



Automotive Simulation Models (ASM)

## ASM Combustion Engine

- Diesel and Gasoline Engine Simulation
- Physical and Mean Value Simulations
- Exhaust System, Turbocharger



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# Virtual Test Benches

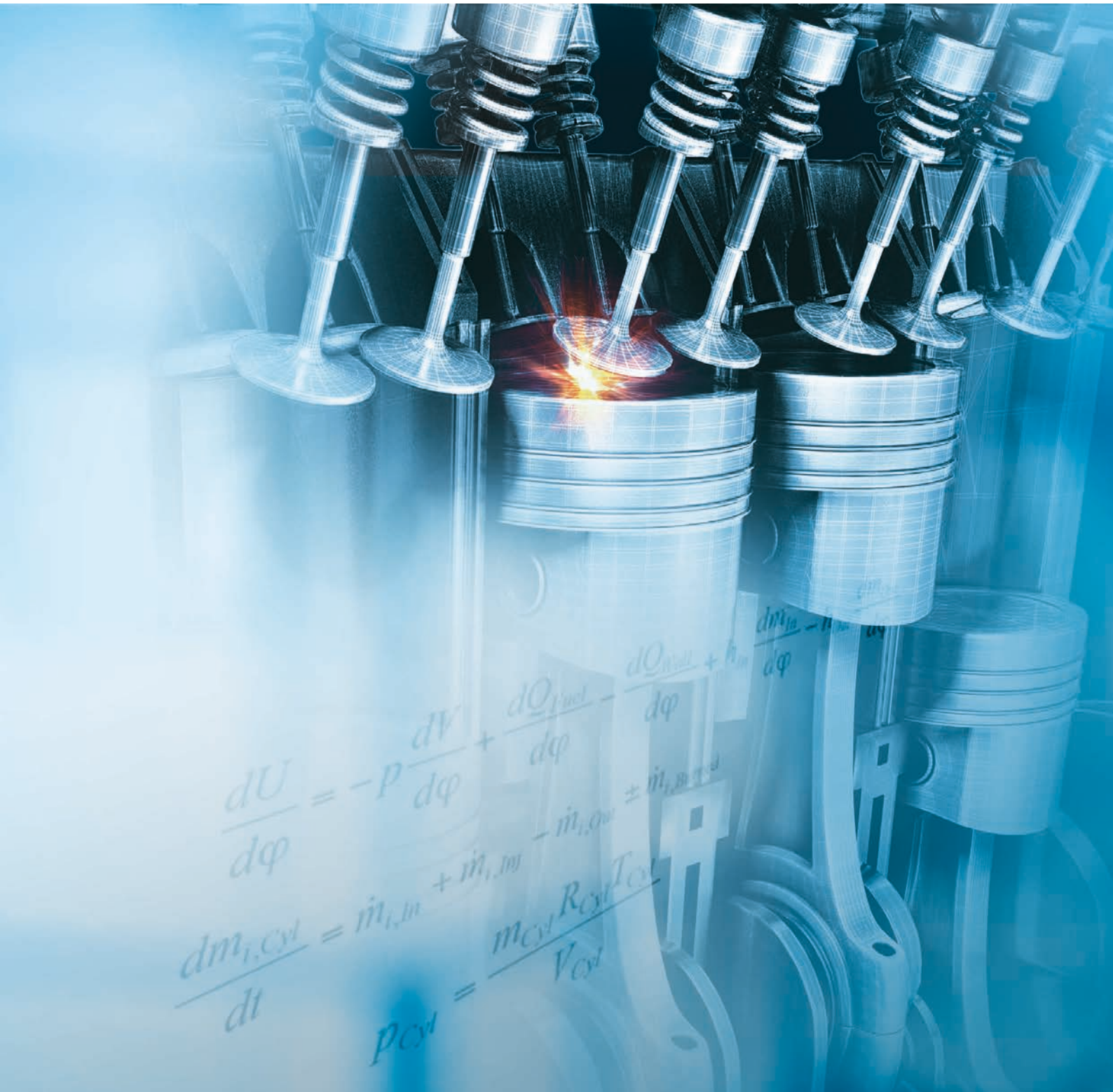
## Efficient Engine Controller Development

Whether you are working on next level emission compliance, developing fuel saving strategies, or going hybrid. There is one common question: How can you test new control software long before your engine is even ready? Do it virtually.

And how can you validate electronic control units (ECUs) before production release?

Again, virtual testing on a simulator is the industry-proven method. With configurable, off-shelf simulation models you are well equipped for tests in all development phases. Sit down, start the engine, and off you go on a virtual test drive at your desk. The advantages are clear: Quick and convenient testing and many savings compared to test beds or prototypes.





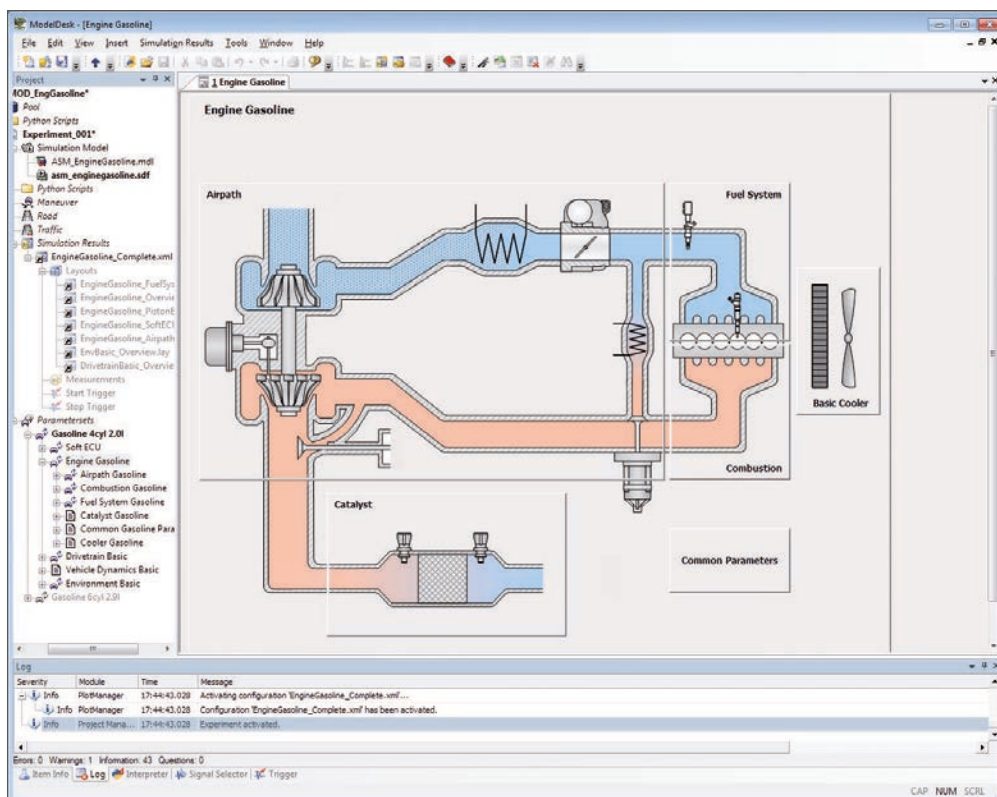


# The Simulation Workbench

## Automotive Simulation Models

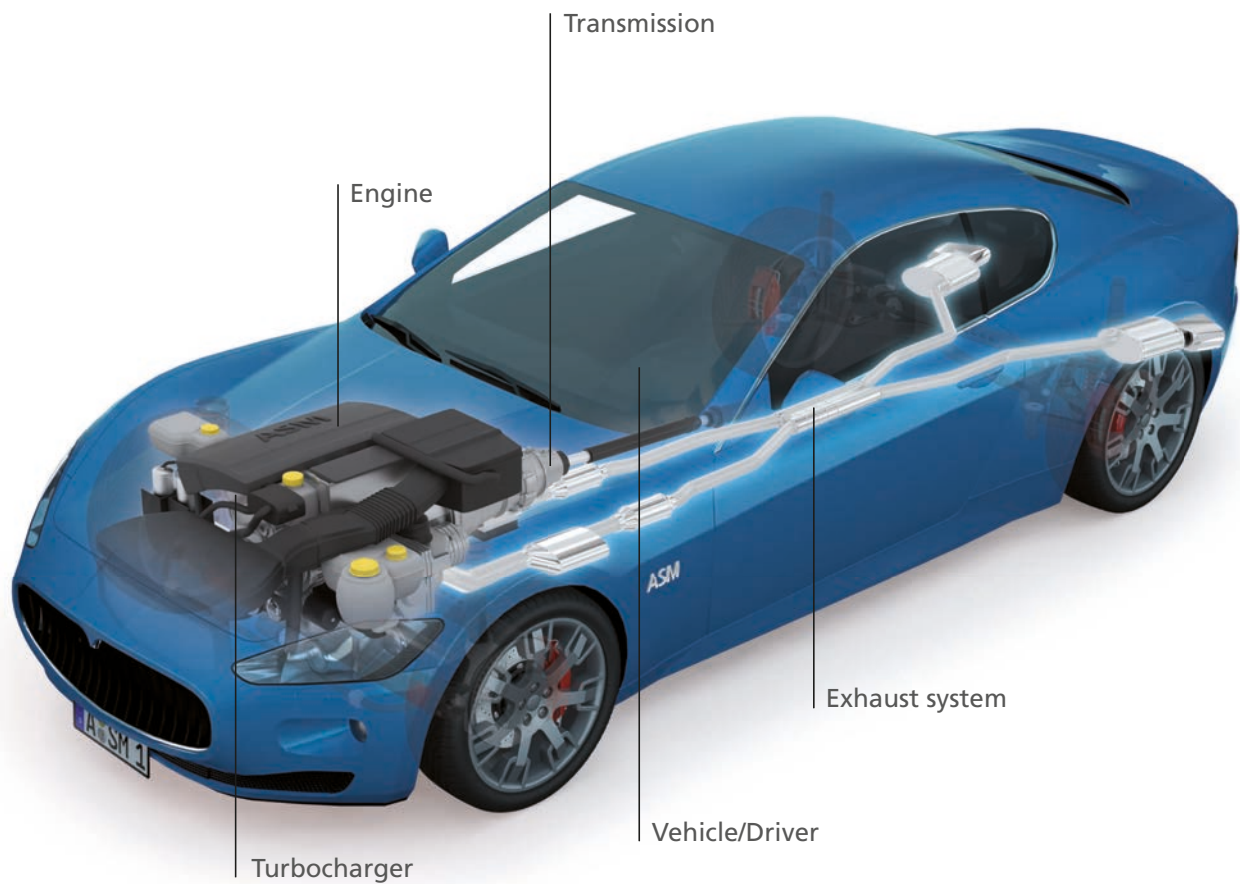
Automotive Simulation Models (ASM) by dSPACE are industry-proven virtual vehicle software. The ASM engine simulation models give you realistic engine, turbocharger and exhaust system behavior simulations in real time. The models are the ideal choice for function design and controller testing in model-based development processes.

Jump-start developments with easy-to-use validated tools: a comfortable user interface for all aspects of your tasks and high-performance simulation models that perform under the hood, ensuring precise simulation results.



## Comfortable User Interface

ModelDesk is the intuitive user interface for defining and initiating tests. Specify the engine and its components with easy-to-use graphical methods. Benefit from efficient workflows and seamless data management.



### High-Performance Models

ASM are open, validated Simulink models that major OEMs and suppliers rely on to develop controllers for all kinds of combustion engines. They support the whole development process from function design to ECU testing.

### Virtual Vehicle

ASM comprises models for engine, battery, suspension, traffic and many other components. You can easily combine them to build a whole virtual vehicle. ASM supports application areas such as combustion engines, vehicle dynamics, electric components and traffic, including the traffic environment.

# Overview

## Engine Simulation Software

ASM Engine supports a broad variety of application tasks in the area of combustion engine simulation. To provide what is needed for these areas, it consists of specialized simulation models and tools.

### Basic Software



**ASM Engine** is the base package for combustion engine simulation.  
**Page 12**

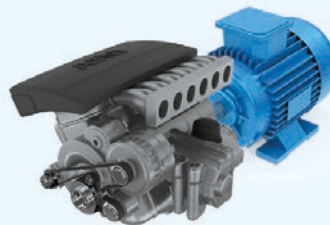


**ASM Engine Simulation Packages** offer ready-to-use configurations for diesel and gasoline engine simulation.  
**Page 26**

### Extension Software



**ASM Drivetrain Basic** simulates the transmission and axles and provides the driver functionality for longitudinal test drives.  
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**ASM Testbench** is a tool for testing the parameterization of engine models.  
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**ASM Diesel Exhaust System** is used to simulate a diesel aftertreatment system together with ASM Engine.  
**Page 36**





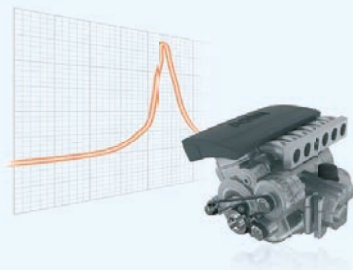
**ModelDesk** is the graphical user interface to manage simulations, parameterizations and parameter sets.

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**ASM Turbocharger** is used to simulate a physical turbocharger together with ASM Engine.

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**ASM InCylinder Optimizer** processes data for the parameterization of thermodynamic engine simulation.

**Page 47**



**ASM Packages** from different domains can be used to extend the detailed engine simulation for more comprehensive simulation tasks.

# Philosophy

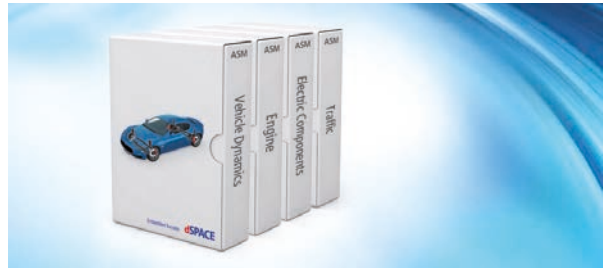
## Supports Model-Based Design

- Real-time-capable Simulink models
- Provides access to internal modeling details, down to block level
- Supports all stages of controller software development (MIL, SIL, HIL)
- Soft-ECU network
- Signal interfaces for automotive applications



## Ready-to-use Commercial-off-the-Shelf (COTS) Models

- One integrated tool chain for parameterization, validation and test automation
- Open documentation, including mathematical equations
- Supports migration, including between MATLAB releases
- Worldwide customer base and mature models



## Complete ASM Product Portfolio

- Supports all automotive-relevant modeling areas
- Easily combinable models for building virtual vehicles
- Different levels of model complexity (e.g., mean value, physical) for all controller design and test use cases



## Comprehensive Engineering and HIL Knowledge

- The one-stop supplier for all HIL-relevant tasks
- Customer training and worldwide support
- Combination of COTS models and customer-specific model engineering



# Combustion Engine Simulation

## Physical and Mean Value Real-Time Combustion Engine Simulation

### Features

- Open MATLAB®/Simulink® models
- Modeling approaches: mean value, physical
- For ECU testing and function development



### Engine Models

When electronic control units (ECUs) are developed for internal combustion engines, the requirements on emissions and fuel consumption reduction, hybridized drives and also comfort and safety aspects lead to ECU software that is complex and networked to a high degree. Developing the ECU functions involves various approaches, depending on the type of engine: from map-based methods up to closed-loop controls that evaluate the thermodynamic combustion process by means of sensors that specifically influence the combustion. The software functions are usually created

through model-based development. Hardware-in-the-loop (HIL) simulation has become the established method to validate the ECU software functions, integrating the ECU into a simulated environment. This requires not only a simulator, which provides the real-time computer and the electrical interfaces, but also suitable simulation models (called plant models) for the various engine types. A crucial requirement on the models is real-time capability. This creates a conflict between the necessary simulation accuracy and the available computing power.

### Mean Value Models

A mean value model calculates the state variables averaged for the entire engine cycle of each cylinder individually. Rotation angle-dependent variables, such as the torque, are superimposed onto the averaged variables for the selected cylinder via modulation.

### Benefit

Mean value models have excellent real-time behavior. They are accurate enough to give plausible signals to conventional engine controls, which makes it possible to check the ECUs' functions and diagnostic capabilities.

