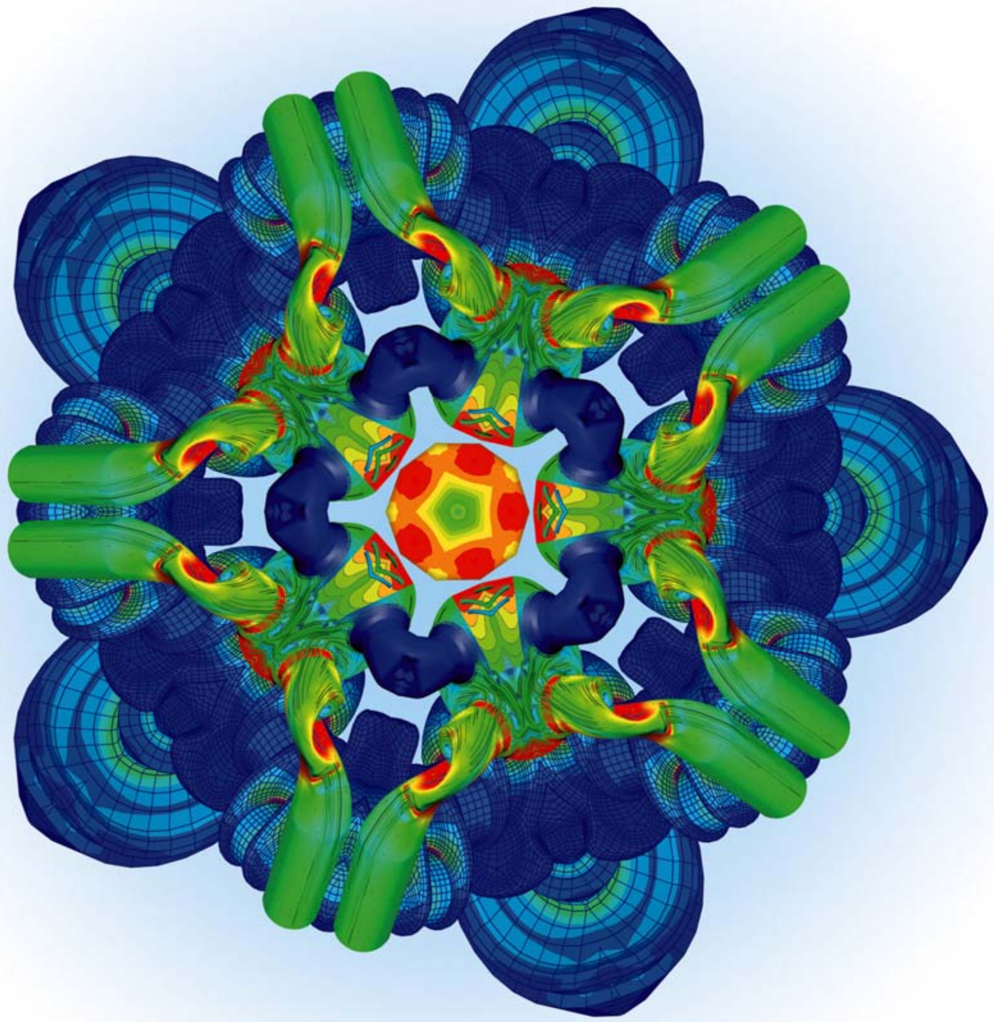
Edition 11/2010

Users Guide

AVL BOOST
VERSION 2010



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A	17-Jul-2009	BOOST v2009 – Users Guide	01.0104.2009
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C	19-Nov-2010	BOOST v2010 – Users Guide	01.0104.2010

This document describes how to run the BOOST software. It does not attempt to discuss all the concepts of 1D gas dynamics required to obtain successful solutions. It is the user's responsibility to determine if he/she has sufficient knowledge and understanding of gas dynamics to apply this software appropriately.

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1. INTRODUCTION

BOOST simulates a wide variety of engines, 4-stroke or 2-stroke, spark or auto-ignited. Applications range from small capacity engines for motorcycles or industrial purposes up to large engines for marine propulsion. **BOOST** can also be used to simulate the characteristics of pneumatic systems.

The **BOOST** program package consists of an interactive pre-processor which assists with the preparation of the input data for the main calculation program. Results analysis is supported by an interactive post-processor.

The pre-processing tool of the **AVL Workspace Graphical User Interface** features a model editor and a guided input of the required data. The calculation model of the engine is designed by selecting the required elements from a displayed element tree by mouse-click and connecting them by pipe elements. In this manner even very complex engine configurations can be modelled easily, as a large variety of elements is available.

The main program provides optimised simulation algorithms for all available elements. The flow in the pipes is treated as one-dimensional. This means that the pressures, temperatures and flow velocities obtained from the solution of the gas dynamic equations represent mean values over the cross-section of the pipes. Flow losses due to three-dimensional effects, at particular locations in the engine, are considered by appropriate flow coefficients. In cases where three-dimensional effects need to be considered in more detail, a link to **AVL**'s three-dimensional flow simulation code **FIRE** is available**.** This means that a multi-dimensional simulation of the flow in critical engine parts can be combined with a fast one-dimensional simulation elsewhere. This feature could be of particular interest for the simulation of the charge motion in the cylinder, the scavenging process of a two-stroke engine or for the simulation of the flow in complicated muffler elements.

The **IMPRESS Chart** and **PP3** post-processing tools analyze the multitude of data resulting from a simulation. All results may be compared to results of measurements or previous calculations. Furthermore, an animated presentation of selected calculation results is available. This also contributes to developing the optimum solution to the user's problem. A report template facility assists with the preparation of reports.

1.1. Scope

This document describes the basic concepts and methods for using the BOOST program to perform engine cycle simulation.

1.2. User Qualifications

Users of this manual:

- Must be qualified in basic UNIX and/or Microsoft Windows.
- Must be qualified in basic engine cycle simulation.

1.3. Symbols

The following symbols are used throughout this manual. Safety warnings must be strictly observed during operation and service of the system or its components.

Caution: Cautions describe conditions, practices or procedures which could result in damage to, or destruction of data if not strictly observed or remedied.

Note: Notes provide important supplementary information.

Convention	Meaning
Italics	For emphasis, to introduce a new term or for manual titles.
`monospace`	To indicate a command, a program or a file name, messages, input / output on a screen, file contents or object names.
MenuOpt	A **MenuOpt** font is used for the names of menu options, submenus and screen buttons.

1.4. Documentation

BOOST documentation is available in PDF format and consists of the following:

BOOST
Release Notes Users Guide Primer Examples Theory Aftertreatment Aftertreatment Primer Linear Acoustics Surface Import 1D-3D Coupling Interfaces Validation

BOOST Hydsim
Release Notes Users Guide Primer
BOOST Real-Time (RT)
Release Notes Users Guide
BOOST Thermal Network Generator (TNG)
Users Guide Primer
AVL Workspace (AWS)
Release Notes GUI Users Guide Python Scripting DoE and Optimization Installation Guide Licensing Users Guide System Requirements and Supported Platforms

Known Issues are available on the AST Service World – Knowledge Base:

Link to AWS Known Software Issues

We Want to Hear from You

Your comments and suggestions help us to improve the quality and practical relevance of our documentation.

If you have any suggestions for improvement, please send them to: ast_doc@avl.com

We look forward to hearing from you.

2. GRAPHICAL USER INTERFACE

Based on the **AVL Workspace Graphical User Interface (AWS GUI),** the pre-processing tool assists the user in creating an engine model for a **BOOST** simulation.

For the general handling of the **AWS GUI** please refer to the GUI Users Guide. The **BOOST** specific operations are described as follows:

2.1. BOOST Specific Operations

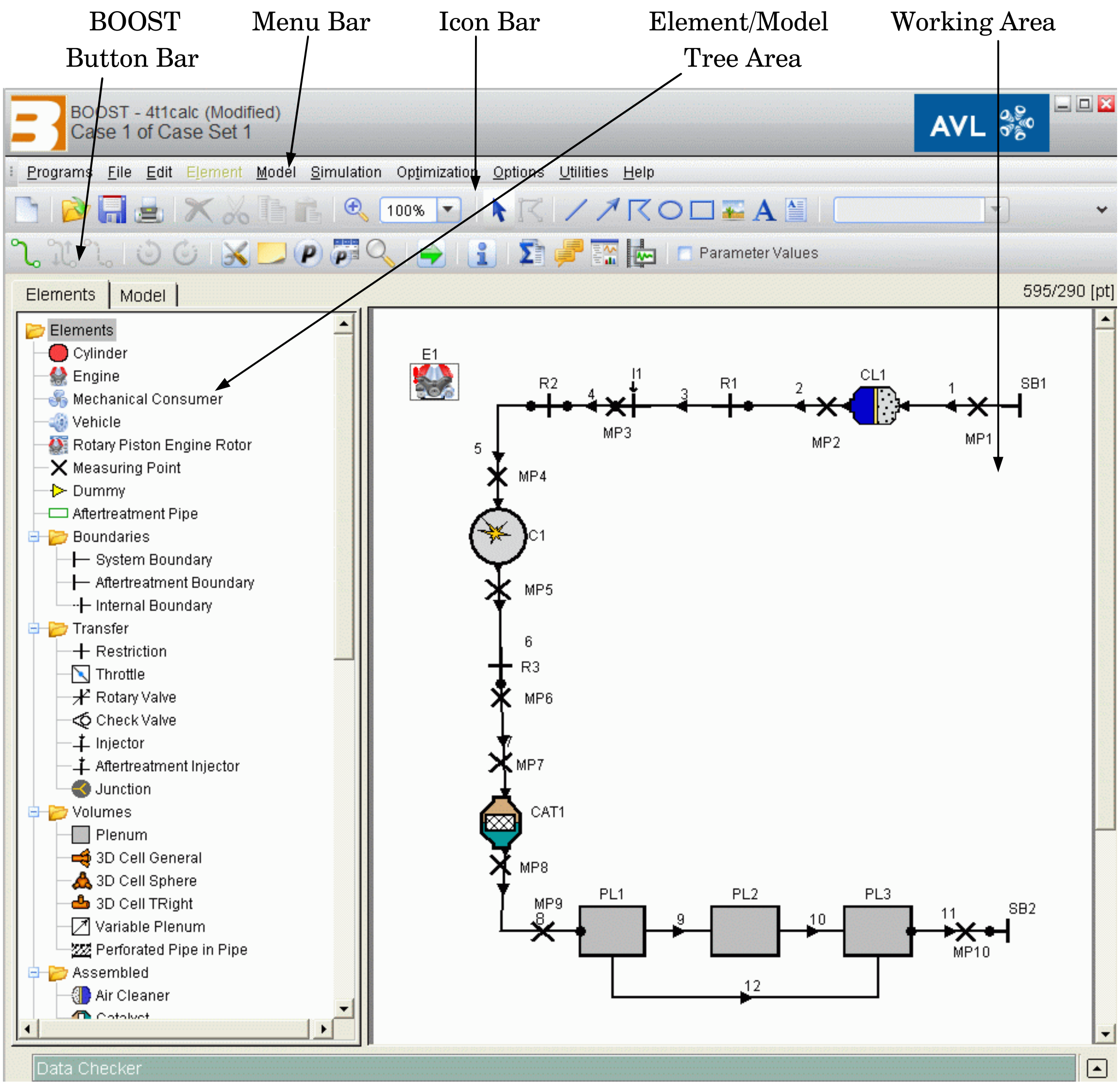


Figure 2-1: BOOST - Main Window

2.1.1. Menu Bar

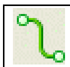
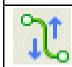
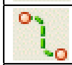
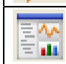
File	**Save activated case**	Saves the current model to a new bwf file, during which the parameter values are set to the data of the activated case and all case sets and cases are removed from the case explorer.
	Import	Imports Boost 3.x (*.bst), GT-Power (*.gtm), CAD (*.xml) models. Refer to section 2.1.5 for details.
Element	**Parameters**	Displays the parameters for the selected element. Parameters can be added or deleted. Alternatively click on an element with the right mouse button and select **Parameters** from the submenu. Refer to section 2.2.1 or the GUI Users Guide, section 2.4.1 for further information.
	Properties	Displays the dialog box for defining the values for the selected element. Alternatively click on an element with the right mouse button and select **Properties** from the submenu.
	Copy Data	First select the source element type in the working area or model tree, then data can be copied from the selected source element to the selected target(s).
Model	**Parameters**	Defines values for the model. Refer to section 2.2.1 or the GUI Users Guide, section 2.5.2 for further information.
	Case Explorer	Define parameter variations. Refer to section 2.5.3 of the GUI Users Guide for further information.
	Solid Materials…	Displays the solid materials GUI. Refer to section 2.2.3 for further information.
	Liquid Materials	Displays the liquid materials GUI. Refer to section 2.2.4 for further information.
	Favorites	This is a is a user defined dialog, which should be designed by template model designers in order to provide users of the template model with a simplified way to enter the required model data. Refer to section 2.5.4 of the GUI Users Guide for further information.
	Favorites Designer	The Favorites dialog is defined in the Favorites Designer, by inserting Favorites GUI elements from the toolbar. Refer to section 2.5.5 of the GUI Users Guide for further information.
Simluation	**Run**	Opens the dialog to start the simulation. This displays both the cases for the current model and the tasks to be performed. Refer to section 2.2.1 or the GUI Users Guide, section 2.6.1 for further information.
	Status	Check the status of the simulation. Refer to section 2.6.2 of the GUI Users Guide for further information.

	Control	Defines parameters used to control the simulation and define the global values used in the simulation. Refer to section 2.3.1 for further information.
	Volumetric Efficiency	Displays and sets the reference element to be used for volumetric efficiency calculations. This can be either a measuring point or a plenum. Refer to section 2.3.1.3 for further information.
	Test Bed Conditions	Displays and sets the test bed reference elements (Measuring Points only) labeled according to document “AVL Standard Sensor Locations Engine Test Bed”. Refer to section 2.3.3 for further information.
	Create Series Results	Prepares the procedure for the Case Series results. Refer to Section 2.3.4 for further information.
	Show Summary	**Cycle Simulation** **Aftertreatment** Opens the ASCII browser and displays the summary values from either the cycle simulation or aftertreatment analysis. Refer to Chapter 5.
	Show Results	Opens the IMPRESS Chart post-processor which is used to examine and plot the simulation results.
	Show Audio	For playing any WAV files from the microphone element.
	Show Messages	**Cycle Simulation** **Aftertreatment** Opens the Message browser and displays the messages generated by the solver during the cycle simulation or aftertreatment analysis. Refer to Chapter 5.
	Show Animation	Opens the PP3 post-processor. Refer to Chapter 5.
	Show Elements	**Cycle Simulation** Opens a browser to display more detailed information on compound perforated elements. **Linear Acoustics** Shows how the elements are translated from the graphical to the linear acoustic ones.
	Import Results	Prepares results of a `BOOSTFILENAME.bst` file run outside the graphical user interface.
	View Logfile	Displays the screen output of the calculation kernel during the simulation or model creation.
Optimization		Refer to the AWS DoE and Optimization manual.

Options	**Job Submission**	Define job submission settings: queues, number of processors per job and number of parallel jobs. Refer to section 2.8.1 of the GUI Users Guide for further information.
	Model Locking	Lock the property dialogs for elements for simplified and protected model views. Refer to section 2.8.2 of the GUI Users Guide for further information.
	GUI Options	Defines the number or recently opened files to be kept in the file menu. Defines the initial position and size of the AVL Workspace window.
	Frame	Set of graphical elements used for page layout, e.g. rectangle (frame), logo and text elements. **None:** Removes the frame from the page. **AVL Report:** The standard AVL frame.
	Frame Definitions	Customized settings of the current frame. Specify text and the customer logo for the frame.
	Units	Used to display and set the units used. Refer to section 2.8.3 of the GUI Users Guide for further information.
	Environment Settings	With the help of these settings the BOOST calculation kernel can be configured.
Utilities	**BURN**	Tool for Combustion Analysis. Refer to section 2.4.1 for further information.
	Search	Displays tables of the input data used in the model. These can be saved in HTML format. Refer to section 2.4.2 for further information.
	License Manager	Controls availability and usage of licenses. Refer to section 2.4.3 for further information.
	License File Definition	If the registration of the FLEXnet license files fails, use this editor to access the Windows-Registry to set the license file.
	Pack Model	Creates a compressed tape archive of all relevant model information. Refer to section 2.4.4 for further information.
	Unpack Model	Unpacks a compressed BOOST Model including results.
	Export GCA parameters	The basis of the required input data for GCA can be exported from a BOOST model.
	Export Pressure Curve	For each operating point the export of the pressure curves for all cylinders is done. After running this feature AVL-EXCITE can import that data. Refer to section 2.4.6 for further information.

	Export Flowmaster 4D-Map	Exports a map which can be loaded into the FLOWMASTER Element "AVL BOOST Engine". Refer to section 2.4.7 for further information.
	Export Engine Data	Exports a characteristic set of Engine Data in xml format for e.g.: usage in a database.
	Calculation List	Refer to section 2.4.8 for further information.
	Export Engine Data	Engine data can be exported from the BOOST model.
	Python Scripts	**Export Active Case Directory** **Open Shell in Active Case Directory** **Export Case Table to HTML-File** **Export Case Table to XML-File** **Convert bst to bwf** Refer to the Python Scripting Manual for more details.
Help	**Contents**	Opens the Users Guide for online help.
	Manuals	Access to manuals in PDF format.
	AVL AST Service World	Information on how to register for the AST Service World. This provides platforms for software downloads, product information and data transfer.
	About	Displays version information.

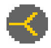
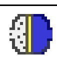
2.1.2. BOOST Icons

	If selected the mouse can be used to connect a pipe between two elements. (pipe, wire, mechanical, aftertreatment, perforated pipe in plenum).
	Reverses the positive flow direction of the selected pipe.
	Changes the attachments of a selected pipe or a wire.
	Rotates the selected object counter-clockwise (90 degrees steps)
	Rotates the selected object clockwise (90 degrees steps)
	Opens the input window for general simulation control (globals) data. Refer to **Simulation|Control**.
	Enter model information.
	Refer to **Model|Parameters** as described above.
	Refer to **Model|Case Explorer** as described above.
	Refer to **Simulation|Run** as described above..
	Refer to **Simulation|Status** as described above..
	Refer to **Simulation|Show Summary** as described above..
	Refer to **Simulation|Show Messages** as described above..
	Refer to **Simulation|Show Results** as described above..

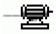
	Refer to **Simulation|Show Animation** as described above..

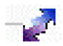
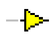
2.1.3. Elements Tree

Cylinder			Engine cylinder element. Refer to Section 4.2.8 for further information.
Engine			Engine Element. Refer to Section 4.5 for further information.
Mechanical Consumer			Mechanical Consumer Element. Refer to Section 4.6 for further information.
Vehicle			Vehicle Element. Refer to Section 4.7 for further information.
Measuring Point			Access to flow data and gas conditions over crank angle at a certain location in a pipe. Refer to Section 4.5 for further information.
Dummy			Import Results for unrecognizable Element importing a GT Power Model.
Aftertreatment Pipe			Pipe in the Aftertreatment mode.
Boundaries	**System Boundary**		Provides the connection of the calculation model to a user-definable ambient. Refer to Section 4.9.1 for further information.
	Aftertreatment Boundary		Provides the connection of the aftertreatment analysis model to a user-definable ambient.
	Internal Boundary		Allows boundary conditions for the calculation model to be specified directly in the last cross section of a pipe where a model ends. Refer to Section 4.9.3 for further information.
Transfer	**Restriction**		Considers a distinct pressure loss at a certain location in the piping system. Refer to Section 4.10 for further information.
	Throttle		Controls the air flow in a pipe as a function of throttle angle.
	Rotary Valve		Controls the air flow in a pipe as a function of crank angle or time. Refer to Section 4.10.3 for further information.
	Check Valve		A pressure actuated valve used to prevent reverse flow. Refer to Section 4.10.4 for further information.

	Injector		Used for engines with external mixture preparation to add the fuel to the air in the intake system. Refer to Section 4.10.5 for further information.
	Junction		Used to connect three or more pipes. In the case of three pipes, a refined junction model may be used. This considers geometric information such as the area ratio of the connected pipes and the angles between the pipes. In other cases a simple constant pressure model is available. Refer to Section 4.10.6 for further information.
Volumes	**Plenum**		An element in which spatial pressure and temperature differences are not considered. Refer to Section for 4.11.1 further information.
	3D Cells		**3D Cell General** **3D Cell Sphere** **3D Cell TRight** Refer to Section 4.11.2 for further information.
	Variable Plenum		Considers the change of the volume and surface area of the plenum over time. Refer to Section 4.11.3 for further information.
	Perforated Pipe in Pipe		Single element representing two pipes. An inner perforated pipe and an outer pipe. Refer to Section 4.11.4 for further information.
Assembled	**Air Cleaner**		The instantaneous pressure loss is determined from the pressure loss specified in a reference point at steady state conditions. Refer to Section 4.12.1 for further information.
	Catalyst		The pressure loss in the catalyst must be defined for a reference mass flow. Its characteristics are determined from this input and additional geometrical information. It is important to note that chemical reactions in the catalyst are not considered by the cycle simulation model. Refer to Section 4.12.2 for further information. Using the aftertreatment analysis mode, chemical reactions can be simulated. Refer to the Aftertreatment Manual.

	Cooler		The treatment of the Air Cooler is similar to the Air Cleaner. The pressure loss, cooling performance and the corresponding steady state mass flow must be defined as reference values. Refer to Section 4.12.3 for further information.
	Diesel Particulate Filter		Pressure drop, loading, regeneration of particulate filters can be simulated using the aftertreatment analysis mode. Refer to the Aftertreatment Manual.
Charging	**Turbocharger**		Turbocharger element. Both simple and full models are available. Refer to Section 4.13.1 for further information.
	Turbine		Turbine Element. Both simple and full models are available. Refer to Section 4.13.2 for further information.
	Turbo Compressor		Either a constant pressure ratio and a constant compressor efficiency, an iso-speed line or a full map may be specified. If an iso-speed line or a compressor map is defined, the pressure ratio and the efficiency are determined according to the instantaneous mass flow rate and the actual compressor speed. Refer to Section 4.13.2 for further information.
	Positive Displacement Compressor		Either a constant mass flow and a constant compressor efficiency, an iso-speed line or a full map may be specified. The iso-speed line of the positive displacement compressor is defined by mass flow and efficiency versus the pressure ratio across the compressor. Refer to Section 4.13.4 for further information.
	Pressure Wave Super Charger		The BOOST PWSC Element covers the flow simulation inside the rotor channels and the interface between the casing and rotor channels. The intake and exhaust casing channels have to be modeled by means of BOOST pipes and restrictions. Allowing an arbitrary number of casing attachments this separation enables the setup of a wide range of possible geometry configurations (gas pockets and related valves).

