. They are used for interface compatibility with the BRAKING_CIRCUIT_BASIC_CTRL block that simulates the wheel brake cylinder pressure of each wheel depending on the inlet and outlet valve control signals. Refer to Braking Circuit Basic Controlled on page 42.




**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| Ctrl_InletValve[FL;FR;RL;RR] | [] | Dummy inport for interface compatibility with the BRAKING_CIRCUIT_BASIC_CTRL block |
| Ctrl_OutletValve[FL;FR;RL;RR] | [] | Dummy inport for interface compatibility with the BRAKING_CIRCUIT_BASIC_CTRL block |
| ECU_Mode | [] | Dummy inport for interface compatibility with the BRAKING_CIRCUIT_BASIC_CTRL block |
| p_Ambient | [bar] | Dummy inport for interface compatibility with the BRAKING_CIRCUIT_BASIC_CTRL block |
| P_MasterBrakeCylinder | [bar] | Pressure master brake cylinder |

| Name | Unit | Description |
|---|---|---|
| Reset | [] | Resets all integrators in the block to their initial conditions |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 🕮). |
| p_Brake[FL,FR,RL,RR] | [bar] | Vector with wheel cylinder braking pressure front left, front right, rear left, and rear right |

**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Const_TimeConst | [s] | Time constant of first-order time delay function |

**Related topics**

References

Brake Hydraulics Basic (ModelDesk Parameterizing 🕮)
History of the BRAKING_CIRCUIT_BASIC Block........................................................................ 99

# Miscellaneous

## Continuous Valve Control

**Description**

In some cases, valves are continuously controlled by an ECU via a control current. The flow area of these valves depends on the valve control current and the pressure difference. The modeled system is based on a look-up-table that calculates the valve control signal from the valve control current and the pressure difference.

The continuous valve control function is available for the inlet, outlet, precharge, and change-over valves. Whether these valves are calculated as digitally or continuously controlled valves is defined via the valve control switches model block. Refer to Valve Control Switches on page 49.

The following illustration shows the Simulink representation of the continuous valve control.


**Inports**

The following table shows the inports.

| Name | Unit | Description |
|---|---|---|
| Ctrl_I_ECU | [A] | Valve control current |
| p_delta | [bar] | Pressure difference between valve inport and outport |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| Ctrl_Valve | [0_1] | Control signal, range 0 … 1 |

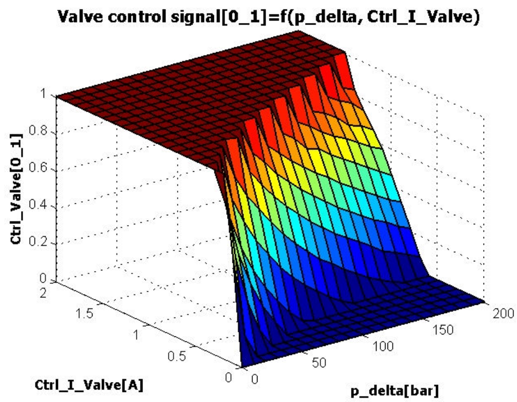
**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Map_ContinuousValveControl | [0_1] | Valve control signal = f(p_delta, Ctrl_I_ECU) |

**Processing information**

The following illustration shows an example of a valve control look-up table:




**Related topics**

References

# Switches and Parameters

**Where to go from here**

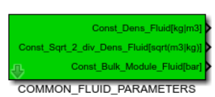
Information in this section



## Common Fluid Parameters

**Description**

There is a central subsystem that provides all parameters that are used several times in the model. The subsystem is a central access point to the parameters for online access. Any modification to a parameter affects all the parts of the model that use it for real-time simulation and Simulink simulation.




**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| Const_Bulk_Module_Fluid | [bar] | Bulk module of the hydraulic fluid |
| Const_Dens_Fluid | [kg/$m^3$] | Density of the hydraulic fluid |
| Const_Sqrt_2_div_Dens_Fluid | [sqrt($m^3$/kg)] | Square root of two divided by the fluid density |

**Parameters**

The following table shows all the common fluid parameters:

| Name | Unit | Description |
|---|---|---|
| Const_BulkModule | [bar] | Bulk module of the hydraulic fluid |
| Const_dens | [kg/$m^3$] | Density of the hydraulic fluid |

**Processing information**

For example, the fluid parameters for the brake fluid DOT4/19 are density 1005 kg/m$^3$ and bulk module 19505 bar [See97].

**Related topics**

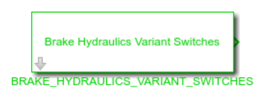
References

Fluid (ModelDesk Parameterizing 📖)
History of the COMMON_FLUID_PARAMETERS Block........................................................... 101

# Brake Hydraulics Variant Switches

**Description**

The BRAKE_HYDRAULICS_VARIANT_SWITCHES block lets you switch between the model types of the master brake cylinder. Refer to Master Brake Cylinder on page 33.




**Parameters**

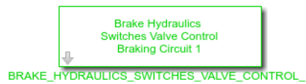
The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Sw_MasterBrakeCylinderType | [1\|2\|3\|4] | Switch to select the master brake cylinder type:<br>▪ 1: Linear<br>▪ 2: Physical<br>▪ 3: Physical with brake booster<br>▪ 4: Brake-by-wire |

# Valve Control Switches

**Description**

Hydraulic valves can be controlled linearly or nonlinearly. If the valve is controlled nonlinearly, the flow area depends on the control current and the pressure difference. In this case, the valve control signal represents the valve control current. The factor defining the flow area is calculated from this signal and the pressure difference via a look-up table. If the valve is controlled linearly, the valve control signal directly represents the factor defining the flow area.




The valve control switches model makes it possible to define linear or nonlinear control for each valve.

**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Sw_Ctrl_ChangeOverValve_1 | [0\|1] | Switch change over valve 1 control<br>▪ 0: Linear<br>▪ 1: Nonlinear |
| Sw_Ctrl_ChangeOverValve_2 | [0\|1] | Switch change over valve 2 control<br>▪ 0: Linear<br>▪ 1: Nonlinear |
| Sw_Ctrl_InletValve_FL | [0\|1] | Switch inlet valve front left control<br>▪ 0: Linear<br>▪ 1: Nonlinear |
| Sw_Ctrl_InletValve_FR | [0\|1] | Switch inlet valve front right control<br>▪ 0: Linear<br>▪ 1: Nonlinear |
| Sw_Ctrl_InletValve_RL | [0\|1] | Switch inlet valve rear left control<br>▪ 0: Linear<br>▪ 1: Nonlinear |
| Sw_Ctrl_InletValve_RR | [0\|1] | Switch inlet valve rear right control<br>▪ 0: Linear<br>▪ 1: Nonlinear |
| Sw_Ctrl_OutletValve_FL | [0\|1] | Switch outlet valve front left control<br>▪ 0: Linear<br>▪ 1: Nonlinear |
| Sw_Ctrl_OutletValve_FR | [0\|1] | Switch outlet valve front right control<br>▪ 0: Linear<br>▪ 1: Nonlinear |
| Sw_Ctrl_OutletValve_RL | [0\|1] | Switch outlet valve rear left control<br>▪ 0: Linear<br>▪ 1: Nonlinear |
| Sw_Ctrl_OutletValve_RR | [0\|1] | Switch outlet valve rear right control<br>▪ 0: Linear<br>▪ 1: Nonlinear |
| Sw_Ctrl_PreChargeValve_1 | [0\|1] | Switch pre charge valve 1 control<br>▪ 0: Linear<br>▪ 1: Nonlinear |
| Sw_Ctrl_PreChargeValve_2 | [0\|1] | Switch pre charge valve 2 control<br>▪ 0: Linear |

| Name | Unit | Description |
|---|---|---|
| | | ▪ 1: Nonlinear |

**Related topics**

References

Braking Circuit and Wheel Units Subsystem of the Advanced Brake Hydraulics........................ 82

# Soft ECU

**Where to go from here**

**Information in this section**

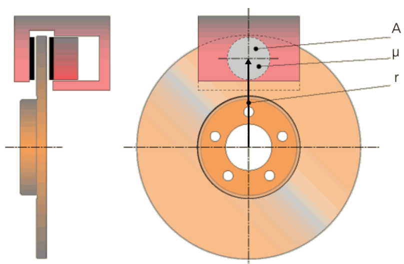
# Soft ECU Brake Basic

## Desired Brake Pressure

**Description**

The DESIRED_BRAKE_PRESSURE block calculates a desired braking pressure from the requested braking torque. The desired brake pressure is used in the brake hydraulics subsystem to perform a soft ECU-controlled deceleration of the vehicle.

To calculate the adequate braking pressure, the model includes an inverse brake disc model (see Brake Disc (ASM Vehicle Dynamics Reference)). The brake request must be activated with an enable flag.

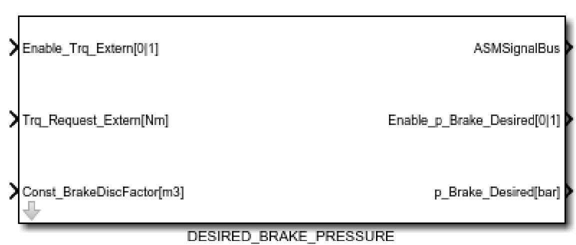



$$p_{Brake} = \frac{T_{Request}}{k_{BrakeDisc}}$$

$$k_{BrakeDisc} = 2\mu r A$$

The brake disc factor $k$ is calculated from the geometrical parameters of the brake disc and is available via a model signal from the brake disc model.

The following illustration shows the Simulink representation of the DESIRED_BRAKE_PRESSURE model.




The DESIRED_BRAKE_PRESSURE block is placed in the Soft_ECU_Brake_Basic and the Soft_ECU_Brake (Advanced) models.

**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| Const_BrakeDiscFactor | [$m^3$] | Brake disc factor k |
| Enable_Trq_Extern | [0\|1] | Enable brake torque request<br>▪ 0: Disable<br>▪ 1: Enable |
| Trq_Request_Extern | [Nm] | Brake torque request for deceleration |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 🕮). |
| Enable_p_Brake_Desired | [0\|1] | Enable flag for desired brake pressure<br>▪ 0: Disable<br>▪ 1: Enable |
| p_Brake_Desired | [bar] | Desired brake pressure |

**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Step size | [s] | Simulation step size |

**Related topics**

References

Brake Disc (ASM Vehicle Dynamics Reference 🕮)
History of the DESIRED_BRAKE_PRESSURE Block........................................................................ 103