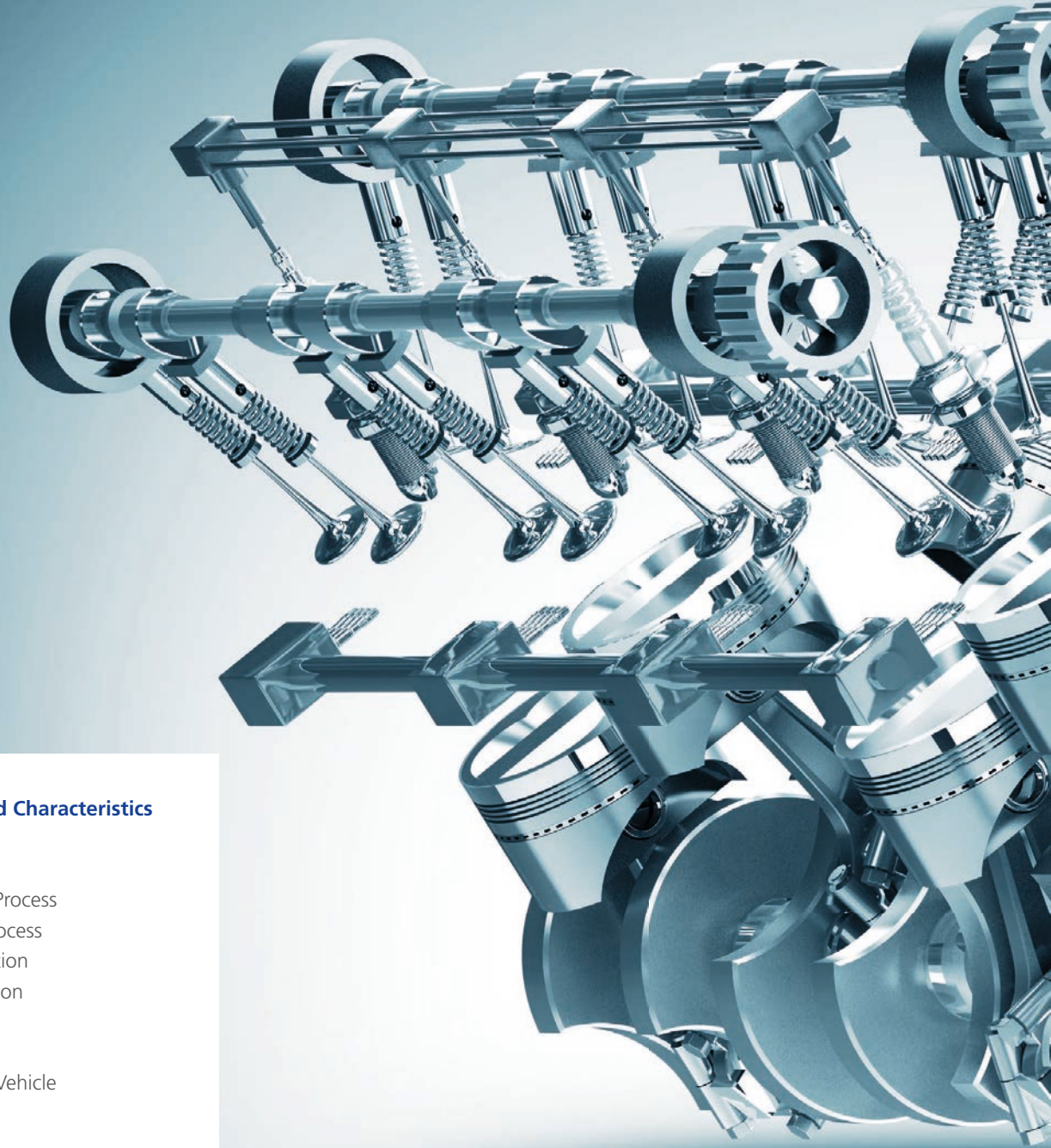
### InCylinder Models

InCylinder Models simulate the state variables of the combustion engine consistently at each time instance and synchronously to the crank angle. On real-time computers, they help calculate the thermodynamic processes in the cylinder and the gas mass flow through the intake and exhaust valves synchronously to the crankshaft rotation.

### Benefit

The quality that simulations reach with InCylinder Models is rather high. InCylinder Models provide crank-angle-synchronous representations of the effects of the combustion and gas exchange process for each cylinder. The models are also required for ECUs that evaluate the cylinder pressure and control each intake and exhaust valve individually in timing and lift.

# ASM Engine



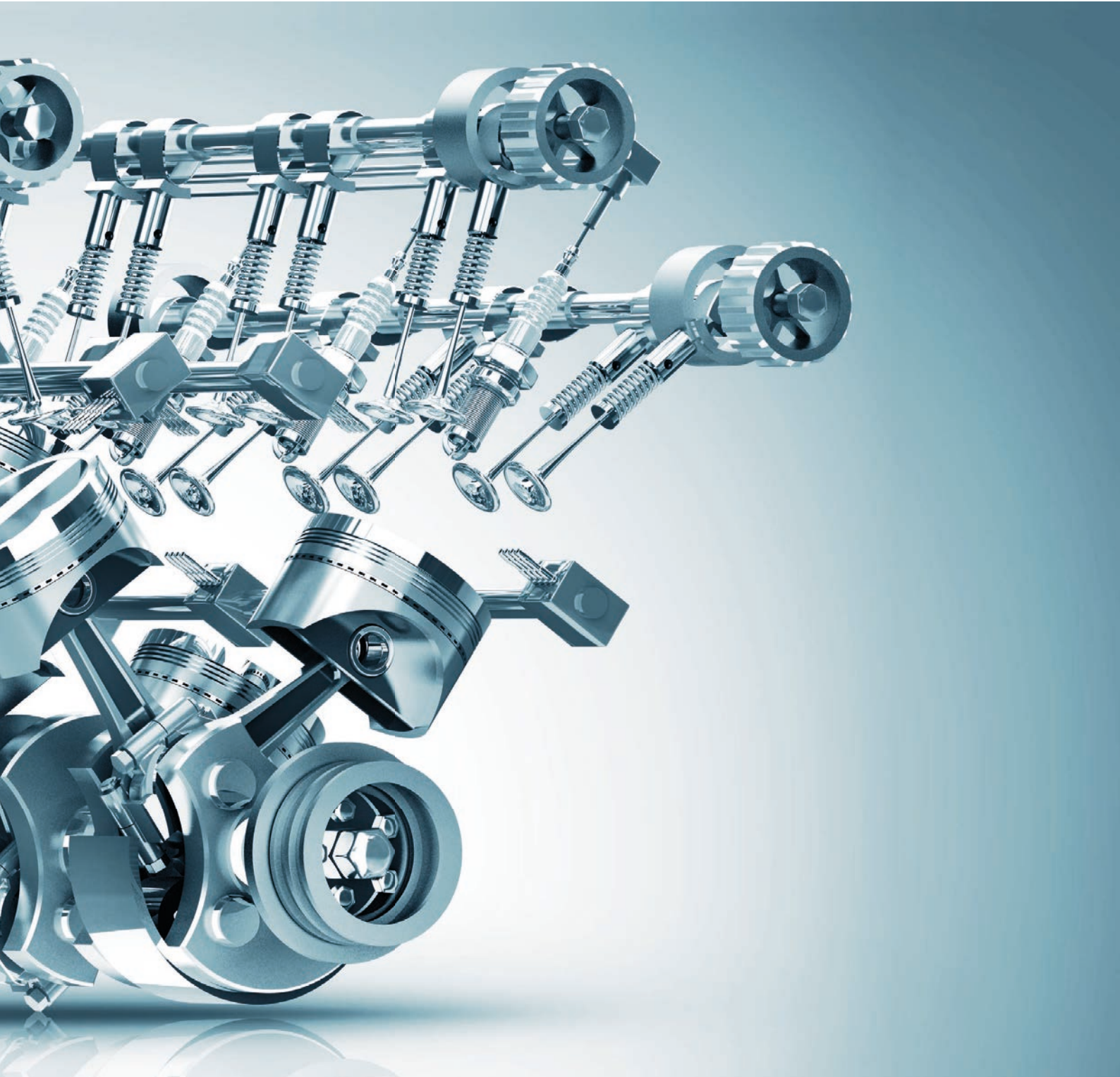
## Components and Characteristics

- Air System
- Fuel System
- Gas Exchange Process
- Combustion Process
- Torque Generation
- Speed Calculation

## Peripherals

- Drivetrain and Vehicle
- Soft ECU
- Environment
- Test Bench







# ASM Engine Components

## Engine Air System

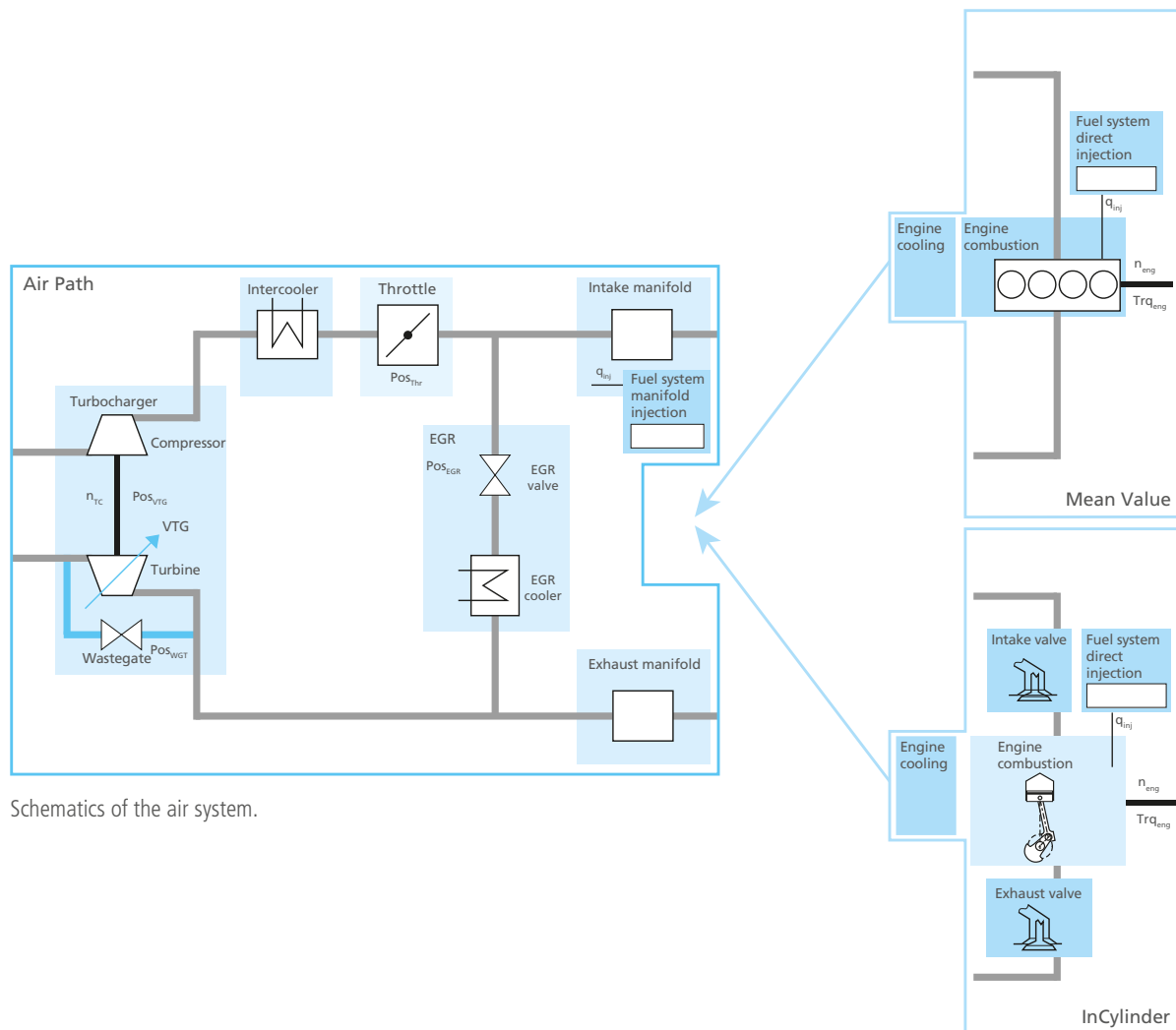
### Air System

The air path simulates the turbocharger, intercooler, throttle, and manifold dynamics on the intake side, and exhaust gas

recirculation (EGR) with the cooler and exhaust manifold on the exhaust side.

### Components and Characteristics

- Map-based turbocharger for boost pressure calculation
- Intercooler for correct temperature simulation
- Throttle for correct mass flow determination
- Intake manifold with calculation of manifold pressure and temperature, fresh air mass and exhaust mass
- Exhaust manifold with calculation of exhaust manifold pressure and temperature
- Exhaust gas recirculation (EGR) of exhaust and fresh air with EGR cooler
- Optional: ASM Turbocharger Model, the physical turbocharger model with compressor and turbine (VTG or wastegate) and with turbine speed calculation



## Direct Injection Fuel System

### Fuel System – Diesel

The common-rail fuel system provides the fuel for injection, which is stored at high pressures in one chamber – the common-rail – for all cylinders.

### Fuel System – Gasoline

The fuel system simulation supports either direct or port injection. For direct injection simulation, a common-rail fuel system is supported.

### Components and Characteristics

- Common-rail
- Pressure control valve
- Fuel metering unit
- High-pressure pump
- Common-rail injector
- Diesel: Multiple injections taken into account
- Gasoline: Direct or port injection
- Gasoline: Current-based or crank-angle-synchronous injection

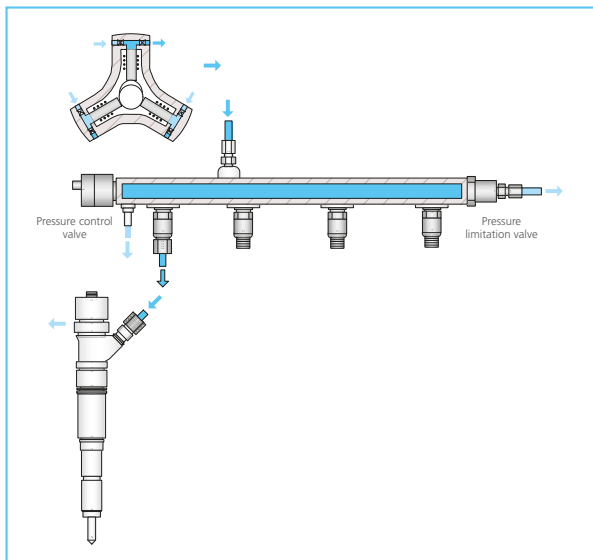
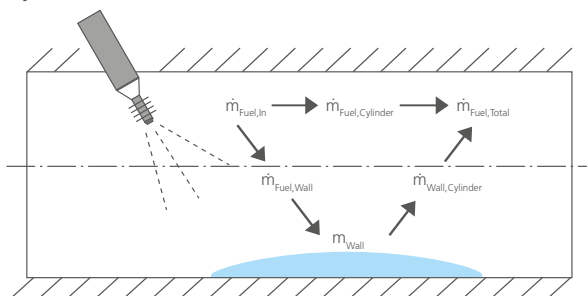


Diagram of a common-rail fuel system.

## Manifold Injection Fuel System

### Fuel System for Manifold Injection

The fuel system injects the fuel for combustion into the manifold, calculating the fuel mass flow from the measured injection time.



The air fuel mixture process takes wall film fuel evaporation into account.

### Wall Film

Some of the injected fuel feeds the cylinder directly, while the rest forms a film on the intake manifold wall. Liquid from the wall film evaporates over time, contributing to the air fuel mixture process and entering the cylinder. The wall film model describes the fuel transport from the injection valve to the cylinder by means of a mean value approach.

### Components and Characteristics

- Manifold fuel injection system (mean value)
- Tank model
- Injectors

## Gas Exchange Process

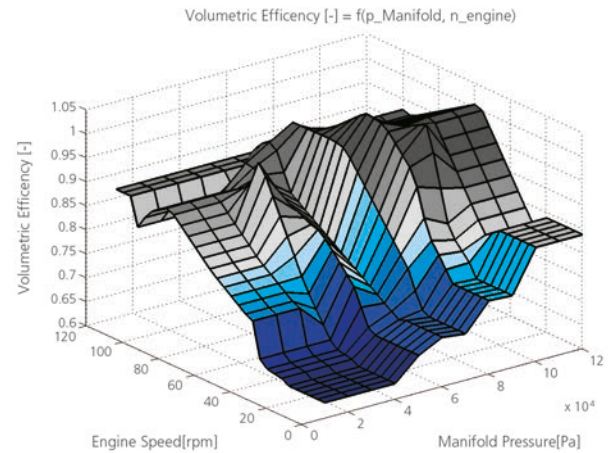
### Mean Value Intake

The mass flow into the engine is determined by the volumetric efficiency map. The volumetric efficiency map will be determined based on engine test bench measurements to replicate the engine breathing behavior as realistically as possible.

Look-up table for gasoline engine volumetric efficiency.