	Waste Gate		A valve actuated by the pressure difference on the valve body plus the pressure difference on a diaphragm mechanically linked to the valve body. Refer to Section 4.13.4 for further information.
	Electrical Device		Electrical Device Element. Both simple and full models are available. Refer to Section 4.13.7 for further information.
External	**Fire Link**		Simulation of three dimensional (3D) flow patterns. Refer to Section 4.14.1 for further information.
	User Defined Element		Allows the user to implement algorithms. For maximum support, the UDE handles the data of the pipe attachments. Empty subroutines are shipped with the **BOOST** installation as a guide for the User to incorporate into his model. Furthermore results obtained from the UDE may be analysed in the post-processor. Refer to Section 4.14.2 for further information.
	CFD Link		With the same functionality as the **FIRE** Link the CFD Link element offers the possibility to link **BOOST** to 3rd party CFD codes.
	CRUISE Link		The **CRUISE** Link element can be used to specify optional channels for the exchange of information between elements in a **BOOST** model and **CRUISE**.
Control	**Engine Control Unit**		Models all the important functions of an electronic engine control. The output of the ECU, such as ignition timing, start of injection or the setting of a control valve is calculated from maps dependent on specified input parameters. Possible input parameters are engine speed or ambient conditions and data from measuring points and plenums. The parameters specified in the baseline maps may be modified by a number of corrections for ambient conditions, acceleration or deceleration of the engine. Refer to Section 4.15.1 for further information.

	MATLAB DLL		The Dynamic Link Library element can be used to include control algorithms or complete engine control models created with a commercial control algorithm design software (e.g. MATLAB/SIMULINK). Information channels are passed between elements and this junction using wires. The information channels include both sensor and actuator channels. The DLL may be written in any programming language provided the compiler supports mixed language programming. This junction is also used to link with the MATLAB s-function. Refer to Chapter 4 for further information.
	MATLAB API		Passes information to and from MATLAB. Information channels are passed between elements and this junction using wires. The information channels include both sensor and actuator channels. Refer to Section 4.15.7 for further information.
	Engine Interface		Used to supply data to elements in a BOOST model which are connected by wires. Refer to Section 4.15.4 for further information.
	PID Controller		Refer to Section 4.15.5 for further information.
	Formula Interpreter		The formula interpreter element allows to specify a function that returns a desired value (OUTPUT) as a function of other variables (INPUT).
	Monitor		The Monitor element is used to produce transient results in the results folder and in the Online Monitor for an arbitrary number of Actuator and Sensor Channels
Acoustic	**Microphone**		A microphone element can be added to any BOOST model in order to extract acoustic data such as overall dB(A) levels or order plots. The microphone is not attached to any pipes but linked in the input for the microphone to one or more system boundaries. Refer to Section 4.16.1 for further information.

	Perforate		This is handled as a flow restriction with a flow coefficient that reflects the open area of the perforate as a function of the total surface area. Refer to Section 4.16.2 for further information.
	Open Gap Chamber		This is a super element, i.e. it is not an element by itself but consists of a number of more fundamental acoustic elements. Refer to Section 4.16.3 for further information.
	Overlapping Pipes		This is a super element, i.e. it is not an element by itself but consists of a number of more fundamental acoustic elements. Refer to Section 4.16.4for further information.
	Folded Boundary Resonator		This is a super element, i.e. it is not an element by itself but consists of a number of more fundamental acoustic elements. Refer to Section 4.16.5 for further information.
User Elements			

2.1.4. Model Tree

A list of elements and connections used in the model is displayed. Click on the required item with the left mouse button, then click the right mouse button and select the required options from the submenu:

Properties opens the selected element's properties window as shown in Figure 4-1.

Parameters opens the selected element's parameters window as shown in Figure 2-2.

Group Elements links all selected elements together.

Sort Elements by Id organizes elements according to their Id.

Sort Elements by Name organizes elements according to their name.

Expand or  expands the model tree.

Collapse or  closes the tree.

Data can be copied from a selected element type in the model tree or working area by selecting **Element|Copy Data**. A window opens where the source element can be selected and copied to the target element.

2.1.5. Import

Select **File | Import** to open a dialog which enables Boost 3.x (`*.bst`), GT-Power (`*.gtm`) or CAD Import (`*.xml`) models to be imported.

- **BOOST 3.x files (*.bst)**

  These files represent a previous version of BOOST models.

- **GT-Power model (*.gtm)**

  These models are made in GT-Power tools. GT-Power versions up to and including 6.2 are supported.

- **CAD Import (*.xml)**

  XML model files are made with BOOST Surface Import utility (BSI). BSI imports CAD surface files (*.stl) and with user help, identifies components, pipes, topology, geometry and flow directions. Please refer to BSI utility documentation for details on how to import CAD surface data.

  Geometry data contained in the STL file, supplemented by user input, is then saved into the *.xml file. CAD Import does not support all the components found in BOOST, only pipes, plenums, 3D cells general, restrictions, catalysts, diesel particulate filters and junctions. Manifolds are supported, but are rendered into separate components, based on preference made in BSI utility.

  To ease import of intake and exhaust branch of an engine, multiple models can be imported, one after the other. The resulting BOOST model will contain XML models side by side, in the order in which they are imported.

If a new model is to be imported, File / New option will dispose of everything done in editor thus far.

After each import message browser is displayed. If successful, it will contain just two messages, Start and End. Any error will be displayed, similarly to one on the screenshot:

CAD Import supports only "Cycle Simulation" task. After import has finished, right-clicking on any component and choosing Properties will bring Task Selection dialog similar to screenshot:

Here, select "Cycle Simulation" only, as others are not supported. Should you define Simulation Task prior to import (via Simulation / Control from menu), make sure "Cycle Simulation" is selected.

After import has finished you might wish to enter all other relevant, non-geometrical data, before running simulation.

2.2. Model Menu

2.2.1. Parameters

Parameters can be assigned to input fields and are defined in **Model | Parameters** or Element properties windows. There are two types of parameters:

1. Global Parameters

   These can be used for any element.

2. Local Parameters

   These can only used for individual elements and are used for:

   - Creating simplified and protected model views
   - Overriding commonly defined values by element-specific, local values.

To assign a new or existing parameter in the properties dialog of an element, click the label to the left of the input value with the right mouse button and select **Assign new parameter (global)** or **Assign new parameter (local)** from the submenu**.**

Then enter a name for the new parameter, e.g. Speed. Select **OK** and it will replace the original input value.

Select **Assign existing parameter** from the submenu, then locate the predefined parameter in the dialog box.

Note: Parameter names should not have any spaces.

2.2.1.1. Assign a Model Parameter

Select **Model | Parameters** to show parameters for all elements used in the model (as shown in the following figure).

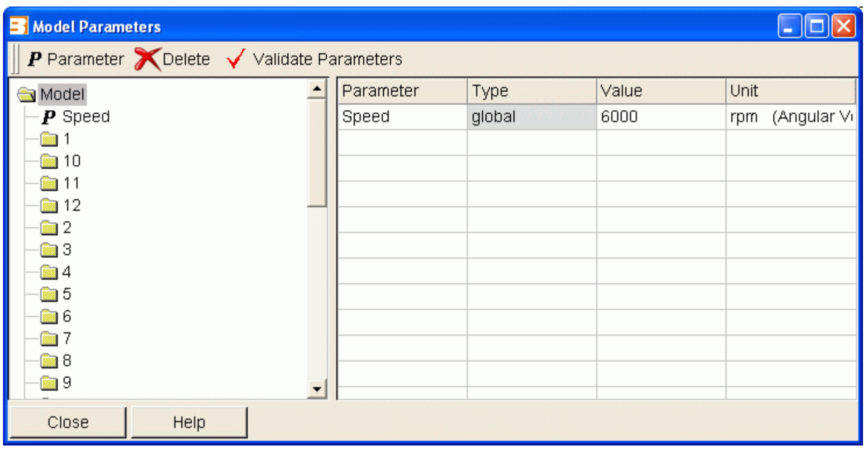


Figure 2-2: Model Parameter Window

The parameter tree on the left shows all existing parameters for all elements of the model. Global parameters can be found at the top of the tree (e.g. Speed). On the right, the values of the parameters can be edited. Constant values or expressions can be used to define a value.

Select **Model** and then select **New Parameter** to add new **global** parameter values. A default parameter name is automatically entered and this can be typed over as required.

Select the required element and then select **New Parameter** to add new **local** parameter values. A default parameter name is automatically entered and this can be typed over as required. Enter the relevant value in the **Value** input field and select the relevant unit from the pull-down menu by clicking on the **Unit** input field.

Select **Delete** to remove the selected parameter.

2.2.1.2. Assign an Element Parameter

Select **Element | Parameters** to show the parameters of the selected element. Only the parameters in the element's domain can be edited in the table.

To edit parameters for one element only, select the element in the working area and then select **Parameters** from the **Element** menu, or click the element with the right mouse button and select **Parameters** from the submenu.

2.2.2. Case Explorer

The Case Explorer defines parameter variations for the model. Select **Model | Case Explorer** to open the following window.

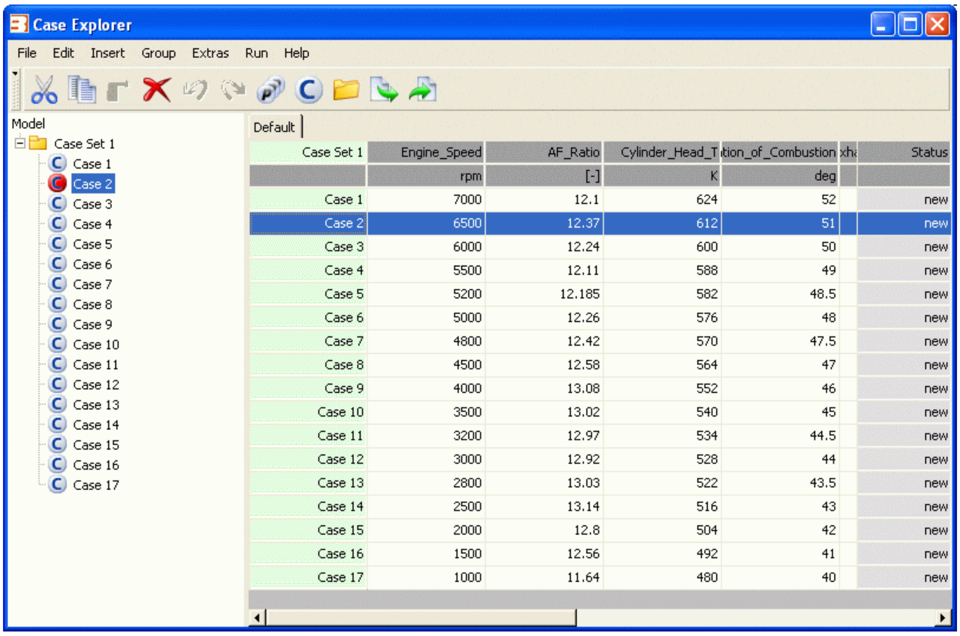


Figure 2-3: Case Explorer Window (Example: ottoser.bwf)

In this window Case 2 is the active case as it is red. To make a case active, double click on it with the left mouse button in the tree and it turns red. The assigned global parameters of the active case are displayed by selecting **Model | Parameters**.

New case parameters, i.e. parameters that will be subject to variation, can be added by clicking . Then select the unused parameter and click  to add the required parameter. Enter the relevant values for each case.

In this window Engine Speed is the main parameter as it follows State. To define it as a main parameter, select it first in the **Parameter Group Editor** window.

☞ **Note:** Only global parameters can be subject to variation with the Case Explorer. When a parameter is defined in the case table, the parameter value is disabled in the **Model|Parameters** dialog.

2.2.3. Solid Materials

An arbitrary number of solid material property sets can be defined under **Model | Solid Materials.**

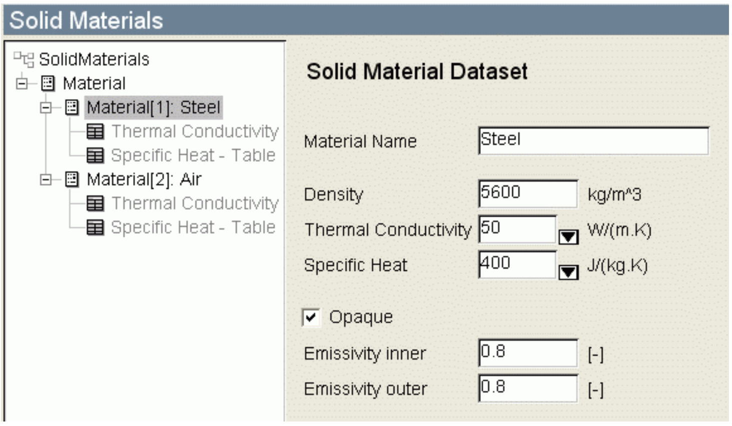


Figure 2-4: Example Table Input for Variable Wall Temperature

The input required for each solid material is as follows:

- material name (used for selecting a certain material in the wall layer specification (see Figure 4-6)
- density
- thermal conductivity (constant or function of temperature)
- specific heat (constant or function of temperature)
- opacity (checked for solids (opaque), not checked for gases (transparent))
- for opaque materials emissivities are required for the inner and outer surface.

The following table gives some property values of materials used typically for engine manifolds:

Material	Density [kg/m^3]	Specific Heat [kJ/kgK]	Specific Heat Capacity [kJ/m^{3}K]
Cast Iron	7200	0.545	3900
Steel	7840	0.46	3600
Aluminum	2700	0.91	2460
PVC (Plastics)	1390	0.98	1360
Ceramics	3500	0.84	2940

2.2.4. Liquid Materials

An arbitrary number of liquid material property sets can be defined under **Model | Liquid Materials.** The following property sets are already available: Water, AdBlue (from BASF, Technisches Merkblatt M 6221 d November 2006), Urea, Diesel.

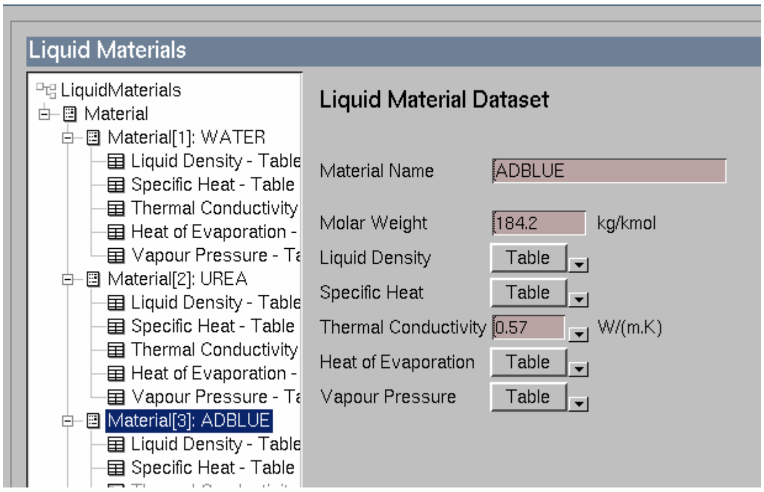


Figure 2-5: Example Table Input for Liquid Material Dataset

The following input is required:

- material name (used for selecting a certain material in the Liquid Injected Fluid section
- molar weight of liquid
- liquid density (constant or function of temperature)
- specific heat (constant or function of temperature)
- thermal conductivity (constant or function of temperature)
- heat of evaporation (constant or function of temperature)
- vapor pressure (constant or function of temperature)

2.3. Simulation Menu

Since the general input data is used to control the input process for each element, **BOOST** requires the specification of the general input data prior to the input of any element.

2.3.1. Control

The global input data must be defined first. Select **Simulation**|**Control** to open the following window. This data is used to prepare the input process for each element.

2.3.1.1. Simulation Tasks

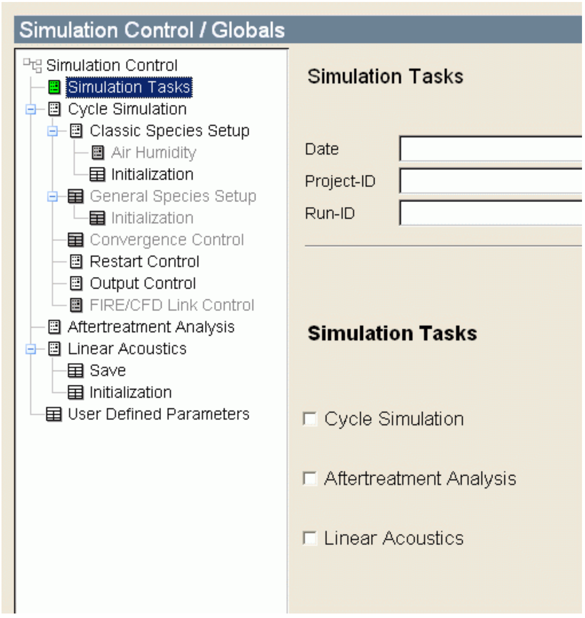


Figure 2-6: Simulation Control – Simulation Tasks Window

Date	The date is when the **BOOST** data set was last changed. It is automatically inserted by the pre-processor.
Project-ID **Run-ID**	Comment lines which may be specified to identify the calculation and may have a length of up to 50 characters.
Simulation Tasks	Depending on the new tasks, at least one of the following should be selected before starting with the model: **Cycle Simulation:** Gas exchange and combustion BOOST calculation. **Aftertreatment Analysis:** Simulation of chemical and physical processes for aftertreatment devices. **Linear Acoustics:** Frequency domain solver to predict the acoustic performance of components.

Aftertreatment Analysis should be activated to run simulations in aftertreatment analysis mode. In this case one catalytic converter or one diesel particulate filter can be linked with aftertreatment connections to aftertreatment boundary conditions. Using these elements a complete aftertreatment analysis model is specified and it can be simulated 'stand-alone' or it can be integrated within an existing BOOST cycle simulation model. Refer to the BOOST Aftertreatment Manual for further details.

Linear Acoustics should be activated to generate a linear acoustic model, which should include one source, one termination and at least one other linear acoustic element. Due to the nature of a linear acoustic simulation the connection of pipes and their flow direction (defined by the arrow) are very important in order to determine inlets and outlets.

Using the linear acoustics mode the acoustic behavior of elements can be investigated. Therefore the following information is needed to define the frequency range of interest:

- **Minimum Frequency:** Determines the beginning of the simulation.
- **Maximum Frequency:** Determines the end of the simulation.
- **Frequency Points:** Determines the number of frequencies calculated between the minimum and maximum in equal steps.

Refer to the BOOST Linear Acoustics Manual for further details.

2.3.1.2. Cycle Simulation

Select **Cycle Simulation** to open the following window:

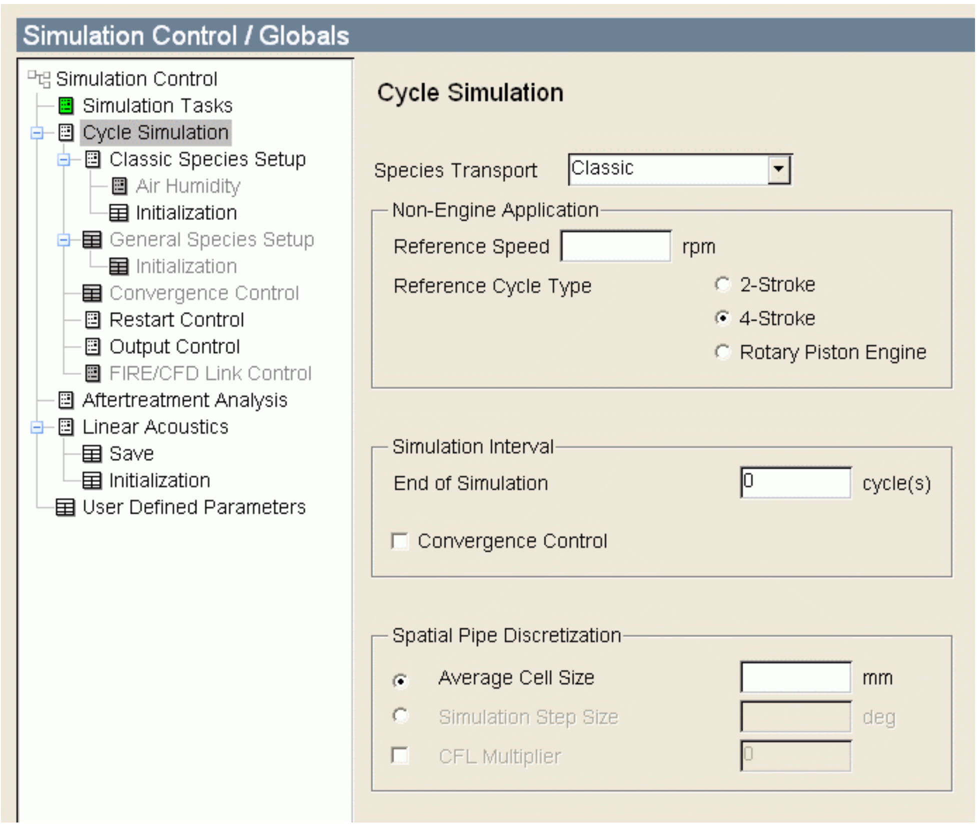


Figure 2-7: Simulation Control – Cycle Simulation Window

Species Transport	The **Classic Species Transport** option is default. In this case the behavior of the GUI and the solver is 100% compatible with previous BOOST versions. If the **General Species Transport** is selected the following changes apply to the model set-up: • The Fuel Data input (section 2.3.1.2.2) is disabled. For General Species Transport the type of the fuel species is defined as described in section 2.3.1.2.2. The lower heating value and the stoichiometric air/fuel ratio are calculated by the solver based on the thermodynamic properties. The resulting values can be found after the calculation in the Summary output. • The number and the type of chemical species are defined on the General Species Setup page (section 2.3.1.2.2.). • The number (and the corresponding input files) of chemistry sets is defined on the General Species Setup page (section 2.3.1.2.2.). • The composition of the fuel (number, type and ratio of species) is defined on the General Species Setup page (section 2.3.1.2.2.). • The name of an external database input file for the calculation of the thermodynamic properties is defined on the General Species Setup page (section 2.3.1.2.2.).
Non-Engine Application (no **Engine** element present in the model)	
Reference Speed	Specifies the relation between the time domain and a virtual engine crank angle domain
Reference Cycle Type	Specifies the periodicity of a virtual engine crank angle domain: 2-Stroke (1 Crank Shaft Revolution per Cycle) 4-Stroke (2 Crank Shaft Revolutions per Cycle) Rotary Piston Engine (assumed to be a 4-Stroke Engine with 3 Eccentric/Crank Shaft Revolutions per Cycle)
Simulation Interval	
End of Simulation	The **End of Simulation** sets the crank angle interval after which the simulation stops and the results will be written to the .bst file. For steady state simulations it must be sufficiently long in order to achieve stable calculation results. It is recommended to use a multiple of the cycle duration. The required calculation period until stable conditions are achieved depends upon the engine configuration.
Convergence Control	Select to access the convergence control input fields described in section 2.3.1.2.3.
Spatial Pipe Discretization	
Average Cell Size	Target Average Cell Size for Spatial Pipe Discretization

Simulation Step Size	Target Calculation Step Size in degree crank angle. From the stability criterion for the pipe flow calculation this input is converted in a required cell size.
CFL Multiplier	The default CFL Multiplier for solving the pipe flow is 0.95. In some calculation cases it is required to reduce this value to improve stability of the pipe solver.