# Soft ECU ESP

**Where to go from here**

Information in this section



## Soft ECU ESP

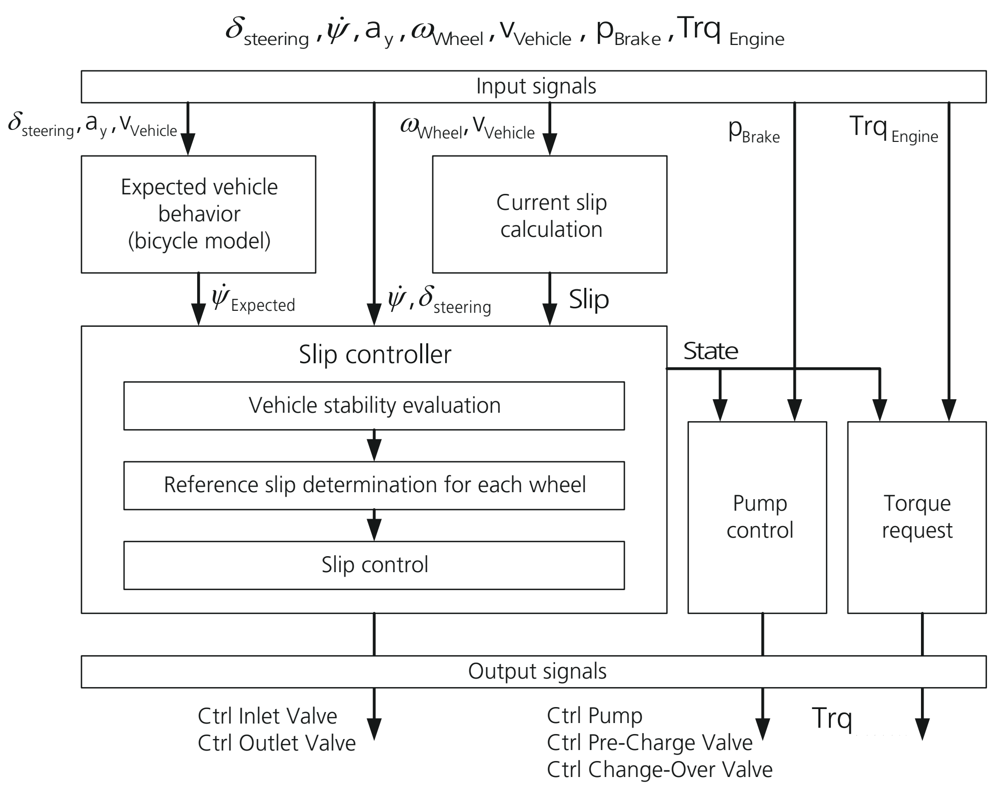
**Description**

Braking under critical conditions, such as on slippery road surfaces and because of a driver's panic reaction can lead to locking wheels. This usually results in a loss of vehicle steering response, because the vehicle loses traction and/or slides off the road. To manage these situations, the anti-lock braking system (ABS) recognizes in time if one or more wheels begin to lock and reacts by modulating the brake pressure in such a way that vehicle steerability is retained while maximum possible braking efficiency is ensured. ABS normally comes into play when the driver brakes hard. At this point, the brake-slip (also known as tire-slip) is required to ensure maximum longitudinal (braking) force.

The electronic stability program (ESP) relies on the vehicle's braking system as a tool for keeping the vehicle stable and on course under critical conditions.

Specific braking interventions are directed to individual wheels to counter understeer and oversteer. ESP can also intervene at the engine side decelerating the vehicle to maintain stability. In addition, anti-slip regulation (ASR) is activated when throttle position and engine torque are not suitable for the road surface conditions.

The following illustration provides an overview of the Soft ECU ESP model.




The slip controller (refer to Slip Controller on page 63) determines if an ABS, ESP, or ASR function must be active and controls the inlet and outlet valves of each wheel brake cylinder.

The current slip (refer to Current Slip on page 61), which is calculated from the vehicle velocity $v_{Vehicle}$ and wheel speed $\omega_{Wheels}$, is observed to check if a wheel blocked and the ABS must be active. In addition, the current slip value is used to detect if the wheels have lost traction on the road and to activate ASR.

In addition, the expected yaw rate (refer to Expected Vehicle Behavior on page 58) is calculated using a bicycle model and compared to the current yaw rate to evaluate the vehicle's stability and activate an ESP intervention, if necessary.

Depending on the slip controller state of an active ABS, ESP, or ASR, the pump controller (refer to Pump Controller on page 67) activates the hydraulic pump and controls the pre-charge and change-over valves.

The torque request component determines if the engine torque must be increased and sends a torque request to the engine ECU.

The input signals of the Soft ECU ESP model differ from those of a real ESP ECU. In a real vehicle, not all required signals can be measured. For example, the vehicle velocity cannot be measured directly and is calculated by the real ECU (e.g., via Kalman filter). This is not implemented in the Soft ECU ESP model because the vehicle velocity can be taken from the vehicle dynamics simulation model.

The output signals are the control signals of the inlet-, outlet-, precharge- and change-over valves, and the hydraulic precharge pump. The output signals are coordinated to the ASM Brake Hydraulics Model, which is required for a correct function of the SoftECU ESP model.

The control strategy and algorithms of a real ESP system are very complex and comprehensive. Compared to a real ECU functionality, the Soft ECU ESP model is a relatively simplified model approach. Therefore, the Soft ECU ESP model will not control the stability of the vehicle dynamics for all test maneuvers such as a real ECU.

**Subsystems**


- Expected Vehicle Behavior on page 58
- Current Slip on page 61
- Slip Controller on page 63
- Pump Controller on page 67
- Torque Request ESP on page 69


**Related topics**

References

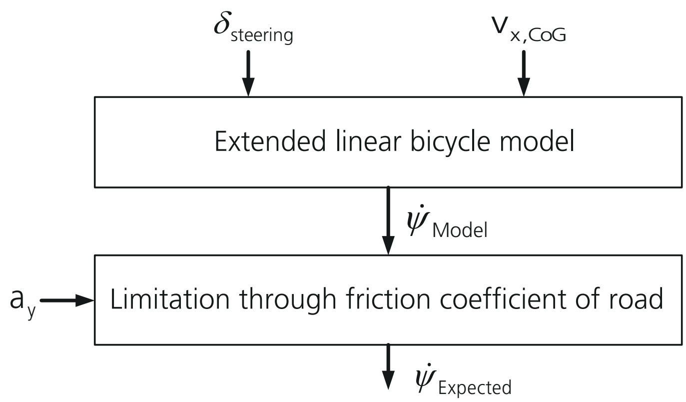


## Expected Vehicle Behavior

**Description**

To evaluate the vehicle's stability, the expected yaw rate depending on the steering wheel angle and the vehicle velocity is required. For this, the driver input signal steering wheel angle and the vehicle velocity are used as part of an extended linear bicycle model to determine the expected yaw behavior of the vehicle.

The following illustration displays how the nominal (expected) yaw rate is calculated.



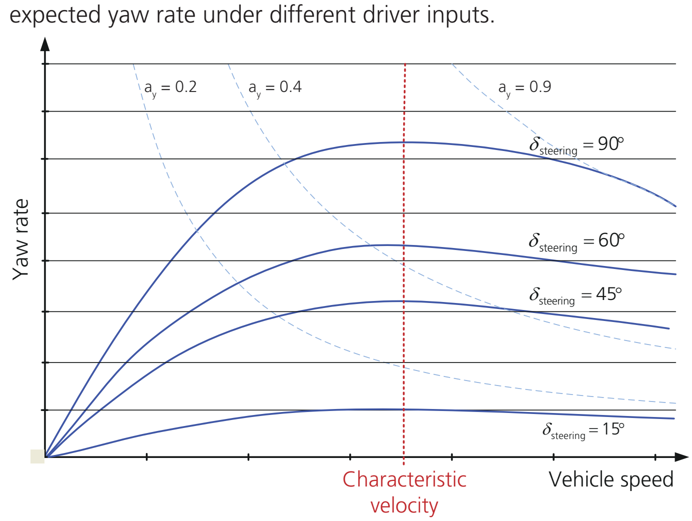

Through the linear bicycle model and the formula for yaw velocity gain $(\dot{\psi}/\delta_{Wheel})$, the yaw rate can be calculated as follows:

$$\dot{\psi} = \delta_{Wheel} \cdot \frac{v_{xCoG}}{(l_F + l_R) \cdot \left(1 + \frac{{v_{xCoG}}^2}{{v_{ch}}^2}\right)}$$

where:

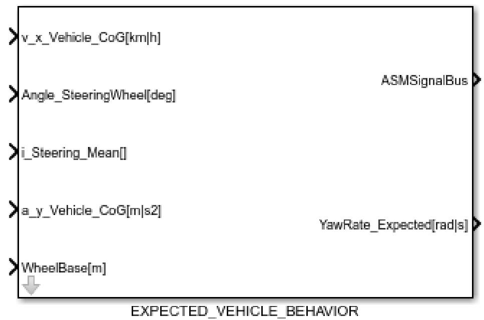
| | |
|---|---|
| $\dot{\psi}$ | is the yaw rate |
| $v_{xCoG}$ | is the vehicle velocity at the center of gravity |
| $v_{ch}$ | is the characteristic velocity |
| $l_F + l_R$ | is the wheelbase of the vehicle |
| $\delta_{Wheel}$ | is the steering angle at the front wheels |
| $\delta_{Steering}$ | is the steering wheel angle |

The characteristic velocity is the point where the yaw rate has its maximum. This point is the same for all steering wheel angles. The following graphic shows the expected yaw rate under different driver inputs.



Because the friction coefficient of the road is not known, the output of the linear bicycle model is limited with the commonly supposed physical limits $\left(a_y/V_{X_{CoG}}\right)$.

The following illustration shows the Simulink representation of the expected vehicle behavior.




**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| a_y_Vehicle_CoG | [m/s$^2$] | Lateral vehicle acceleration in center of gravity (CoG) |
| Angle_SteeringWheel | [deg] | Steering wheel angle |
| i_Steering_Mean | [] | Mean steering ratio |
| v_x_Vehicle_CoG | [km/h] | Longitudinal vehicle velocity (CoG) |
| WheelBase | [m] | Vehicle wheelbase |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 📖). |
| YawRate_Expected | [rad/s] | Expected yaw rate |

**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Const_v_ch | [km/h] | Characteristic vehicle velocity |

**Processing information**

The following formula describes how the characteristic velocity can be calculated [Mit04].

$$V_{ch}^2 = \frac{c_{\alpha F} c_{\alpha R} l^2}{m(c_{\alpha R} l_R - c_{\alpha F} l_V)}$$

where:

| | |
|---|---|
| $V_{ch}$ | is the characteristic velocity |
| $c_{\alpha F}$ | is the front cornering stiffness |
| $c_{\alpha R}$ | is the rear cornering stiffness |
| $m$ | is the vehicle mass |
| $l$ | is the wheelbase of the vehicle |
| $l_F$ | is the length of the CoG to the front wheel |
| $l_R$ | is the length of the CoG to the rear wheel |

Typical values of the characteristic velocity are 70-120 km/h. If the characteristic velocity cannot be calculated (e.g., if the cornering stiffness is unknown), the value can be determined via simulation. For this, the vehicle dynamics simulation must be parameterized with a moderate driving maneuver so that the vehicle drives in a stable working point. Then, the characteristic velocity parameter can be changed so that the current and expected yaw rate have the same value.

**Related topics**

References

Expected Vehicle Behavior (ModelDesk Parameterizing 📖)
History of the EXPECTED_VEHICLE_BEHAVIOR Block............................................................. 104

# Current Slip

**Description**

The current slip is required to observe if a wheel is blocked and ABS must be active, or to detect if the wheels have lost traction on the road to activate ASR.

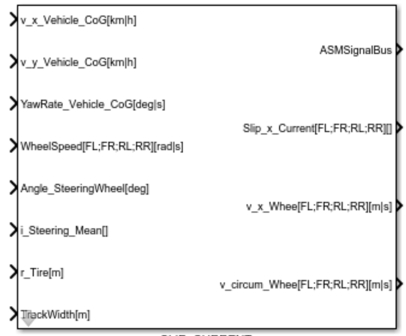
The current longitudinal slip of each tire is calculated from the vehicle velocity and the wheel speed. The sign for decelerating (brake) slip values is negative and positive for accelerating slip.

$$\lambda_x = \frac{\omega r_W - v_{Wx}}{v_{Wx}}$$

where:

| | |
|---|---|
| $\lambda_x$ | is the longitudinal slip |
| $v_{Wx}$ | is the vehicle longitudinal velocity at the wheel center |
| $\omega$ | is the rotational wheel speed |
| $r_W$ | is the tire radius |

The following illustration shows the Simulink representation of the current slip.




