ASM – Turbocharger Model

- dSPACE Automotive Simulation Models – ASM
- Turbocharger Model
- NEW: Support for ASM – Gasoline Engine Simulation Package
Turbocharger Model

Real-Time Turbocharger Model

Key Features

- Open MATLAB®/Simulink® model
- Real-time simulation and offline simulation
- Physical turbocharger model with calculation of shaft speed
- Extension to gasoline and diesel engine models

Description

Application Areas
The Turbocharger Model is an extension to the Diesel and Gasoline Engine Simulation Packages and provides a physical turbocharger model that can be configured for different types of turbochargers. It is fully integrated into the dSPACE tool chain and is typically used on a dSPACE Simulator for hardware-in-the-loop testing of electronic control units (ECUs) or during the design phase of controller algorithms for early validation by offline simulation.

Key Benefits
The Turbocharger Model provides a more realistic model of turbocharger components and the engine air path than the map-based turbocharger model contained in the Diesel and Gasoline Engine Simulation Packages. Unlike the map-based turbocharger, the Turbocharger Model calculates the turbine shaft speed, which is required by ECUs with turbine speed sensor. All Simulink blocks in the model are visible, so it is easy to add or replace components with customer models to adapt the turbocharger properties perfectly to individual projects.

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

Offline and Online Simulation
The Turbocharger Model can be used in combination with real controllers in a hardware-in-the-loop environment (HIL or online mode). The model supports real-time code generation via Real-Time Workshop® from The MathWorks® and dSPACE’s RTI for online simulation on a dSPACE real-time system.
Main Features and Benefits

<table>
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<tr>
<th>Feature</th>
<th>Description</th>
<th>Benefit</th>
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<tbody>
<tr>
<td>Open Simulink model</td>
<td>■ All model blocks are visible</td>
<td>■ Customer models can easily be added or used to replace model components</td>
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<tr>
<td>ASMPParameterization</td>
<td>■ Model parameterization comprising calculation and visualization of parameters</td>
<td>■ Structured parameter handling and fast parameterization (p. 9)</td>
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<td>Online simulation</td>
<td>■ Real-time simulation on real-time hardware</td>
<td>■ Hardware-in-the-loop simulations with ECUs</td>
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<td>Offline simulation</td>
<td>■ Simulations as early as the design phase</td>
<td>■ Controller validation in early development stages</td>
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<td>ASMSignalBus</td>
<td>■ Simulation signals are part of a structured Simulink signal bus</td>
<td>■ Standardized and fast access to model variables (p. 8)</td>
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<td>Online tunable</td>
<td>■ Direct parameter access during real-time simulations</td>
<td>■ Online parameter optimizations and behavior studies (p. 7)</td>
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<tr>
<td>parameters</td>
<td></td>
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<td>Model interoperability</td>
<td>■ ASM models are easy to combine to create a virtual vehicle</td>
<td>■ An entire virtual vehicle can be simulated (p. 10)</td>
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Order Information

<table>
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<tr>
<th>Classification</th>
<th>Type</th>
<th>Order Number</th>
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<tr>
<td>Extension Model</td>
<td>ASM – Turbocharger Model</td>
<td>ASM_L_TC</td>
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Relevant Hardware and Software

Hardware

| Required          | Minimum system              | Pentium 3 processor, 800 MHz                             |
|                  |                             | 512 MB RAM                                              |
| Recommended system| Pentium 4 processor, 1.4 GHz or higher | Memory \( \geq 1024 \) MB RAM |
| dSPACE Simulator, equipped with | DS1005 or DS1006 |

Software for Online Simulation

| Required          | Integrated development environment | MATLAB®/Simulink® from The MathWorks® |
|                  | dSPACE implementation software     | Real-Time Workshop® |
|                  | dSPACE experiment software         | Real-Time Interface (RTI) |
|                  | dSPACE simulation software         | ASM – Diesel Engine Simulation Package or NEW: ASM – Gasoline Engine Simulation Package |
| Operating system  | Windows 2000, Windows XP (32-bit version only) |