2.3.1.2.1. Classic Species Setup

Select **Classic Species Setup** to open the following window:

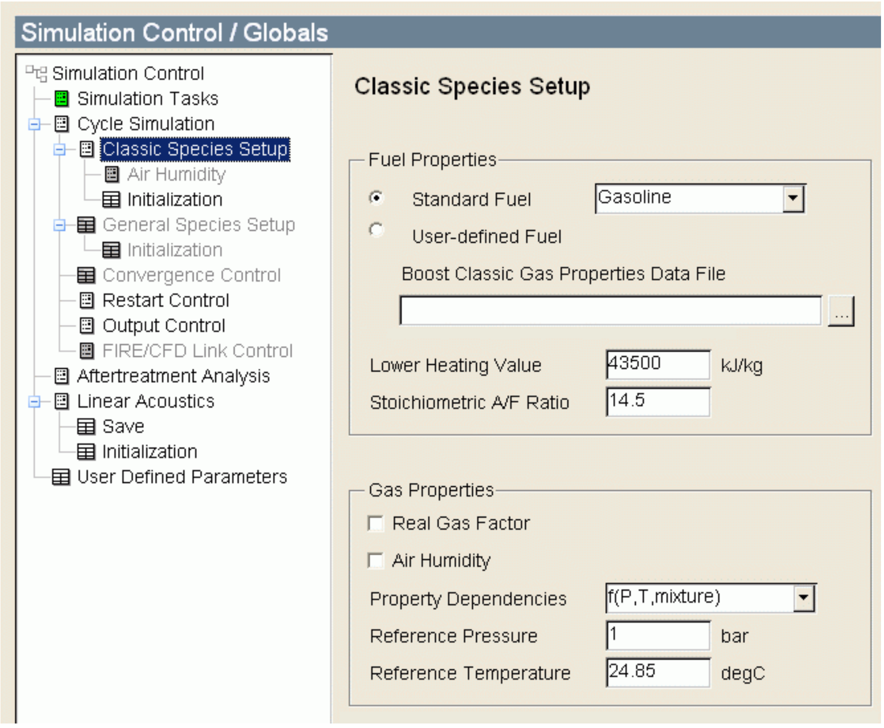


Figure 2-8: Simulation Control – Classic Species Setup Window

Fuel Properties	
Standard Fuel	**BOOST** provides accurate gas properties for the following standard fuels: • Gasoline • Diesel • Methane • Methanol • Ethanol • Hydrogen • Butane • Pentane • Propane For each fuel, default values for the lower heating value and for the stoichiometric air/fuel ratio are also available. If more accurate data is available, the default values may be overwritten.

User-defined Fuel	A Gas Properties Data file can be loaded which was generated with the **BOOST Classic Gas Properties Tool** allowing the User to compose his own Fuel Blend.
Lower Heating Value	Lower Heating Value Input (overruling default value).
Stoichiometric A/F Ratio	Stoichiometric A/F Ratio Input (overruling default value).
Gas Properties	
Real Gas Factor	In addition to Dissociation Phenomena, which are already considered in the genuine BOOST Gas Property Database, the Real Gas Behavior of Combustion Products is modeled by using the second virial coefficient (refer to the Theory manual).
Air Humidity	Select to activate the Air Humidity input fields described below.
Property Dependencies	**f(P, T, mixture):** In general, **BOOST** uses variable gas properties, which means that at any location in the system the gas properties are determined from the actual gas composition, actual pressure and actual temperature. **f(mixture):** The properties are taken for a fixed pressure and temperature but are calculated from the actual gas composition. **const:** Constant gas properties are evaluated based on a perfect gas approach with a Gas Constant R = 287.0 J/kg/K and an Isentropic Exponent k = 1.4.
Reference Pressure	Reference Pressure at which the Dependency **f(mixture)** is evaluated.
Reference Temperature	Reference Temperature at which the Dependency **f(mixture)** is evaluated.

Air Humidity

Air Humidity	Select **Relative** or **Absolute**.
Relative Air Humidity	Ratio of vapor pressure to saturation vapor pressure [Pa/Pa].
Absolute Air Humidity	Mass of water contained in a unit volume of moist air [kg/m3]).
Reference Temperature	Reference Temperature for Air Humidity Input (required for Relative and Absolute Input).
Reference Pressure	Reference Pressure for Air Humidity Input (required for Relative and Absolute Input).
Adaptation of A/F-Ratio Input	If the input for the **Stoichiometeric Air/Fuel-Ratio** is referenced to dry air, an Adaptation for humid air can be selected.

Initialization

In this dialog predefined initialization sets for Classic Species Transport can be specified and later on used for the specification of boundary and initial values in the respective elements.

Ratio	For the characterization of Combustion Products one of the following types can be selected: A/F-Ratio Air Equivalence Ratio Excess Air Ratio

2.3.1.2.2. General Species Setup

Select **General Species Setup** to open the following window:

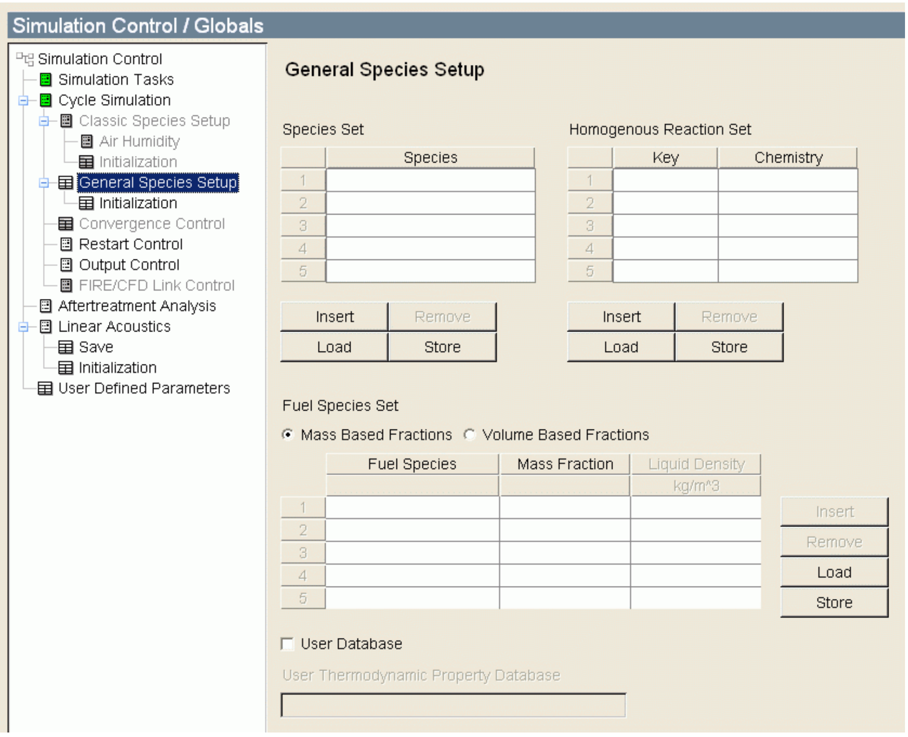


Figure 2-9: Simulation Control – General Species Setup

The specification of the chemical species, the chemistry models and the fuel composition is shown in Figure 2-9.

Species Set	The list of chemical species is either typed in (by using the Insert/Remove options) or read in from an ASCII input file.
Homogenous Reaction Set	For each chemistry model an arbitrary key (string) is defined. In the BOOST model a specific chemistry model is referred through this key.

Fuel Species Set	Select **Mass Based Fractions** or **Volume Based Fractions.** Use Insert/Remove to define the number of components. For each component the corresponding ratio must be specified. The liquid density of the fuel is required for the volume based option only.
User Database	If the species list contains species names that are not available in the internal database the solver will stop with an error message. However, by activating this option an external database file can be specified. The file can contain an arbitrary number of data-sets. BOOST expects the User Database in the following format: **User Thermodynamics Property Database**

```
THERMO
   300.000  1000.000  5000.000
O                 L 1/90O   1               G   200.000  3500.000  1000.000    1
 2.56942078E+00-8.59741137E-05 4.19484589E-08-1.00177799E-11 1.22833691E-15    2
 2.92175791E+04 4.78433864E+00 3.16826710E+00-3.27931884E-03 6.64306396E-06    3
-6.12806624E-09 2.11265971E-12 2.91222592E+04 2.05193346E+00 6.72540300E+03    4
O2                TPIS89O   2               G   200.000  3500.000  1000.000    1
 3.28253784E+00 1.48308754E-03-7.57966669E-07 2.09470555E-10-2.16717794E-14    2
-1.08845772E+03 5.45323129E+00 3.78245636E+00-2.99673416E-03 9.84730201E-06    3
-9.68129509E-09 3.24372837E-12-1.06394356E+03 3.65767573E+00 8.68010400E+03    4
H                 L 7/88H   1               G   200.000  3500.000  1000.000    1
 2.50000001E+00-2.30842973E-11 1.61561948E-14-4.73515235E-18 4.98197357E-22    2
…
```

In addition to the fourteen fit coefficients (lines 2, 3 and 4) it also contains the species' name, its elemental composition, its electronic charge and an indication of its phase. The following table provides the exact input specification.

Table 1: Format for Thermodynamic Data

Card number	Contents	Format	Card Column
1	Species Name (must start in Column 1)	18A1	1 to 18
	Date (not used in the code)	6A1	19 to 24
	Atomic symbols and formula	4(2A1,I3)	25 to 44
	Phase of species (S, L, or G for solid, liquid or gas)	A1	45
	Low temperature	E10.0	46 to 55
	High temperature	E10.0	56 to 65
	Common temperature (if needed)	E8.0	66 to 73
	Atomic symbols and formula (if needed)	1A1, I3	74 to 78
	The integer "1"	I1	80
2	Coefficients a_1-a_5 for upper temperature interval	5(E15.0)	1 to 75
	The integer "2"	I1	80

3	Coefficients a_6 and a_7 for upper temperature interval and a_1-a_3 for the lower	5(E15.0)	1 to 75
	The integer “3”	I1	80
4	Coefficients a_4-a_7 for lower temperature interval	5(E15.0)	1 to 60
	The integer “4”	I1	80

Initialization

The **Initialization** window (definition of sets of Pressure, Temperature, Fuel Vapor, Combustion Products and A/F ratio) and the **Initialization Mass Fractions** window are available. Here sets of Pressure, Temperature and Mass Fractions for each species can be defined. These sets can then be used for the specification of boundary and initial values in the respective elements.

Ratio	For the characterization of Combustion Products one of the following types can be selected: A/F-Ratio Air Equivalence Ratio Excess Air Ratio

2.3.1.2.3. Convergence Control

A convergence control can be performed, where either a convergence flag is set or the calculation stops, if a prescribed convergence criterion is fulfilled. The convergence criterion is that the variation of the cycle averaged values ("transients") of some parameters in **BOOST** elements over the last three consecutive cycles is less than a **prescribed threshold**.

Select **Convergence Control** in the Cycle Simulation window (Figure 2-7), then select the **Convergence Control** sub-group in the tree to open the following window.

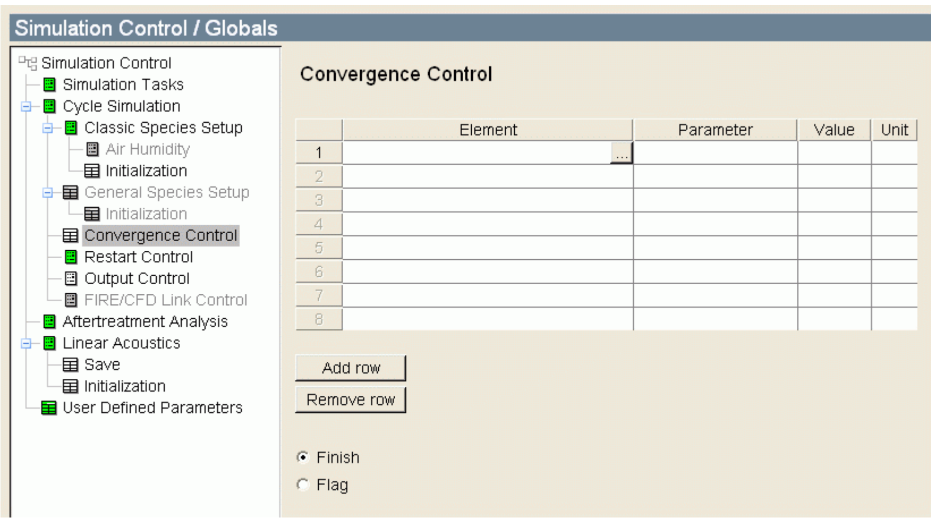


Figure 2-10: Simulation Control – Convergence Control Window

Finish **Flag**	Select either the calculation should **Finish** or a **Flag** for external applications should be available after achieving the Convergence Criterion.

The controlled elements, parameters and the corresponding threshold values can be specified.

The convergence criterion is that the variation of the cycle averaged values (transients) of some parameters in BOOST elements over the last three consecutive cycles is less than a prescribed threshold.

The following elements and variables can be used for convergence control:

1. Cylinder:
   - IMEP
2. Measuring point:
   - Convergence (combination of pressure, velocity and temperature)
3. Turbocharger:
   - Rotational speed
   - Turbine discharge coefficient
   - Turbine-to-total massflow
   - Turbine work
   - Compressor work
   - Compressor pressure ratio
   - Boost pressure
4. Turbo Compressor:
   - Compressor work
   - Compressor pressure ratio
   - Boost pressure
5. Positive Displacement Compressor:
   - Compressor work
   - Compressor pressure ratio
   - Boost pressure
6. Plenum:
   - Pressure
   - Temperature
   - Mass
7. Microphone:
   - Overall linear sound pressure level
   - Overall ‘A’ weighted sound pressure level

For each selected variable the threshold value has to be specified.

2.3.1.2.4. Restart Control

Select **Restart Control** to open the following window.

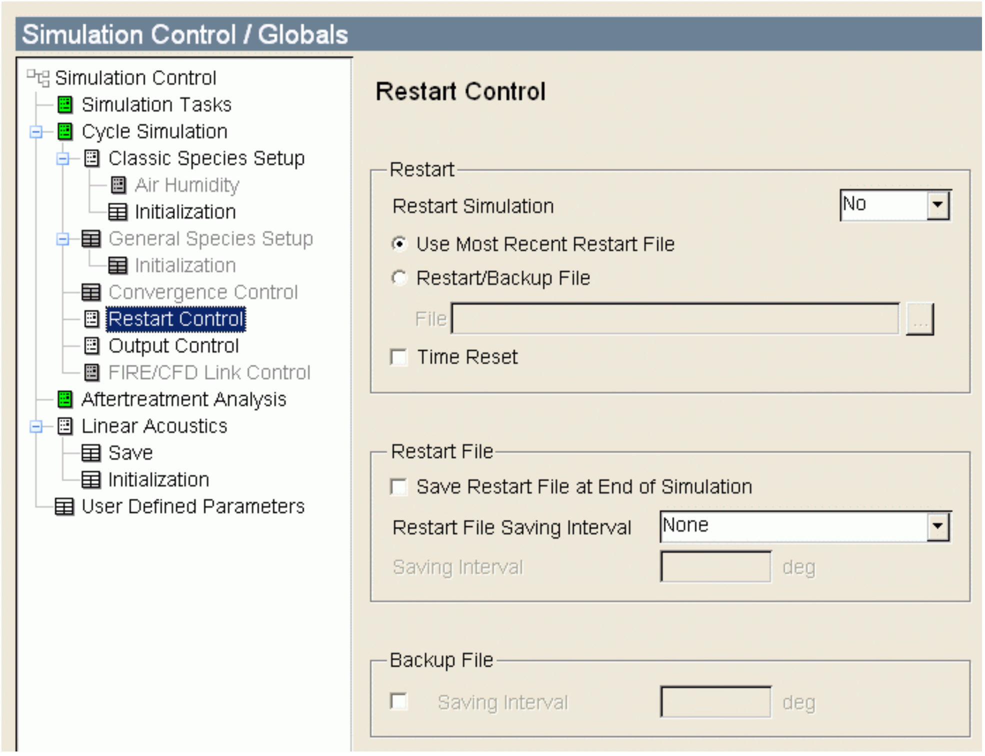


Figure 2-11: Simulation Control – Restart Control Window

Restart	
Restart Simulation	An already completed calculation can be continued: • **Yes** The new calculation starts with initial conditions taken from a restart file; for a single calculation the maximum calculation period is the sum of the calculation period of the initial calculation and that of the restarted calculation. • **No** The new calculation starts with the initial values specified in the model.
Use Most Recent Restart File	In the case of a restart, the program checks for the most recent file and takes the stored conditions for the initialization. The same directory as the input file is checked first and then the parent directory of the input file (one level up) for each restart file. This allows individual cases to be restarted from other cases provided it cannot find both restart files in its own case directory. Note that the restart file for a case is copied to the parent directory on completion of that case. If neither `.rs0` nor `.rs1` exist, the program run will be interrupted with an error message.
Restart/Backup File	An individual Restart or backup file can be selected for the initial conditions of a restart calculation.

Time Reset	Select **Time Reset** to avoid long transient output. In a restart, this causes only the transient results from the restart on to be written to the `.bst`-file. The transient results will be lost from the calculation where the restart file was obtained. If **Time Reset** is deselected, the complete history will be stored on the `.bst`-file and can be analyzed using the transient analysis feature of the **BOOST** post-processor.
Restart	
Save Restart File at End of Simulation	This option forces the saving of a restart file at the end of the simulation.
Restart File Saving Interval	**None** No restart file is saved **Specific Interval** This can be selected in order to save restart data at regular crank angle intervals. **Every Simulation Step** A restart file is saved every simulation time-step (this option is very run-time consuming) **Cyclic** A restart file is saved at every cycle end event. The restart files have same name as the model with the extension `.rs0` and `.rs1`. The first restart file is written to `.rs0` and the second to `.rs1`. The third restart file is written to `.rs0`, thus only the penultimate and last restart files exist.
Saving Interval	If Specific Interval is selected, enter the desired saving interval.
Backup File	
Saving Interval	Backup files are not recursively overwritten but stored with a filename extension corresponding to their individual crank-angle.

2.3.1.2.5. Output Control

Select **Output Control** to open the following window.

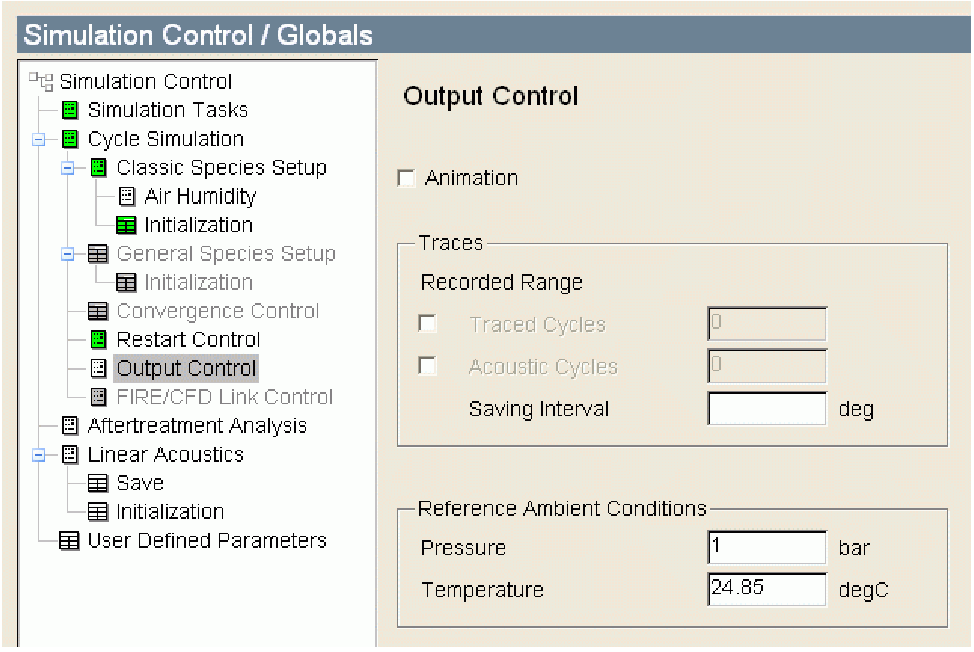


Figure 2-12: Simulation Control – Output Control Window

Animation	Special output for the animated display of the results with the **BOOST** post-processor is provided for last calculated cycle.
Traces	
Traced Cycles **Recorded Range**	This option allows to extend the number of cycles for which traces are available.
Acoustic Cycles **Recorded Range**	This option allows to extend the underlying period for post-processing Acoustic results are available.
Saving Interval	Input for the Increment for which the Traces results should be output.
Reference Ambient Conditions	
Pressure **Temperature**	The reference conditions (pressure and temperature) are required in order to calculate specific engine performance data such as delivery ratio, volumetric efficiency etc. related to ambient conditions. It is the user's responsibility to ensure that these conditions match the conditions at the system boundary from which the engine aspirates its air. Otherwise, the results might be misleading.