## Inports

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| Angle_SteeringWheel | [deg] | Steering wheel angle |
| i_Steering_Mean | [] | Mean steering ratio |
| r_Tire | [m] | Tire radius |
| TrackWidth | [m] | Vehicle track width |
| v_y_Vehicle_CoG | [km/h] | Lateral vehicle velocity (CoG) |
| v_x_Vehicle_CoG | [km/h] | Longitudinal vehicle velocity (CoG) |
| WheelSpeed | [rad/s] | Wheel speed for each wheel |
| YawRate_Vehicle_CoG | [deg/s] | Vehicle yaw rate in center of gravity (CoG) |

## Outports

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 🕮). |
| Slip_x_Current | [] | Longitudinal slip for each wheel |
| v_circum_Whee | [m/s] | Circumference velocity of each wheel |
| v_x_Wheel | [m/s] | Longitudinal translational wheel velocity for each wheel |

## Related topics

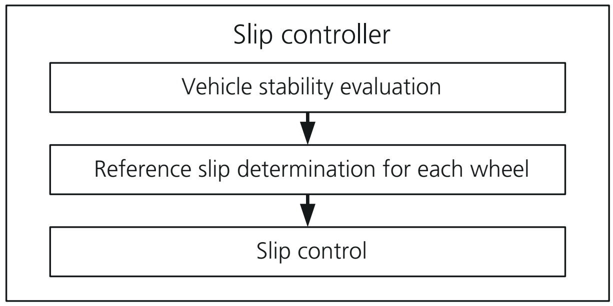
References

# Slip Controller

### Description

The slip controller determines if an ABS, ESP, or ASR function must be active and controls the inlet and outlet valves of each wheel brake cylinder.

The following illustration displays the structure of the Slip Controller model.




### Vehicle stability evaluation

The slip controller evaluates the stability of the vehicle and determines if a control mode must be activated.

**ABS** ABS is activated if the vehicle velocity is positive and the absolute current slip of at least one wheel is greater than the ideal ABS/ESP slip, which is a parameter of the slip controller.

**ESP** ESP is activated if the vehicle velocity is positive and the yaw rate error (difference between current yaw rate and expected yaw rate) is greater than the yaw rate threshold, which is a parameter of the slip controller.

**ASR** ASR is activated if the accelerator pedal position is greater than the accelerator pedal threshold (parameter of the slip controller) and the absolute current slip is greater than the ideal ASR slip, which is a parameter of the slip controller.

Each switch point is implemented with a relay functionality with dynamic threshold to hide toggling effects.

### Reference slip determination

Depending on the controller mode ABS, ESP, or ASR, the individual reference slip value for each wheel is determined.

For ABS and ASR, the ideal ABS/ESP and ASR slip values (parameter of the slip controller) are set as slip reference values.

For ESP, the control function has to determine which wheels to brake in which driving conditions.

The following table shows which wheel is braked under which driving condition.

| Turn direction | Positive yaw rate error | Negative yaw rate error |
|---|---|---|
| Right turn | Oversteer<br>Wheel to brake : front left | Understeer<br>Wheel to brake : rear right |

| Turn direction | Positive yaw rate error | Negative yaw rate error |
|---|---|---|
| Left turn | Understeer<br>Wheel to brake : rear left | Oversteer<br>Wheel to brake : front right |

For the braked wheels, the ideal ABS/ESP slip value (parameter of the slip controller) is set. For the unbraked wheels, a slip value of zero is set as reference slip. In extreme driving situations, for example, situations with high yaw rate error or high yaw rate acceleration, additional wheels are braked and the reference slip value is increased.

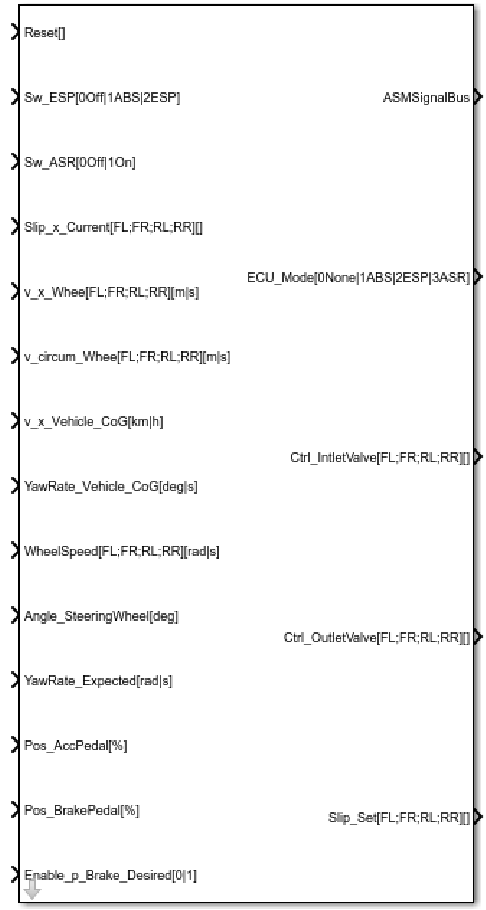
If the ESP is active during a driver brake intervention, the ideal ABS/ESP slip value is set as reference value for all wheels. For the wheel that has to be braked more strongly to stabilize the vehicle, the value is increased.

**Slip control**

The reference and current slip are used for the slip control algorithm to calculate the in- and outlet valve actuation. The ABS and ESP control rate parameters determine the valve control dynamics. A low value results in a slow valve and therefore slow wheel speed control and a high value results in a fast control. The control rate parameter must have a value between zero and one.

In the ABS control mode, the wheel deceleration for high current slip values is considered by the slip control algorithm. The maximum wheel deceleration parameter defines at which wheel deceleration the inlet valve is to be closed completely. This affects how fast the valve is closed. A high deceleration value results in a slow and small deceleration value in a fast valve and therefore wheel speed control.

The following illustration shows the Simulink representation of the slip controller.




SLIP_CONTROLLER

**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| Angle_SteeringWheel | [deg] | Steering wheel angle |
| Enable_p_Brake_Desired | [0\|1] | Flag that indicates if braking pressure is required from an external ECU (e.g., ACC ECU) |
| Pos_AccPedal | [%] | Position of accelerator pedal |
| Pos_BrakePedal | [%] | Position of brake pedal |
| Reset | [] | Reset |
| Slip_x_Current | [] | Current longitudinal slip |
| Sw_ASR | [0\|1] | Switch for ASR functionality (to activate ASR, Sw_ESP must be set to ABS or ESP)<br>▪ 0: Off<br>▪ 1: On |
| Sw_ESP | [0\|1\|2] | Switch for ESP functionality:<br>▪ 0: Off |

| Name | Unit | Description |
|---|---|---|
| | | ▪ 1: ABS<br>▪ 2: ESP |
| v_circum_Whee | [m/s] | Circumference wheel velocity for each wheel |
| v_x_Vehicle_CoG | [km/h] | Longitudinal vehicle velocity (CoG) |
| v_x_Wheel | [m/s] | Longitudinal translational wheel velocity for each wheel |
| YawRate_Expected | [rad/s] | Expected yaw rate |
| YawRate_Vehicle_CoG | [deg/s] | Vehicle yaw rate in center of gravity (CoG) |
| WheelSpeed | [rad/s] | Wheel speed of each wheel |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 📖). |
| Ctrl_IntletValve | [] | Control signal of inlet valves (normally open) of each wheel<br>▪ 0: Valve fully open<br>▪ Const_Ctrl_Max (e.g. 1): Valve fully closed |
| Ctrl_OutletValve | [] | Control signal of outlet valves (normally closed) of each wheel<br>▪ 0: Valve fully closed<br>▪ Const_Ctrl_Max (e.g. 1): Valve fully open |
| ECU_Mode | [0\|1\|2\|3] | ECU mode that indicates if an ECU intervention is active:<br>▪ 0: None<br>▪ 1: ABS<br>▪ 2: ESP<br>▪ 3: ASR |
| Slip_Set | [] | Absolute reference slip set value |

**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Const_CtrlRate_ABS | [0_1] | Valve control rate ABS |
| Const_CtrlRate_ESP | [0_1] | Valve control rate ESP |
| Const_a_Max_Wheel | [m/s$^2$] | Maximum wheel deceleration to close inlet valve completely |
| Const_AccPosThresh_ASR | [%] | Accelerator pedal position threshold to activate ASR |
| Const_Ctrl_Max | [] | Maximum value of valve control signal to open/close the valve cross section completely |
| Const_SlipIdeal | [] | Ideal absolute slip for ABS and ESP |
| Const_SlipIdeal_ASR | [] | Ideal absolute slip for ASR |

| Name | Unit | Description |
|---|---|---|
| Map_YawRateThresh_ESP | [m/s$^2$] | Yaw rate threshold (difference between current and expected yaw rate) to activate ESP [m/s$^2$]=f(v) |
| Step size | [s] | Simulation step size |

**Related topics**

References

Slip Controller (ModelDesk Parameterizing 📖)

# Pump Controller

**Description**

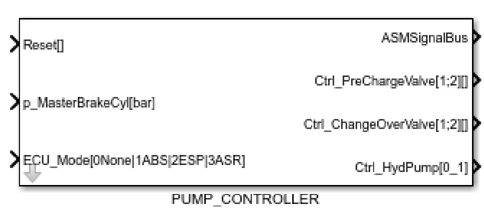
Depending on the slip controller state (see Slip Controller on page 63), the pump controller determines if the hydraulic pump and the pre-charge and change-over valves must be activated.

The hydraulic pump (see Pump on page 39) is used to pump the hydraulic fluid back from the braking circuit reservoir (see Reservoir on page 30) to the fluid reservoir of the master brake cylinder or to build up braking pressure without brake intervention by the driver. Therefore, the hydraulic pump is switched on if the ABS, ESP, or ASR are active. If ABS, ESP or ASR mode is set from active to inactive, the pump is switched off with a short time delay.

The pre-charge valve is switched on if the hydraulic pump is active and the brake pedal is not pressed. This ensures that the pump can force braking fluid from the fluid reservoir of the master brake cylinder to the braking circuit.

The change-over valve is switched on if the ESP or ASR is active to ensure that pressure is built up in the hydraulic pump.

The following illustration shows the Simulink representation of the pump controller.



**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| ECU_Mode | [0\|1\|2\|3] | ECU mode that indicates if an ECU intervention is active:<br>▪ 0: None<br>▪ 1: ABS<br>▪ 2: ESP<br>▪ 3: ASR |
| p_MasterBrakeCyl | [bar] | Master brake cylinder pressure |
| Reset | [] | Reset |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 📖). |
| Ctrl_ChangeOverValve | [] | Control signal for change-over valves 1 and 2 (normally open)<br>▪ 0: Valve fully open<br>▪ 1: Valve fully closed |
| Ctrl_HydPump | [0_1] | Control signal for hydraulic pump |
| Ctrl_PreChargeValve | [] | Control signal for pre-charge valves 1 and 2 (normally closed)<br>▪ 0: Valve fully closed<br>▪ 1: Valve fully open |

**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Step size | [s] | Simulation step size |

**Related topics**

References

## Torque Request ESP

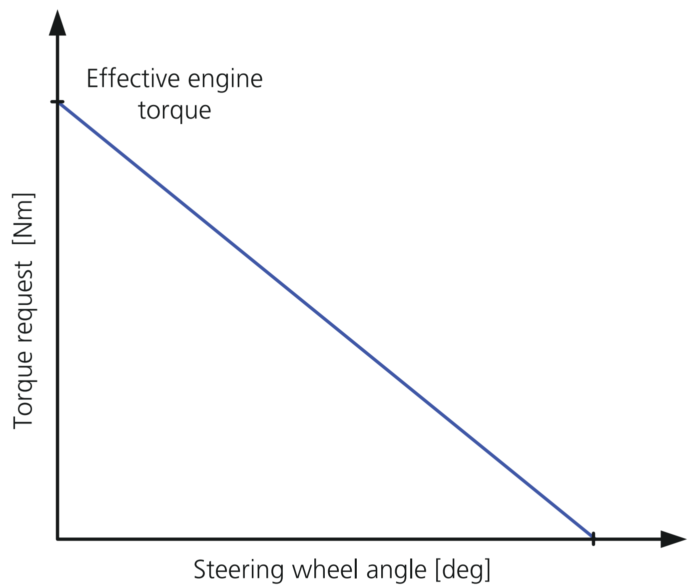
**Description**

During an ESP or ASR intervention the Soft ECU ESP sends a torque request to the combustion engine ECU to decrease the engine torque.