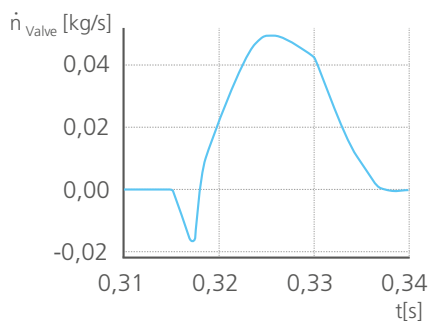
### Components and Characteristics

- Intake manifold
- Map-based approach



### In-Cylinder Valve Model

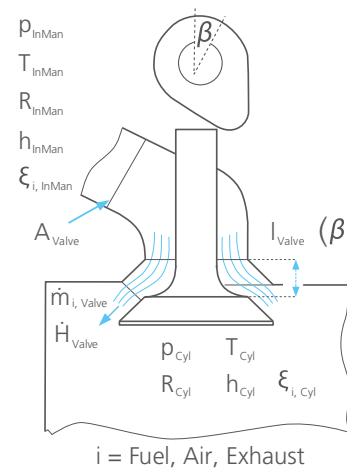
Intake and exhaust valve models calculate the enthalpy and gas mass flow for the cylinder gas exchange process. The individual lift and timing of the valve models makes them suitable for applications such as camless engines, variable valve timing (VVT), variable valve lift (VVL), and cylinder deactivation.



Intake mass flow of the gas exchange process.

### Components and Characteristics

- Valve with enthalpy and gas mass flow
- Variable valve timing and lift



The valves are modeled as isentropic adiabatic orifices with variable lift and timing.

## Combustion Process

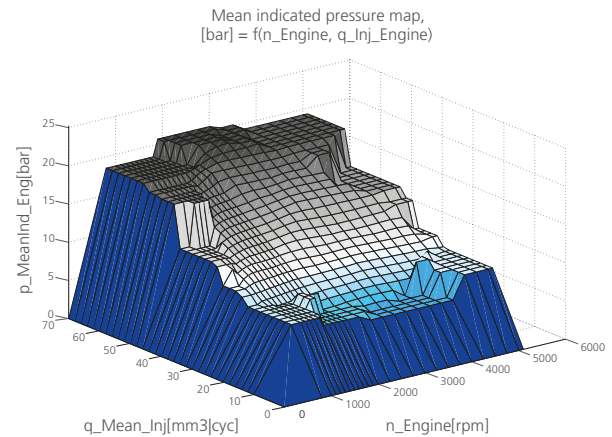
### Mean Value Combustion

The indicated mean effective pressure is determined on the basis of the operating point. The indicated pressure is scaled by means of combustion relevant efficiencies, in order to account for manipulations in the ignition or injection angle as well as for variations on the air-to-fuel ratio. The pressure is evaluated for each cylinder individually.

Look-up table for gasoline engine mean indicated pressure.

### Components and Characteristics

- Engine combustion pressure determination
- Map-based approach



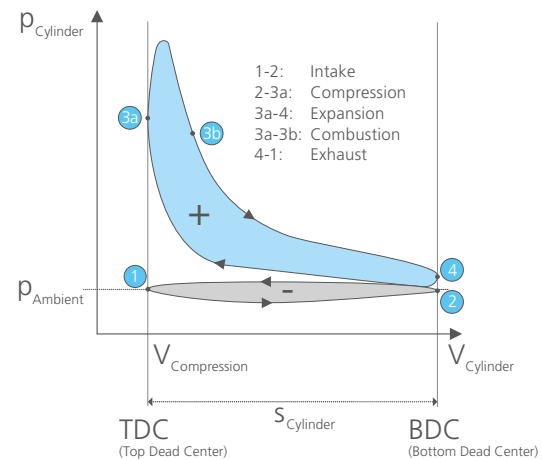
### In-Cylinder Combustion

Processes inside the cylinder are modeled using the first law of thermodynamics, including effects like wall heat flow, intake and exhaust valve enthalpy flow, burn function and mechanical work.

The in-cylinder model calculates the pressure over the entire working cycle of a cylinder.

### Components and Characteristics

- Engine pressure calculation over entire working cycle
- Thermodynamic effects taken into account



## Combustion Process

### Injection-Related Combustion Process – Diesel

The entire combustion process can be related to multiple individual crank-angle-synchronous injections. The heat release simulation model ensures that individual injection patterns are considered during each simulation time step with low latency.

### Components and Characteristics – Diesel

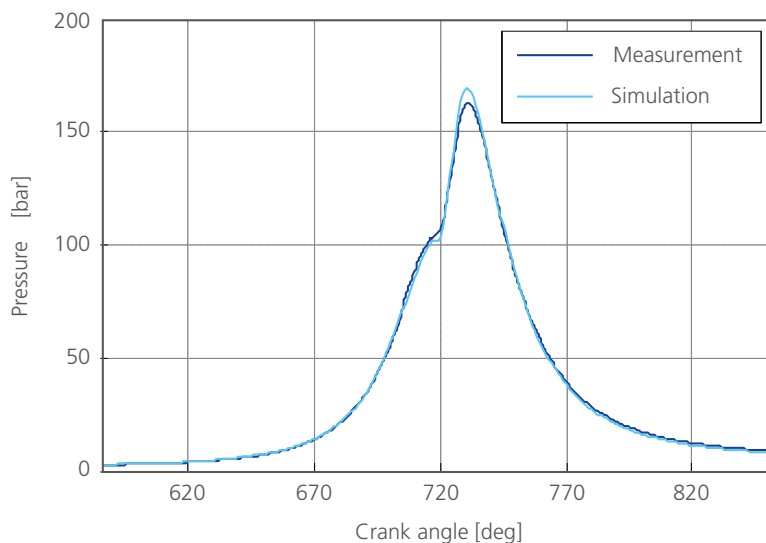
- In-cylinder pressure and temperature calculation based on a phenomenological combustion model
- Mixing-controlled combustion model (Chmela)
- Combustion rate depends on fuel injection quantity and injection angle
- Ignition delay as a function of the current thermodynamic state of the individual cylinders

### Injection-Related Combustion Process – Gasoline

The combustion process simulation is modeled by using a Vibe burn function. Direct or port injection systems are supported.

### Components and Characteristics – Gasoline

- In-cylinder pressure and temperature calculation based on a phenomenological combustion model
- Form function-based combustion model (Vibe)
- Combustion rate depends on fuel injection quantity and ignition angle
- Ignition delay, combustion function form factor and combustion duration can be provided by look-up tables or by functional approaches (Csallner)



In-cylinder pressure characteristics.



## Engine Torque Generation

### Mean Value Torque Generation

The piston engine model comprises the air flow through the inlet valve and the combustion torque calculation for each cylinder individually. The effects of the ignition angle and the air/fuel ratio on the combustion torque are included as efficiencies. Friction torque is taken into account for effective torque calculation. A torque modulation will be applied to reflect combustion top dead center related oscillations. Optionally, the engine torque can be superposed with compression torque modulation or mean gas exchange losses.

$Trq_{eff}$  – Effective torque

$p_{ind}$  – Induced pressure

$i$  – Engine constant (0.5 for four strokes)

$V_D$  – Engine displacement

$Trq_{frict}$  – Friction torque

$$Trq_{eff} = \frac{p_{ind} \cdot i \cdot V_D}{2\pi} - Trq_{frict}$$

Mathematical equation for torque calculation.

### In-Cylinder Torque Generation

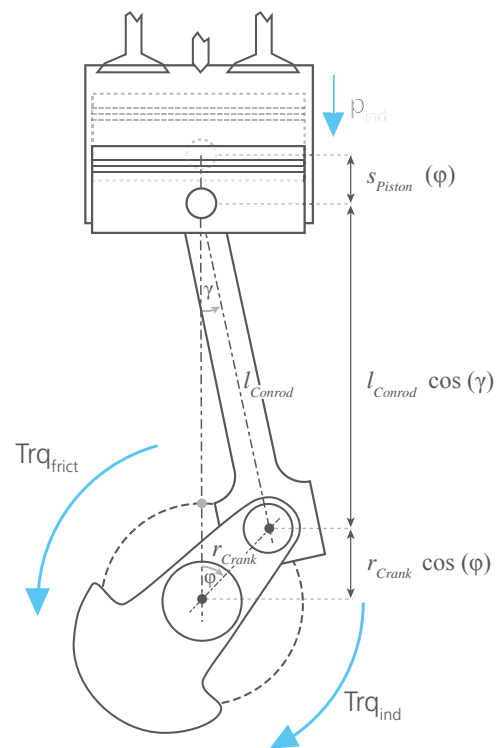
The cylinder selective pressure will be used to evaluate the indicated engine torque. Based on the crankshaft kinematics the gas torque can be determined by using the pressure and the crank-angle-dependent lever.

### Components and Characteristics

- Engine torque evaluation block
- Friction torque
- Basic cooling system

### Components and Characteristics

- Mean value engine model with combustion torque modulation
- Effect of lambda and ignition angle by efficiency tables
- Cylinder inlet by volumetric efficiency
- Friction torque
- Pump torque
- Basic cooling system



Piston engine model includes crank-angle-based torque calculation.

## Engine Speed Calculation

### Mean Value Crankshaft

The crankshaft model comprises the gas exchange torque, the combustion torque, the friction torque, the mass torque due to the crankshaft kinematics, and the load torque due to a crank-angle-synchronous engine speed calculation.

### Components and Characteristics

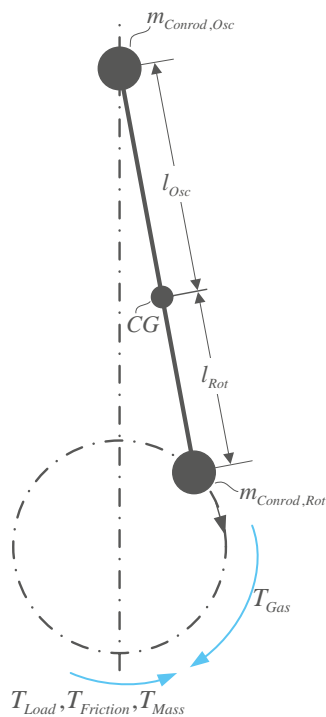
- Crankshaft for engine speed calculation (crankshaft kinematic included)

### In-Cylinder Crank Mechanism

The crank mechanism of the InCylinder model applies the crank-angle-dependent balance of the effective engine torque, the load torque from the drivetrain and the mass torque. The mass torque is calculated by separating the connection rod into a rotating and an oscillating mass. Consequently, the crankshaft dynamics are used in combination with the crankshaft kinematics to solve the equation of motion for the crankshaft.

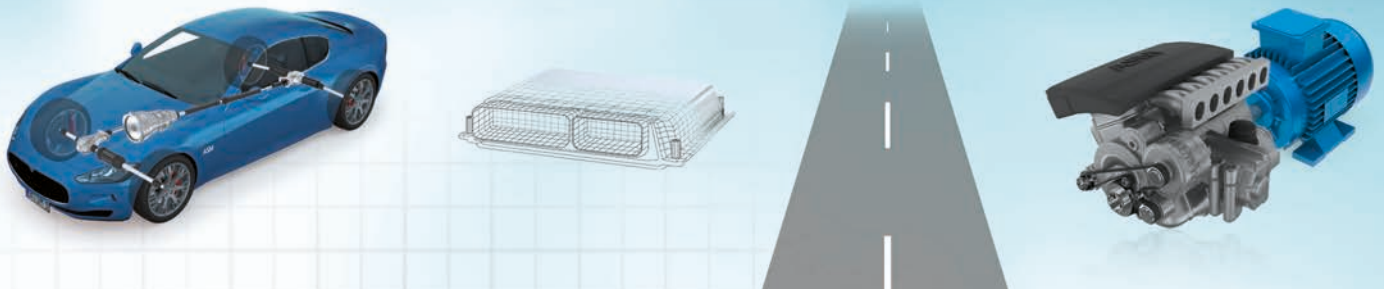
### Components and Characteristics

- Crank mechanism
- Crankshaft dynamics and kinematics



Separation of conrod into oscillating and rotating masses.

# ASM Engine Peripherals



## Drivetrain and Vehicle

### Drivetrain and Engine Test Bench

The drivetrain model calculates the speeds of the vehicle drivetrain, and the speeds of the transmission. The drivetrain can be disconnected in test bench mode, in which the engine speed can be controlled by a dynamometer and the engine torque by actuating the accelerator pedal. For stationary machines (without drivetrain), the load torque can be stimulated manually.

### Components and Characteristics

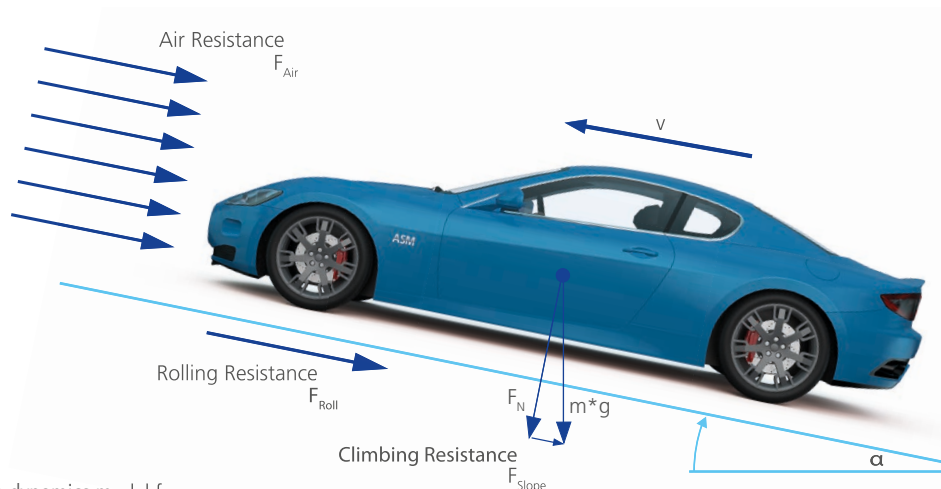
- Automatic transmission with torque converter and lockup clutch
- Manual transmission with mechanical clutch
- Differential
- Starter
- Test bench for engine speed and torque control
- Manual load torque for stationary machines

### Vehicle Dynamics

The vehicle speed is calculated according to the external forces on the vehicle. It is described by a longitudinal model of a passenger car or truck. Air resistance, slope, braking, and rolling resistance are taken into account.

### Components and Characteristics

- Climbing resistance (slope)
- Air resistance
- Rolling resistance
- Braking



Basic vehicle dynamics model for sufficient engine simulation.

## Soft ECUs

### Software Controllers

The included soft ECUs are needed in scenarios where a real ECU is not available, as in offline simulation. For example, a combination of soft and real ECUs can be used in HIL scenarios where real transmission ECUs are not available.



The soft ECU provides controls for engine and transmission.

### Diesel and Gasoline Soft ECU

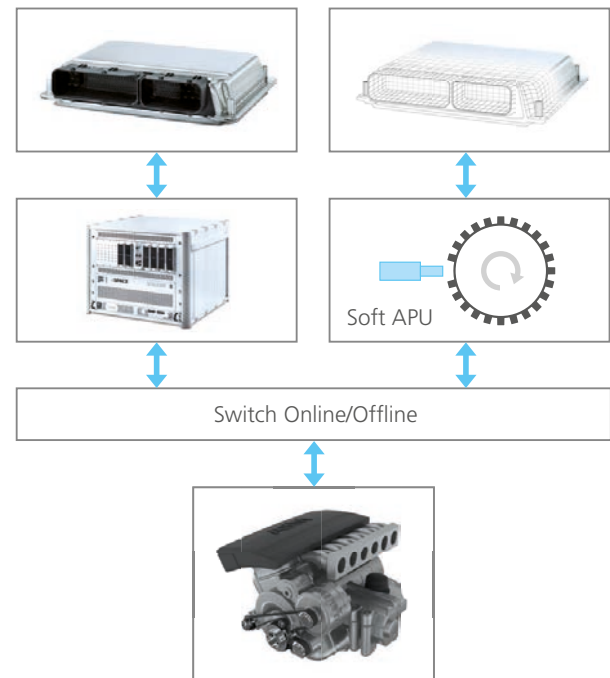
The soft ECU is basic engine ECU controller software without any diagnostics, used for testing the engine model in closed-loop operation when no real ECU is connected. Its inputs are standard sensor signals and the outputs are standard actuators to realize a seamless integration in a HIL environment. The diesel and the gasoline soft ECUs have an engine-torque-based controller concept. The controllers are built on a modular basis for easy adaption in customer projects.

### Components and Characteristics

- Engine operation detection
- Engine torque calculation
- Torque-to-injection-quantity conversion
- Controllers for fuel system, incl. multiple injection patterns
- Controllers for air system
- Diesel: Multiple injection patterns can be generated
- Gasoline: Stratified and homogeneous combustion modes are supported

### Diesel and Gasoline Soft APU

ASM Engine models were designed especially for seamless connection to a real ECU. During online simulation in particular, control signals such as injection timing signals have to be measured with low latencies. The dSPACE I/O hardware therefore includes an angular processing unit (APU) that ensures crank-angle-synchronous measurement. Both the ASM mean value engine models and the ASM Engine InCylinder models provide a software APU mode to ensure that the behavior of the soft ECU is always crank-angle-synchronous, even in offline simulation. The model interface signals are identical in the offline and online modes to ensure a smooth transition between the two simulation environments. The mean value engine models have to provide the crank angle. Additionally, the InCylinder engine models have to ensure the crank-angle-synchronous I/O signals during offline simulation, which are usually generated by the dedicated I/O functions on the real-time hardware.