2.3.1.2.6. FIRE/CFD Link Control

Number of BOOST-only cycles / **Number of FIRE/CFD-only cycles**	If a BOOST-FIRE simulation is performed this data has to be specified. During the number of "Boost only cycles" the BOOST-simulation is performed using the shadow network as 1D-approximation of the 3D FIRE domain. During the number of "Fire only cycles" the FIRE-simulation is performed applying fixed boundary conditions generated during the last cycle of the "Boost only" simulation. The third step is the coupled simulation, where the BOOST and FIRE calculations are performed simultaneously and full data exchange FIRE -> BOOST and BOOST -> FIRE appears. The calculation in the BOOST shadow network also is performed. A data exchange from the coupled BOOST-FIRE-simulation to the shadow network appears, but does not appear in the other direction. Please refer to the BOOST-FIRE 1D-3D Coupling Manual for further information.

2.3.1.3. User Defined Parameters

This can be used in order to supply the boost calculation kernel with additional input information. Therefore a **Parameter Key** and a corresponding **Value** has to be specified. For more information about this feature please contact boost_support@avl.com.

2.3.2. Volumetric Efficiency

The **BOOST** pre-processor allows a plenum or a measuring point to be specified as a reference location for the calculation of the air delivery ratio and the volumetric efficiency related to intake manifold conditions.

Select **Simulation**|**Volumetric Efficiency** and then select the desired element with the left mouse button to display the relevant information. Select **OK** to complete the selection process.

2.3.3. Test Bed Conditions

Displays and sets the test bed reference elements (Measuring Points only) labeled according to the document “AVL Standard Sensor Locations Engine Test Bed”:

R 11: Downstream Engine Intake Air Filter

R 21: Downstream Compressor

R 2_1: Downstream Intercooler

R 31: Engine Out Exhaust

R 41: Engine Out Exhaust downstream Turbine

Related Simulation Pressures and Temperatures (type and unit according to the mentioned document above) are displayed in the Transients Results of the Test Bed Element.

2.3.4. Creation of Series Results

Select **Simulation|Create Series Results** and then select **Cycle Simulation**.

In the first column of the table you can select whether you want series-results created for each of the case-sets. Series-results can only be created for case-sets with one or more parameters assigned through case-explorer. In the **Main Parameter** column you can select main-parameter for each case-set. The **State** column indicates the state of creation process for each case-set. Creation process is started by pressing **Run-Creation** button.

When calculating series results via **Simulation | Run | Creation of Series Results** BOOST always creates series results versus the left-most parameter of the first parameter group in the case explorer. The same behavior is valid for optimizations e.g. via the Design Explorer.

Description of states:

New - always set when the dialog is opened

Started - creation of results has started

Done - creation process finished successfully

Failed - creation process failed

The creation process can fail for a number of reasons, the most common being that the simulation has not been run for some or all of the cases in the case-set.

Starting from a single case model, it is possible to create a case series calculation. This allows parameters to be assigned for a set of cases so that a series of operating points or engine variants can be calculated at one time.
Refer to section 2.5.3 of the GUI Users Guide for a detailed description of the Case Explorer. Also refer to the BOOST case series calculation (`ottoser.bwf` – Examples Manual) for details.

2.4. Utilities

2.4.1. BURN

The BURN utility can be used for combustion analysis, which is the inverse process of the combustion calculation performed in the BOOST cylinder. That is, the rate of heat release (ROHR) can be obtained from measured cylinder pressure traces. The resulting ROHR can be used to specify the combustion characteristics of a single zone or two zone model.

For the analysis, general data is necessary about the type of engine and fuel, geometry data for the cylinder and data describing the operating point. After the analysis the results can be examined, especially the calculated rate of heat release (ROHR).

Select **BURN** from the **Utilities** menu to open the following window.

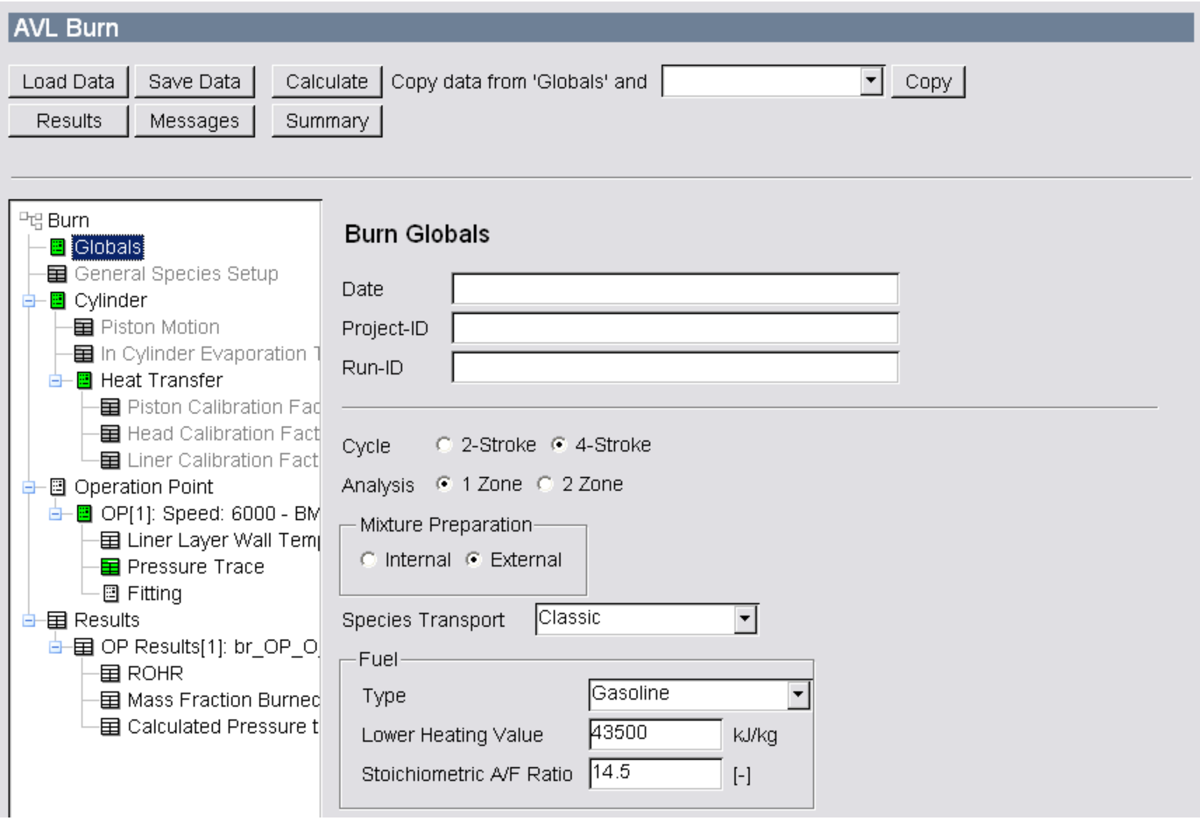


Figure 2-13: Burn - Global Window

The following buttons are available:

Load Data	Loads predefined data from the required directory.
Save Data	Saves the current data with a different file name.
Calculate	Starts the calculation. A window appears in which the customer can check the operating points.
Results	Opens the IMPRESS Chart post-processor which can be used to examine and plot the simulation results.
Messages	Opens the Message browser and displays the messages generated by the solver during the simulation (refer to Chapter 5).

Summary	Opens the ASCII browser and displays the summary values from the simulation (refer to Chapter 5).
Copy Data from 'Globals' and...... Copy	Select the required cylinder from the pull-down menu and then select Copy. This allows existing data specified for a cylinder in the model to be used for the combustion analysis.

Alternatively while inputting the cylinder data for a **BOOST** model, select **Table** under the **Combustion** sub-group. In this case the resulting ROHR can be accepted immediately after calculation.

2.4.1.1. Globals

The global data shown in Figure 2-13 is described under section 2.3.

Analysis: Select either **1 zone** or **2 zone** (burned and unburned) for the number of zones considered in the combustion analysis.

2.4.1.2. Cylinder

The cylinder specifications are the same as those necessary for the BOOST cylinder.

Number of Cylinders	The total number of cylinders in the engine. This is used to calculate the mass flows to each individual cylinder by dividing the air and fuel mass flows by this number.
Bore, Stroke, Compression Ratio, Conrod Length	Main geometry data of the cylinder.
Piston Pin Offset	The direction of positive **Piston Pin Offset** is defined as the direction of the rotation of the crankshaft at TDC.
Effective Blow By Gap, Mean Crank Case Pressure	For the consideration of blow-by from the cylinder, an equivalent **Effective Blow-By Gap** has to be specified, as well as the **Average Crankcase Pressure.** The actual blow-by mass flow is calculated from the conditions in the cylinder, the pressure in the crankcase and the effective flow area calculated from the circumference of the cylinder and the effective blow-by gap.
User Defined Piston Motion	If the piston motion and volume changes cannot be derived from the main cylinder geometry data, the piston position can be defined as a Table depending on crank angle, by selecting User Defined Piston Motion, input fields under Piston Motion. Only the relative position must be specified, a value of 0 meaning piston at TDC, a value of 1 meaning piston at BDC.

In Cylinder Evaporation	For direct injection engines the rate of evaporation can be defined. The Rate of Evaporation defines the addition of fuel vapor to the cylinder charge. The specified curve is normalized, so that the area beneath the curve is equal to one. The actual amount of fuel added is either defined directly or by the target A/F-Ratio. The latent heat of evaporation of the fuel (**Evaporation Heat**) is defined independent of the main fuel definition. The **Heat from Wall** specifies the fraction of the evaporation energy taken from the wall as opposed to the gas. An input value of 1 means that all the fuel evaporates on the wall and the in cylinder evaporation will have no affect on the gas mixture in the cylinder. An input value of 0 means the fuel evaporates in the gas mixture in the cylinder.

2.4.1.3. Heat Transfer

Four different models are available for modeling the Heat Transfer in the Cylinder:

- Woschni 1978
- Woschni 1990
- Hohenberg
- AVL 2000

The extension of the Woschni model by Lorenz is not available, because engines with prechamber are not considered for the combustion analysis.

For the wall heat transfer the surfaces of **Piston**, **Cylinder Head** and **Liner** must be specified. The variation of the wetted liner surface is considered automatically, only the surface with piston at TDC must be input. With the **Calibration Factor** the wall heat transfer calculated from the specific model may be increased or decreased. The factors may also be specified as tables accessible in the specific substructures.

Layer Discretization is available for the Liner wall heat transfer.

The wall temperatures are specified in the following section.

2.4.1.4. Operation Point

It is possible to perform the analysis for more than one operating point with a single procedure. Therefore two types of input data are available:

- Data independent of the operating point, e.g. cylinder geometry, mixture preparation and fuel type. The number of combustion analysis zones can be set to single zone analysis (1 Zone) or two zone analysis (2 Zone: burned and unburned) using the **Analysis** option.

  Global and **Cylinder** data is independent of the operating point. If a **BOOST** model is loaded or the **BURN** tool is applied while specifying the combustion data for a **BOOST** model, this data can be copied from a **BOOST** model by selecting a cylinder from the pull-down menu and then selecting **Copy** (as shown in Figure 2-13). Additional operating point data can be loaded for the first operating point to be calculated. The necessary global and cylinder data corresponds to the data required for the preparation of a **BOOST** model.

- Data describing the operating point, e.g. engine speed, wall temperatures, valve timing and mass flows.

  Select the **Operation Point** sub-group folder to add or remove operating points by using **Insert Row and Operating Point** and **Remove Row and Operating Point**. The values for engine speed and load cannot be specified directly in the table but after specifying data each operating point, the table can be used to examine these values.

  Select the required **Operating Point**, e.g. OP(1) and specify the following:

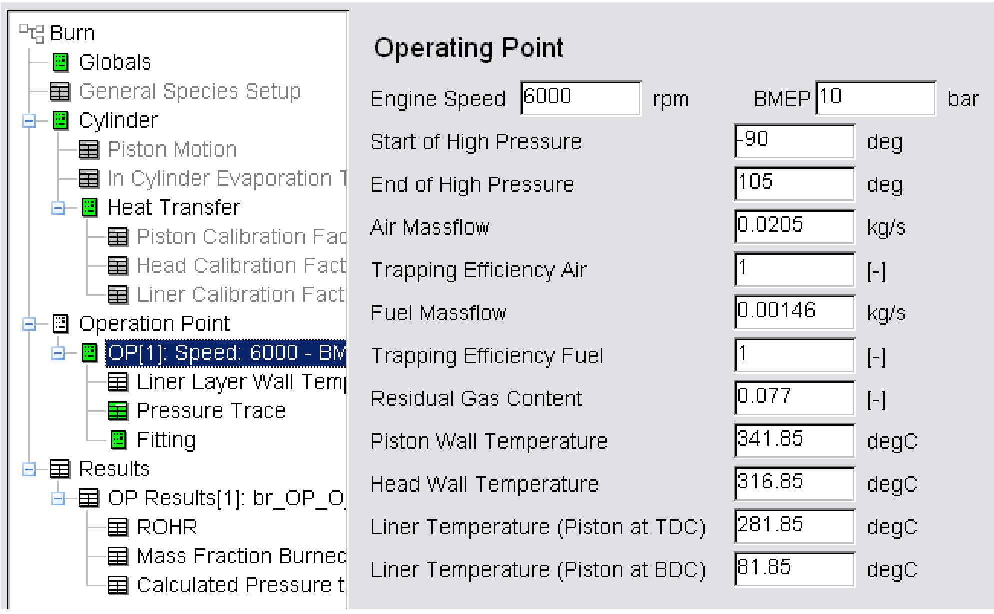


Figure 2-14: Burn - Operating Point Window

Engine Speed / BMEP	Engine Speed and measured Mean Effective Pressure (BMEP). Load as **BMEP**. The load does not influence the results and is used only to describe the operating point.
Start of High Pressure	Crankangle for the start of the high pressure phase. Should be set to Intake Valve Closing (IVC). This defines the starting crankangle for the combustion analysis calculation.
End of High Pressure	Crankangle for the end of the high pressure phase. Should be set to Exhaust Valve Opening (EVO). This defines the end crankangle for the combustion analysis calculation.
Air Massflow / Fuel Massflow	Specify for the whole engine. The value for a single cylinder is determined by dividing these numbers by the number of cylinders in the engine, assuming an even distribution to the cylinders.
Trapping Efficiency Air / Trapping Efficiency Fuel	If the assumption of even distribution is not valid **Trapping Efficiency Air** and **Trapping Efficiency Fuel** also can be used to consider such an effect.
Wall Temperature	**Wall Temperature** must be defined for piston, head and liner in the same way as it is done for **BOOST**.

1. Pressure Trace

Select the **Pressure Trace** sub-group and specify the required data or read it in as a table. The pressure traces are required over a whole cycle. For a four stroke example that is from 0 to 720 (inclusive) i.e. the data at 0 deg and 720 deg should be defined.

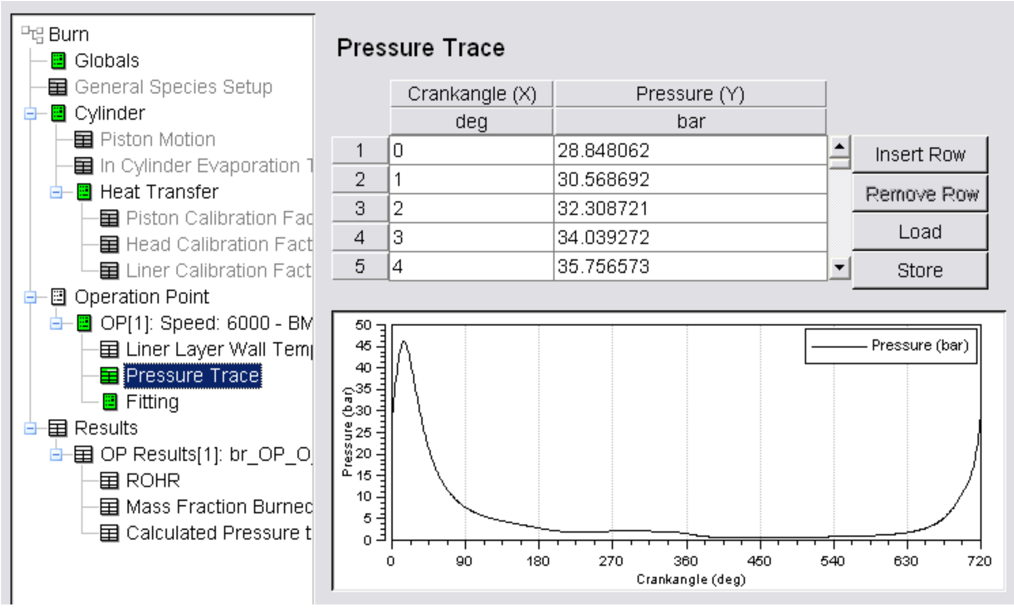


Figure 2-15: Burn - Pressure Trace Window

2. Fitting

In order to compensate for noise, errors or inaccuracies in the measured cylinder pressure curve, filtering and four fitting adaptations are available to adjust the measured pressure curve. The resulting adapted pressure curve is then used for the combustion analysis. The compression ratio and pressure at IVC fitting alter the target pressure curve of the adaptation. **TDC Offset** and **Pressure Offset** change the measured cylinder pressure curve to get an adapted pressure curve. The measured pressure curve can be adjusted up and down for pressure and left or right for crankangle. In both cases any adjustment made is the same across the entire range of the defined measured curve. The fitting adaptations are also intended for small adjustments to the measured curve and are not suitable for large pressure or crankangle offsets.

Select the **Fitting** sub-group to open the following window:

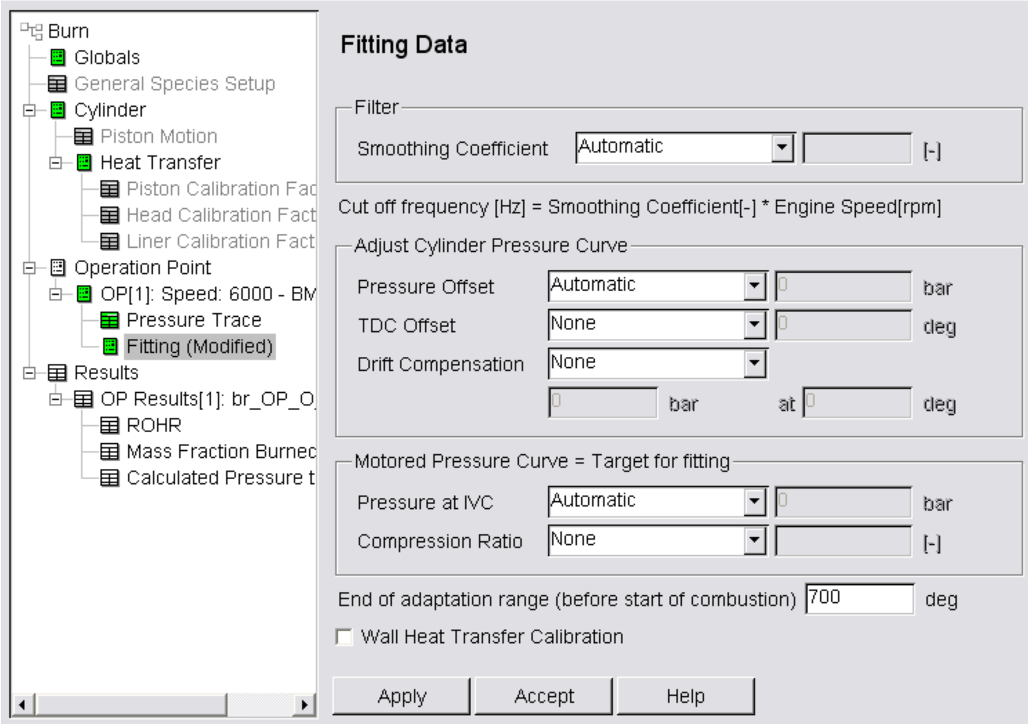


Figure 2-16: Burn - Fitting Data Window

Filter	The filtering of the pressure curve is done first and separately from the other adaptations. A low pass FIR filter is applied to the input measured cylinder pressure. The cut off frequency for the filtering is calculated by multiplying the input smoothing coefficient by the engine speed. For the **Smoothing Coefficient**, select **Manual** from the pull-down menu to specify a value or select **Automatic** to set the smoothing coefficient to 1.5.