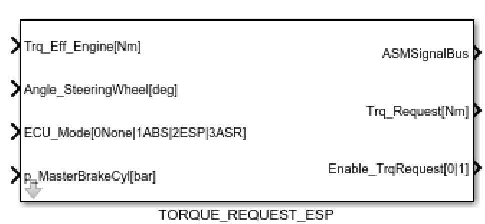
If the ASR or ESP is activated, a percentage value of the current effective engine torque, at this point in time, is set as torque request value. The percentages are defined as parameters for an ASR and ESP intervention.

If ASR mode is set from active to inactive, the torque request is deactivated with a short time delay to hide toggling effects.

Alternatively, during an ESP intervention the value of the torque request can be defined to be steering wheel-dependent. If the ESP is switched to active, the torque request value is calculated from a linear relation of torque request and the steering wheel angle. The steering wheel angle where the torque request value should be zero is defined as parameter. The following illustration displays this behavior.




The following illustration shows the Simulink representation of the torque request ESP model.



**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| Angle_SteeringWheel | [deg] | Steering wheel angle |
| ECU_Mode | [0\|1\|2\|3] | ECU mode that indicates if an ECU intervention is active:<br>▪ 0: None<br>▪ 1: ABS<br>▪ 2: ESP<br>▪ 3: ASR |
| p_MasterBrakeCyl | [bar] | Master brake cylinder pressure |
| Trq_Eff_Engine | [Nm] | Effective engine torque |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 🕮). |
| Enable_TrqRequest | [0\|1] | Enable flag for torque request<br>▪ 0: Disable<br>▪ 1: Enable |
| Trq_Request | [Nm] | Torque request value |

**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Const_Angle_ZeroTrq | [deg] | Steering wheel angle with zero torque request |
| Const_TrqRequest_ASR | [%] | Torque request of ASR in % of current engine torque at ASR activation |
| Const_TrqRequest_ESP | [%] | Torque request of ESP in % of current engine torque at ESP activation |
| Sw_TrqRequest | [0\|1] | Switch for torque request:<br>▪ 0: Off<br>▪ 1: On |
| Sw_TrqRequestSet_ESP | [0\|1] | Switch for torque request to set ESP:<br>▪ 0: Constant % of engine torque<br>▪ 1: Steering wheel angle-dependent |
| Step size | [s] | Simulation step size |

**Related topics**

References

History of the TORQUE_REQUEST_ESP Block........................................................................111
Torque Request ESP (ModelDesk Parameterizing 📖)

# Map Inputs

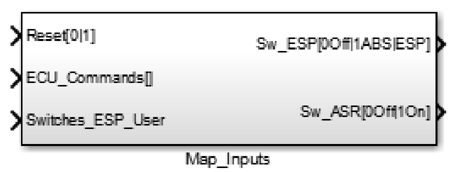
## Map Inputs

**Description**

The Map_Inputs subsystem provides the user signals for the soft ECU brake subsystem.

The Switches_ESP_User input signal bus includes the ESP user switch signals from the UserInterface subsystem. The Sw_ESP_Control_Mode signal is included in the signal bus and defines if the soft ECU user signals are set via constant blocks of the UserInterface or via user signals of the maneuver scheduler which are defined within the Scenario Editor.

The following illustration shows the Simulink representation of the model.




**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| ECU_Commands | [] | ECU command from the maneuver scheduler, where the numerical value of this signal has the following meaning:<br>▪ 2010: ECU functionality Off<br>▪ 2011: ECU functionality ABS<br>▪ 2012: ECU functionality ESP<br>▪ 2020: ASR On<br>▪ 2021: ASR Off |
| Reset | [0\|1] | Reset |
| Switches_ESP_User | [] | Signal bus with ESP user switch signals from MDLUserInterface subsystem |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| Sw_ASR | [0\|1] | Switch for ASR functionality:<br>▪ 0: Off<br>▪ 1: On |

| Name | Unit | Description |
|---|---|---|
| Sw_ESP | [0\|1\|2] | Switch for ESP functionality:<br>▪ 0: Off<br>▪ 1: ABS<br>▪ 2: ESP |

**Related topics**

References

Maneuver Scheduler (ASM Environment Reference 📖)

# Models

**Where to go from here**

Information in this section

## Overview of the Models

**Introduction**

The library contains basic and advanced models for brake hydraulics and soft ECU.

**Brake hydraulics model**

The ASM Brake Hydraulics Library contains the master brake cylinder and two brake hydraulics demos.

**Master Brake Cylinder** Refer to Master Brake Cylinder on page 33.

**Brake Hydraulics Basic** The basic demo includes a simple simulation of the braking circuit dynamics. Refer to Brake Hydraulics Basic Model on page 77.

**Brake Hydraulics (Advanced)** The advanced demo is for simulating a complete standard ESP brake hydraulics system, including wheel brake cylinder, different types of valves, accumulators, chambers, and pumps. Refer to Brake Hydraulics (Advanced) Model on page 79.

**Soft ECU model**

The ASM Brake Hydraulics Library contains two soft ECU brake demo models.

**Soft ECU Brake Basic** The basic demo model includes only the DESIRED_BRAKE_PRESSURE block to calculate the desired master brake cylinder pressure from a braking torque request. A brake torque request is sent from ACC or hybrid ECUs, for example. Refer to Soft ECU Brake Basic on page 85.

**Soft ECU Brake (Advanced)** The advanced demo model can be used for simulating an ESP ECU system that improves the vehicle's stability with an electronic stability program (ESP) including an anti-lock braking system (ABS) and an anti-slip regulation (ASR) functionality. The DESIRED_BRAKE_PRESSURE block to calculate a desired master brake cylinder pressure from a braking torque request is also included in this model. Refer to Soft ECU Brake (Advanced) Model on page 87.

## How to Replace a Model

**Subject**

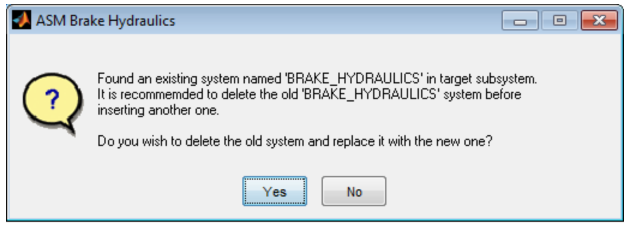
You can use either the basic or the advanced demo for simulation.

**Method**

**To replace a model**

1 To replace one Soft ECU Brake model or one brake hydraulics with another, drag it from the library and drop it to the model.

A confirmation prompt opens.




2 Click Yes to delete the old demo.

---

**Result**

The old model is deleted and replaced by the new one. The new demo is connected automatically.

# Brake Hydraulics Basic Model

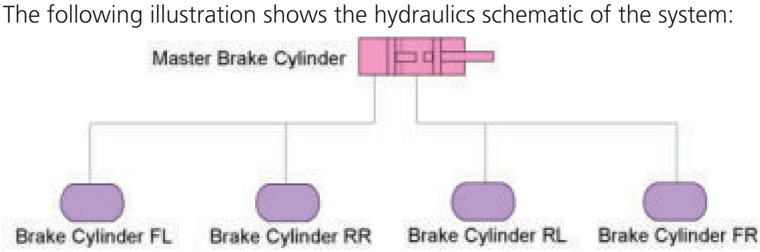
---

**Overview**

The BRAKE_HYDRAULICS_BASIC model simulates the braking system for a passenger car without an Electronic Stability Program (ESP). The braking circuit system calculates the pressure in the brake cylinder for each wheel.

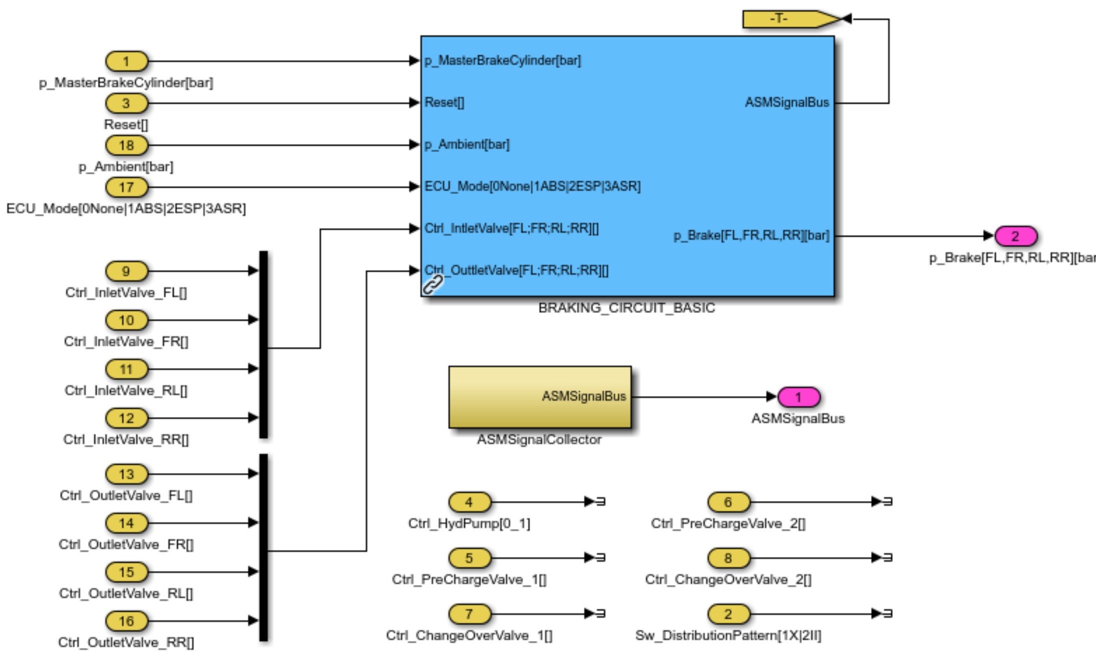
> **Note**
>
> The friction pad and brake disc model is not part of the brake hydraulics library.

The following illustration shows the hydraulics schematic of the system:




The following illustration shows the first-level model structure with the braking circuit subsystem. The control signal inputs from the vehicle stability control system have no function in the basic brake hydraulics model. They are used for interface compatibility with the advanced brake hydraulics model.

For detailed descriptions of the subsystems, refer to the relevant chapters.