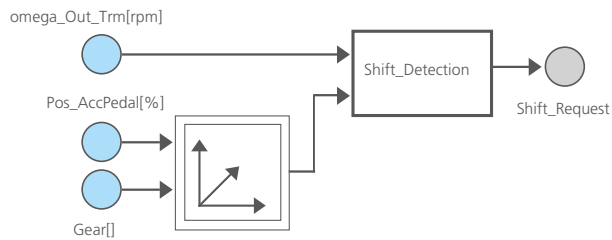
Online and offline operation with a real or a soft ECU.

### Transmission Soft ECU

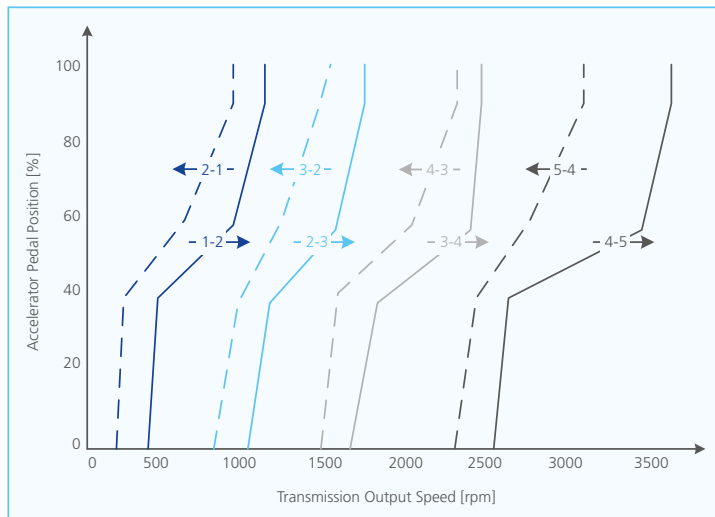
The transmission soft ECU shifts the gear of the automatic transmission according to the current driving situation and controls the torque converter and lockup clutch. The transmission soft ECU is ready for use in hybrid applications, in which the ECU needs to control a separate clutch (e.g., for parallel hybrid topologies).

### Components and Characteristics

- Automatic gear shifting
- Park, reverse, neutral, and drive mode
- Tip-shift control supported
- Lockup clutch control
- Engine speed and accelerator pedal included
- Support of hybrid drivetrain applications



The shift detection system of the soft ECU.



Transmission speed depending shift strategy.



## Environment

### Road

The road subsystem allows environmental conditions such as the road slope, ambient pressure, and temperature to be set.

### Components and Characteristics

- Slope
- Ambient pressure and temperature

### Maneuver

Maneuvers define how a vehicle moves. Depending on the maneuver mode, they either provide stimulus signals directly to certain vehicle components such as the ignition key, accelerator pedal, brake pedal, clutch pedal and gear lever, or give instructions to a driver model which controls the vehicle.

### Components and Characteristics

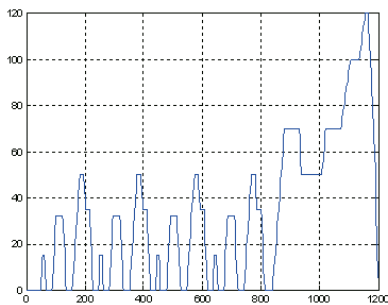
- Manual control in offline mode (Simulink)
- Manual control in online mode (ControlDesk)
- Time-dependent, predefined stimulus maneuvers
- Driver maneuvers (velocity profiles: e.g., FTP75, NEDC, J10-15)
- Maneuvers and stimuli can be adapted by the user as required

### Driver

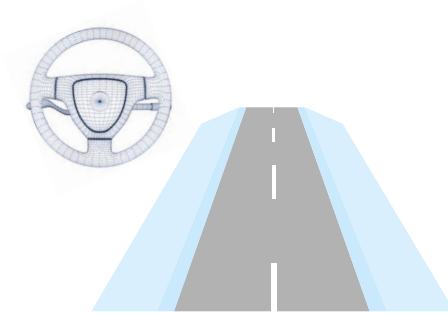
The driver model controls the vehicle. Its main task is to drive the vehicle at a desired velocity. The vehicle is controlled by an accelerator pedal, brake pedal, clutch pedal and gear shifter.

### Components and Characteristics

- Longitudinal controller for accelerator and brake pedal, comprising feedforward and feedback control
- Gear and clutch control for manual transmission



Velocity profile according to NEDC.

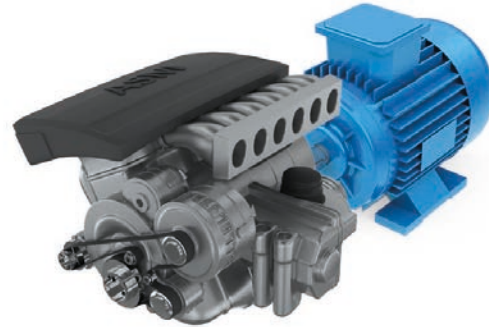


The engine model can be simulated in a complete environment, which is useful for longitudinal driving maneuvers.

## Testbench

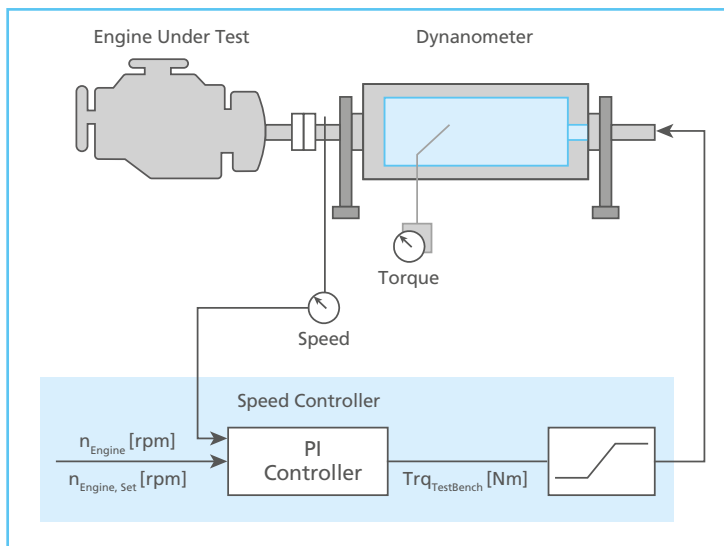
### ASM Testbench

ASM Testbench is a tool for testing the parameterization of engine models. You can use it to compare simulation results to measurements. You can also compare different simulation results. The results of each simulation run are saved and listed in a table so that different simulation runs can be selected for plotting. The test bench operates on the basis of stimuli data.



### Components and Characteristics

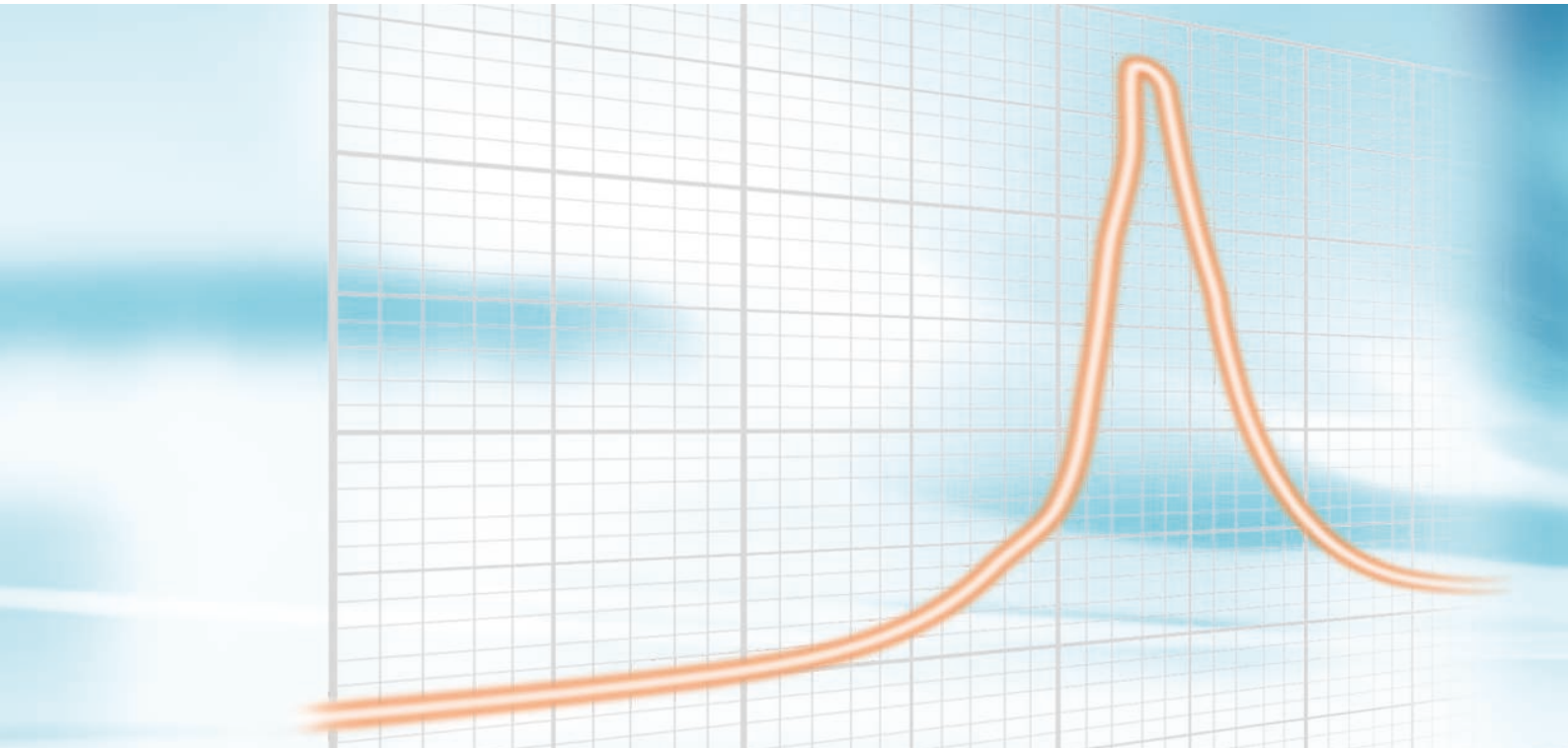
- Stimulated test bench (dynamometer)
- Stimulus data based on operating point concept
- Comparison of simulation results and measurements
- Plot set for viewing different signals



ASM Testbench simulates a dynamometer and provides analysis tools for testing the combustion engine models.

# Simulation Packages and Features

## Engine Model Comparison



Feature	Gasoline Basic	Gasoline	Diesel	InCylinder Gasoline	InCylinder Diesel
No. of cylinders	Unlimited	20	20	12	12
Exhaust gas recirculation (EGR)	-	Yes	Yes	Yes	Yes
Map-based turbocharger	Yes	Yes	Yes	Yes	Yes
Physical turbocharger	-	Yes	Yes	Yes	Yes
Common rail system	-	Yes	Yes	Yes	Yes
Pump nozzle	-	-	Yes	-	-
Fuel injection	Intake manifold	Direct, intake manifold	Direct	Direct, intake manifold	Direct
Wall film evaporation	Yes	Yes	-	-	-
Combustion modes	Homogeneous	Homogeneous, Stratified	Diffusion	Homogeneous	Diffusion
Exhaust system	Basic variant	Basic variant	DPF, DOC <sup>1)</sup>	Basic variant	DPF, DOC <sup>1)</sup>
Soft ECU, engine	Yes	Yes <sup>2)</sup>	Yes <sup>2)</sup>	Yes <sup>2)</sup>	Yes <sup>2)</sup>
Combustion simulation	Mean value	Mean value	Mean value	Physical	Physical
Valve simulation	Mean value	Mean value	Mean value	Physical	Physical

<sup>1)</sup> DPF: Diesel particulate filter, DOC: Diesel oxidation catalyst

<sup>2)</sup> torque-based



# ASM – Gasoline Engine Basic Simulation Package

Basic mean-value engine model with combustion torque modulation

## Main Model Components

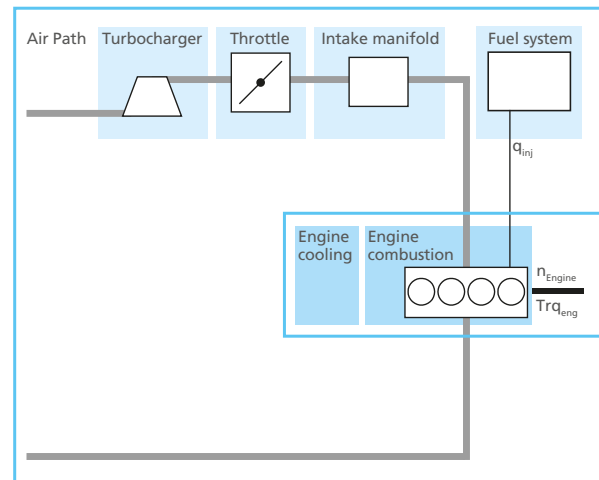
- Air system
- Fuel system
- Piston engine
- Turbocharger
- Drivetrain (basic)
- Vehicle dynamics (longitudinal)
- Environment (basic)

## Features at a Glance

- Unrestricted number of cylinders
- Intake manifold with calculation of intake manifold pressure and temperature
- Map-based turbocharger for boost pressure calculation
- Fuel injection system with fuel tank model
- Wall film evaporation taken into account
- Longitudinal driver for standard cycles (FTP75, NEDC, J10-15, etc.)
- Easy to expand into a comprehensive virtual vehicle by adding ASM Vehicle Dynamics
- Simulation with real ECU in hardware-in-the-loop (HIL) system and simulated soft ECU in model-in-the-loop (MIL) simulation
- Start/stop system support

## Simulation Model Characteristics

The actual physical engine characteristics are represented by a mean-value engine model with crank-angle-based torque generation, dynamic manifold pressure, temperature calculation, and an injection model. To simulate the engine in an automotive system (car or truck), the engine model incorporates a longitudinal drivetrain model with manual and automatic transmission, a clutch, a torque converter, a starter, and a test bench mode. Models for the environment and driver complement the virtual powertrain.



Schematic of the basic air system.



# ASM – Gasoline Engine Simulation Package

## Mean-value engine models with combustion torque modulation

### Main Model Components

- Air system
- Fuel system
- Piston engine
- Turbocharger
- Drivetrain (basic)
- Vehicle dynamics (longitudinal)
- Environment (basic)

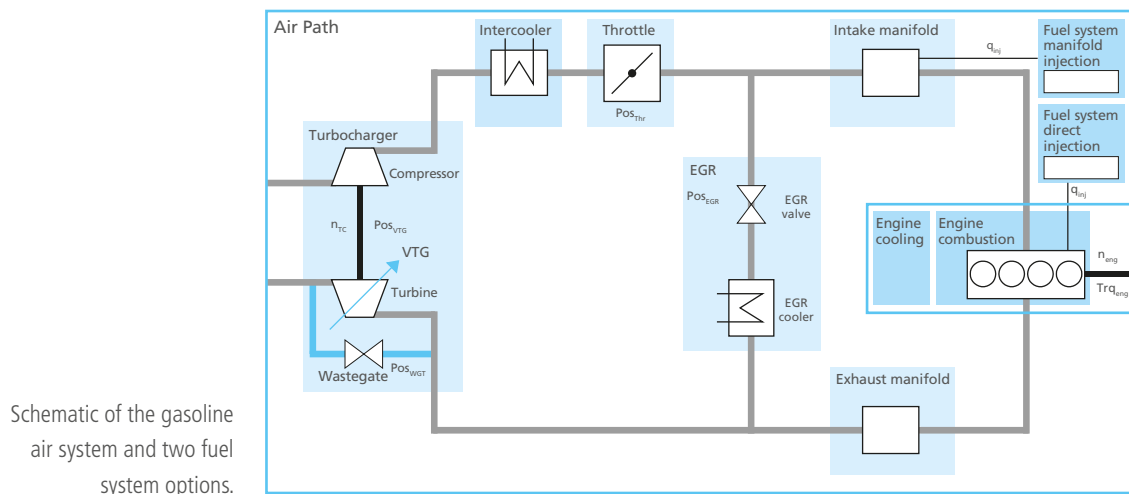
### Features at a Glance

- Up to 20-cylinder gasoline applications
- Map-based turbocharger for boost pressure calculation
- Gasoline fuel injection system: common-rail system including direct injector, intake manifold injector and tank model
- Gasoline engine with homogenous and stratified combustion modes
- Exhaust gas recirculation (EGR) of exhaust and unburned air with EGR cooler
- Longitudinal driver for standard cycles (FTP75, NEDC, J10-15, etc.)
- Easy to expand into a comprehensive virtual vehicle by adding ASM Vehicle Dynamics
- Simulation with real ECU in hardware-in-the-loop (HIL) systems and simulated soft ECU in model-in-the-loop (MIL) simulation
- Start/stop system support

### Simulation Model Characteristics

The physical engine characteristics are represented by a mean-value engine model with crank-angle-based torque modulation, dynamic manifold pressure, temperature calculation, and several fuel injection models. A soft ECU is included for scenarios where a real ECU is not available, for example, in offline simulation. To simulate the engine in an

automotive system (car or truck), the engine model incorporates a longitudinal drivetrain model with manual and automatic transmission, a clutch, a torque converter, a starter, and a test bench mode. Models for the environment and driver complement the virtual powertrain.