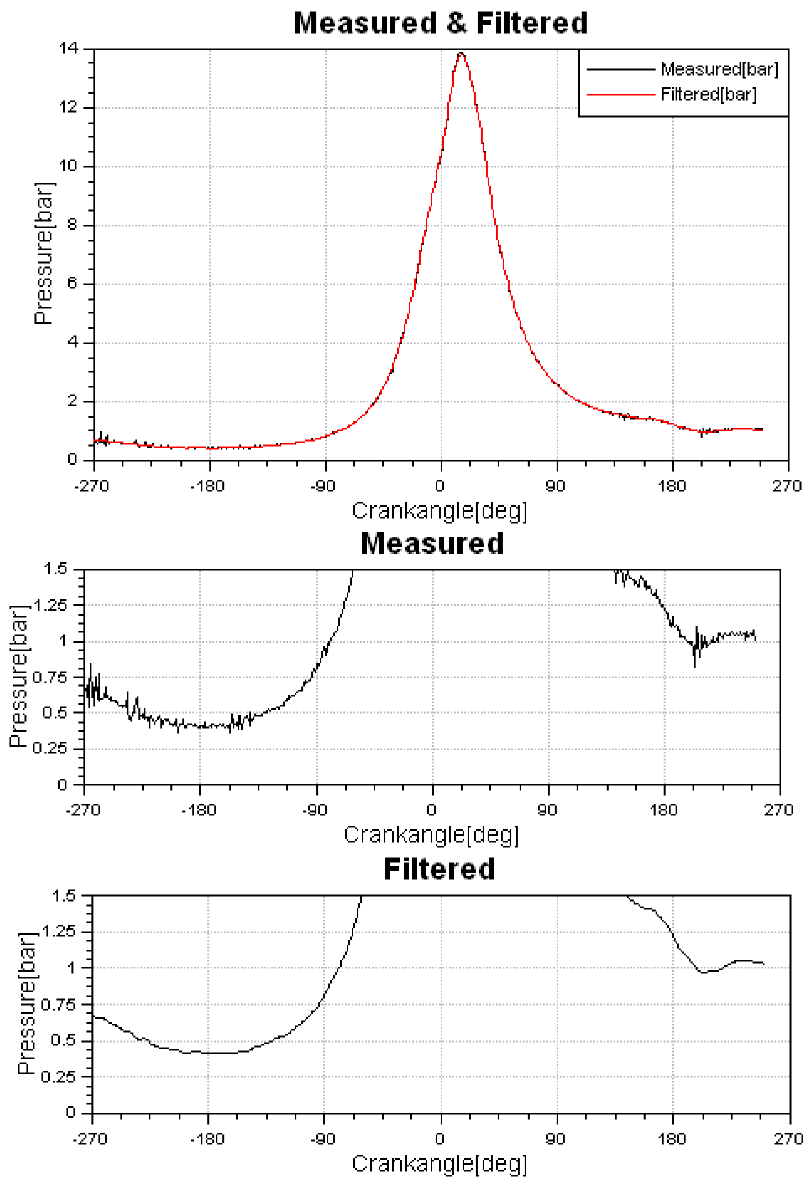


Figure 2-17: Pressure Curve - Measured & Filtered

Adjust Cylinder Pressure Curve	The fitting adaptations are performed by comparing the input measured cylinder pressure curve and a simulated compression curve between start of high pressure (SHP) and the start of combustion (SOC). This is shown with the thick line in Figure 2-18. SHP and SOC (Ignition Timing/Start of Injection) are input directly in the Operating Point window, see Figure 2-14. From the **Pressure Offset** and **TDC Offset** pull-down menus, select **Manual** to specify a value which will be applied directly for any adaptations or **Automatic** to perform the fitting process automatically. The **Automatic** setting will allow adjustment of the parameter based on a fitting algorithm. The four fitting adaptations are nested, so if all four are set to **Automatic** the fitting process can take some time. The **None** option turns off the process. The target of the adaptation is always to minimize the differences between the measured pressure curve and the simulated compression curve between start of high pressure (SHP) and start of combustion (SOC).

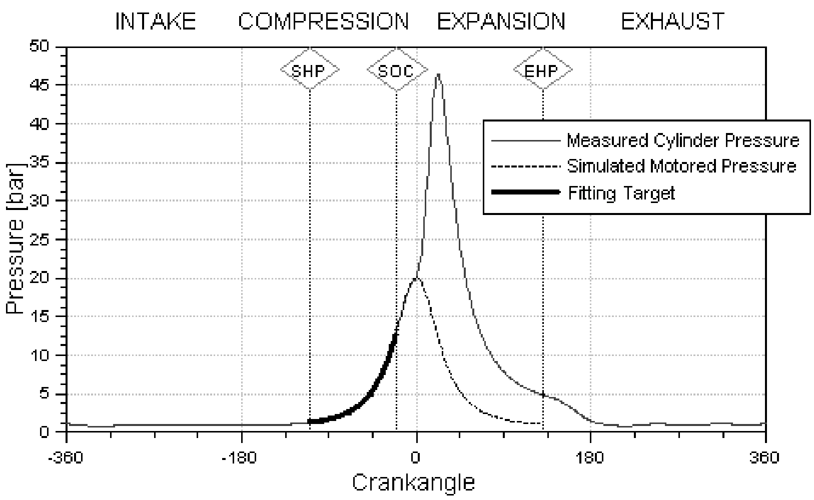


Figure 2-18: Fitting Target

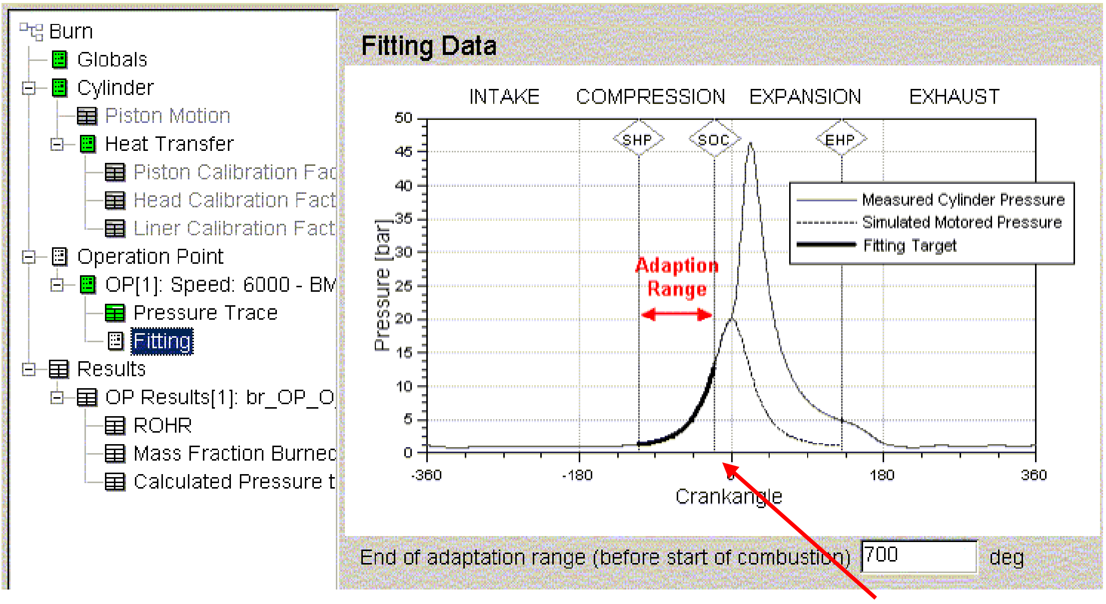


Figure 2-19: Fitting - End of Adaptation Range

Pressure Offset	The cylinder pressure offset compares the simulated compression curve between SHP and SOC to the input measured pressure. To calculate the simulated compression curve between SHP and SOC the pressure at SHP (=IVC) must be given. This option must be enabled to permit a pressure adjustment to the measured curve. Any cylinder pressure offset is applied equally across the entire measured range.

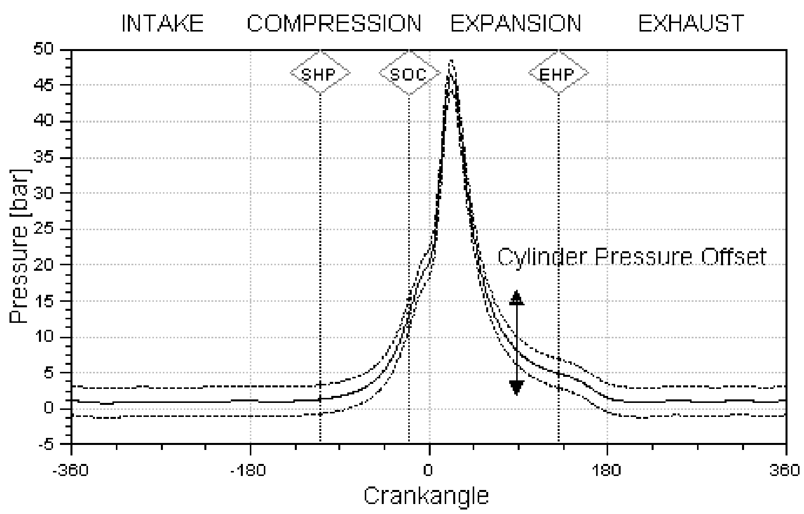


Figure 2-20: Adjust Cylinder Pressure Curve - Pressure Offset

TDC Offset	This option must be enabled to permit a crankangle adjustment to the measured curve. Any TDC Shift set for the measured curve is applied across the entire measured range.

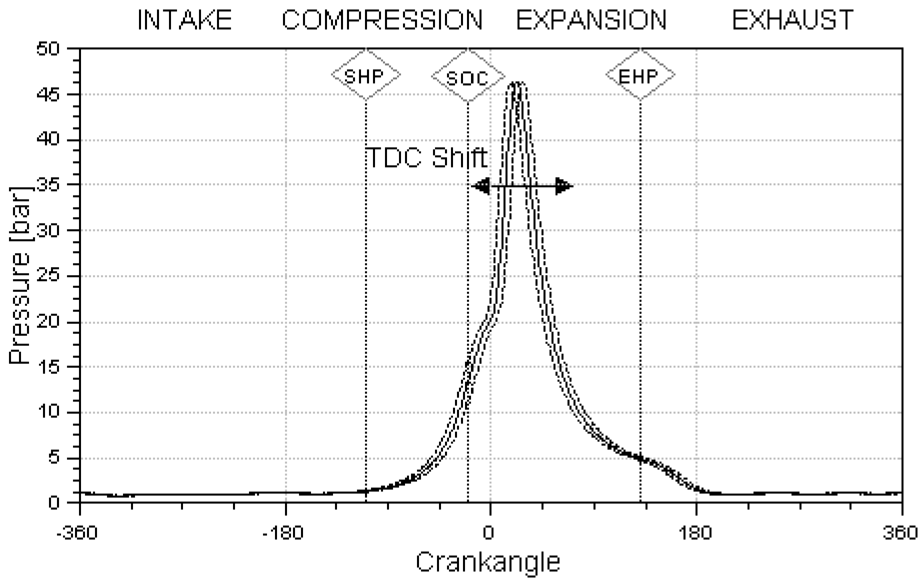


Figure 2-21: Adjust Cylinder Pressure Curve - TDC Offset

Drift Compensation	The drift compensation algorithm is a simplified method to correct a cyclic temperature drift (short term drift also known as thermoshock) of the cylinder pressure transducer. The cyclic temperature drift acts over a large crank angle range and tends to over predict the actual cylinder pressure, particularly just after firing top dead centre (FTDC). The effect then reduces for the remainder of the cycle. Characteristic values to describe temperature drift are determined firstly by cyclic heating under atmospheric condition of the transducer in a special tester and secondly in real engine operation by comparative measurement with a highly accurate reference transducer [G2]. The effect of drift will be seen most clearly in the predicted mass fraction burn curve (integral of heat release) of the combustion analysis. This will show a slowly increasing mass burned fraction after the end of combustion rather than a flat level line. Drift compensation corrects the cylinder pressure curve after FTDC proportionally, so that at a specified point the specified pressure difference is correct. The drift correction will be greatest at the specified crankangle point and zero at Firing TDC (0 deg CA) and gas exchange TDC (360 deg CA). A positive drift is when the measurement is too large and needs to be reduced at the specified point. In the following example a drift compensation of 1 bar is applied at 25 deg after TDC.

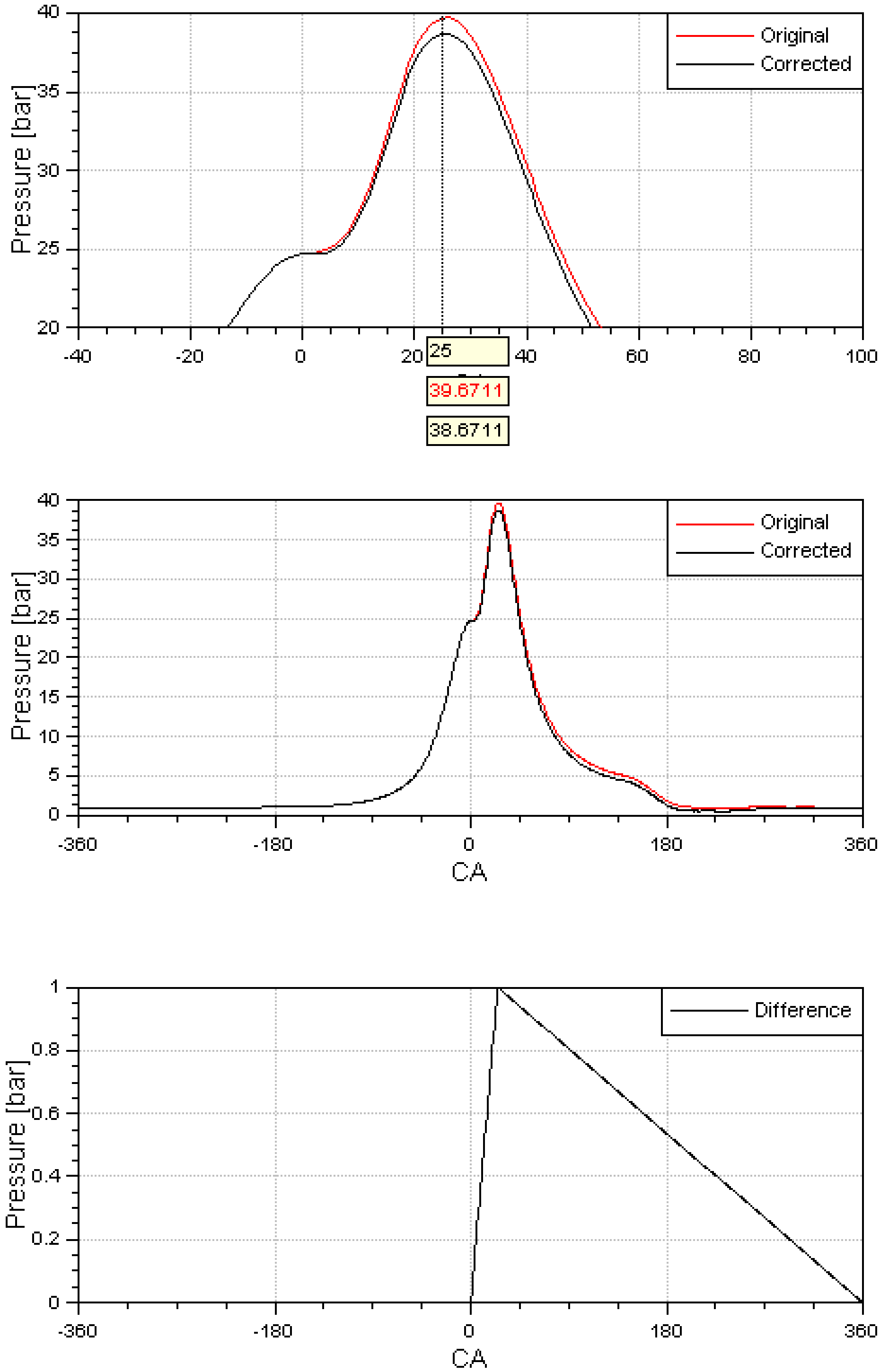
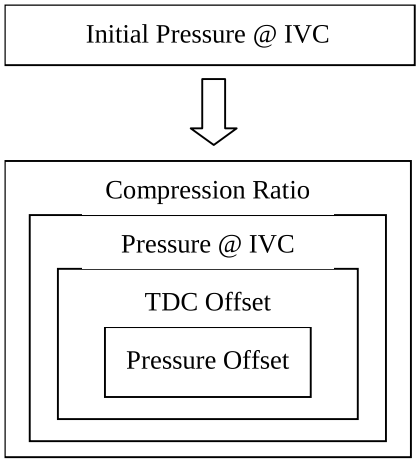


Figure 2-22: Drift Compensation

Motored Pressure Curve = Target for Fitting	The simulated compression curve is first calculated by determining the initial pressure at IVC and then performing the adaptation. The adaptations are nested with the compression ratio at the top level followed by the pressure at IVC, the TDC offset and finally the pressure offset at the deepest level.



The initial pressure at IVC is estimated by

- Determining the mass at IVC from the air and fuel flow rates, trapping efficiencies and residual gas content
- Determining the density from the volume and mass at IVC
- Determining the gas properties from estimated pressure and temperature

Pressure at IVC	The pressure at IVC is used to set initial conditions for the determination of the simulated compression curve. Like the compression ratio option, by itself this option will have no effect on the adapted pressure curve. This is because it will only change the target (simulated compression curve) of the adaptation but without **TDC Offset** or **Pressure Offset** no adaptation will be made. If the adaptation for **Pressure at IVC** is **None** then this pressure will be read directly from the pressure curve at SHP.

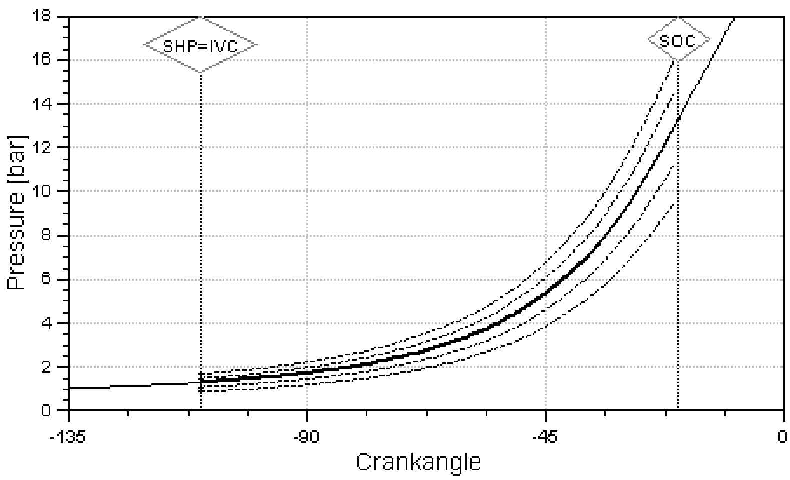


Figure 2-23: Pressure at IVC Adaptation

Compression Ratio	The compression ratio used to calculate the simulated compression curve is adjusted with this option. The pressure at IVC used to determine the simulated compression curve is fixed unless the **Pressure at IVC** option is activated.

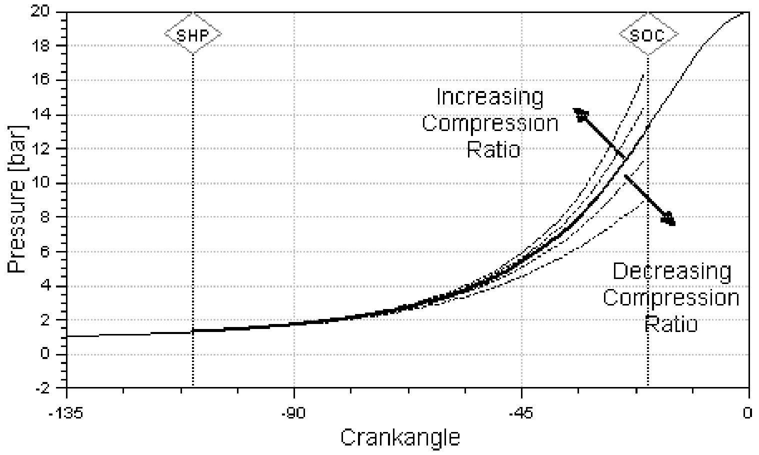


Figure 2-24: Compression Ratio Adaptation

Compression Ratio and Pressure at IVC	If both the compression ratio and pressure at IVC options are used then the simulated compression curve has two degrees of freedom.

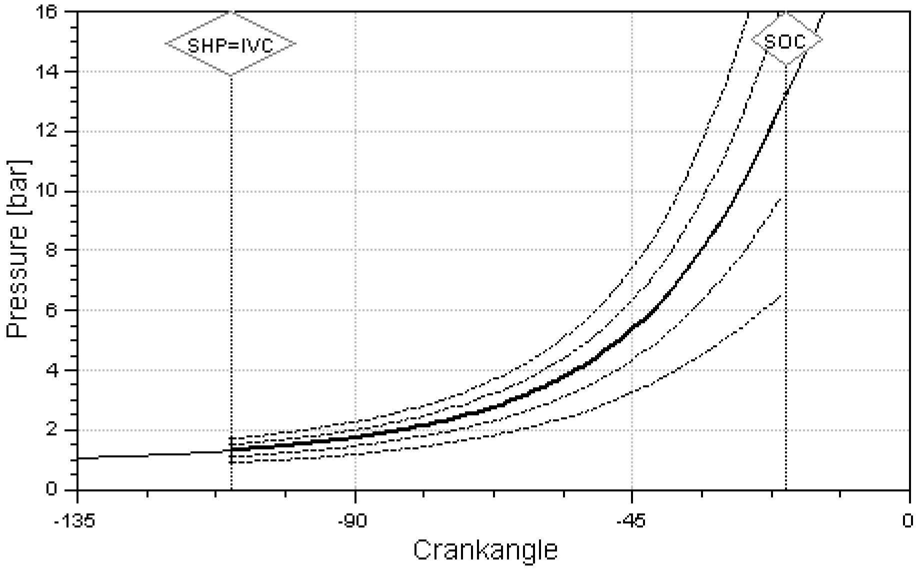


Figure 2-25: Compression Ratio and Pressure at IVC Adaptation

End of Adaptation Range	Crankangle at which the adaptation range finishes. The adaptation is performed by comparing the two pressure curves between the start of high pressure and this value. The target curve is a motored compression curve so the adaptation range should end before the start of combustion.

☞ **Note:** Choosing all three types of fitting may increase calculation time for one operating point.

Wall Heat Transfer Calibration	When activated repeated calculations (max 5) are performed where the wall heat transfer calibration factors are adjusted with the target of getting an energy balance of 1.0. All wall heat factors (head, liner and piston) are adjusted by the same amount. This includes table input where each value in the table is adjusted by the same %. Adjustment is calculated as follows: Δ% for calibration factors = (1 - Energy Balance) * fuel energy / wall heat energy Where, Energy Balance = released energy / fuel energy

☞ **Note:** Wall heat transfer calibration should be used with caution as it could calibrate for other differences apart from wall heat transfer. It is intended for fine tuning of already calibrated models.