## Inports

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| Ctrl_ChangeOverValve_1 | [] | Dummy input |
| Ctrl_ChangeOverValve_2 | [] | Dummy input |
| Ctrl_HydPump | [] | Dummy input |
| Ctrl_InletValve_FL | [] | Dummy input |
| Ctrl_InletValve_FR | [] | Dummy input |
| Ctrl_InletValve_RL | [] | Dummy input |
| Ctrl_InletValve_RR | [] | Dummy input |
| Ctrl_OutletValve_FL | [] | Dummy input |
| Ctrl_OutletValve_FR | [] | Dummy input |
| Ctrl_OutletValve_RL | [] | Dummy input |
| Ctrl_OutletValve_RR | [] | Dummy input |
| Ctrl_PreChargeValve_1 | [] | Dummy input |
| Ctrl_PreChargeValve_2 | [] | Dummy input |
| ECU_Mode | [] | Dummy input |
| ECU_Mode | [0\|1\|2\|3] | Dummy input |

| Name | Unit | Description |
|---|---|---|
| p_Ambient | [bar] | Dummy input |
| p_MasterBrakeCylinder | [bar] | Master brake cylinder pressure |
| Reset | [] | Resets all integrators in the block to their initial conditions |
| Sw_DistributionPattern | [1\|2] | Dummy input |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 📖). |
| p_Brake[FL,FR,RL,RR] | [bar] | Vector with wheel cylinder braking pressure front left, front right, rear left, and rear right |

**Subsystems**

- Braking Circuit Basic on page 44

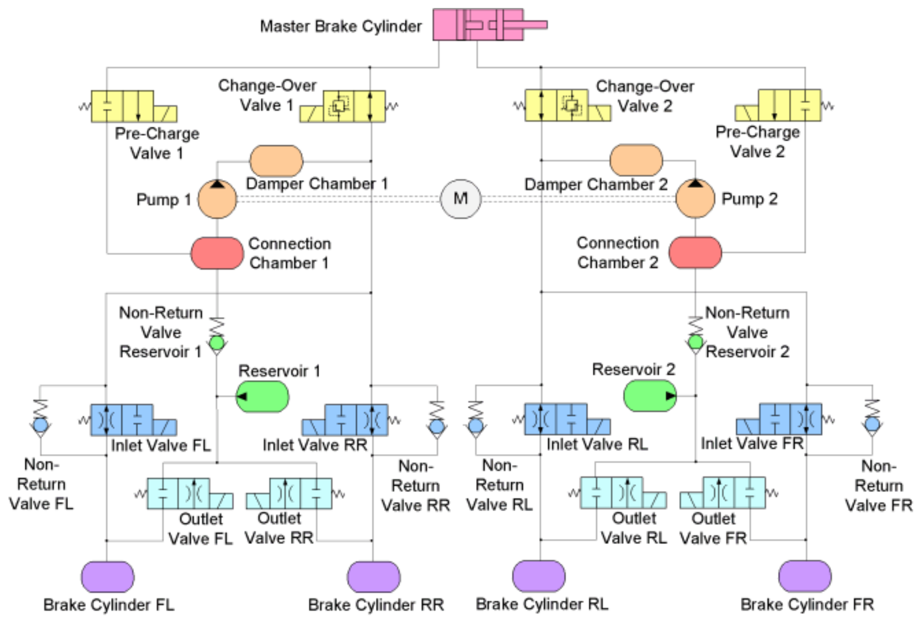
# Brake Hydraulics (Advanced) Model

**Overview**

The BRAKE_HYDRAULICS model simulates the brake hydraulics of a standard Electronic Stability Program (ESP) braking system for passenger cars. It consists of a dual-circuit transmission system with a diagonal distribution pattern (X distribution) in which each circuit brakes a front wheel and the diagonally opposite rear wheel or a II distribution pattern to simulate a system with a front-axle/rear-axle split.

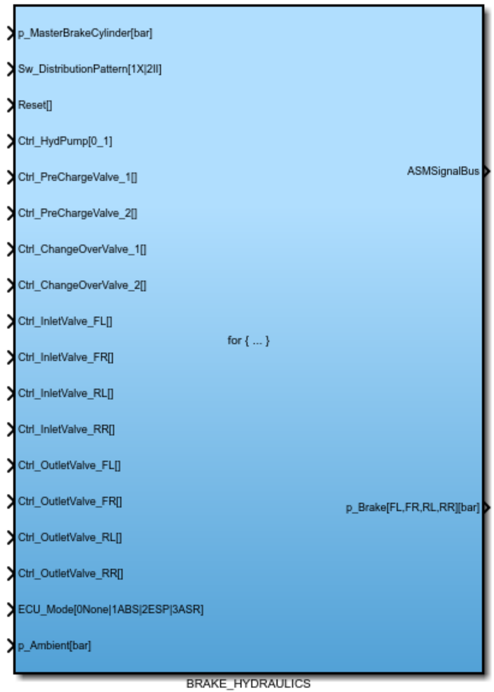
The model contains all components that are necessary to simulate a state-of-the-art ESP braking system (for example, Bosch 8.0 and 9.0, Continental Teves MK25 and MK60, TRW), such as valves, chambers, accumulators, and braking cylinders.

The following illustration depicts the hydraulics schematic diagram of the modeled system for an X distribution pattern:




Detailed descriptions of the subsystems can be found in the corresponding chapters.

Differential equations that describe hydraulic systems often lead to stiff terms, because of the low compressibility of the hydraulic fluid. This effect occurs in a high gear if the system contains components with a low volume. The simulation of these stiff differential equations leads to numerical problems if the simulation step size is not small enough [Bor03]. To avoid this numerical instability, the brake hydraulics system is calculated n-times during one large sampling step using a For-Iterator. For more information on the For-Iterator subsystem, refer to Local Subsystem Oversampling (ASM User Guide 📖). The valves are modeled as an orifice with a continuously controllable cross-section. The control signal can represent a linear regulation of the valve flow area or a valve control current value for a nonlinear behavior where the flow area depends on this control current and the pressure difference. The control signal type used is set in the Valve Control Switches component.



BRAKE_HYDRAULICS

**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| Ctrl_ChangeOverValve_1 | [0_1] | Control signal change-over valve braking circuit 1 |
| Ctrl_ChangeOverValve_2 | [0_1] | Control signal change-over valve braking circuit 2 |
| Ctrl_HydPump | [0_1] | Control signal hydraulics pump |
| Ctrl_InletValve_FL | [0_1] | Control signal inlet valve front left, braking circuit 1 |
| Ctrl_InletValve_FR | [0_1] | Control signal inlet valve front right, braking circuit 2 |
| Ctrl_InletValve_RR | [0_1] | Control signal inlet valve rear right, braking circuit 1 |
| Ctrl_InletValve_RL | [0_1] | Control signal inlet valve rear left, braking circuit 2 |
| Ctrl_OutletValve_FL | [0_1] | Control signal outlet valve front left, braking circuit 1 |
| Ctrl_OutletValve_FR | [0_1] | Control signal outlet valve front right, braking circuit 2 |
| Ctrl_OutletValve_RL | [0_1] | Control signal outlet valve rear left, braking circuit 2 |
| Ctrl_OutletValve_RR | [0_1] | Control signal outlet valve rear right, braking circuit 1 |
| Ctrl_PreChargeValve_1 | [0_1] | Control signal precharge valve braking circuit 1 |
| Ctrl_PreChargeValve_2 | [0_1] | Control signal precharge valve braking circuit 2 |
| ECU_Mode | [0\|1\|2\|3] | ECU mode that indicates which ECU intervention is active:<br>▪ 0: None<br>▪ 1: ABS<br>▪ 2: ESP<br>▪ 3: ASR |

| Name | Unit | Description |
|---|---|---|
| p_Ambient | [bar] | Ambient pressure |
| p_MasterBrakeCylinder | [bar] | Master brake cylinder pressure |
| Reset | [] | Resets all the integrators in the block to their initial conditions. |
| Sw_DistributionPattern | [1\|2] | Switch to select the distribution pattern<br>▪ 1: X distribution<br>▪ 2: II distribution |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 📖). |
| p_Brake[FL,FR,RL,RR] | [bar] | Vector with wheel cylinder braking pressure front left, front right, rear left, and rear right |

**Subsystems**


- Common Fluid Parameters on page 48
- Braking Circuit and Wheel Units Subsystem of the Advanced Brake Hydraulics on page 82


**Related topics**

Basics

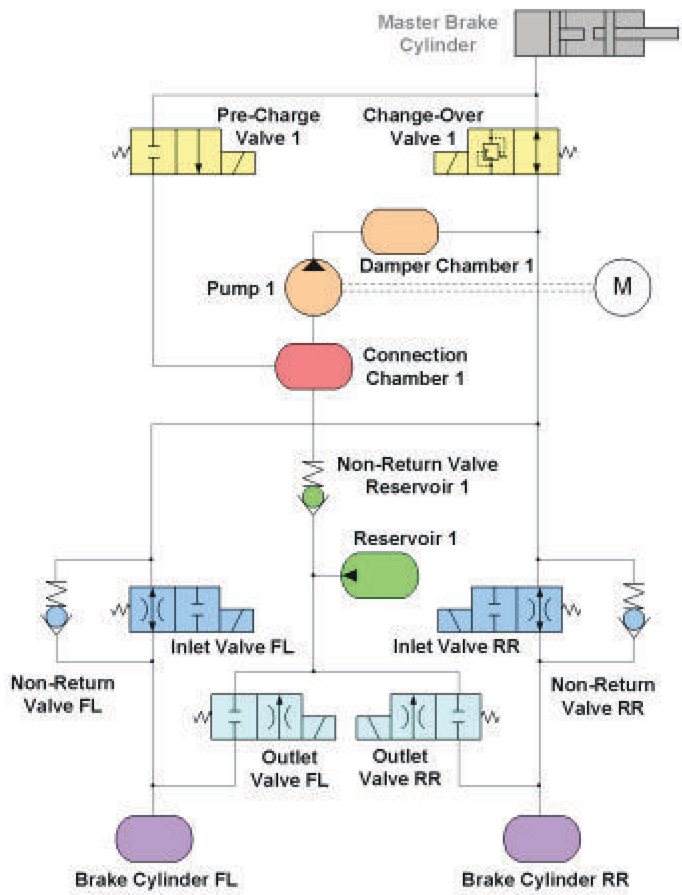
Local Subsystem Oversampling (ASM User Guide 📖)

# Braking Circuit and Wheel Units Subsystem of the Advanced Brake Hydraulics

**Overview**

BrakingCircuit_1 simulates the hydraulic system of the front left and rear right wheels for an X distribution pattern or the front left and front right wheel for a II distribution pattern. BrakingCircuit_2 simulates the hydraulic system of the front right and rear left wheels for an X distribution pattern or the rear left and rear right wheel for a II distribution pattern.

The following illustrations show the components of BrakingCircuit_1 for an X distribution pattern. It consists of the two wheel braking cylinders with their inlet and outlet valves which are placed in the model as Unit subsystem for each wheel, the reservoir with the non-return valve, the hydraulic pump with the damper chamber, and the precharge and change-over valve which are placed in the BrakingCircuit subsystem of the Simulink model. The connection chamber is required as a connecting element between the two valves and the pump. The physical representation of this chamber is the volume of the hydraulic pipe.