# ASM – Diesel Engine Simulation Package

## Mean-value engine models with combustion torque modulation

### Main Model Components

- Air system
- Fuel system
- Piston engine
- Diesel aftertreatment system
- Turbocharger
- Drivetrain (basic)
- Vehicle dynamics (longitudinal)
- Environment (basic)

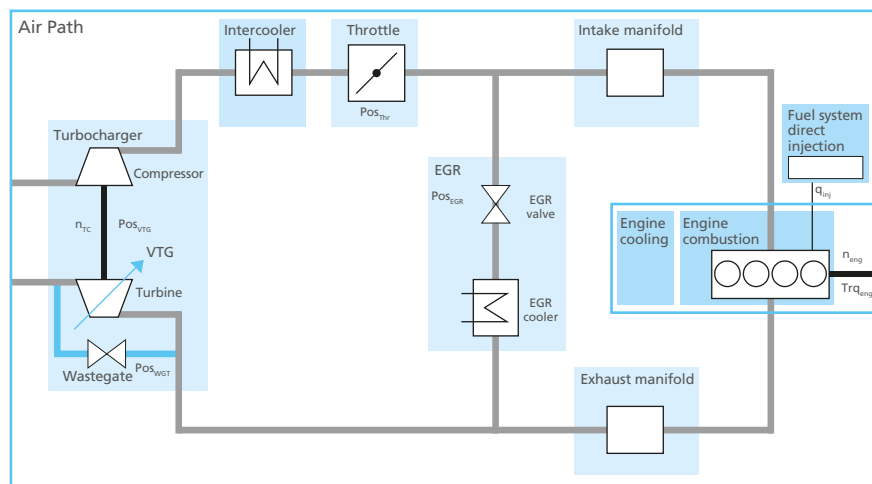
### Features at a Glance

- Up to 20-cylinder diesel/gasoline applications
- Map-based turbocharger for boost pressure calculation
- Diesel fuel injection systems: common rail injector, unit injector, unit pump and tank model
- Diesel exhaust system including diesel oxidation catalyst (DOC) and diesel particulate filter (DPF)
- Exhaust gas recirculation (EGR) of exhaust and unburned air with EGR cooler
- Low pressure EGR
- Longitudinal driver for standard cycles (FTP75, NEDC, J10-15, etc.)
- Easy to expand into a comprehensive virtual vehicle by adding ASM Vehicle Dynamics
- Simulation with real ECU in hardware-in-the-loop (HIL) systems and simulated soft ECU in model-in-the-loop (MIL) simulation
- Start/stop system support

### Simulation Model Characteristics

The physical engine characteristics are represented by a mean-value engine model with crank-angle-based torque modulation, dynamic manifold pressure, temperature calculation, and several fuel injection models. A soft ECU is included for scenarios where a real ECU is not available, for example, in offline simulation. To simulate the engine in an

automotive system (car or truck), the engine model incorporates a longitudinal drivetrain model with manual and automatic transmission, a clutch, a torque converter, a starter, and a test bench mode. Models for the environment and driver complement the virtual powertrain.



Schematic of the diesel air system.

# ASM – Gasoline Engine InCylinder Simulation Package

Real-time engine models with in-cylinder pressure and temperature simulation

## Main Model Components

- Air system
- Fuel system
- Valve system
- Piston engine
- Turbocharger
- Drivetrain (basic)
- Vehicle dynamics (longitudinal)
- Environment (basic)

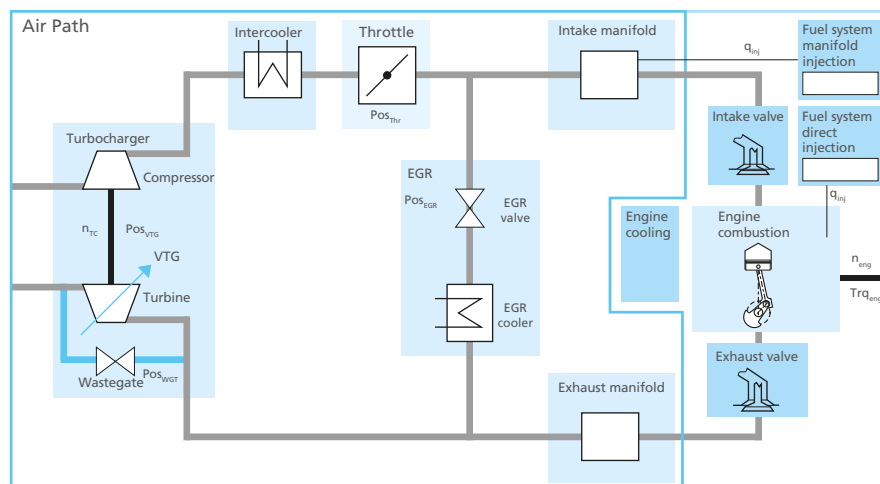
## Features at a Glance

- Simulation of in-cylinder pressure and temperature in real time: e.g., in response to injection, ignition event or variable valve timing
- Gasoline applications with up to 12 cylinders with direct or port injection and turbocharger for real-time simulation. Unlimited number of cylinders for offline simulation
- Gas exchange simulation related to the lift of the intake and exhaust valves
- Fuel injection systems: direct or port injection
- Exhaust gas recirculation (EGR) of exhaust and fresh air with EGR cooler
- Start/stop system support
- Air path topology (e.g., V-engine or in-line engine) configurable via parameter

## Simulation Model Characteristics

The Gasoline Engine InCylinder Simulation Package is an open Simulink model for developing and testing electronic control units (ECUs) with engine management based on the in-cylinder pressure. The model simulates in-cylinder pressure in real time by means of a zero-dimensional thermodynamic approach. The gasoline combustion process is reflected by

considering ignition delay, combustion duration and typical burn function trajectories. In the combustion process, gas exchange simulation is related to the lift of the intake and exhaust valves. The gas-dynamical behavior of the air path and exhaust path is implemented as a mean value system with manifold pressure, temperature, and mass calculation.



The inlet and exhaust valves are modeled as isentropic orifices. They can handle variable valve timing (VVT), variable valve lift (VVL), and the simulation of engines without a camshaft. To simulate the engine within an automotive system (car or truck), the engine model incorporates a basic longitudinal drivetrain model. Models for the environment and driver complement the virtual powertrain.

Schematic of the gasoline air system.

# ASM – Diesel Engine InCylinder Simulation Package

Real-time engine models with in-cylinder pressure and temperature simulation

## Main Model Components

- Air system
- Fuel system
- Valve system
- Piston engine
- Diesel aftertreatment system
- Turbocharger
- Drivetrain (basic)
- Vehicle dynamics (longitudinal)
- Environment (basic)

## Features at a Glance

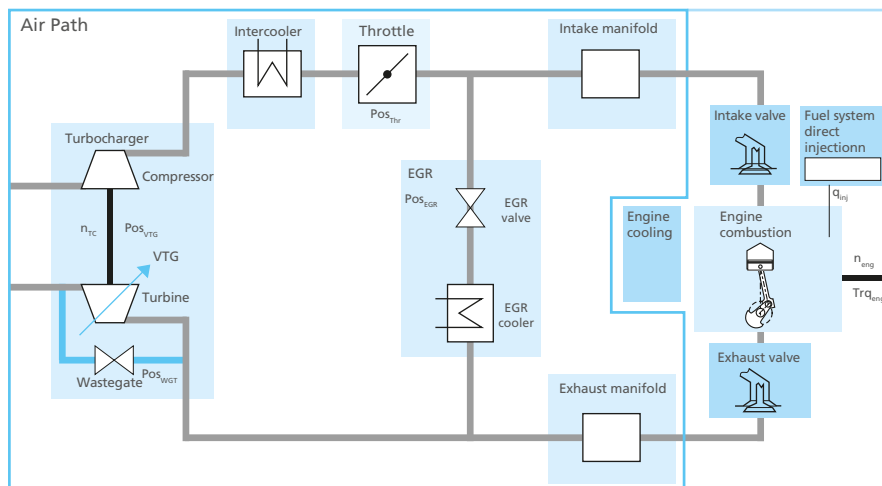
- Simulation of in-cylinder pressure and temperature in real time: e.g., in response to injection
- Diesel applications with up to 12 cylinders with common rail and turbocharger for real-time simulation. Unlimited number of cylinders for offline simulation
- Multiple injection patterns such as pre-, main and post-injection
- Gas exchange simulation related to the lift of the intake and exhaust valves
- Fuel injection systems: common rail direct injector
- Exhaust gas recirculation (EGR) of exhaust and fresh air with EGR cooler
- Start/stop system support
- Diesel exhaust system including diesel oxidation catalyst (DOC) and diesel particulate filter (DPF)
- Air path topology (e.g., V-engine or in-line engine) configurable via parameter

## Simulation Model Characteristics

The ASM Diesel Engine InCylinder Simulation Package is an open Simulink model for developing and testing electronic control units (ECUs) with engine management based on the in-cylinder pressure. The model simulates in-cylinder pressure in real time by means of a zero-dimensional thermodynamic

approach. The diesel combustion process simulation can handle multiple injection patterns such as pre-, main and post-injection. In the combustion process, gas exchange simulation is related to the lift of the intake and exhaust valves. The gas-dynamical behavior of the air path and exhaust path is implemented as

a mean value system with manifold pressure, temperature, and mass calculation. The inlet and exhaust valves are modeled as isentropic orifices. The exhaust path is equipped with a diesel oxidation catalyst and diesel particulate filter by default. To simulate the engine within an automotive system (car or truck), the engine model incorporates a basic longitudinal drivetrain model. Models for the environment and driver complement the virtual powertrain.



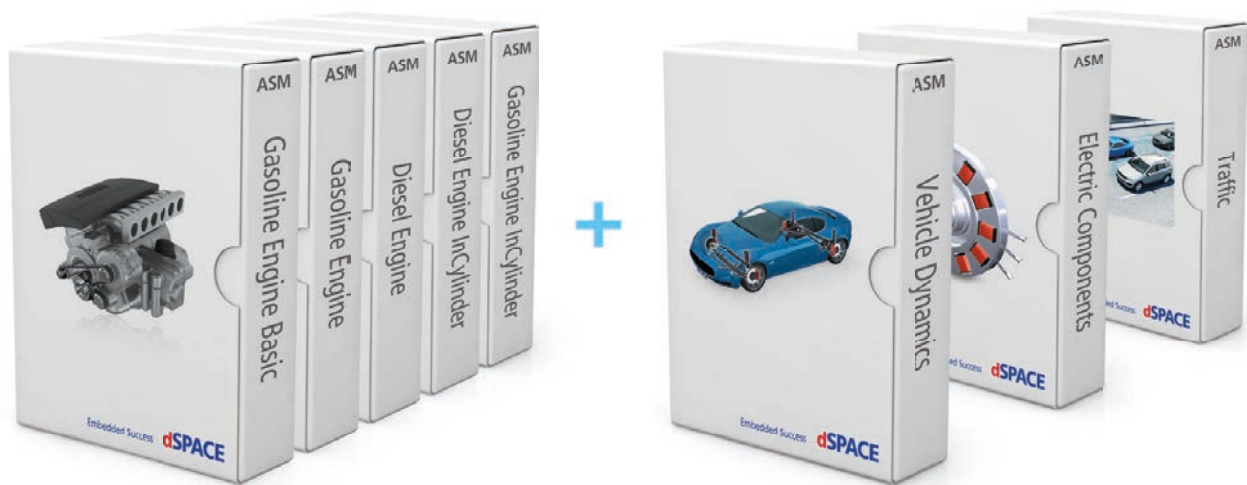
Schematic of the diesel air system.

# ASM Tool Suite

## Simulation packages for complete vehicle and environment simulation

### Complete Tool Suite

The ASMs' standardized interfaces make it easy to expand a single model, such as an engine or body model, or even create a whole virtual vehicle including an electrified drivetrain. Adding the traffic environment allows for advanced driver assistance system (ADAS) simulation scenarios.



ASM simulation packages can be easily extended and supplemented as required.

### ASM Vehicle Dynamics

The ASM Vehicle Dynamics Models provide an excellent basis for developing and testing ECUs, in electronic stability systems, electric power steering or active damping, for

example. They are ideal for vehicle dynamics investigations in early development phases. There are models for passenger vehicles, trucks and trailers.

### ASM Electric Components

Vehicle electrical systems, electric drives and inverters, as well as starter batteries and high-voltage batteries, are all virtualized precisely by ASM Electric Components. The model

supports tasks such as developing and testing hybrid ECUs, battery management systems or indicator light controls.

### ASM Traffic

The comprehensive ASM Traffic model supports the simulation of the traffic environment for developing and testing driver assistance systems. Different sensor models in the

simulated test vehicle detect the other road users and also the static and dynamic objects in the virtual environment.

# Diesel Exhaust System

## Components and Characteristics

- Diesel Oxygen Catalyst (DOC)
- Diesel Particulate Filter (DPF)
- Selective Catalytic Reduction (SCR)
- Physical and chemical process simulation







# ASM Diesel Exhaust System

## Real-Time Diesel Exhaust System Model

### Application Areas

The ASM Diesel Exhaust System Model is an extension to the ASM Diesel Engine and ASM Diesel Engine InCylinder Simulation Package and provides variable configurations of diesel exhaust aftertreatment systems, supporting a DOC, a DPF and an SCR system.

### Key Benefits

The various exhaust model components can be combined to match the aftertreatment system being tested, which ensures that it complies with the desired fuel consumption and emission standards.

## Exhaust Aftertreatment (HC, CO, particles)

### Diesel Oxygen Catalyst Model

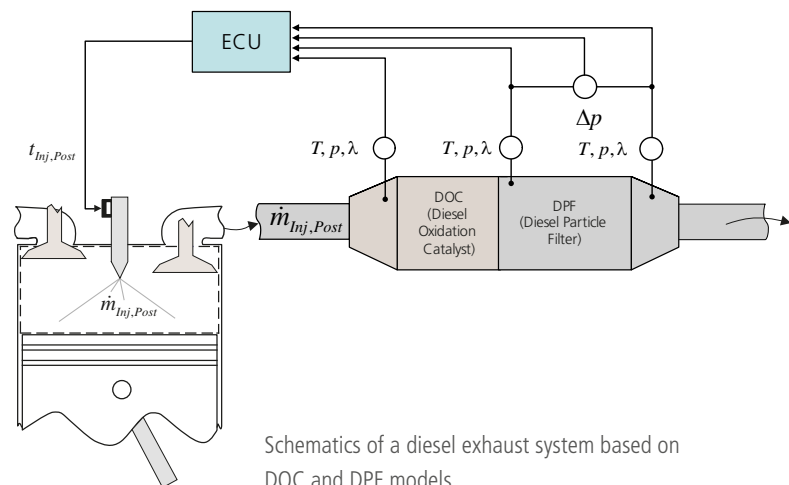
The diesel oxygen catalyst model simulates the physical results of the oxidation process on the exhaust gas. The underlying but unmodeled chemical process can be described by using excess  $O_2$  (oxygen) in the exhaust gas stream to oxidize CO (carbon monoxide) to  $CO_2$  (carbon dioxide), and HC (hydrocarbons) to  $H_2O$  (water) and  $CO_2$ .

### Diesel Particulate Filter Model

The diesel particulate filter model is designed to remove diesel particulate matter (DPM) from the exhaust gas. The DPF model uses a one-layer approach and a lumped parameter model (consistent state throughout the entire system). It supports filter regeneration based on post-injection or additional injection. Depending on the pressure difference over the DPF, the engine management system can increase the exhaust temperature with post-injections to remove accumulated DPM from the filter.