2.4.1.5. Run the Calculation

After specifying the data select **Save Data** and save it as an input file. This can be used for later examination by selecting **Load Data**.

Select **Calculate** to start the calculation. A window appears in which the user can check the operating points. Then select **Run Calculation(s)** to perform the calculation of all operating points.

2.4.1.6. Results

The basic results for each operating point can be examined under the **Results** sub-group. The results of the fitting procedures are shown and the energy balance confirms the validity of the analysis.

Fitted Values: The results of the fitting (adaptation) process on the measured pressure curve and the Energy Balance from the calculation. Energy Balance is defined as the ratio between the energy set free through combustion and lost to the exhaust divided by the energy brought in by the trapped fuel. A valid analysis should show an energy balance value less than but close to 1.

Vibe Values: Following a calculation a vibe curve is fitted to the rate of heat release. These are the calculated vibe parameters (start, duration and m parameter) as well as the mass fraction burn points from the vibe fit curve.

Combustion Values: Crankangles from the calculated mass burned fraction curve corresponding to different burn percentages are shown.

In the **ROHR** sub-group, the resulting rate of heat release is shown. In addition to the heat release, the net heat release (**net ROHR**) is also shown, which does not consider the wall heat transfer.

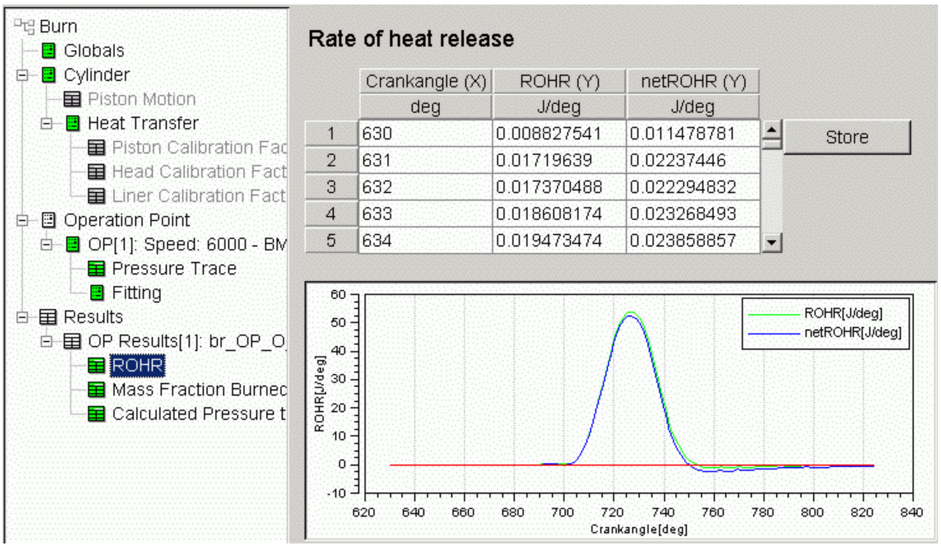


Figure 2-26: Burn Results - ROHR

In the **Mass Fraction Burned** sub-group, the cumulative mass fraction burned that has been calculated is displayed.

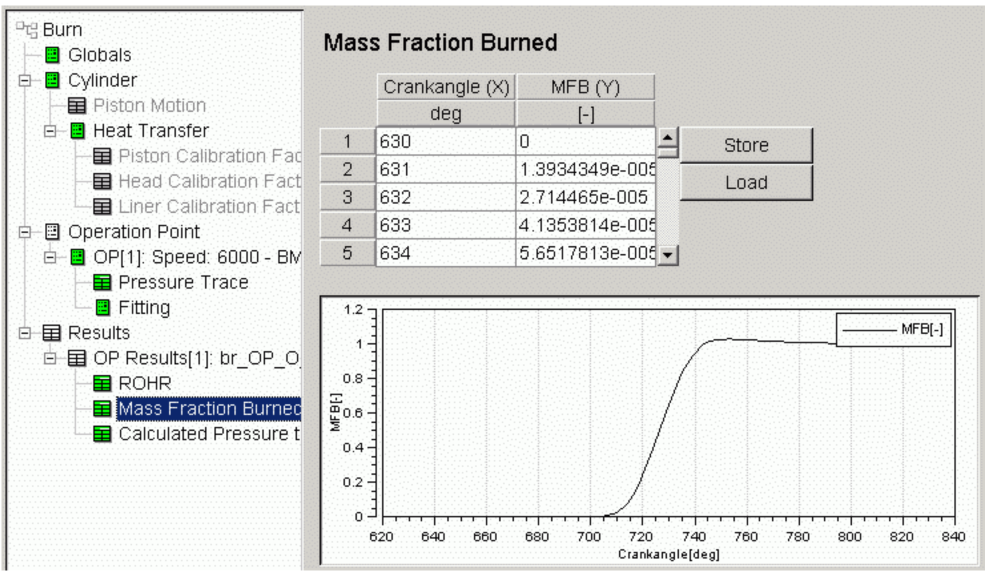


Figure 2-27: Burn Results - Mass Fraction Burned

In the **Calculated Pressure Trace** sub-group, the pressure traces after fitting and filtering are shown.

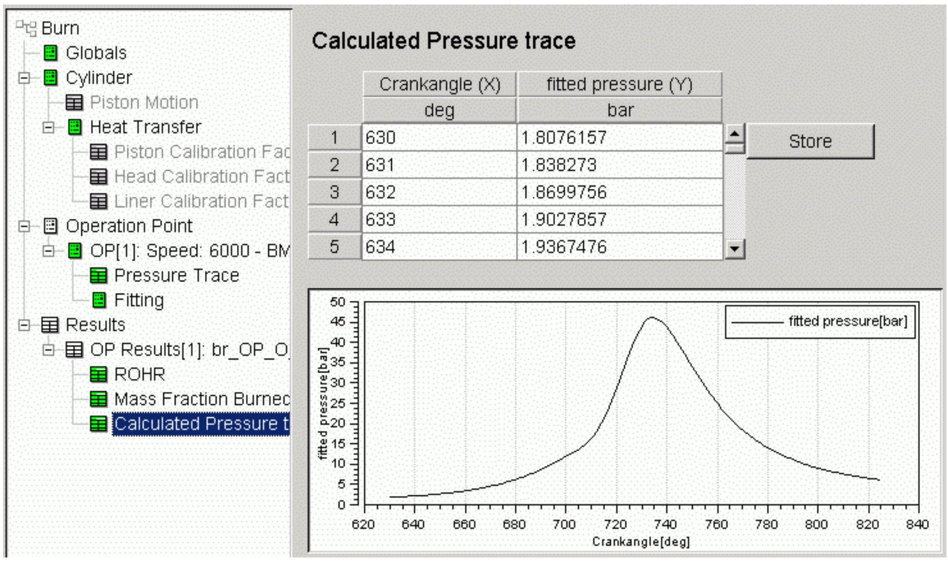


Figure 2-28: Burn Results - Calculated Pressure Trace

If the analysis is started from modeling an engine with **BOOST,** the user is asked to accept the resulting ROHR for one of the operating points and the resulting ROHR is used as input data for the table.

2.4.1.7. Post-processing

Select Results to open IMPRESS Chart and load the combustion analysis results data as shown in the following figure.

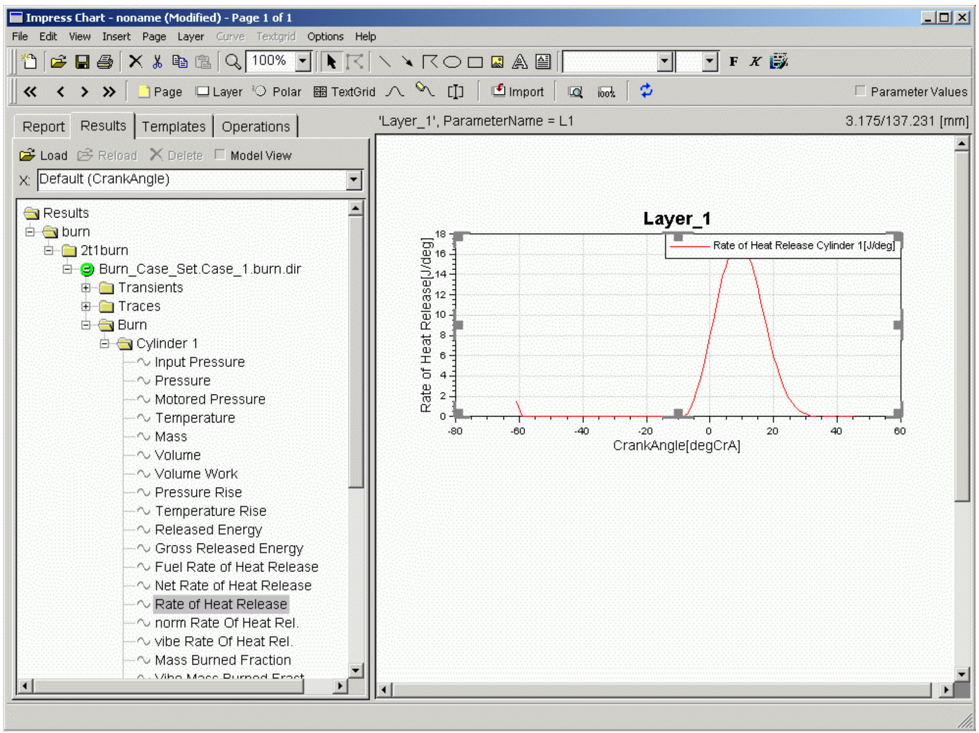


Figure 2-29: Burn Post-processing

The Messages and Summary buttons can also be used to display these results in a similar manner following a standard BOOST cycle simulation calculation.

2.4.2. Search

The Search utility can be used to displays tables of the input data used in the model. These can be saved in HTML format. The current search options are:

- Initialization data =ALL=
- Initialization data =PIPES=
- Geometry of and initial conditions in the Pipes
- Geometry and Comments of Pipes
- Volumes
- Volumes and Comments
- Flow coefficients =RESTRICTIONS=
- Vibe

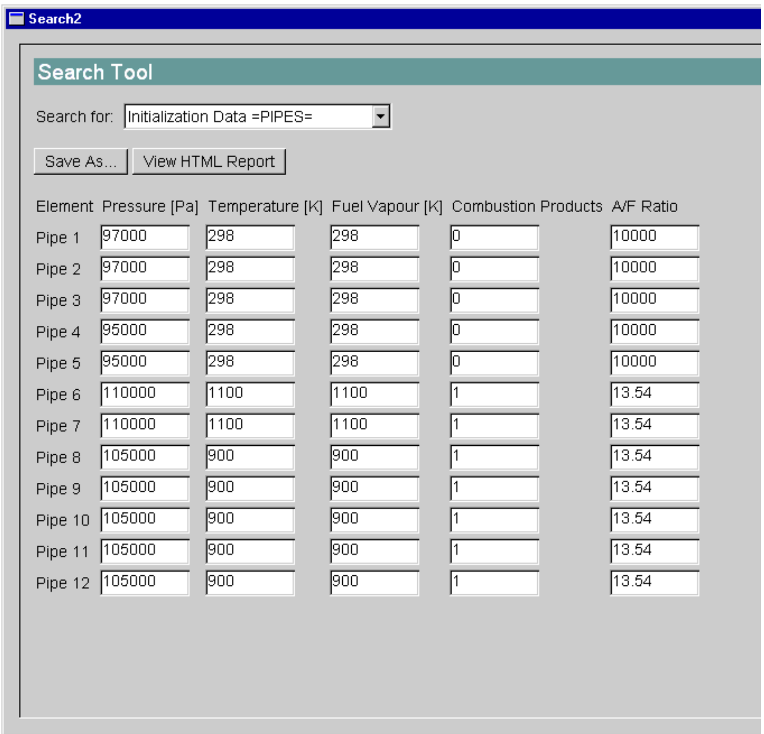


Figure 2-30: Search Utility Displaying Initialization Data for Pipes

2.4.3. License Manager

The License Manager dialog shows the active license configuration, i.e. the status of each license used by Boost. If necessary, the license configuration can be changed by enabling/disabling the appropriate check-box and will then be active at the next Boost startup. There are restrictions regarding license requirements, for example, a license cannot be disabled if it is required by an enabled license and vice versa. If all licenses are disabled, Boost will be in demonstration mode at the next startup. All features will be available except **Save** and **Run Simulation**.

Select **Utilities|License Manager** to open the following window:

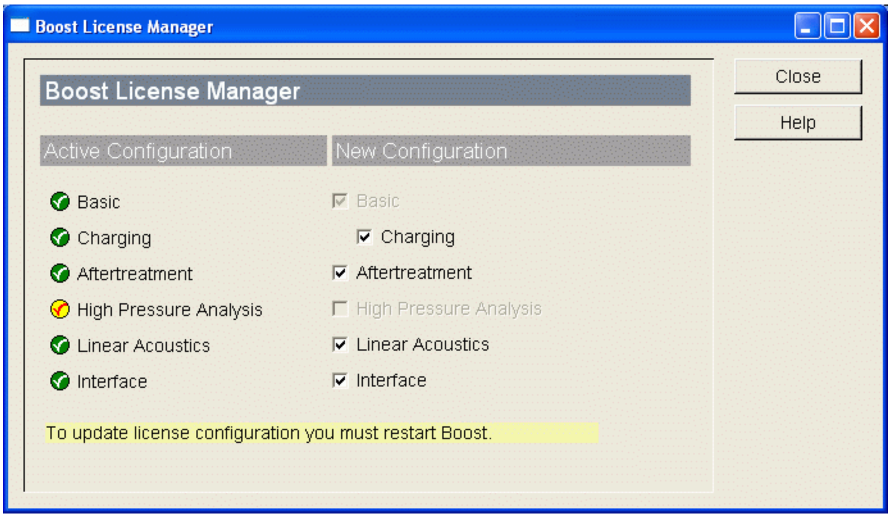


Figure 2-31: License Manager Window

The active configuration is shown on the left with the different license options:

	License is available and not checked out.
	License is available and checked out.
	License is not available.

For a new configuration, select the required license and then restart BOOST.

2.4.4. Pack Model

This creates a compressed tape archive of all files related to the current active model. These include input data, results, model layout, simulation messages and system information. On success, a message box will be displayed showing the path and name of the created file. The base name of the created file will match the current active model and will have the extension *.tar.gz*.

This utility can be used for sending models to the **BOOST** support team to check problems or errors.

2.4.5. Export GCA Parameters

The basis of the required input data for GCA can be exported from a BOOST model using **Utilities | Export GCA Parameters**.

Select the cylinder from which to export the data and also the path and filename for the GCA parameter file name (.gpa) to be created.

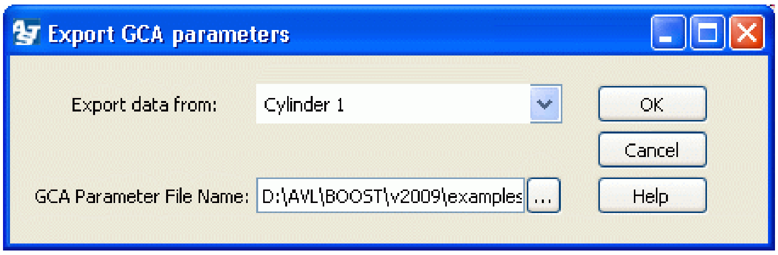


Figure 2-32: Export GCA Parameters Utility

This file can then be opened in Concerto (or IndiCom) via the GCA/Burn interface.

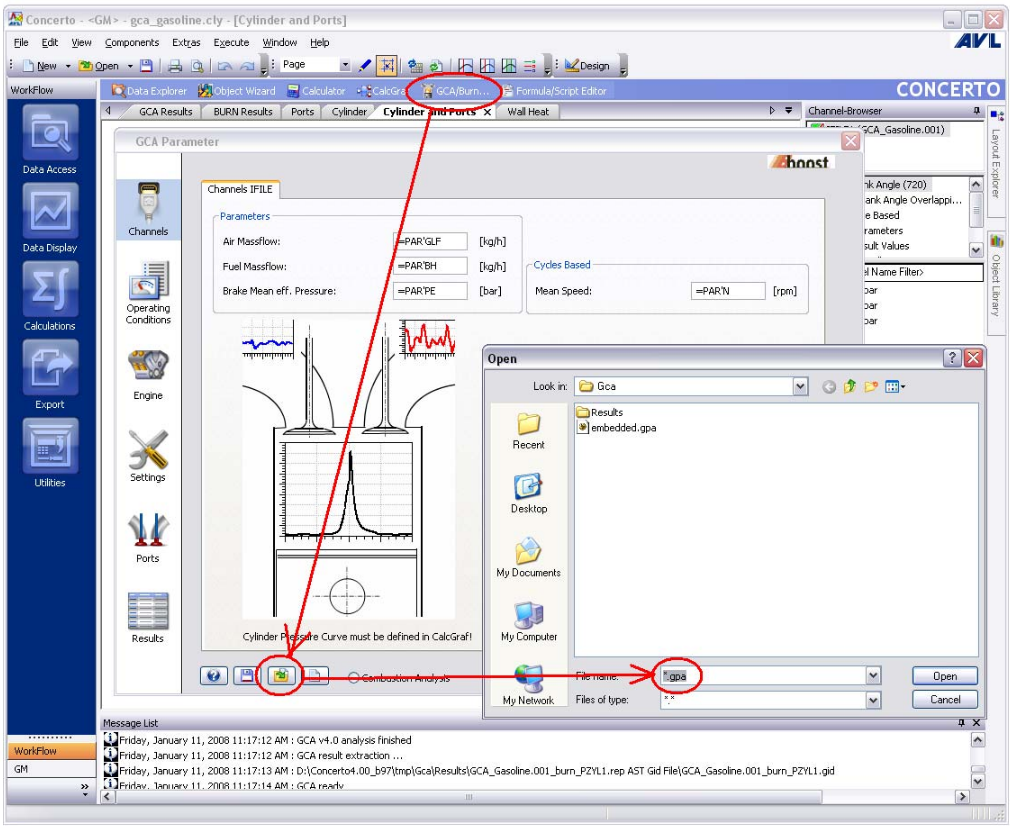


Figure 2-33: Opening GCA Parameter file (.gpa) in Concerto

It is important to check the imported data and set the correct links from the measured IFILE before running the gas exchange and combustion analysis (see GCA Product Guide for more information)

Assumptions

- Only the cylinder data itself is exported exactly. The attached pipe geometry needs to be manually set. This is especially true for tapered pipes attached to the cylinder.
- GCA only supports one dependency for a set of valve flow coefficients, so these are assumed to all be the same as the first (if there are multiple)
- Downstream ends of intake pipes are connected to the cylinder
- Upstream ends of exhaust pipes are connected to the cylinder

2.4.6. Export Pressure Curves

Select **Utilities|Export Pressure Curves** to run this export function. For each operating point the export of the pressure curves for all cylinders is done. After running this feature AVL-EXCITE can import that data.

In order to create the export for EXCITE, the model should be set up in a way which allows the calculation for different load signals for a set of speed points. This can be reached by models containing an Engine Control Unit.

The Engine Control Unit must be set to the control mode "Load Signal". For the load signal a parameter should be defined which can be set in the case explorer afterwards. The name of the parameter is not restricted. Refer to the Engine Control Unit window in Figure 2-34.

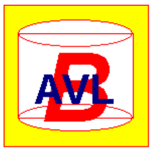
In the Globals the engine speed should also be defined as a parameter.

The calculations should be set up in a predefined schema to allow the export component the data access. Here are the rules for the case and case set definition:

- Each case set represents one load signal
- Each case of a case set represents a speed corresponding to the load signal of the current case set
- The case set definition should be identical in relation to the speed points → all case sets should contain the same speeds (case order should also be the same)

2.4.7. Export Flowmaster 4D Map

This feature allows the export of a map which can be loaded into the FLOWMASTER Element "AVL BOOST Engine". Flowmaster Element:



The map consists of three independent variables "Speed", "Load" and "Temperature", and one dependent variable "rejected heat". The feature can be launched from the menu **Utilities|Export Flowmaster 4D-Map**.

To export a 4D-map, the model should be set up in a way which allows the calculation for different load signals for a set of speed points and depending on a reference temperature. This can be reached by models containing an Engine Control Unit.

The Engine Control Unit must be set to the control mode "Load Signal". For the load signal a parameter should be defined which can be set in the case explorer afterwards. The name of the parameter is not restricted.

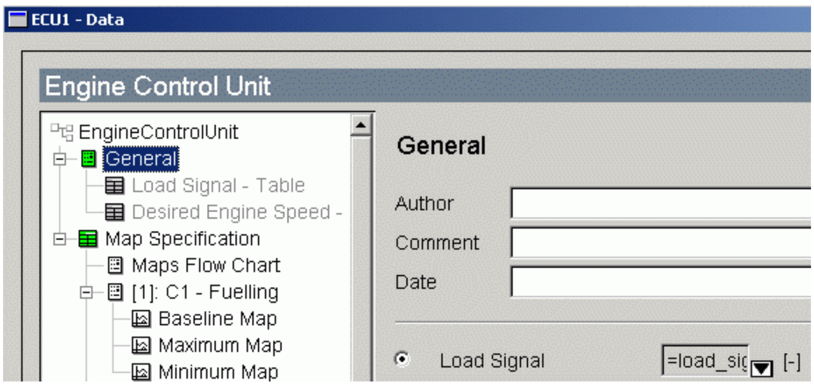


Figure 2-34: ECU - General Window

In the Globals, the engine speed should also be defined as a parameter.