The mathematical description of the braking circuit leads to a system of differential equations with five state variables. These are the pressures in the damper chamber, the connection chamber, and the reservoir, and the volume of the two wheel brake cylinders. The equation can be written as

$$\begin{bmatrix} \dot{p}_{Damp} \\ \dot{V}_{WBC,rear} \\ \dot{V}_{WBC,front} \\ \dot{p}_{\mathrm{Res}} \\ \dot{p}_{Con} \end{bmatrix} = \begin{bmatrix} \frac{E}{V_{Damp}}\left[q_{CO}(p_{MBC}, p_{Damp}) - q_{IN,rear}(p_{Damp}, V_{WBC,rear}) - q_{IN,front}(p_{Damp}, V_{WBC,front}) + q_{Pump}(p_{Con}, p_{Damp}) + q_{Non\mathrm{Ret},rear}(V_{WBC,rear}, p_{Damp}) + q_{Non\mathrm{Ret},front}(V_{WBC,front}, p_{Damp})\right] \\ q_{IN,rear}(p_{Damp}, V_{WBC,rear}) - q_{OUT,rear}(V_{WBC,rear}, p_{res}) - q_{Non\mathrm{Ret},rear}(V_{WBC,rear}, p_{Damp}) \\ q_{IN,front}(p_{Damp}, V_{WBC,front}) - q_{OUT,front}(V_{WBC,front}, p_{\mathrm{Res}}) - q_{Non\mathrm{Ret},front}(V_{WBC,front}, p_{Damp}) \\ p_{\mathrm{Res}} \cdot \left(\frac{p_{\mathrm{Res}}}{p_{0,\mathrm{Res}}}\right)^{\frac{1}{\kappa}} \cdot \frac{\kappa}{V_{0,\mathrm{Res}}} \cdot \left[q_{OUT,rear}(V_{WBC,rear}, p_{\mathrm{Res}}) + q_{OUT,front}(V_{WBC,front}, p_{\mathrm{Res}}) - q_{Non\mathrm{Ret},\mathrm{Res}}(p_{\mathrm{Res}}, p_{Con})\right] \\ \frac{E}{V_{Con}}\left[q_{PC}(p_{MBC}, p_{Con}) + q_{Non\mathrm{Ret},\mathrm{Res}}(p_{\mathrm{Res}}, p_{Con}) - q_{Pump}(p_{Con}, p_{Damp})\right] \end{bmatrix}$$

where:

| | |
|---|---|
| $p_{<\text{index}>}$ | is the pressure |
| $q_{<\text{index}>}$ | is the fluid quantity |
| $V_{<\text{index}>}$ | is the volume |
| $E_{<\text{index}>}$ | is the bulk module of the brake fluid |

The indices stand for the components as follows:

| Index | Meaning |
|---|---|
| Damp | Damper chamber |
| Con | Connection chamber |
| Res | Reservoir |
| WBZ,front | Wheel brake cylinder front left |
| WBZ,rear | Wheel brake cylinder rear right |
| MBC | Master brake cylinder |
| CO | Change-over valve |
| PC | Precharge valve |
| IN,front | Inlet valve front left |
| IN,rear | Inlet valve rear right |
| OUT,front | Outlet valve front left |
| OUT,rear | Outlet valve rear right |
| NonRet,front | Non-return valve front left |
| NonRet,rear | Non-return valve rear right |
| NonRet,Res | Non-return valve reservoir |
| Pump | Hydraulic pump |

Detailed descriptions of the equations of the individual components can be found in the following chapters.

**Subsystems**


- Precharge Valve on page 12
- Change-over Valve on page 14
- Inlet Valve on page 19
- Outlet Valve on page 21
- Continuous Valve Control on page 23
- Table-Based Valves on page 25
- Valve Control Switches on page 49
- Non-Return Valve (at Reservoir) on page 17
- Reservoir on page 30
- Damper Chamber on page 27
- Connection Chamber on page 29
- Wheel Brake Cylinder on page 36
- Pump on page 39


# Braking Circuit Basic Model of the Advanced Brake Hydraulics

**Overview**

The Braking Circuit Basic model simulates a simplified braking circuit system based on a first-order time delay approach where the wheel brake cylinder pressure is controlled by the inlet and outlet valve control signal. This system can be used if the parameters of the advanced braking circuit are not available or if a basic simulation of the braking circuit together with the Soft ECU Brake is sufficient.

There are two Braking Circuit Basic models:

- Braking Circuit Basic on page 44
- Braking Circuit Basic Controlled on page 42

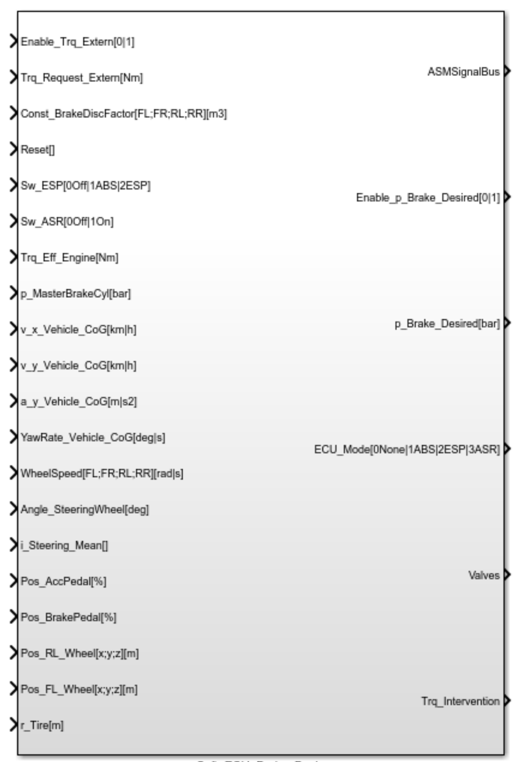
# Soft ECU Brake Basic

**Description**

In applications, such as ACC or hybrid systems, the ECUs send external brake torque requests to the brake ECU. For this, the DESIRED_BRAKE_PRESSURE block is included in the Soft ECU Brake Basic model to calculate a desired master brake cylinder pressure from a braking torque request.

The vehicle stability is not improved by the Soft ECU Brake Basic model. For this, the advanced Soft ECU Brake system with the electronic stability program (ESP) is required, see Soft ECU on page 53.

The following illustration shows the Simulink representation of the Soft ECU Brake Basic model.



**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| a_y_Vehicle_CoG | [m/s$^2$] | Dummy inport |
| Angle_SteeringWheel | [deg] | Dummy inport |
| Const_BrakeDiscFactor | [m$^3$] | Brake disc factor for each wheel |
| Enable_Trq_Extern | [0\|1] | Enable brake torque request:<br>▪ 0: Disable<br>▪ 1: Enable |
| i_Steering_Mean | [] | Dummy inport |
| p_MasterBrakeCyl | [bar] | Dummy inport |
| Pos_AccPedal | [%] | Dummy inport |
| Pos_RL_Wheel | [m] | Dummy inport |
| Pos_FL_Wheel | [m] | Dummy inport |
| r_Tire | [m] | Dummy inport |
| Reset[] | [] | Dummy inport |
| Sw_ASR | [0\|1] | Dummy inport |
| Sw_ESP | [0\|1\|2] | Dummy inport |
| Trq_Eff_Engine | [Nm] | Dummy inport |
| Trq_Request_Extern | [Nm] | Brake torque request for deceleration |
| v_x_Vehicle_CoG | [km/h] | Dummy inport |
| v_y_Vehicle_CoG | [km/h] | Dummy inport |
| YawRate_Vehicle_CoG | [deg/s] | Dummy inport |
| WheelSpeed | [rad/s] | Dummy inport |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 🕮). |
| ECU_Mode | [0\|1\|2\|3] | Dummy outport |
| Enable_p_Brake_Desired | [0\|1] | Enable flag for desired brake pressure:<br>▪ 0: Disable<br>▪ 1: Enable |
| p_Brake_Desired | [bar] | Desired brake pressure |
| Trq_Intervention | [] | Dummy outport |
| Valves | [] | Dummy outport |

**Related topics**

References



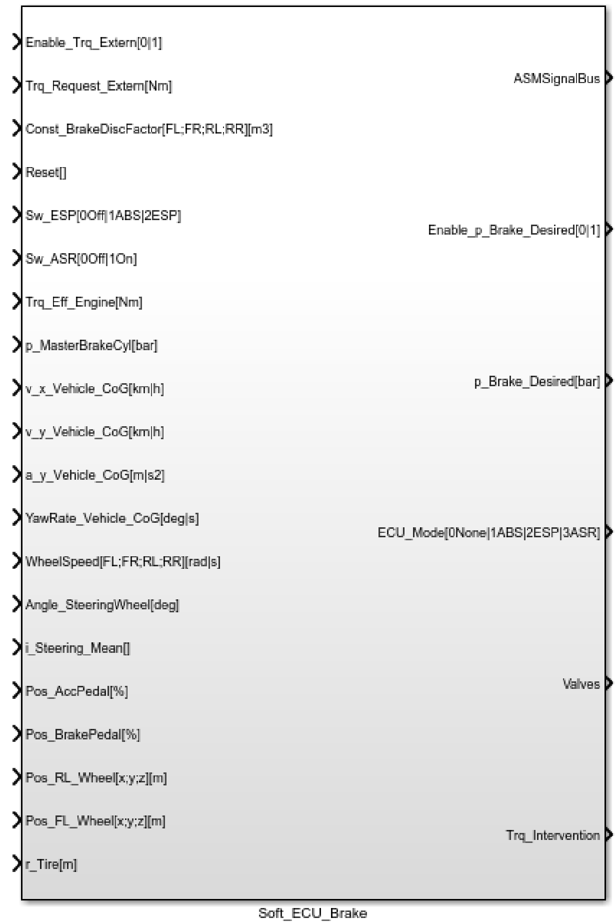
# Soft ECU Brake (Advanced) Model

**Description**

The advanced Soft ECU Brake model consists of two components. The Soft ECU ESP that improves the vehicle's stability with an electronic stability program (ESP) including an anti-lock braking system (ABS), and an anti-slip regulation (ASR) functionality (see Soft ECU ESP on page 56).

In addition, external brake torque requests, for example, from an ACC or hybrid ECU, are supported. For this, the **DESIRED_BRAKE_PRESSURE** block is included in the model to calculate the desired master brake cylinder pressure from a braking torque request (Desired Brake Pressure on page 54).

The following illustration shows the Simulink representation of the Soft ECU Brake model.




**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| a_y_Vehicle_CoG | [m/s$^2$] | Lateral vehicle acceleration |
| Angle_SteeringWheel | [deg] | Steering wheel angle |
| Const_BrakeDiscFactor | [m$^3$] | Brake disc factor for each wheel |
| Enable_Trq_Extern | [0\|1] | Enable brake torque request:<br>▪ 0: Disable<br>▪ 1: Enable |
| i_Steering_Mean | [] | Mean steering ratio |
| p_MasterBrakeCyl | [bar] | Pressure of master brake cylinder |
| Pos_AccPedal | [%] | Position of accelerator pedal |
| Pos_FL_Wheel | [m] | Position vector (x,y,z) to front left wheel |
| Pos_RL_Wheel | [m] | Position vector (x,y,z) to rear left wheel |

| Name | Unit | Description |
|---|---|---|
| r_Tire | [m] | Tire radius |
| Reset[] | [] | Reset |
| Sw_ASR | [0\|1] | Switch for ASR functionality (to activate ASR, Sw_ESP must be set to ABS or ESP):<br>▪ 0: Off<br>▪ 1: On |
| Sw_ESP | [0\|1\|2] | Switch for ESP functionality:<br>▪ 0: Off<br>▪ 1: ABS<br>▪ 2: ESP |
| Trq_Eff_Engine | [Nm] | Effective engine torque |
| Trq_Request_Extern | [Nm] | External brake torque request for deceleration |
| v_x_Vehicle_CoG | [km/h] | Longitudinal vehicle velocity (CoG) |
| v_y_Vehicle_CoG | [km/h] | Lateral vehicle velocity (CoG) |
| WheelSpeed | [rad/s] | Wheel speed for each wheel |
| YawRate_Vehicle_CoG | [deg/s] | Yaw rate of vehicle in center of gravity (CoG) |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide). |
| ECU_Mode | [0\|1\|2\|3] | ECU mode that indicates if an ECU intervention is active:<br>▪ 0: None<br>▪ 1: ABS<br>▪ 2: ESP<br>▪ 3: ASR |
| Enable_p_Brake_Desired | [0\|1] | Enable flag for desired brake pressure:<br>▪ 0: Disable<br>▪ 1: Enable |
| p_Brake_Desired | [bar] | Desired brake pressure |
| Trq_Intervention | [] | Structured signal bus with torque request signals |
| Valves | [] | Structured signal bus with pump and valve control signals |

**Related topics**

References

Desired Brake Pressure........ 54
Soft ECU ESP........ 56

# Blocks from Former Versions

## Pressure Intervention Soft ECU

**Description**

It must be possible to decelerate the vehicle without a driver brake pedal action. This brake intervention is controlled by a real or soft ECU, for example. Refer to Desired Brake Pressure on page 54. If the enable inport flag is set, the block outport pressure is set with the maximum value of the master brake cylinder pressure or the desired external pressure. If the enable flag is not set, the block outport pressure is the master brake cylinder pressure.