### Components and Characteristics

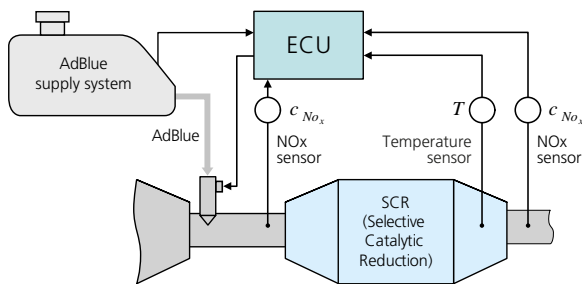
- Pressure drop over DOC/DPF
- Temperature before and after DOC/DPF
- Lambda before and after DOC/DPF
- Particulate mass in DPF
- DPF regeneration by post-injection or additional injection



## Exhaust Aftertreatment (NO<sub>x</sub>)

### Selective Catalytic Reduction (SCR) Model

NO<sub>x</sub> reduction by injecting AdBlue can be simulated with the selective catalytic reduction (SCR) model. This model calculates the physical and chemical processes of AdBlue injection into the exhaust gas. The SCR system also contains a complete dosing system, including a tank model with temperature and pressure simulation.



### Components and Characteristics

- Zero-dimensional approach
- Series connection of identical cells
- Number of cells represents the sectional discretization
- Outputs of one cell are inputs of the following cell
- AdBlue dosing system configurations with and without air supply are provided as demo models
- Urea decomposition upstream of the SCR catalyst

Schematic of the models for a diesel SCR catalyst with an AdBlue dosing system.

## Complete Diesel Aftertreatment System

### Modular System Components

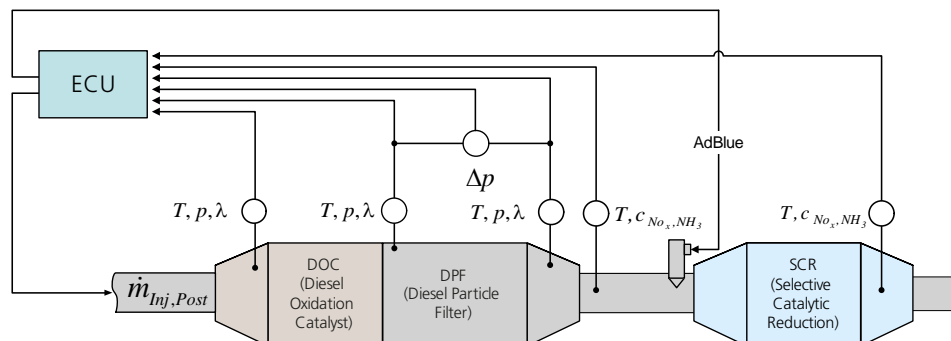
The exhaust system components can be combined as required. This makes it easy to configure a complete diesel

aftertreatment system consisting of DOC, DPF, and SCR catalyst models, depending on the individual configuration.

### Simulation Model Characteristics

The ASM Diesel Exhaust System Model covers typical sensor variables for ECUs in DOC and DPF applications, such as temperatures, pressures and lambda values. These applications investigate effects of soot trapped by filtering material and of DPF regeneration. The oxidation of post-injections and of fuel introduced by catalytic burners is also included in the model.

With its solution for simulating common AdBlue dosing systems with and without air supply and its modeling concept for evaluating the urea decomposition and chemical process of the catalytic reduction, the ASM Diesel Exhaust System Model can be used as a basis for modeling today's aftertreatment systems.



Schematic of a diesel exhaust system with DOC, DPF and SCR models.

# Turbocharger



# ASM Turbocharger

## Real-Time Turbocharger Model

### Application Areas

The ASM Turbocharger Model simulates an exhaust gas turbocharger that consists of a compressor, a turbine, and a turbocharger shaft. Turbochargers with variable turbine geometry (VTG) or wastegate can be simulated. The ASM Turbocharger Model is an alternative to the map-based turbocharger that is included in the gasoline and diesel engine models.

### Key Benefits

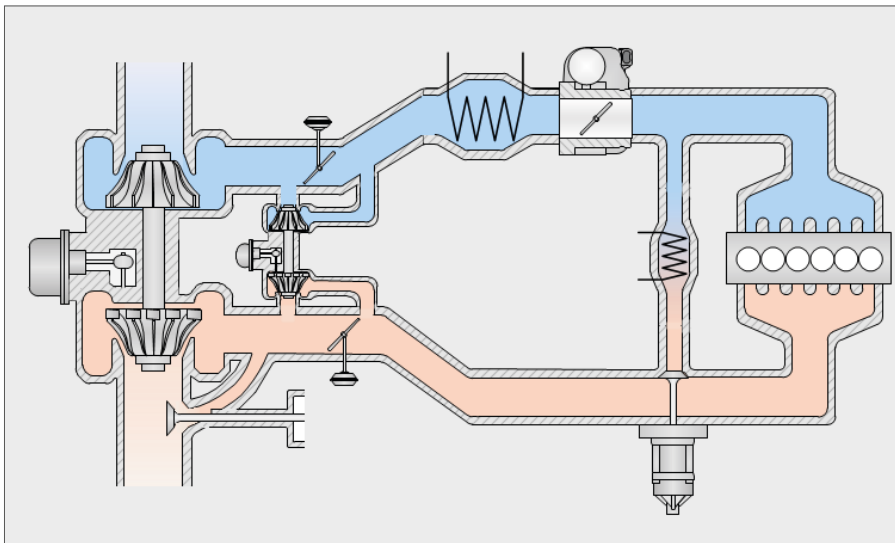
The ASM Turbocharger Model provides more realistic simulation results than purely map-based models. ASM Turbocharger calculates the turbine shaft speed on a physical basis, which is required by ECUs with a turbine speed sensor. Consequently, sophisticated air path control algorithms including turbocharger control strategies can be tested.

### Simulation Model Characteristics

The turbine model calculates the mass flow, the output temperature, and the resulting power output according to wastegate or VTG position. The compressor model calculates the boost pressure, the power consumption and the output temperature. The compressor and turbine are connected by a shaft, and the model provides the shaft speed.

### Features and Characteristics

- Air path simulation with the precision of a physical model
- Contains models for compressor, turbine, and turbocharger shaft
- Simulation of single-stage or sequential two-stage turbocharger possible.
- Wastegate valve and variable turbine geometry (VTG)
- Switching between map-based and the physical model
- Parameterization and model can handle data in SAE J922 format
- For truck applications turbocharger data is also available to show an exemplary parameterization

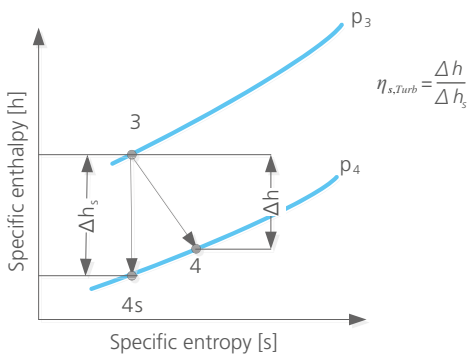


Schematic of the two-stage turbocharger.

## Turbocharger Model

### Turbine

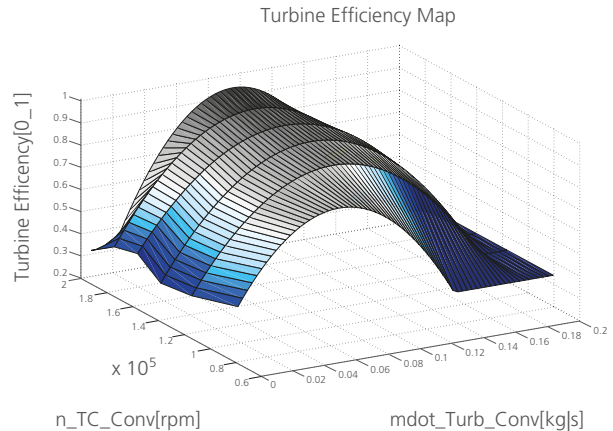
In the turbine, the energy of the exhaust gas is used to generate a torque on the turbocharger shaft. The model calculates the mass flow, the output temperature, and the resulting power output according to the wastegate or VTG position. The turbine model considers variable turbine geometry (VTG). Maps to calculate turbine mass flow and turbine efficiency are implemented for different VTG positions. Interpolation is done between the VTG positions.



Thermodynamic change of state of the turbine.

### Characteristics

- Turbine power and turbine output temperature
- Temperature calculated according to isentropic efficiency
- Turbine mass flow and efficiency in maps
- Wastegate- or VTG-controlled
- VTG characteristics are considered by turbine parameterization
- Optional consideration of turbine heat losses
- Optional dependency of efficiency maps on blade speed ratio



Look-up table for turbine efficiency.

## Turbocharger Model

### Turbocharger Shaft

The turbocharger shaft is the mechanical connection between the turbine and the compressor. It transfers the torque from the turbine to the compressor. The model provides the shaft speed.

### Characteristics

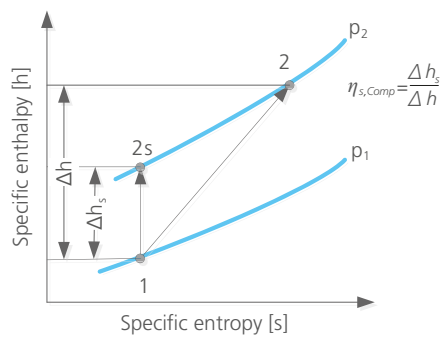
- Provides the shaft speed
- Considers mechanical friction and inertia of the shaft

### Compressor

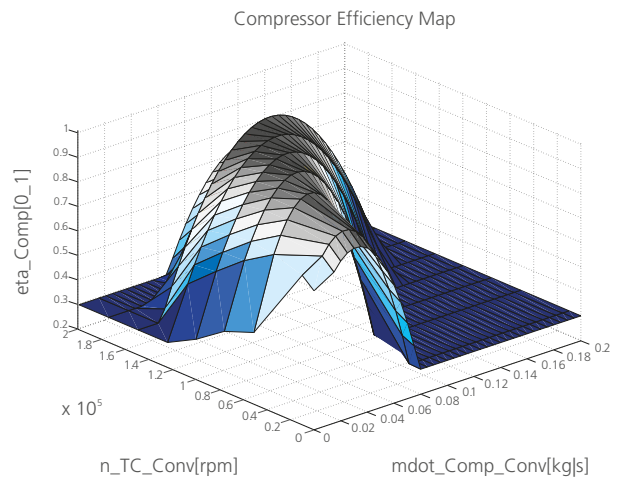
Powered by the turbine's torque, the compressor densifies the air entering the engine's combustion chamber. The model calculates the boost pressure and the temperature after compression, using the equations for compressor power and compressor output temperature.

### Characteristics

- Compressor power and output temperature
- Temperature calculated according to isentropic efficiency
- Compressor pressure ratio and efficiency in maps
- Optional consideration of surge condition



Thermodynamic change of state of the compressor.



Look-up table for compressor efficiency.



# ModelDesk

## The Graphical User Interface

### The ModelDesk Concept

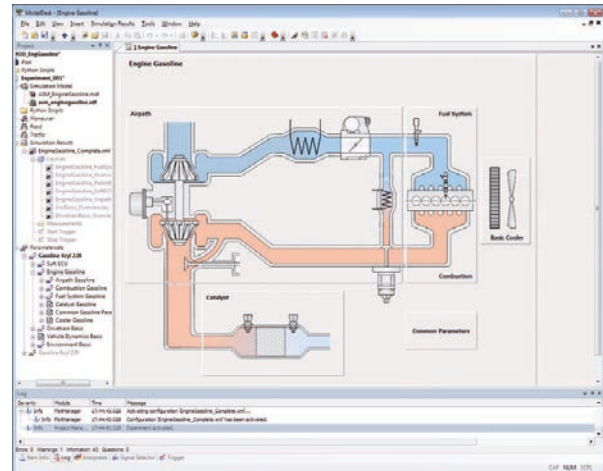
ModelDesk is a graphical user interface for simulation, intuitive model parameterization and parameter set management. It also provides project handling and allows parameter sets to be downloaded to offline and online simulations. It supports tool automation via COM interface. ModelDesk can be used seamlessly from parameterization to offline and online simulation, and finally to parameter and result management.

### Main Features

- Offline and online simulations
- Graphical user interface
- Parameter set management
- Tool automation
- Custom model parameterization

### Benefits

- Seamless simulation process from MIL to HIL
- Intuitive, graphically supported parameterization
- Parameterization during online (dSPACE Simulator) and offline (Simulink) simulations
- Managing parameter sets and entire projects



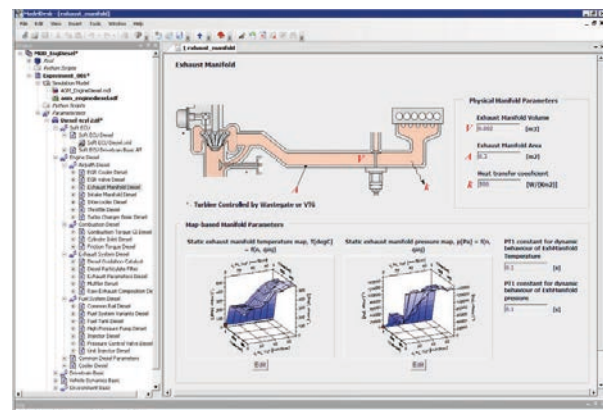
ModelDesk's top-level dialog for selecting model subsystems for configuration and parameterization.

## Graphical Handling

### Graphically Supported Parameterization

The model components and their subsystems are represented by graphics that are structured in a hierarchy. The model components to be parameterized can be selected from the top level. Users have the simulation model in front of them and can browse through its systems, guided by graphical representations of the modeled components.

ModelDesk's top-level dialog for selecting model subsystems for configuration and parameterization.

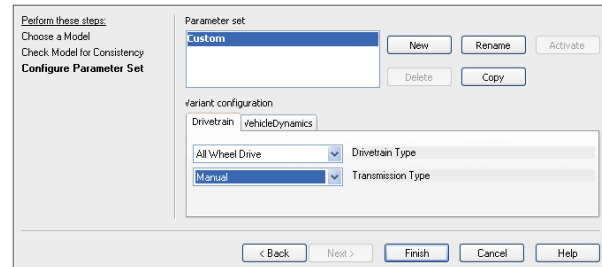


## Configuration

### Configuration Handling

The vehicle configuration is defined with the configuration wizard. For example, there are settings for diesel and gasoline engines, transmission types, etc.

Quick selection of vehicle configurations.

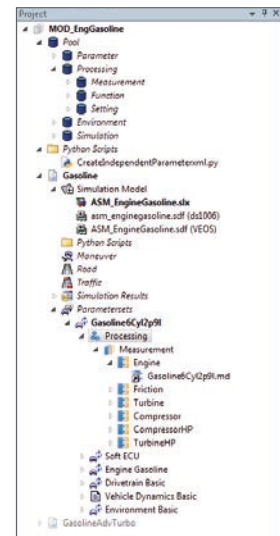


## Navigation

### The Project Navigator

ModelDesk's Project Navigator provides the way to organize and manage large-scale model parameterization projects. Parameter files can be created and assigned to each model component (piston, valves, cooling, etc.), and complete engine parameter sets can be created and managed. Existing parameter files can be selected from a parameter pool and applied by drag & drop.

The Project Navigator is used to manage the parameterization projects. A click on the component buttons in the visualized drivetrain model leads to the related parameter pages.

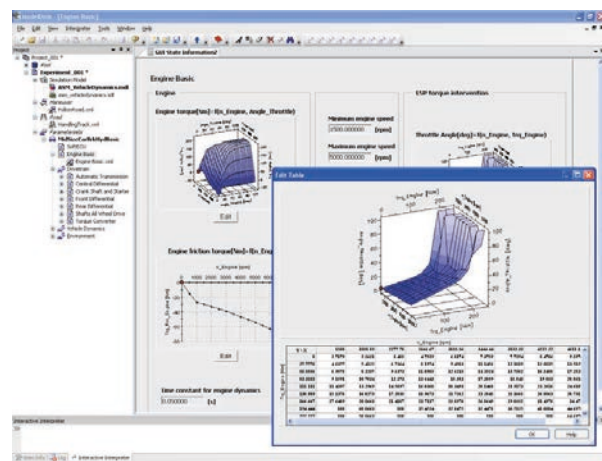


## Parameterization

### Parameter Handling

For manual parameter entry, ModelDesk has parameter pages with illustrations for each component. Parameters are entered in controls next to the components. Table parameters can be visualized as 3-D graphs and modified using a table editor.

Parameter page to modify characteristics of automotive components (large), together with the Table Editor for parameterizing characteristic maps (small).