And finally a temperature parameter should be defined in the cylinder. Currently it is necessary to define one of the following 3 input data as a workspace parameter:

- Cylinder - Heat Transfer - Piston - Wall Temperature

- Cylinder - Heat Transfer - Cylinder Head - Wall Temperature
- Cylinder - Heat Transfer - Variable Wall Temperature - Coolant Temperature

The calculations should be set up in a predefined schema to allow the export component the data access. Here are the rules for the case and case set definition:

- Each case set represents one load signal at one temperature
- Each case of a case set represents a speed corresponding to the load signal at one temperature of the current case set
- The case set definition must be identical in relation to the speed points → all case sets should contain the same speeds

Select **Utilities|Export Flowmaster 4D-Map** to open the following window:

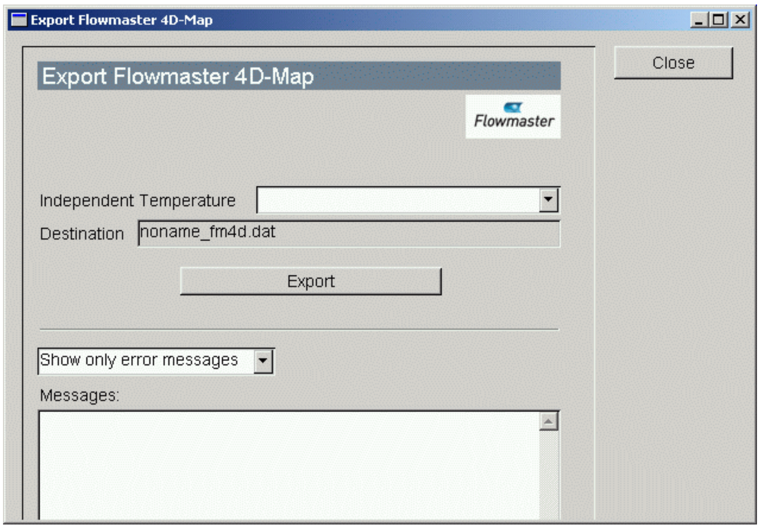


Figure 2-35: Export Flowmaster 4D Map Window

The only setting which is necessary for the export is the definition of the temperature which will be one independent variable of the exported map.

2.4.8. Calculation List

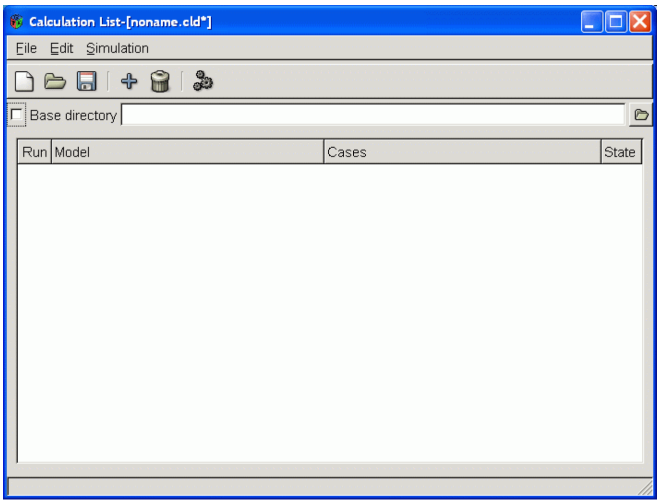


Figure 2-36: Calculation List Window

3. DESIGN A BOOST CALCULATION MODEL

To create a calculation model, double-click the required element in the Element tree with the left mouse button. In the working area move the displayed element to the desired location with the left mouse button.

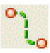
The positioning of the elements in the working area is assisted by a grid. The spacing of the grid points and the total size of the working area may be adjusted by selecting **File | Page Setup.** If a symbol must be positioned between grid points, snapping to the grid can be suppressed by pressing the shift key together with the left mouse button.

It is recommended to locate all required elements in the working area and then connect them with the pipes. Finally the measuring points should be located in the pipes. The elements are numbered automatically in the order which they were inserted.

3.1. Pipe Design

Select  to insert a pipe. All possible points for a pipe attachment are indicated by small circles. Triangles are displayed for cylinders, air cleaners, catalysts and coolers to represent intake and exhaust connections. Select the desired circle (or triangle) with the left mouse button to attach the pipe to the element.

Define the shape of the pipe by placing as many reference points in the working area as required with the left mouse button. The last of the series of points must be located at a possible pipe attachment and then click the right mouse button to complete the connection.

The appearance of a pipe may be modified by selecting it with the mouse and then selecting . The pipe defined points become visible and can be moved with the left mouse button. Additional points may be inserted by clicking the line between two reference points with the left mouse button. The modification is finished by clicking the right mouse button.

Attachment points of pipes at a plenum, a variable plenum, an air cleaner, catalyst or air cooler may be relocated by dragging the attachment point with the left mouse button. The direction in which the pipe was designed is suggested as the direction of positive flow (indicated by an arrow). The direction can be reversed by selecting .

3.2. Required Input Data

The following list is a summary of data required as input for a **BOOST** model.

Engine Data

- bore, stroke, number of cylinders, con rod length
- numbering of cylinders, principle arrangement of manifolds (diagram or sketch)
- compression ratio, firing order and firing intervals
- number of valves, inner valve seat diameters
- valve lift curves, cold valve clearances
- flow coefficients of the ports (incl. reference area), swirl number (incl. definitions)

Turbocharging System Data	• compressor and turbine maps including efficiencies, • mass flow characteristic of waste-gate valve, • intercooler size and hot effectiveness
Fuel Data	• lower heating value, stoichiometric air-fuel ratio
Boundary Conditions	• ambient pressure, ambient temperature • max. permissible charge air temperature • pressure loss of air cleaner and intercooler • pressure loss of exhaust system • dimensions of engine compartment
Drawings	• detailed drawings of the complete intake and exhaust system • (including all receivers, mufflers, throttles and pipes) • drawings of the cylinder head • (including the port geometry, flange areas and valve positions)
Measurements	• measured full load performance of the engine • (BMEP, BSFC, air-fuel ratio, fuelling, air flow, volumetric efficiency) • mean pressures and temperatures in the intake and the exhaust system • (including location of the measuring points) • combustion data, cylinder pressure traces • friction measurement results (including definition of procedure)
For Transient Simulation	• Inertia of engine and power consumption devices • Inertia of rotor assembly (TC) • Inertia of supercharger reduced to drive shaft (mechanically driven compressors)

3.3. Modeling

In principle, the following requirements must be met by the engine model:

1. The lengths in the piping system must be considered correctly.
2. The total volumes of the intake and exhaust systems must be correct.

As experience shows, major problems may occur when specifying the dimensions of pipes. The length of a pipe is determined along the centerline and may be difficult to measure. Also, the engine model should meet the requirement that both the lengths of the single pipes and the total length (e.g. the distance between inlet orifice and intake valves of the cylinder) are considered properly.

The modeling of steep cones or even steps in the diameter of a pipe by specifying a variable diameter versus pipe length should be avoided. A flow restriction should be used instead.

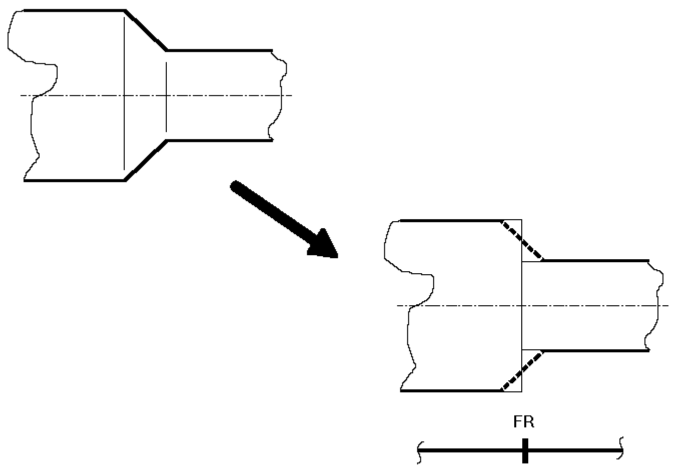


Figure 3-1: Modeling of Steep Cones

If the modeling of steep cones is necessary, the mass balance (i.e. the difference of the in-flowing at out-flowing mass) of this pipe should be checked carefully by the user. In this context it is important to mention that the plenum elements do not feature a length in the sense of a distance which must be passed by a pressure wave. For this reason it is sometimes difficult to decide on a correct modeling of a receiver; on one hand a plenum could represent a convenient modeling approach while on the other a more detailed modeling with several pipes and junctions could be required. The decision must be made on the basis of the crank angle interval which pressure waves need to propagate throughout the receiver. This means that for high engine speeds a detailed pipe junction model is required, whereas for low engine speeds a plenum model may produce excellent results.

The following figure illustrates both options for the example of the intake receiver of a four cylinder engine with frontal air feed.

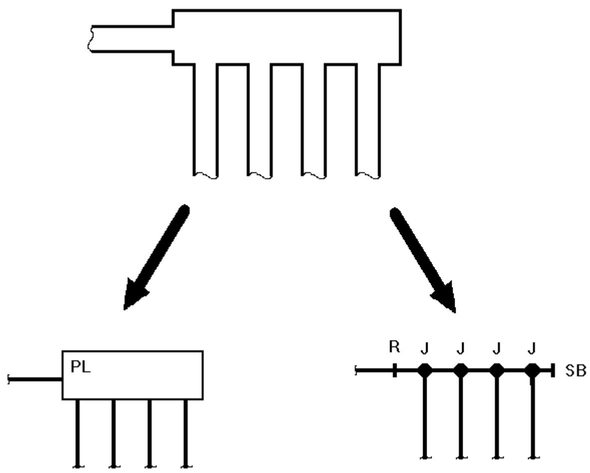


Figure 3-2: Modeling of an Intake Receiver

The plenum model may predict equal air distribution whereas in reality this is often a critical issue especially for long receivers with small cross sectional areas. For the latter, the pipe junction model is preferred. The step in the cross sectional area at the inlet to the intake receiver is modeled with a flow restriction. Ensure correct modeling of the length of the intake runners (refer to **Figure 7-13**).

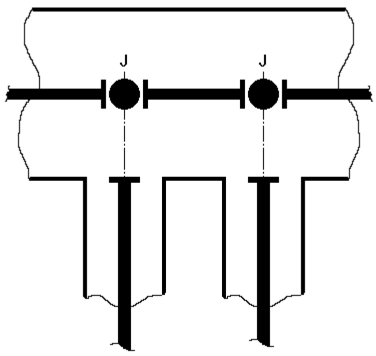


Figure 3-3: Modeling of an Intake Receiver with Pipes and Junctions

The following figure shows three different models for an intake receiver of a four cylinder engine:

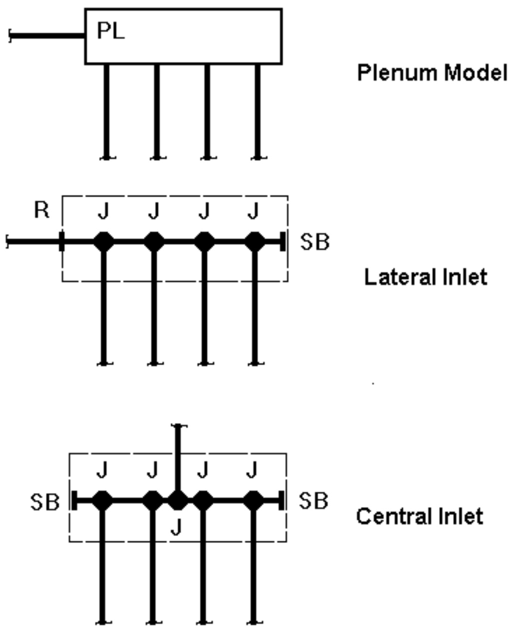


Figure 3-4: Intake Receiver Models

The first model is a simple plenum model. The second is a pipe and junction model with lateral inlet, and the third is a pipe and junction model with central inlet. The total volume of the receiver was kept constant. Figure 3-5 shows the predicted volumetric efficiency and air distribution for the three models. The air distribution is expressed as the difference between the maximum and minimum volumetric efficiency of an individual cylinder related to the average volumetric efficiency.

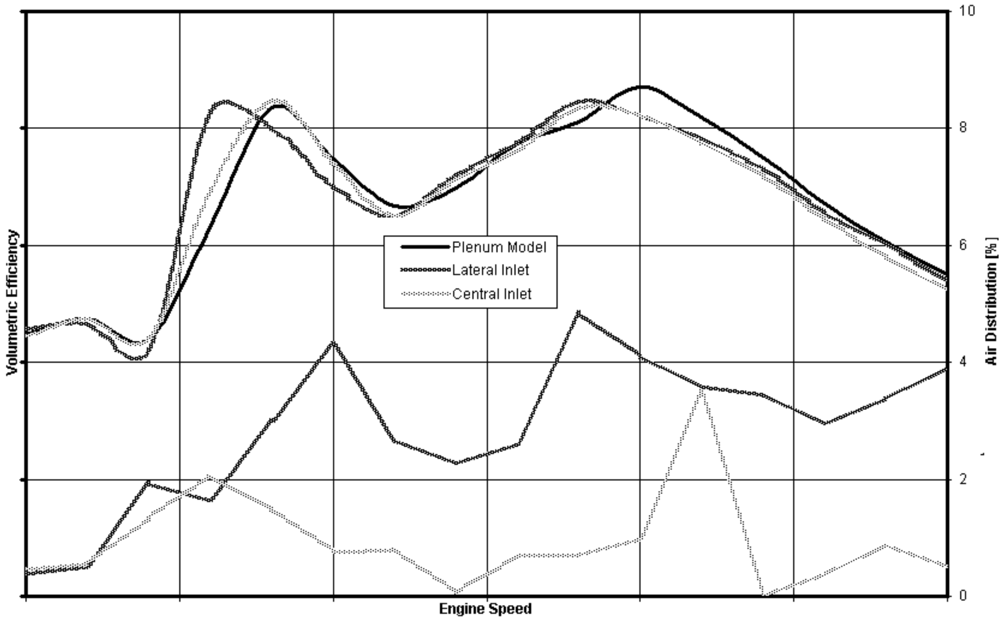


Figure 3-5: Influence of Intake Receiver Modeling on Volumetric Efficiency and Air Distribution

The predicted overall volumetric efficiency is similar for all three models, except for shifts in the resonance speeds. As the plenum model does not account for pressure waves in the intake receiver, equal volumetric efficiencies are calculated for all cylinders. The lateral air feed proves to be most critical with respect to air distribution especially at higher engine speeds.

Modeling of the ports deserves special attention, especially modeling of the exhaust ports. The flow coefficients are measured in an arrangement similar to the following figure:

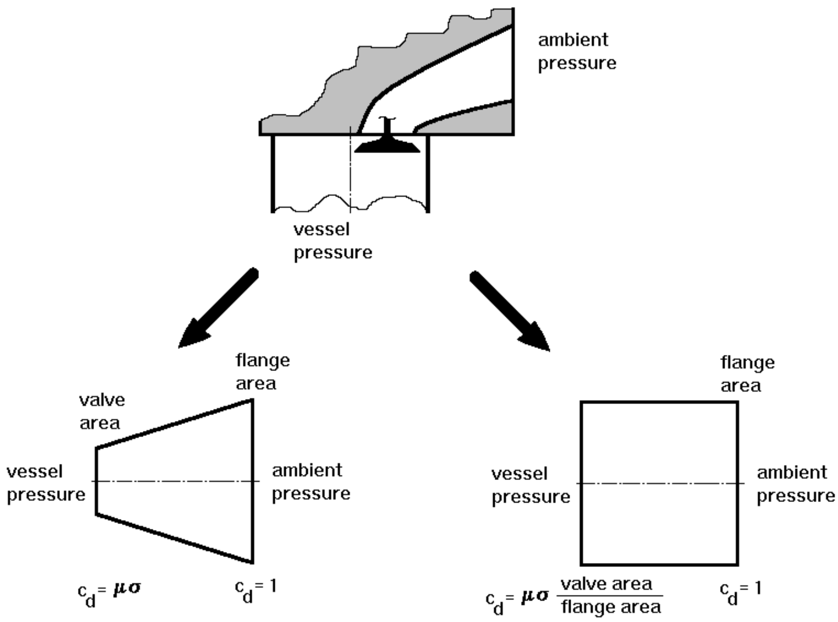


Figure 3-6: Exhaust Port Modeling

The measured mass flow rate is related to the isentropic mass flow rate calculated with the valve area and the pressure difference across the port. The model shown on the bottom left of the above figure would produce mass flow rates which are too high (too low in the case of a nozzle shaped exhaust port), because the diffuser modeled causes a pressure recovery increasing the pressure difference at the entry of the pipe modeling the port. The mass flow rate is calculated with the increased pressure difference and the valve area, and is therefore greater than the measured one. This problem can be overcome either by a correction of the flow coefficients or by switching to a model as shown on the bottom right of the above figure. Due to modeling the pipe as a straight diameter pipe with flange area, there is no pressure recovery. However, the flow coefficients need to be corrected by the ratio of the different areas. This can be done easily by the scaling factor.

For modeling a multi-valve engine two options are available:

1. A pipe is connected to each valve (refer to Figure 3-7, left side):

   The branched part of the intake and exhaust port is modeled by two pipes and a junction. For this junction, the refined model should be used exclusively, as the constant pressure model causes very high pressure losses. This modeling is required only if the two valves feature different valve timings, the geometry of the runner attached to each valve is different or a valve deactivation systems is used.

2. All intake and all exhaust valves are modeled by one pipe attachment (refer to Figure 3-7, right side):

   The number of valves is taken into account by specifying the flow coefficients and scaling factor in such a way that the total effective flow area of all considered valves is obtained. This modeling is preferred as it requires fewer elements and is therefore less complicated and more efficient.

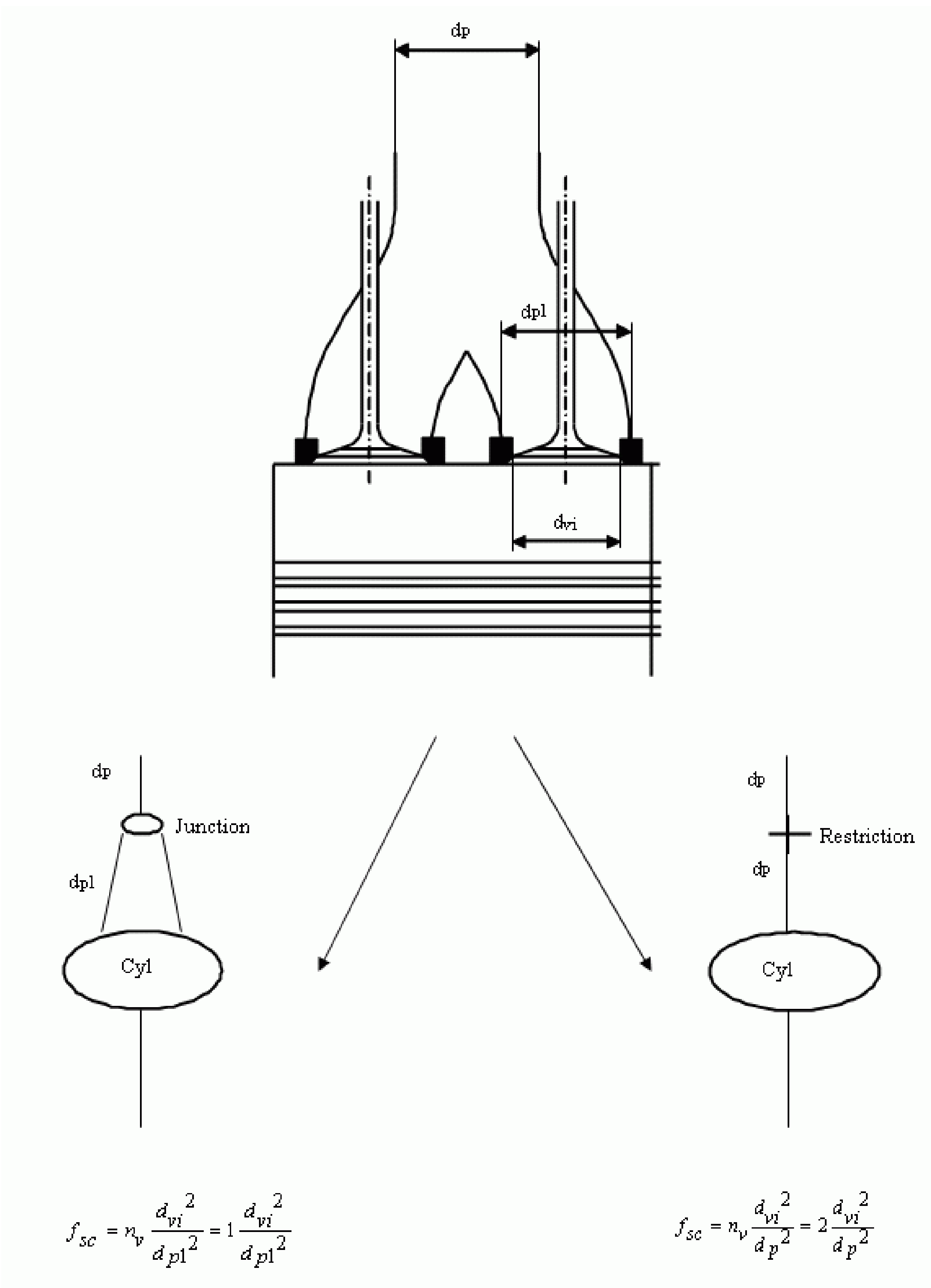


Figure 3-7: Modeling Multi-Valve Engines

4. ELEMENTS

Once the engine model is designed, the input data for each element must be specified.

4.1. General Information

4.1.1. Data Input Window

Double click the required element in the Element tree to display it in the working area. Select the displayed element with the right mouse button and select **Properties** from the submenu to open the relevant data input window. The following window relates to the general data of the pipe.