The following illustration shows the Simulink representation of the pressure intervention soft ECU model:


**Inports**

The following table shows the inports:

| Name | Unit | Description |
|---|---|---|
| Enable_p_Brake_Desired | [0\|1] | Enable the desired brake pressure as block output pressure<br>▪ 0: Disable<br>▪ 1: Enable |
| p_Ambient | [bar] | Ambient pressure |
| p_Brake_Desired | [bar] | Desired brake pressure that is set as block output pressure if the enable flag is set |
| p_MasterBrakeCylinder | [bar] | Master brake cylinder pressure |

**Outports**

The following table shows the outports:

| Name | Unit | Description |
|---|---|---|
| ASMSignalBus | [] | Signal bus that contains signals of ASM components. Refer to ASMSignalBus (ASM User Guide 🕮). |
| p_Influenced | [bar] | Influenced output pressure |

**Parameters**

The following table shows the parameters:

| Name | Unit | Description |
|---|---|---|
| Step size | [s] | Simulation step size |

**Related topics**

References

Desired Brake Pressure........................................................................................................... 54
History of the PRESSURE_INTERVENTION_SOFT_ECU Block................................................... 108

# New Features/Migration History of the ASM Brake Hydraulics Blockset

**Introduction**

The following topics provide an overview of the changes to the ASM products in the previous Releases.

For an overview of the new features and migration of the current Release, refer to Automotive Simulation Models (ASM) (New Features and Migration 📖).

**Where to go from here**

Information in this section

# General Changes to the ASM Brake Hydraulics Blockset

**Release 2016-B**

**Look-up table migration** The discontinued Simulink blocks Lookup and Lookup2D in the ASM library blocks were updated to the new standard Simulink Look-up table (n-D) block. Refer to Changes to all ASM Products (ASM User Guide 🕮).

The look-up tables were updated in the following blocks within this library:

- BRAKE_CYLINDER_FL
- BRAKE_CYLINDER_FR
- BRAKE_CYLINDER_RL
- BRAKE_CYLINDER_RR
- CONTINUOUS_CTRL_CHANGE_OVER_VALVE_1
- CONTINUOUS_CTRL_CHANGE_OVER_VALVE_2
- CONTINUOUS_CTRL_INLET_VALVE_FL
- CONTINUOUS_CTRL_INLET_VALVE_FR
- CONTINUOUS_CTRL_INLET_VALVE_RL
- CONTINUOUS_CTRL_INLET_VALVE_RR
- CONTINUOUS_CTRL_OUTLET_VALVE_FL
- CONTINUOUS_CTRL_OUTLET_VALVE_FR
- CONTINUOUS_CTRL_OUTLET_VALVE_RL
- CONTINUOUS_CTRL_OUTLET_VALVE_RR
- CONTINUOUS_CTRL_PRE_CHARGE_VALVE_1
- CONTINUOUS_CTRL_PRE_CHARGE_VALVE_2
- CONTINUOUS_VALVE_CONTROL
- CHANGE_OVER_VALVE_1_TABLE
- CHANGE_OVER_VALVE_2_TABLE
- INLET_VALVE_FL_TABLE
- INLET_VALVE_FR_TABLE
- INLET_VALVE_RL_TABLE
- INLET_VALVE_RR_TABLE
- MASTER_BRAKE_CYLINDER
- OUTLET_VALVE_FL_TABLE
- OUTLET_VALVE_FR_TABLE
- OUTLET_VALVE_RL_TABLE
- OUTLET_VALVE_RR_TABLE
- PRE_CHARGE_VALVE_1_TABLE
- PRE_CHARGE_VALVE_2_TABLE
- PUMP_1
- PUMP_2

**License check of ASM Utils blocks** The ASM_UTILS license was discontinued. The ASM Utils blocks now check the license of the ASM blockset in which they are used.

The Utils blocks in the following blocks within this library were updated:
- BRAKE_CYLINDER_FL
- BRAKE_CYLINDER_FR
- BRAKE_CYLINDER_RL
- BRAKE_CYLINDER_RR
- CHANGE_OVER_VALVE_1
- CHANGE_OVER_VALVE_2
- CONNECTION_CHAMBER_1
- CONNECTION_CHAMBER_2
- DAMPER_CHAMBER_1
- DAMPER_CHAMBER_2
- INLET_VALVE_FL
- INLET_VALVE_FR
- INLET_VALVE_RL
- INLET_VALVE_RR
- NON_RETURN_VALVE_FL
- NON_RETURN_VALVE_FR
- NON_RETURN_VALVE_RES_1
- NON_RETURN_VALVE_RES_2
- NON_RETURN_VALVE_RL
- NON_RETURN_VALVE_RR
- OUTLET_VALVE_FL
- OUTLET_VALVE_FR
- OUTLET_VALVE_RL
- OUTLET_VALVE_RR
- PRE_CHARGE_VALVE_1
- PRE_CHARGE_VALVE_2
- RESERVOIR_1
- RESERVOIR_2

**Release 2013-A**

Simulation of X- and II-brake system structures is now possible.

**Release 6.2**

This blockset is now available in the operator version. It is a model variant specifically designed for offline simulation with Simulink®.

The model offers the same functionality, simulation quality, and parameterization options as the standard simulation package. The operator version is compatible with the standard model (developer version) and can be parameterized in ModelDesk, the parameterization software.

The fundamental difference of this model is the way the library components are implemented: They are encapsulated in separate systems to ensure good performance during Simulink simulation. The systems are accessible from the model so that their input/output behavior can be studied.

# History of the BRAKE_CYLINDER Block

**Release 6.2**

A SIM.Step size parameter has been added to the block. Now all the parameters of a library block are parameterized via the mask.

A MDL.BrkHyd.UpSampleFaktor parameter has been added to the block. The upsample factor for oversampling the brake hydraulics has been added to the masks. Now all the parameters of a library block are parameterized via the mask.

**Note**

The simulation step size (SIM.Step size parameter) and the upsample factor (MDL.BrkHyd.UpSampleFaktor parameter) are not accessible from ModelDesk. To change these parameters, edit the `sim_ini.m` function in `%PROJECT_ROOT%\Simulation.current\IniFiles`.

**Related topics**

References



# History of the BRAKE_HYDRAULICS_SWITCHES_VALVE_CONTROL_x Block

**Release 2016-B**

The valve control mode is renamed from digital to linear and from continuous to nonlinear. The functionality of the control mode is not changed.

**Release 7.3**

The switch has been moved from BRAKE_HYDRAULICS_SWITCHES_VALVE_CONTROL_x to support the multi-instance feature.

# History of the BRAKE_HYDRAULICS_VARIANT_SWITCHES Block

**Release 7.3**

Goto/from tags have been moved out of the library block to support the multi-instance feature.

# History of the BRAKING_CIRCUIT_BASIC Block

**Release 2017-A**

Dummy inports have been added to the block for compatibility with the BRAKING_CIRCUIT_BASIC_CTRL block. The functionality was not changed.

**Release 6.2**

A SIM Step size parameter has been added to the block. Now all the parameters of a library block are parameterized via the mask.

**Related topics**

References

Braking Circuit Basic........................................ 44

# History of the BRAKING_CIRCUIT_BASIC_CTRL Block

**Release 2017-A**

This block is new. It simulates the wheel brake cylinder pressure of each wheel depending on the inlet and outlet valve control signals and the master brake cylinder pressure. The brake pressure dynamics are based on a first-order time delay model approach.

**Related topics**

References

Braking Circuit Basic Controlled........................................ 42

# History of the CHANGE_OVER_VALVE_x Block

**Release 7.3**

To be compatible to the operator version, the model structure below the mask has been changed.

**Release 6.5**

Valves are sometimes continuously controlled by an ECU via a control current. The flow area of these valves depends on the valve control current and the pressure difference. The new blocks are based on a look-up table that calculates the valve control signal from the valve control current and the pressure difference.

The following new blocks are available:
- CHANGE_OVER_VALVE_1
- CHANGE_OVER_VALVE_2

**Release 6.2**

New Sw_nom_state mask parameter to switch between the nominal valve open states normally closed or normally open.

New Sw_FlowDirection mask parameter to switch the valve flow directions between one-way and two-way.

**Related topics**

References

Change-over Valve........................................................................................................................... 14

## History of the CHANGE_OVER_VALVE_x_TABLE Block

**Release 7.1**

The new Sw_FlowDirection_TableValve mask parameter was added to switch between the valve flow directions one-way and two-way.

The new Sw_Mirror_TableValve mask parameter was added. This is a switch parameter to enable or disable the mirror of the table for negative pressure difference.

During migration the default values of the new Sw_FlowDirection_TableValve and Sw_Mirror_TableValve parameters are set so that the simulation results match former results. No additional migration steps are therefore required.

**Release 6.5**

The new blocks are based on a look-up table that calculates the valve flow from a control signal (for example, the valve control current) and the pressure difference. This model approach can be useful if the fluid flow was measured on a test bench or is available from a data sheet.

The following blocks are available:
- CHANGE_OVER_VALVE_1_TABLE
- CHANGE_OVER_VALVE_2_TABLE

## History of the COMMON_FLUID_PARAMETERS Block

**Release 2013-A**

Outports for common parameters were added.

**Related topics**

References

Common Fluid Parameters ........ 48

## History of the CONNECTION_CHAMBER Block

**Release 6.2**

A **SIM Step size** parameter has been added to the block. Now all the parameters of a library block are parameterized via the mask.

A **MDL.BrkHyd.UpSampleFaktor** parameter has been added to the block. The upsample factor for oversampling the brake hydraulics has been added to the masks. Now all the parameters of a library block are parameterized via the mask.

**Note**

The simulation step size (**SIM.Step size** parameter) and the upsample factor (**MDL.BrkHyd.UpSampleFaktor** parameter) are not accessible from ModelDesk. To change these parameters, edit the`sim_ini.m` function in `%PROJECT_ROOT%\Simulation.current\IniFiles`

**Related topics**

References

Connection Chamber ........ 29

## History of the CONTINUOUS_CTRL_INLET_VALVE_x Block

**Release 7.3**

The **MDL.BrkHyd.OutletValve.FR.Map_ContinuousValveControl** parameter has been renamed to **MDL.BrkHyd.InletValve.FR.Map_ContinuousValveControl**.

**Release 6.5**

Valves are sometimes continuously controlled by an ECU via a control current. The flow area of these valves depends on the valve control current and the pressure difference. The new blocks are based on a look-up table that calculates the valve control signal from the valve control current and the pressure difference.

The following new blocks are available:

- CONTINUOUS_CTRL_INLET_VALVE_FL
- CONTINUOUS_CTRL_INLET_VALVE_FR
- CONTINUOUS_CTRL_INLET_VALVE_RL
- CONTINUOUS_CTRL_INLET_VALVE_RR

**Related topics**

References

Continuous Valve Control........................................................ 23

## History of the CONTINUOUS_CTRL_OUTLET_VALVE_x Block

**Release 6.5**

Valves are sometimes continuously controlled by an ECU via a control current. The flow area of these valves depends on the valve control current and the pressure difference. The new blocks are based on a look-up table that calculates the valve control signal from the valve control current and the pressure difference.