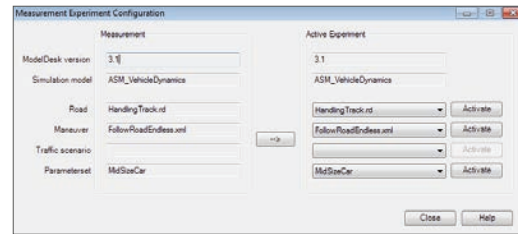


## Simulation

### Simulation Management

ModelDesk includes powerful functions for directly executing and displaying simulations, and managing their results:

- Starting and stopping a simulation
- Plotters for visualization
- Saving, comparing and managing simulation and measurement data
- Saving simulation experiments (driving maneuvers, roads, traffic, etc.)



Configuration of a simulation experiment consisting of a vehicle model, road, maneuver and vehicle parameters.

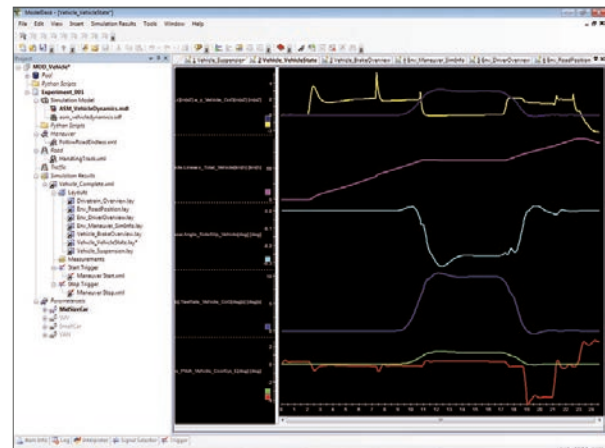
### Plotter

ModelDesk features an integrated plotter which displays signals from the ASMSignalBus. The signals have the same structure as in the Simulink model. The bus can include user-defined signals. Plotter configurations can be defined and stored, and the same single configuration can be used seamlessly online (HIL simulations) and offline (Simulink simu-

lations). A configuration includes the following data: simulation results, measurements, and parameter sets consisting of engine parameters, the test bench, and/or maneuver. A configuration collects together all the sources and conditions that the plotted results are based on.

### Features

- Plots of ASM signal buses
- Plots of user-defined signals
- Plotter configurations can be saved
- The same configuration to be used online and offline
- Plot printouts
- Configuration comprises measurements, simulation and parameters



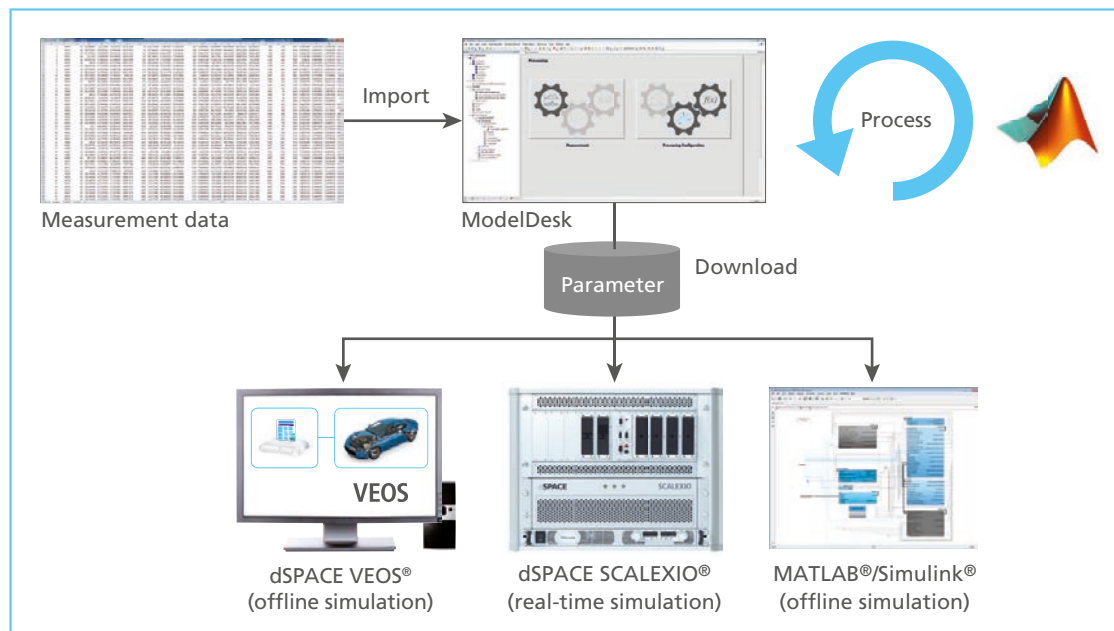
ModelDesk's plotter displaying various simulation signals.

## Processing

### Parameter Processing

ModelDesk provides a fully integrated parameterization workflow. Users can include initial data, such as measurements, functions and settings, flexibly and process it into parameters optimized for simulation models. Users can write the processing routines for parameters in the well-known

MATLAB programming environment. In addition to this customizable parameter calculation, sophisticated error handling procedures have been integrated to support the users during parameterization.



The processing feature transfers measurements, settings, and functions into parameters optimized for simulation.

### Features

- Read and process measurement data
- Function administration
- Settings administration
- Execute functions with appropriate error handling
- Adapt parameter as a result of a processing function

### Use Cases

- Engine parameterization based on test bench measurement
- And also:
- Battery parameterization based on impedance spectroscopy
  - Suspension kinematic parameterization based on kinematic and compliance test bench data

### Custom Models and Demo Projects

This feature can also be used in combination with custom components to parameterize own libraries with ModelDesk. Demo projects for the ASM Engine Models provide predefined parameterization routines to deliver a consistent calculation of all model parameters.

## Custom Model Parameterization

### Graphical Parameterization of Custom Models

Graphical parameterization of model parts that were replaced by custom models or custom extensions to ASM

is supported by ModelDesk. This allows you to manage all the parameters of a project from a single source.

### Features

- Automatic generation of new parameter pages based on custom models
- Controls provided according to parameter dimension (scalar, vector, table)
- Display of original ASM and customized models as one system

### Benefits

- Centralized parameter management
- Graphical parameterization without detailed modeling knowledge

### Model Preparation

To use custom model parameterization, the customer models have to be prepared in libraries according to ASM guidelines in order to parameterize them in ModelDesk. These rules mainly define how parameters are declared. Libraries can

include multiple model components, and each subsystem will be treated separately during parameterization, equipped with an individual parameter page.

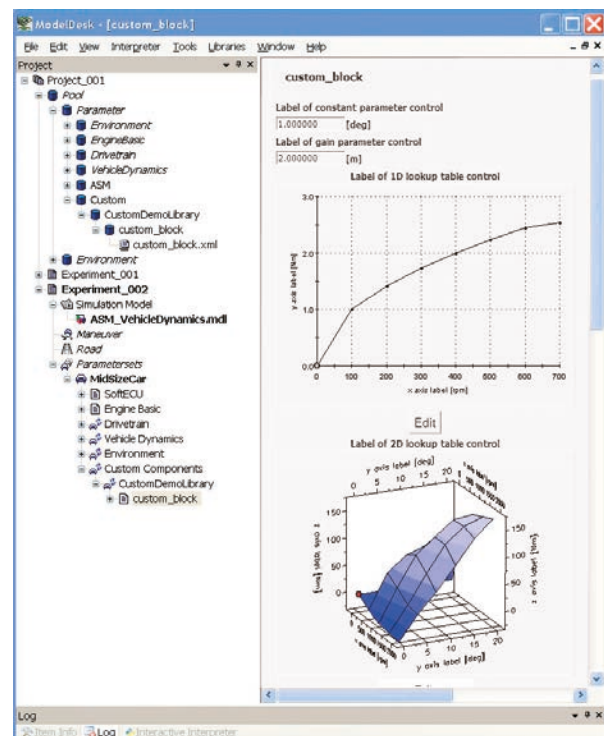
### Custom Library Registration

ModelDesk's registration function lets you select new custom libraries to parse them and make their parameters available graphically. During registration, parameter pages are created. Each page lists the controls of declared parameters. Controls can be single entry fields for scalar types, multiple entry fields for vectors, or complex tables for table-based parameters.

### Navigating Custom Parameters

Whenever a model containing blocks from a registered custom library is loaded into a ModelDesk experiment the related parameter pages of these blocks are provided. They can be selected in the Navigator. Each library is represented as a branch in the hierarchy with links to the subsystem pages. The new pages can be used in exactly the same manner as the standard pages.

Custom parameter page created by ModelDesk. Controls for scalar, vector or table parameters are automatically labeled with the unit and caption as defined in the custom library.

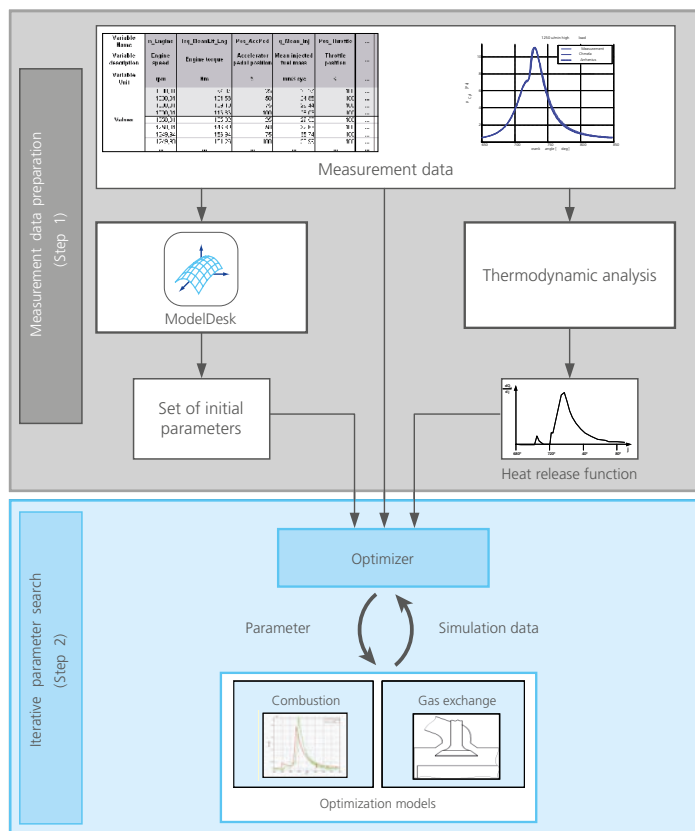


## In-Cylinder Parameterization

### ASM InCylinder Optimizer

Parameterization of engine models based on the thermodynamical in-cylinder approach requires dedicated functionality. Several simulated variables, such as the mean effective torque, in-cylinder mass fractions, and the in-cylinder pressure curve for each crank angle have to fit the measurement data. ASM Diesel Engine InCylinder and ASM Gasoline Engine

InCylinder therefore use a two-step process for parameterizing the model. The first step uses ModelDesk to generate a set of initial parameters for the model. The second step is fully automated and uses an optimization algorithm to fine-tune all the parameters needed to ensure that the simulated and measured data match.



Two-step process for in-cylinder engine parameterization.

# Automation Features

## Tool Automation

### Remote Control for ModelDesk

To perform long-term tests or parameter studies, ModelDesk provides script-based tool automation. This offers users maximum flexibility for defining custom simulation scenarios. Tool automation can be performed by means of scripting languages like Python and MATLAB M scripts.

### Functionality

All ModelDesk's functions for experiment management and model parameterization that are available via its GUI can now also be accessed via its COM (Component Object Model by Microsoft Windows) interface. You can load existing model parameterization projects and activate predefined experiments. All the engine parameters such as the volumetric displacement, number of cylinders, throttle valve area, injection valve characteristics, and also environment or maneuver settings like reference torque or vehicle velocity, can be controlled from within scripts.

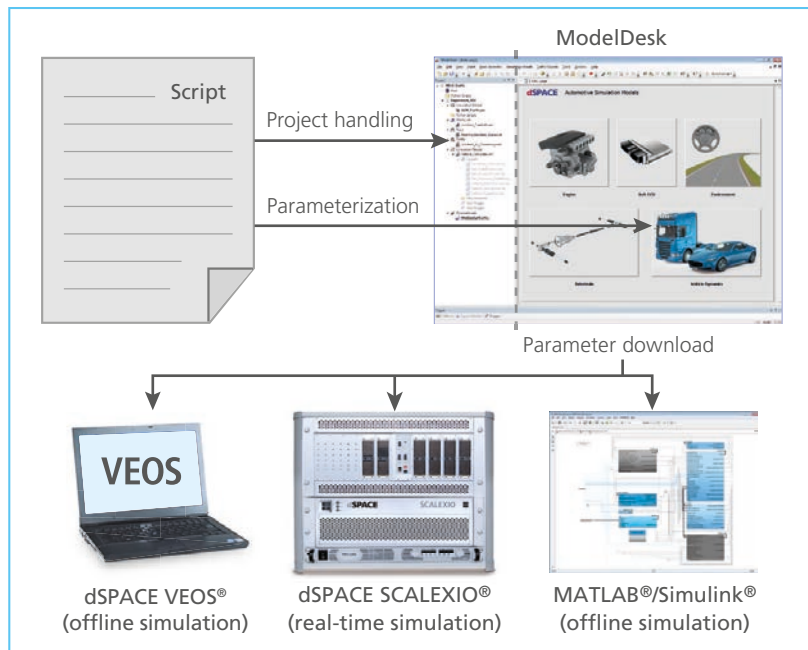
### Features

- Script-based tool automation
- Direct access to project and experiment management
- Direct alteration of all vehicle model parameters
- Direct alteration of maneuver segments
- Direct alteration of road features

### Benefits

- Simulation-based parameter studies
- Automated marginal condition analyses/detection
- Long-term behavior studies
- Sequential maneuver executions
- Seamless integration into automation systems for HIL test

The script-based tool automation for ModelDesk provides functionality for parameter set management and for direct model parameterization. The parameters of online and offline simulations can be changed during a simulation run.





## Tool Automation

### Example: Driving Cycle Test for Different Engine Variants Used for Fuel Consumption Analysis

```

TestDescription = [
  { 'TestName' : 'Engine 4Cyl 1.6l',
    'Maneuver'  : 'FTP75',
    'ParameterSet' : { 'Name' : 'Engine_4Cyl_1p6l' } },
  { 'TestName' : 'Engine 4Cyl 2l',
    'Maneuver'  : 'FTP75',
    'ParameterSet' : { 'Name' : 'Engine_4Cyl_2l' } } ]
try:
  Initialize(TestEnvironment)

  for Test in TestDescription:
    DownloadManeuver(Test['Maneuver'])
    ActivateParameterSet(Test['ParameterSet'])
    RunManeuver(TestEnvironment)
    GetResults(TestEnvironment)
    EvaluateResults()

finally:
  CleanUp(TestEnvironment)

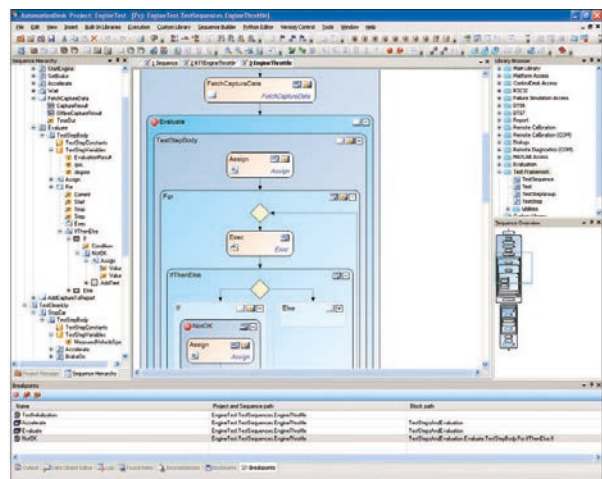
```

Simplified extract from a Python script that shows how to define several tests and perform them in a loop.