Software for Offline Simulation

| Required          | Integrated development environment | MATLAB®/Simulink® from The MathWorks |
|                  | Operating system                   | Windows 2000, Windows XP (32-bit version only) |
|                  | dSPACE simulation software         | ASM – Diesel Engine Simulation Package or NEW: ASM – Gasoline Engine Simulation Package |
| Optional          | Other dSPACE ASM Packages          | – |

1) The ASM – Gasoline Engine Basic Simulation Package is not supported.
**Turbocharger Model**

**Feature Overview**

- Air path simulation with the precision of a physical model
- Extension to ASM – Diesel Engine Simulation Package and ASM – Gasoline Engine Simulation Package
- Contains models for compressor, turbine, and turbocharger shaft
- Wastegate valve and variable turbine geometry (VTG)
- Turbine power and turbine output temperature
- Temperature calculated according to isentropic efficiency
- Turbine mass flow and efficiency in maps
- Compressor power and output temperature

**Features at a Glance**

- Compressor pressure ratio and efficiency in maps
- Offline and online simulation
- Real-time-capable
- Easy to insert in ASM – Diesel Engine Simulation Package and ASM – Gasoline Engine Simulation Package
- Modular, library-based implementation
- Easy variable access
- Fully integrated into dSPACE tool chain
- Online tunable parameters
- Comprehensive documentation with complete formula listing

*Schematics of the turbocharger system.*
**Turbocharger Model Concept**
The physical turbocharger model consists of a compressor, a turbine, and the turbocharger shaft. Turbochargers with VTG or wastegate can be simulated. The Turbocharger Model is an alternative to the map-based turbocharger that is included in the gasoline and diesel engine models. You can switch between the map-based and physical model.

**Characteristics**
- Alternative to map-based model
- Switching between the two models
- Wastegate valve and VTG
- Calculates the engines air path with the precision of a physical 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 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.

**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

Look-up table for Turbine efficiency.  
Look-up table for Turbine mass flow.
Turbocharger Model

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

Characteristics
- Provides the shaft speed

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

Turbocharger Model

Wastegate Valve
To protect the engine from critical speed and provide constant boost pressure for varying engine speeds, the turbocharger is controlled by an electronic control unit. In wastegate-controlled turbochargers, some exhaust gas bypasses the turbine through the wastegate valve. A model of the wastegate valve is provided.

Characteristics
- Mass flow through the wastegate valve is calculated as a function of pressure ratio and wastegate control signal
- Modeled as an isentropic adiabatic flow through an orifice with a variable flow cross-section
- Temperature changes are not considered

Look-up table for Compressor pressure ratio.

Look-up table for Compressor efficiency.
Technical Aspects

Parameters Tunable Online
Every parameter in the model is implemented as a single constant block and can be tuned during real-time simulation on a dSPACE Simulator. ControlDesk provides access to the parameters in online mode.

Signal and Parameter Management

The turbocharger Simulink model with the main components and signals.
Signal and Parameter Management

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 comprises all relevant signals and displays them in a clear structure.
The parameterization of a model is a crucial task. The Turbocharger Model is parameterized individually, according to specific requirements. Parameterization is based on measurement data for compressor and turbine and parameters such as the inertia of the turbocharger shaft.

The GUI-based tool supports the loading of engine test bench measurements from Excel format, the mapping of measurements to model variables including unit conversion, and automatic generation of look-up tables using several kinds of interpolation and extrapolation functions. These are open M-functions that you can modify as required. Last but not least, the tool provides structured access to model components and enables you to manage parameter sets for individual model configurations.

The user interface of the comprehensive parameterization tool.
### ASM Philosophy

#### Concept

**Model Design Philosophy**

For optimum support of customer-specific requirements, dSPACE has chosen an open model concept. This means that models are visible to users right down to the level of standard Simulink blocks. Thus the dSPACE Automotive Simulation Models provide enormous flexibility for projects that require dedicated simulation models. The open model approach allows perfect adaptation to individual projects and requirements. This can be achieved by modifying models or by replacing or adding components.

#### Virtual Vehicle

dSPACE Automotive Simulation Models are a collection of well coordinated models that you can easily combine to build anything from extended models to a whole virtual vehicle. As well as gasoline and diesel engines, there are models for vehicle dynamics and brake hydraulics. Combined models interoperate in one simulation.

![Several ASM packages can be combined to make a virtual car.](image-url)