The following blocks are new:

- CONTINUOUS_CTRL_OUTLET_VALVE_FL
- CONTINUOUS_CTRL_OUTLET_VALVE_FR
- CONTINUOUS_CTRL_OUTLET_VALVE_RL
- CONTINUOUS_CTRL_OUTLET_VALVE_RR

## History of the CONTINUOUS_CTRL_PRE_CHARGE_VALVE_x Block

**Release 6.5**

Valves are sometimes continuously controlled by an ECU via a control current. The flow area of these valves depends on the valve control current and the pressure difference. The new blocks are based on a look-up table that calculates the valve control signal from the valve control current and the pressure difference.

The following new blocks are available:
- CONTINUOUS_CTRL_PRE_CHARGE_VALVE_1
- CONTINUOUS_CTRL_PRE_CHARGE_VALVE_2

# History of the DAMPER_CHAMBER Block

**Release 6.2**

A SIM Step size parameter has been added to the block. Now all the parameters of a library block are parameterized via the mask.

A MDL.BrkHyd.UpSampleFaktor parameter has been added to the block. The upsample factor for oversampling the brake hydraulics has been added to the masks. Now all the parameters of a library block are parameterized via the mask.

**Note**

The simulation step size (SIM.Step size parameter) and the upsample factor (MDL.BrkHyd.UpSampleFaktor parameter) are not accessible from ModelDesk. To change these parameters, edit the `sim_ini.m` function in `%PROJECT_ROOT%\Simulation.current\IniFiles`.

**Related topics**

References

Damper Chamber.......... 27

# History of the DESIRED_BRAKE_PRESSURE Block

**Release 2017-B**

Memory was added to the DESIRED_BRAKE_PRESSURE block to avoid an algebraic loop in the ASM Operator mode.

**Related topics**

References

Desired Brake Pressure.......... 54

# History of the EXPECTED_VEHICLE_BEHAVIOR Block

| | |
|---|---|
| **Release 2017-A** | This block is new in the Soft ECU ESP subsystem. It simulates a vehicle bicycle model to calculate the expected yaw rate. |
| **Related topics** | References<br>Expected Vehicle Behavior........ 58 |

# History of the INLET_VALVE_x Block

| | |
|---|---|
| **Release 7.3** | To be compatible to the operator version, the model structure below the mask has been changed. |
| **Release 6.2** | New Sw_nom_state mask parameter to switch between the nominal valve open states normally closed or normally open.<br>New Sw_FlowDirection mask parameter to switch the valve flow directions between one-way and two-way. |
| **Related topics** | References<br>Inlet Valve........ 19 |

# History of the INLET_VALVE_x_TABLE Block

| | |
|---|---|
| **Release 7.1** | The new Sw_FlowDirection_TableValve mask parameter was added to switch between the valve flow directions one-way and two-way.<br>The new Sw_Mirror_TableValve mask parameter was added. This is a switch parameter to enable or disable the mirror of the table for negative pressure difference.<br>During migration the default values of the new Sw_FlowDirection_TableValve and Sw_Mirror_TableValve parameters are set so that the simulation results match former results. No additional migration steps are therefore required. |

| | |
|---|---|
| **Release 6.5** | The new blocks are based on a look-up table that calculates the valve flow from a control signal (for example, the valve control current) and the pressure difference. This model approach can be useful if the fluid flow was measured on a test bench or is available from a data sheet.<br>The following blocks are available:<br>▪ INLET_VALVE_FL_TABLE<br>▪ INLET_VALVE_FR_TABLE<br>▪ INLET_VALVE_RL_TABLE<br>▪ INLET_VALVE_RR_TABLE |
| **Related topics** | References<br> |

## History of the MASTER_BRAKE_CYLINDER Block

| | |
|---|---|
| **Release 2019-A** | In brake-by-wire mode, the MASTER_BRAKE_CYLINDER block uses the ambient pressure as the output pressure if no brake pressure is specified via the Enable_p_Brake_Desired[0\|1] inport. |
| **Release 2018-B** | Two new inports were added to the MASTER_BRAKE_CYLINDER block:<br>▪ p_Brake_Desired<br>▪ Enable_p_Brake_Desired<br>In addition, a new brake-by-wire brake cylinder model was added to the block to set an externally requested brake pressure. |
| **Release 6.5** | The MASTER_BRAKE_CYLINDER block supports the connection to the brake booster model from the ASM Vehicle Dynamics Blockset.<br>The MASTER_BRAKE_CYLINDER block has the new F_PushRod[N] inport and the new A_Piston[m2] outport. During migration, the new outport is automatically connected to a terminator block and the inport is connected to a constant block of value 0. |
| **Release 6.2** | A new p_Ambient input port was added for the ambient pressure. The p_Ambient mask parameter was removed. |

**Related topics**

References



# History of the NON_RETURN_VALVE_RES_x Block

**Release 2019-B**

The block had internal adaptations. These have no effect on the simulation result and its functionality.

**Release 7.3**

To be compatible to the operator version, the model structure below the mask has been changed.

# History of the NON_RETURN_VALVE_x Block

**Release 7.3**

To be compatible to the operator version, the model structure below the mask has been changed.

**Related topics**

References



# History of the OUTLET_VALVE_x Block

**Release 7.3**

To be compatible to the operator version, the model structure below the mask has been changed.

**Release 6.2**

New Sw_nom_state mask parameter to switch between the nominal valve open states normally closed or normally open.

New Sw_FlowDirection mask parameter to switch the valve flow directions between one-way and two-way.

**Related topics**

References



## History of the OUTLET_VALVE_x_TABLE Block

**Release 7.1**

The new Sw_FlowDirection_TableValve mask parameter was added to switch between the valve flow directions one-way and two-way.

The new Sw_Mirror_TableValve mask parameter was added. This is a switch parameter to enable or disable the mirror of the table for negative pressure difference.

During migration the default values of the new Sw_FlowDirection_TableValve and Sw_Mirror_TableValve parameters are set so that the simulation results match former results. No additional migration steps are therefore required.

**Release 6.5**

The new blocks are based on a look-up table that calculates the valve flow from a control signal (for example, the valve control current) and the pressure difference. This model approach can be useful if the fluid flow was measured on a test bench or is available from a data sheet.

The following blocks are available:
- OUTLET_VALVE_FL_TABLE
- OUTLET_VALVE_FR_TABLE
- OUTLET_VALVE_RL_TABLE
- OUTLET_VALVE_RR_TABLE

## History of the PRE_CHARGE_VALVE_x Block

**Release 2019-B**

The block had internal adaptations. These have no effect on the simulation result and its functionality.

**Release 7.3**

To be compatible with the operator version, the model structure below the mask has been changed.

**Release 6.2**

New Sw_nom_state mask parameter to switch between the nominal valve open states normally closed or normally open.

New Sw_FlowDirection mask parameter to switch the valve flow directions between one-way and two-way.

**Related topics**

References

Precharge Valve........ 12

## History of the PRE_CHARGE_VALVE_x_TABLE Block

**Release 7.1**

The new Sw_FlowDirection_TableValve mask parameter was added to switch between the valve flow directions one-way and two-way.

The new Sw_Mirror_TableValve mask parameter was added. This is a switch parameter to enable or disable the mirror of the table for negative pressure difference.

During migration the default values of the new Sw_FlowDirection_TableValve and Sw_Mirror_TableValve parameters are set so that the simulation results match former results. No additional migration steps are therefore required.

**Release 6.5**

The new blocks are based on a look-up table that calculates the valve flow from a control signal (for example, the valve control current) and the pressure difference. This model approach can be useful if the fluid flow was measured on a test bench or is available from a data sheet.

The following new blocks are available:

- PRE_CHARGE_VALVE_1_TABLE
- PRE_CHARGE_VALVE_2_TABLE

## History of the PRESSURE_INTERVENTION_SOFT_ECU Block

**Release 7.2**

The model gets the brake pressure request from the soft ECU brake and the master brake cylinder, and provides the pressure value to the braking circuit.

| | |
|---|---|
| **Related topics** | References |



## History of the PUMP_CONTROLLER Block

| | |
|---|---|
| **Release 2019-B** | The block had internal adaptations. These have no effect on the simulation result and its functionality. |
| **Release 2017-A** | This block is new in the Soft ECU ESP subsystem. It controls the hydraulic pump and the precharge and change-over valves of the brake hydraulics. |
| **Related topics** | References |



## History of the RESERVOIR Block

**Release 6.2**

A **SIM Step size** parameter has been added to the block.

A **MDL.BrkHyd.UpSampleFaktor** parameter has been added to the block. The upsample factor for oversampling the brake hydraulics has been added to the mask.

Now all the parameters of a library block are parameterized via the mask.

**Note**

The simulation step size (**SIM.Step size** parameter) and the upsample factor (**MDL.BrkHyd.UpSampleFaktor** parameter) are not accessible from ModelDesk. To change these parameters, edit the `sim_ini.m` function in `%PROJECT_ROOT%\Simulation.current\IniFiles`.

**Related topics**

References

Reservoir ........ 30

## History of the SLIP_CONTROLLER Block

**Release 2017-A**

This block is new in the Soft ECU ESP subsystem. It determines the reference slip for each wheel. These values and the current slip are used to control the inlet and outlet valves of the brake hydraulics. The controller supports ABS, ESP, and ASR interventions.

## History of the SLIP_CURRENT Block

**Release 2017-A**

This block is new in the Soft ECU ESP subsystem. It calculates the current slip and velocities of each wheel.

**Related topics**

References

Current Slip ........ 61

## History of the SOFT_ECU_BRAKE Block

**Release 2017-A**

The SOFT_ECU_BRAKE block was renamed DESIRED_BRAKE_PRESSURE. The functionality did not changed.

**Release 7.2**

The Soft ECU Brake calculates a brake pressure from the requested braking torque. The brake pressure is used in the brake hydraulics subsystem to perform soft-ECU-controlled deceleration of the vehicle.

# History of the TORQUE_REQUEST_ESP Block

| | |
|---|---|
| **Release 2019-B** | The block had internal adaptations. These have no effect on the simulation result and its functionality. |
| **Release 2017-A** | This block is new in the Soft ECU ESP subsystem. It sets a torque request for the engine ECU during an ESP or ASR intervention. |

**Related topics**

References



# History of the Brake Hydraulics Demo Model

**Release 2018-B**

To adapt the structure of the brake hydraulics model to a battery electric and hybrid vehicle brake system (brake-by-wire), the master brake cylinder was moved outside the hydraulic demo model.

The PRESSURE_INTERVENTION_SOFT_ECU subsystem was deleted. Its functionality was integrated in the MASTER_BRAKE_CYLINDER block.

The general functionality of the demo model was not changed.

This applies to the following blocks:
- BRAKE_HYDRAULICS block
- BRAKE_HYDRAULICS_BASIC block

**Release 2017-A**

The dSPACE ASM Brake Hydraulics Library contains two new Soft ECU Brake demo models.

The *basic* demo includes only the Desired Brake Pressure model to calculate a desired master brake cylinder pressure from a braking torque request. A brake torque request is sent from ACC or hybrid ECUs, for example.

The *advanced* demo can be used for simulating an ESP ECU system that improves the vehicle's stability with an electronic stability program (ESP) including an anti-lock braking (ABS) and an anti-slip (ASR) functionality. The Desired Brake Pressure component to calculate a desired master brake cylinder pressure from a braking torque request is also included.

# Appendix

## Bibliography

**List of literature**

The following literature provides more details:

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