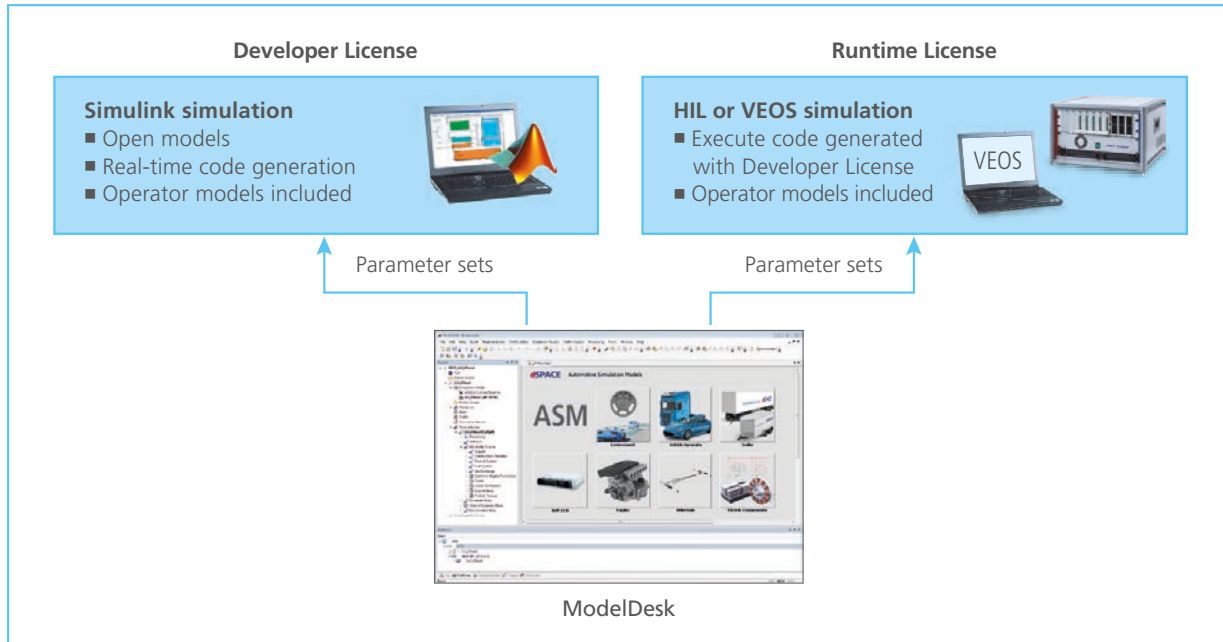
### Test Automation

AutomationDesk is dSPACE's environment for powerful and convenient test automation.

With the ModelDesk Access Library, tests created in AutomationDesk can control ModelDesk directly. Tasks such as changing parameters, switching between configurations and initiating simulation runs can therefore all be automated. A comprehensive report details the results.



# ASM Versions and Licenses



## The ASM License Concept

The ASM models come with two different license types: the Developer License and Runtime License. This lets users integrate the models in various kinds of applications, without losing any of the characteristic ASM flexibility.

- **Exchangeability** – You can use both licenses on one PC or split them to have one PC for model maintenance and one PC for simulation platform operation.

- **Mutual Parameterization** – Both license types let you parameterize all models with ModelDesk’s parameterization options for simulation on a PC (offline) or on dSPACE real-time hardware (online).

- **Seamless 3-D Animation** – The vehicle dynamics and traffic models provide access to MotionDesk with both license types. The models must include the MotionDesk blockset.

## The Benefits

- A simulation environment that seamlessly covers the offline and real-time worlds
- ModelDesk is the parameterization tool throughout the entire process, which means that you can reuse parameter sets.

- Cost-efficient license types for offline and online (real-time) simulation
- Simulation models are parameterized and reconfigured in ModelDesk with the Runtime License also. This enables real-time simulation on a dSPACE platform without an additional MATLAB license.

### ASM Developer License

The Developer License is designed specifically for modifying, parameterizing and preparing the open Simulink models for simulation on a real-time platform. The license lets you generate real-time code. Moreover, the license can be used for Simulink simulation on a PC (offline).

### Properties

- Modular *developer models* viewable down to the Simulink block level
- Modular, encapsulated *operator models*, designed specifically for Simulink simulation (offline)
- Easy substitution or extension of ASM models by customer-specific model parts
- Support for real-time and VEOS code generation
- Simulink simulation on a PC (offline)

---

### ASM Runtime License

The Runtime License is designed specifically for simulation on a real-time platform (online) and Simulink simulation of *operator models* (offline).

### Properties

- Code execution on dSPACE real-time hardware (dSPACE Simulator, SCALEXIO)
- Code execution on dSPACE VEOS
- Code already generated from the models via the Developer License
- Simulink simulation of *operator models*, which are modular, encapsulated, and designed specifically for Simulink simulation (offline).

# Technical Aspects

## Parameters, Signals, and Performance

### Parameters Sets and Examples

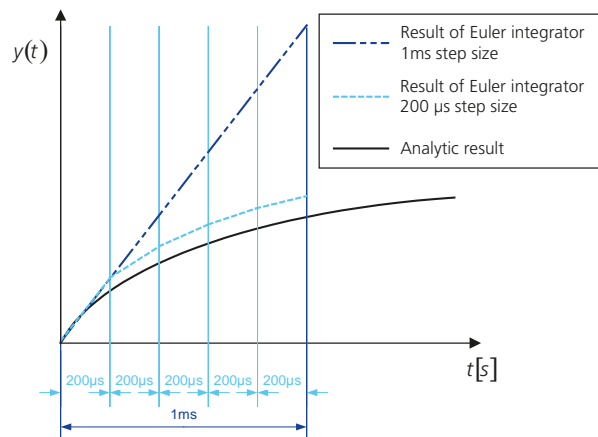
The model is preconfigured with default data, which means that all parameters and tables have suitable values and are fully functional. The model comes with standard driving maneuvers (FTP75, JP\_JC08, US06, etc.) as well as common engine cycles (ETC, WHTC, etc.). It is therefore ready to use immediately after installation.

### Performance

At a sample time of 1 ms, the model's turnaround time is about 10% of the total available processing time when executed on a dSPACE processor board clocked at 2.8 GHz. There is therefore enough headroom for I/O operations and other calculations.

### Subsystem Oversampling

To guarantee numerically stable integration of submodels with stiff behavior, local subsystem oversampling is used. Simulink's For Iterator subsystem evaluates stiff differential equations n-times during one major simulation step.



Subsystem oversampling for a step response of a first-order delay element.

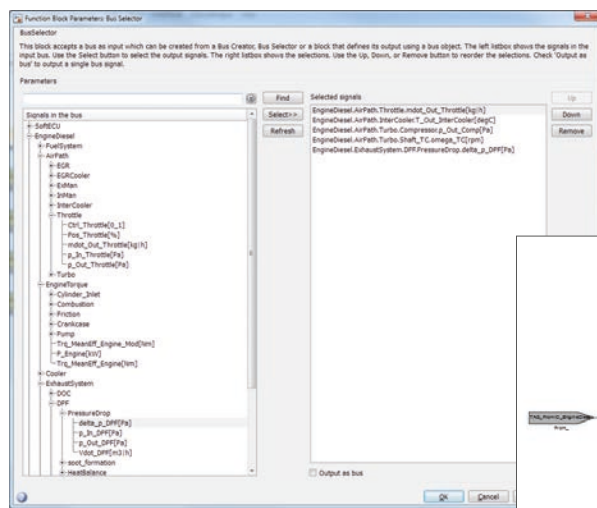
### In-Cylinder Subsystem Oversampling

Additionally, subsystem oversampling is applied in the In-Cylinder models to achieve an adequate signal discretization and resolution. For example, 100  $\mu$ s sample time corresponds with a 3.6° crank angle resolution at 6000 rpm. In case of real-time simulation of in-cylinder engine models,

the oversampled subsystem needs to be triggered by the real-time hardware to ensure consistent processing of the corresponding IO interface. If higher requirements concerning the cylinder pressure signal resolution exist, solutions are available to achieve even better discretization performance.

### Parameters Tunable Online

The parameters of the model can be tuned while the model is performing a real-time simulation on a dSPACE Simulator. A parameter (vehicle mass, etc.) is implemented as a single constant block in the model. ControlDesk provides access to each parameter when the model is used in online mode.

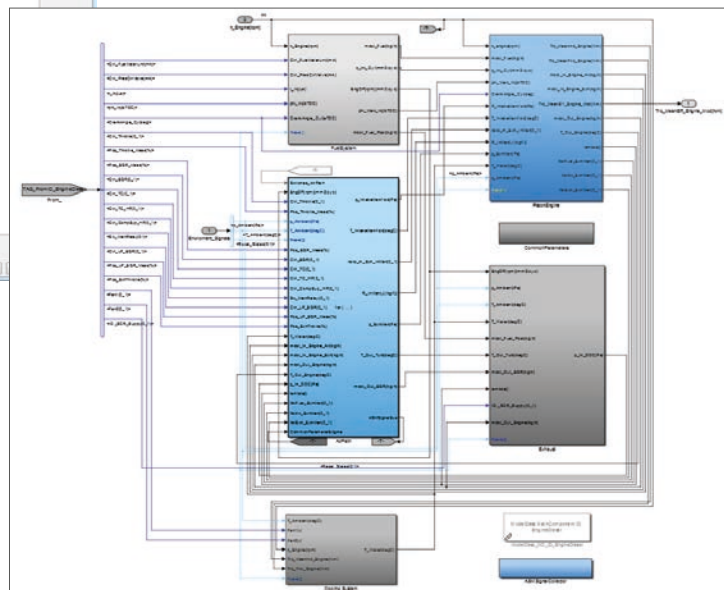


### ASMSignalBus

The ASMSignalBus comprises the relevant signals of all model components in a hierarchical structure. Signals for I/O access with an interface board or for display with a Simulink Scope can be chosen conveniently via a Simulink Bus Selector.

ASMSignalBus displays all the relevant signals in a clear structure.

The Simulink engine model with the main components and signals.



# Offline Simulation

## Operator Version for PC-based Offline Simulation

### ASM Operator Version

The Operator Version of the ASM is a model variant specifically designed for offline simulation with Simulink. It is therefore the ideal choice for PC-based application investigations during function development. The model offers the same functionality, simulation quality and parameterization options as the standard simulation package, whose range of applications runs from function design to hardware-in-the-loop testing.

The fundamental difference with 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 in the model so that their input/output behavior can be studied.

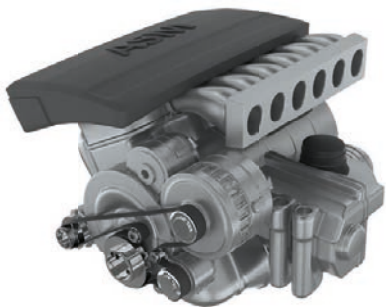
### Key Features

- Component-based Simulink libraries
- Encapsulated on lower levels (S-functions)
- For offline simulation only
- Full MATLAB/Simulink support
- Full ModelDesk support
- Same functionality, level of detail and parameterization options as a standard ASM package

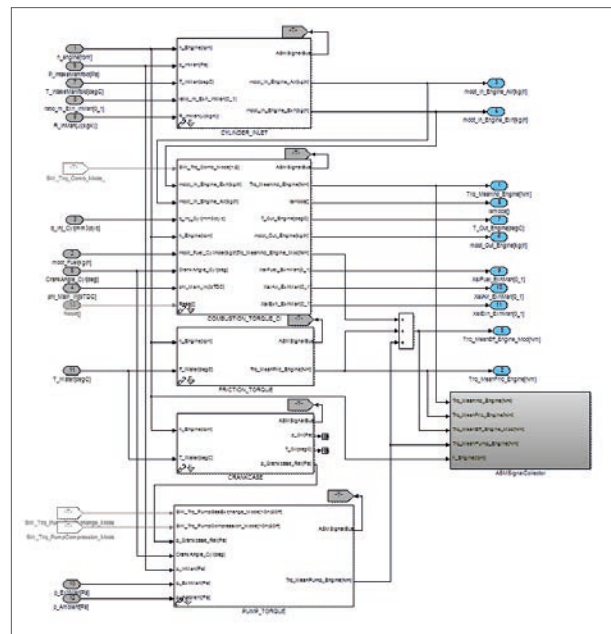
### Use Cases

Typical applications are closed-loop tests on controller functions with model-in-the-loop (MIL) and/or software-in-the-loop (SIL), and also application investigations such as:

- Parameter studies
- Drive cycle studies
- Frontloading by offline model commissioning



Model structure of the ASM Operator Version. Each component has a corresponding block in the library.





## Main Features and Benefits

Feature	Description	Benefit
Open Simulink models	<ul style="list-style-type: none"> <li>Almost all models are open down to the Simulink block level</li> </ul>	<ul style="list-style-type: none"> <li>Custom models can easily be added or used to replace model components</li> </ul>
ModelDesk	<ul style="list-style-type: none"> <li>Graphical user interface with parameter and simulation management</li> </ul>	<ul style="list-style-type: none"> <li>Easy, intuitive parameterization and seamless simulation handling</li> </ul>
Online simulation	<ul style="list-style-type: none"> <li>Real-time simulation on real-time hardware</li> </ul>	<ul style="list-style-type: none"> <li>Hardware-in-the-loop simulations with ECUs</li> </ul>
Offline simulation	<ul style="list-style-type: none"> <li>Simulations as early as the design phase</li> </ul>	<ul style="list-style-type: none"> <li>Controller validation in early development stages</li> </ul>
ASMSignalBus	<ul style="list-style-type: none"> <li>Simulation signals are part of a structured Simulink signal bus</li> </ul>	<ul style="list-style-type: none"> <li>Standardized and fast access to model variables</li> </ul>
Online tunable parameters	<ul style="list-style-type: none"> <li>Direct parameter access during real-time simulations</li> </ul>	<ul style="list-style-type: none"> <li>Online parameter optimizations and behavior studies</li> </ul>
Model interoperability	<ul style="list-style-type: none"> <li>ASM models are easy to combine to create a virtual vehicle</li> </ul>	<ul style="list-style-type: none"> <li>An entire virtual vehicle can be simulated</li> </ul>

## Order Information

Classification	Type	Order Number
Packages	ASM – Gasoline Engine Basic Simulation Package	<ul style="list-style-type: none"> <li>Please inquire</li> </ul>
	ASM – Gasoline Engine Simulation Package	<ul style="list-style-type: none"> <li>Please inquire</li> </ul>
	ASM – Diesel Engine Simulation Package	<ul style="list-style-type: none"> <li>Please inquire</li> </ul>
	ASM – Gasoline Engine InCylinder Simulation Package	<ul style="list-style-type: none"> <li>Please inquire</li> </ul>
	ASM – Diesel Engine InCylinder Simulation Package	<ul style="list-style-type: none"> <li>Please inquire</li> </ul>
	ASM – Vehicle Dynamics Simulation Package for VEOS®	<ul style="list-style-type: none"> <li>Please inquire</li> </ul>
	ASM – Vehicle Dynamics Simulation Package	<ul style="list-style-type: none"> <li>Please inquire</li> </ul>
	ASM – Truck and Trailer Simulation Package	<ul style="list-style-type: none"> <li>Please inquire</li> </ul>
Libraries	ASM – Turbocharger Model	<ul style="list-style-type: none"> <li>ASM_L_TC</li> </ul>
	ASM – Electric Components	<ul style="list-style-type: none"> <li>ASM_L_EC</li> </ul>
	ASM – Brake Hydraulics Model	<ul style="list-style-type: none"> <li>ASM_L_BH</li> </ul>
	ASM – Pneumatics	<ul style="list-style-type: none"> <li>ASM_L_PNEU</li> </ul>
	ASM – Diesel Exhaust System Model	<ul style="list-style-type: none"> <li>ASM_L_DEXH</li> </ul>
	ASM – Traffic	<ul style="list-style-type: none"> <li>ASM_L_TRF</li> </ul>

## Relevant Software and Hardware

Software		
Required	Integrated development environment	<ul style="list-style-type: none"> <li>MATLAB/Simulink from MathWorks</li> <li>Simulink® Coder™ (formerly Real-Time Workshop®)<sup>2)</sup></li> <li>Simulink Accelerator<sup>1)</sup></li> </ul>
	dSPACE implementation software	<ul style="list-style-type: none"> <li>Real-Time Interface (RTI)<sup>2)</sup></li> </ul>
	dSPACE experiment software	<ul style="list-style-type: none"> <li>ControlDesk®<sup>2)</sup> Next Generation</li> </ul>
	Additional software	<ul style="list-style-type: none"> <li>Microsoft® Excel®</li> </ul>
	Operating system	<ul style="list-style-type: none"> <li><a href="http://www.dspace.com/go/os_compatibility">www.dspace.com/go/os_compatibility</a></li> </ul>

Hardware		
Required	Minimum system	<ul style="list-style-type: none"> <li>Pentium® 4 processor, 1.4 GHz or higher</li> <li>Memory = 2 GB RAM</li> <li>Graphics accelerator card matching the requirements of MotionDesk<sup>3)</sup></li> </ul>
	Recommended system	<ul style="list-style-type: none"> <li>Intel® Core™ i5 Processor, 3 GHz or higher</li> <li>Memory ≥ 4 GB RAM</li> <li>Dual-head graphics accelerator card matching the requirements of MotionDesk<sup>3)</sup></li> </ul>
	SCALEXIO or dSPACE Simulator (equipped with DS1005 PPC Board or DS1006 Processor Board) <sup>4)</sup>	

<sup>1)</sup> Offline simulations only.

<sup>2)</sup> Online simulations only.

<sup>3)</sup> Graphics accelerator required for MotionDesk, which is part of the ASM Vehicle Dynamics Simulation Package. More details on graphics card requirements and compatibility at [www.dspace.com/go/mdhwrequ](http://www.dspace.com/go/mdhwrequ)

<sup>4)</sup> ASM Traffic, ASM Truck, ASM Trailer, and ASM Engine InCylinder Models support the DS1006 only.

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