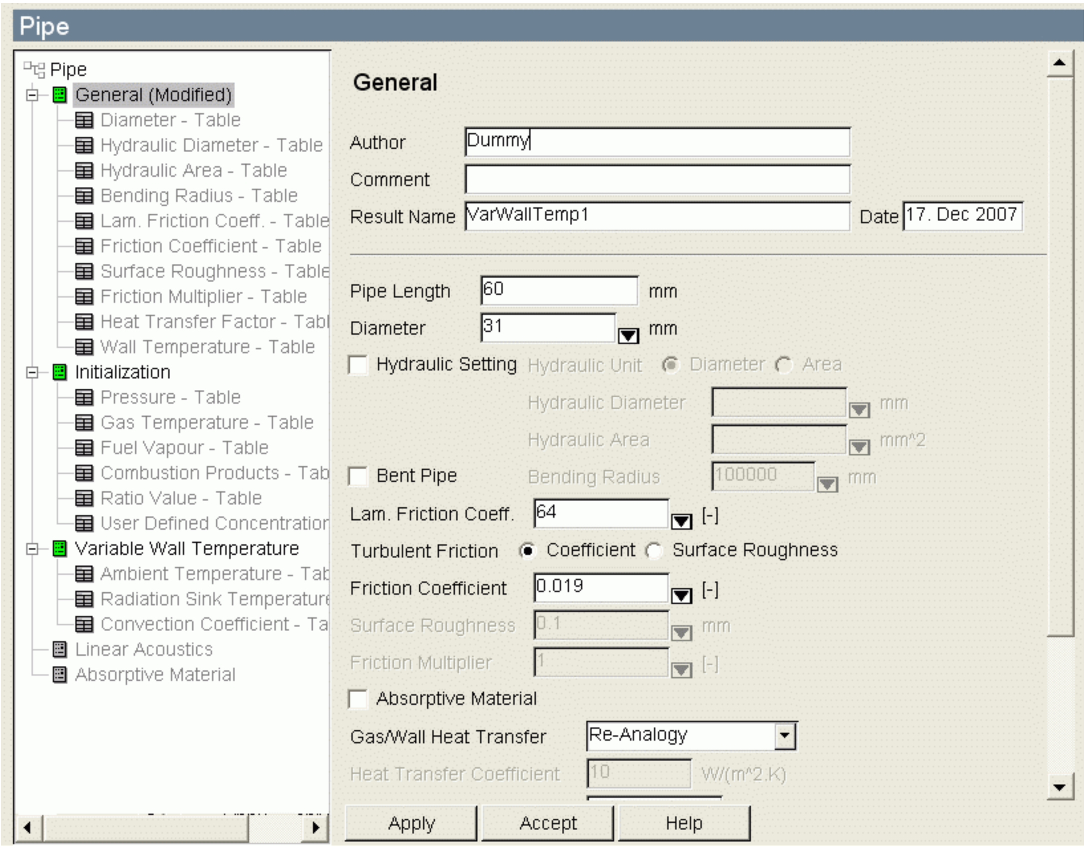


Figure 4-1: Data Input Window

Data input windows are available for sub-groups displayed in the tree shown in the above figure by clicking on the required sub-group with the left mouse button.

New or existing parameters can be inserted in the input fields by clicking on the label to the left of the field with the right mouse button and selecting the required option from the submenu. Refer to section **2.2.1** for further information.

While inputting data, the following options are available:

Apply: The specified data is saved when the error check is valid. The sub-group icon turns green.

Accept: The specified data is saved but no error check is executed and/or insufficient data is accepted by the user after a warning dialog. The sub-group icon turns yellow.

Reset: Returns to the previous applied settings.

Revert: Returns to the default settings.

Help: Online help is available.

OK: Confirms data input completion and exits the element.

Cancel: Modified data input is not saved. This also exits the element.

If all required data for the element is applied and/or accepted, the red exclamation point disappears, indicating that the input process for that element is completed.

If any input data is missing after selecting apply or accept, a window appears with a list of the missing data and a red exclamation point is displayed on the element. However, the user should be aware that incomplete or incorrect data usually renders a calculation of the data set impossible.

After confirming the element input data, the calculation model must be stored in a file with the extension `.BWF` by selecting **File|Save as**.

4.1.1.1. Sub-group Icons

The Sub-group icons inform the user as to their status as follows:

Green Sub-group Icon: Valid data has been specified.

White Sub-group Icon: Data has not yet been specified.

Grey Sub-group Icon: Disabled.

Red Sub-group Icon: Insufficient data.

Yellow Sub-group Icon: Insufficient data has been accepted by the user.

Select a **Sub-group** icon with the right mouse button to access the following options:

Expand or displays all available items in a folder.

Collapse or closes a folder.

Show All displays the complete list of items in the tree.

Show Enabled Only displays the available green and white sub-group icons.

Show Invalid Only displays the gray sub-group icons.

4.1.2. Table Window

Depending on the selected sub-group, the user can enter a constant value or a list of values where the **Table** icon is displayed. The **Table** window represents a standard window used throughout the program to specify values dependent on a certain parameter.

As shown in Figure 4-2, select the **Table** icon and select **Table** from the submenu. Then select the **Table** button which appears on the input field to open the following window.

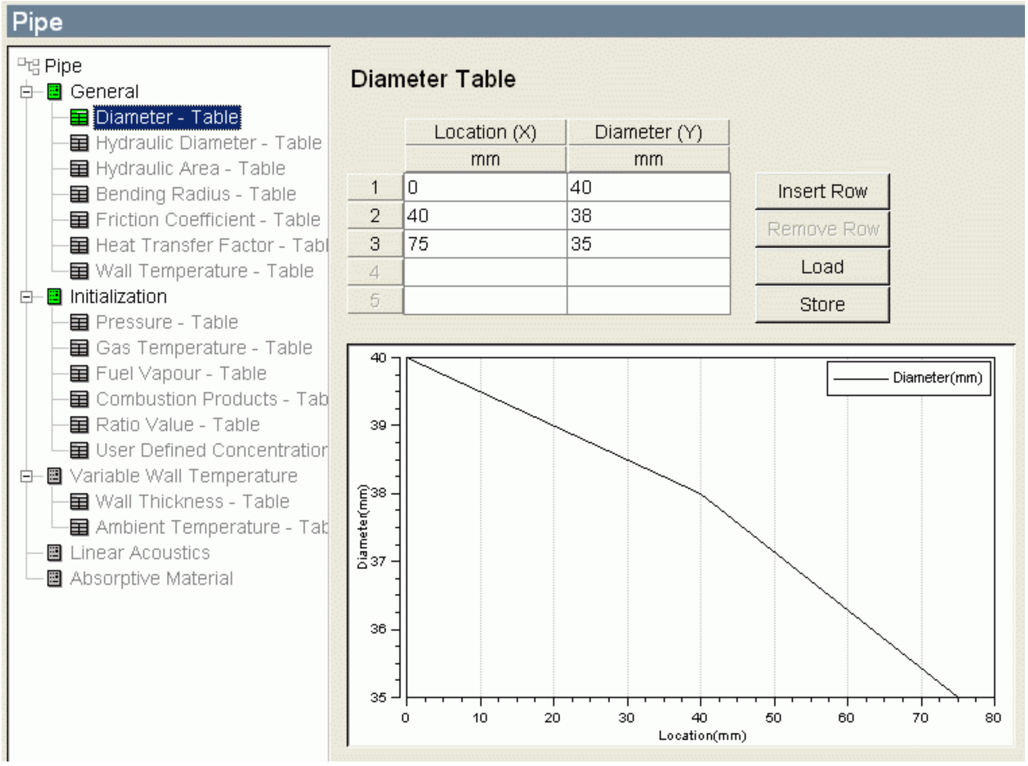


Figure 4-2: Table Window

Select Insert Row to add a line and enter the relevant values. Select Remove Row to delete a selected line.

New or existing parameters can be inserted in the table by clicking on the active field with the right mouse button and selecting the required option from the submenu. Refer to section **2.2.1** for further information.

Large data arrays can be read from an external file by selecting **Load**. If the data has been specified in the pre-processor, it may be saved in an external file by selecting **Store**. These files have the default extension `.dat`. It is ASCII format with one pair of data in each record. The values are separated by one or more blanks. No heading lines are allowed.

If data is defined versus time, the total time interval for which the values are specified may be less than, equal to or greater than the cycle duration. If the time interval is shorter than the specified maximum calculation period, **BOOST** treats the specified function as a periodic function.

☞ **Note:** A data point at 0 degrees and 360 degrees or 720 degrees is needed to obtain a period of 360 or 720 degrees for the specified function.

0 degree crank angle corresponds to the Firing Top Dead Center (TDC) of cylinder 1 (or the selected cylinder at the cylinder input).

The data entered in the table is plotted in the graph as shown in Figure 4-2. The axes and legend of the graph can be manipulated as desired. Click with the left mouse button, then click the right mouse button and select the required option from the following context menu.

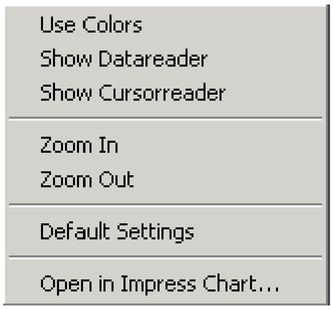


Figure 4-3: Graph Context Menu

4.1.3. Initialization

The initial or boundary conditions can be defined with either Local Initialization or Global Initialization. In the case of Global Initialization the parameters are taken from one of the predefined sets that can be selected with the Preference drop down menu.

Predefined initialization sets can be defined in the Globals section (See Simulation->Control->Initialization sub tree item).

Preference

For Global Initialization all the parameters are taken from the selected predefined set, no other input is required. For Local Initialization this is optional but if selected can be used as a starting point for the required parameters. These can then be set individually be editing the appropriate number.

Pressure	...	Initial/Boundary gas pressure
Gas Temperature	...	Initial/Boundary gas temperature.
Fuel Vapor	...	Initial/Boundary fuel vapor fraction.
Combustion Products	…	Initial/Boundary combustion product fraction.
Ratio Type	...	Defines the units (or type) for the Ratio Value It can be either: A/F - Ratio : (Air Fuel Ratio) Air Equivalence Ratio Excess Air Ratio
Ratio Value	...	Initial/Boundary value which determines the burned fuel fraction in the combustion products.

For initialization of pipes the values can be given as function of pipe location while the Boundary Conditions (System/Internal Boundary) can be specified as function of time.

4.1.4. Flow Coefficients

The following table may be used to determine flow coefficients for well manufactured pipe attachments. Values between the specified points can be obtained by linear interpolation.

Table 4-1: Flow Coefficients – Standard Values

Relative Edge Distance	Relative Inlet Radius				
	0.0	**.02**	**.06**	**.12**	**.20**
0.0	.815	.855	.910	.950	.985
0.025	.770	.840	.910	.950	.985
0.075	.750	.830	.910	.950	.985
0.20	.730	.825	.910	.950	.985
>0.50	.710	.820	.910	.950	.985

The relative inlet radius is defined as the inlet radius divided by the (hydraulic) pipe diameter r/D_h.

The relative edge distance is defined as the protrusion of the pipe end through the wall in which it is mounted, divided by the (hydraulic) pipe diameter L/D_h. A relative edge distance equal to zero represents a pipe mounted flush with the wall, refer to Figure 4-4.

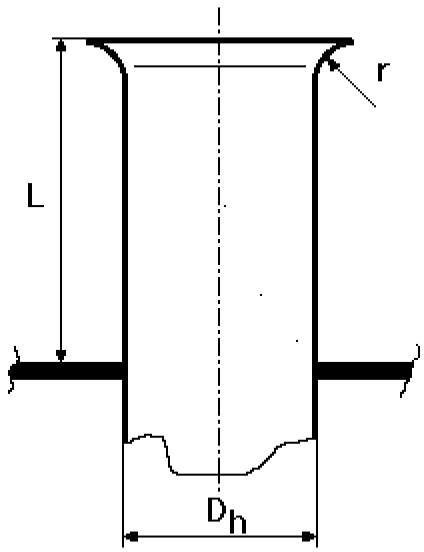


Figure 4-4: Mounting of a Pipe End

For flow out of a pipe into the ambient, a flow coefficient of `1.0` is normally used if there is no geometrical restriction in the orifice.

Table 4-2: Flow Coefficients – Directions

FLOW COEFFICIENTS	INFLOW	OUTFLOW
System Boundary	Flow into pipe *	Flow out of pipe **
Plenum	Flow into plenum	Flow out of plenum
Variable Plenum	Flow into plenum	Flow out of plenum
Air Cleaner	Flow into cleaner	Flow out of cleaner
Catalyst	Flow into catalyst	Flow out of catalyst
DPF	Flow into DPF	Flow out of DPF
Air Cooler	Flow into cooler	Flow out of cooler
Junction (Constant Pressure)	Flow into junction	Flow out of junction
User defined Element	Flow into element	Flow out of element

* (typically less than 1 for flow from large volume into pipe)

** (typically 1 for flow out of pipe into a large volume)

The outflow coefficient should generally be less than one (flow into a pipe from a volume) but this is dependent on the actual volume (and other factors) so there is no hard and fast rule. The exception is the system boundary where the outflow (pipe to boundary) should typically be one and the inflow (boundary to pipe) less than one.

4.2. Pipe

Click on **Aftertreatment** or **Linear Acoustics** for relevant information.

For thermodynamic engine simulation programs which consider the gas dynamics of the intake and exhaust systems, the pipe element is one of the most important elements in the engine model. One dimensional flow is calculated in the pipes by solving the appropriate equations. This means that the pipe is the only element where the time lag caused by the propagation of pressure waves or the flow itself is considered.

BOOST allows the pipe diameter (given the same cross-sectional area), bend radius, friction coefficient, wall heat transfer factor, wall temperature, as well as the initial values for pressure, gas temperature, A/F ratio, concentration of fuel vapor and concentration of combustion products to be specified depending on the location in the pipe by selecting **Table** ▼. If this feature is used, the pipe length must be specified first.

4.2.1. Hydraulic Settings

The hydraulic diameter is defined as

$$d_h = \frac{4A}{C} \tag{4.2.1}$$

A cross-sectional area

C circumference of the cross-section

In **BOOST** this value is not only available for accounting of non-circular flow cross sections but can also be used for modeling multiple flow channels represented by one pipe (e.g.: catalyst channels). It determines the instantaneous Reynolds number and consequently the flow regime type (laminar, transition or turbulent) and can be either directly input or specified via the Hydraulic Area.

4.2.2. Bending Radius

For table input of the pipe bend radius, the pipe radius for a whole section is taken as the value at the highest (or furthest) point defined. That is, the first value defined for table input of bend radius will effectively be ignored.

For example, in the following table the bending radius is,

120mm from 0 - 105mm (along the length of the pipe)

60mm from 105mm to 210mm

10000mm from 210mm to 315mm

	Location (X)	Bending Radius (Y)
	mm	mm
1	0	0
2	105	120
3	210	60
4	315	10000
5		

Figure 4-5: Example Table Input for Bending Radius

The bend angle for a pipe section is then calculated from the length of the defined section divided by the bending radius.

Using the same example as before, between 105mm and 210mm:

$$\text{bend angle} = \frac{210 - 105}{60} = 1.75\ \text{radians} = 100\ \text{degrees}$$

4.2.3. Friction Coefficients

4.2.3.1. Turbulent friction: direct specification

The pipe wall friction coefficient for turbulent flow depends on the absolute surface roughness Rz of the pipe, pipe diameter and the Reynolds number of the flow in the pipe. For fully turbulent flow, the standard values for the friction coefficient may be taken from the following table:

Material (Roughness [mm])	**Pipe Diameter [mm]**			
	30	**60**	**100**	**150**
Plastics (0.0015)	0.011	0.01	0.01	0.01
Steel new (0.05)	0.023	0.019	0.017	0.016
Steel old (0.17)	0.032	0.027	0.023	0.021
Cast Iron (min. 0.25)	0.037	0.029	0.026	0.023
Cast Iron (max. 0.5)	0.044	0.037	0.031	0.028

Values between the specified diameters may be obtained by linear interpolation.

4.2.3.2. Turbulent friction: surface roughness based specification

Using the specified value for the absolute surface roughness Rz **BOOST** calculates the turbulent friction coefficient according the [P7] (“Moody’s diagram”).

4.2.3.3. Laminar friction

For the laminar flow regime the default value for the Laminar Friction coefficient (Hagen-Poisseuille-Law: 64) can be modified.

4.2.4. Absorptive Material

Absorptive Material, such as glass fibers, can be added to any pipe in a BOOST model including perforated pipe in pipe element. The absorptive material is defined by entering the flow resistivity and material porosity which can be calculated from more fundamental parameters of the material such as fiber radius and material density.

Flow Resistivity	The flow resistivity or specific flow resistance per unit thickness of an absorptive material is defined as follows, $$R = -\frac{1}{u}.\frac{\Delta p}{\Delta x}$$ The Users Guide shows how to calculate this parameter from fundamental material properties. Typical value for resistivity would be about 30000 Ns/m4

Material Porosity	The material porosity represents the fraction of air space within the material (0 to 1). This will be a function of the packing density of the material. For example, a Material Porosity of 0.9 defines that 10% of the volume is filled with material and 90% is space for the gases. **Material Porosity** = 1 - (Packing Density)/(Material Density)

4.2.5. Heat Transfer Factor

The heat transfer coefficient for the calculation of the heat flux from or to the pipe walls is calculated from the Reynolds' analogy. The heat transfer factor allows the user to increase or to reduce the heat transfer as the calculated heat transfer coefficient is multiplied by this factor.

4.2.6. Variable Wall Temperature

BOOST can model the variation of the pipe wall temperature. This takes into account the heat transfer from the outer pipe wall to a surrounding ambient and heat flux from the gas flow to the pipe wall.

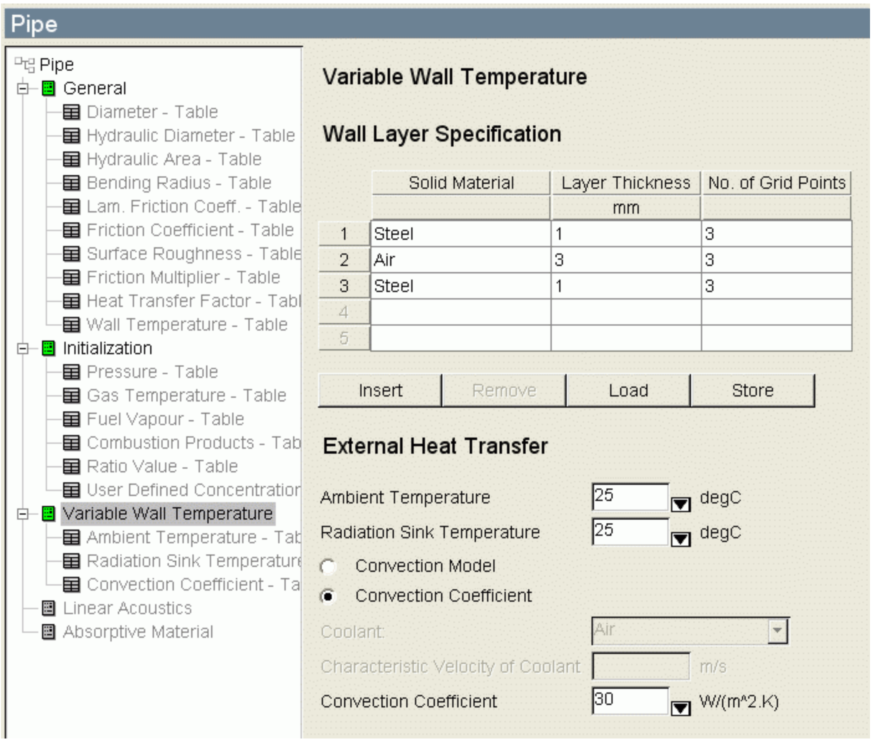


Figure 4-6: Example Table Input for Variable Wall Temperature

Additional input required for the variable wall temperature model is as follows:

- number of wall layers
- thickness of each layer
- number of grid points used for the discretization of each layer
- material properties for each layer
- temperature in the ambient of the pipe
- radiation sink temperature for the pipe

- wall-ambient heat transfer model (direct or model based specification of the external heat transfer factor)

An arbitrary number of solid material property sets can be defined under **Model | Solid Materials** (refer to section **2.2.3**).

4.2.7. Chemistry

For a General Species Transport Calculation chemical reactions can be taken into account in the pipe. If activated, a chemistry set needs to be specified.

4.2.8. Initialization

The conditions within the pipe can be defined with **Local Initialization** or **Global Initialization**. For **Global Initialization** the parameters are taken from a predefined set which is selected from the **Preference** pull-down menu. Predefined initialization sets can be defined under **Simulation | Control | Initialization**.

For **Local Initialization** a predefined set can be used as a starting point for the required parameters. These can then be set individually by editing the appropriate number.

Input can be constant or by a **Table** ▼, where it may be specified as a function of distance from the upstream pipe end. The first value must be specified at the upstream pipe end (Location = 0) and the last value at the downstream pipe end (Location = Length).

Preference	All parameters are taken from the selected predefined set.
Pressure	Initial gas pressure in the pipe.
Gas Temperature	Initial gas temperature in the pipe.
Fuel Vapor	Initial fuel vapor fraction in the pipe.
Combustion Products	Initial combustion product fraction in the pipe.
Ratio Type	This defines the units (or type) for the **Ratio Value**. Select: • A/F - Ratio : (Air Fuel Ratio) • Air Equivalence Ratio • Excess Air Ratio
Ratio Value	The ratio value (dependent on **Ratio Type** for the initial gas composition in the pipe).

4.3. Mechanical Connection

The Mechanical Connection couples two Mechanical Components (Engine-Turbine, TurboCharger-ElectricalDevice-Mechanical Consumer-Vehicle) either via their Power Exchange (**Simplified Model**) or their Rotational Speed (**Full Model**).

While the **Simplified Model** requires only input for Mechanical Efficiency, the **Full Model** needs also Input for Gear Ratio (= $Speed_{Upward}/Speed_{Downward}$; Mechanical Connection Arrow indicates the Direction from Up- to Downward) and Slip (Difference of ideal driven component speed and actual driven component speed related to the ideal driven component speed).

The **Clutch**, available for the Mechanical Connection Full Model, is located between the Upward Connection and the Gear Transmission. It requires the following input:

- **Clutch Release Position** (constant value or time dependent Table). This value is treated discrete: for values greater than 0.5 the Clutch is disengaged while for values less or equal 0.5 it is engaged; crossing 0.5 initiates an Engagement/Disengagement)
- **Engagement time** (Period between start and end of Engagement/Disengagement)

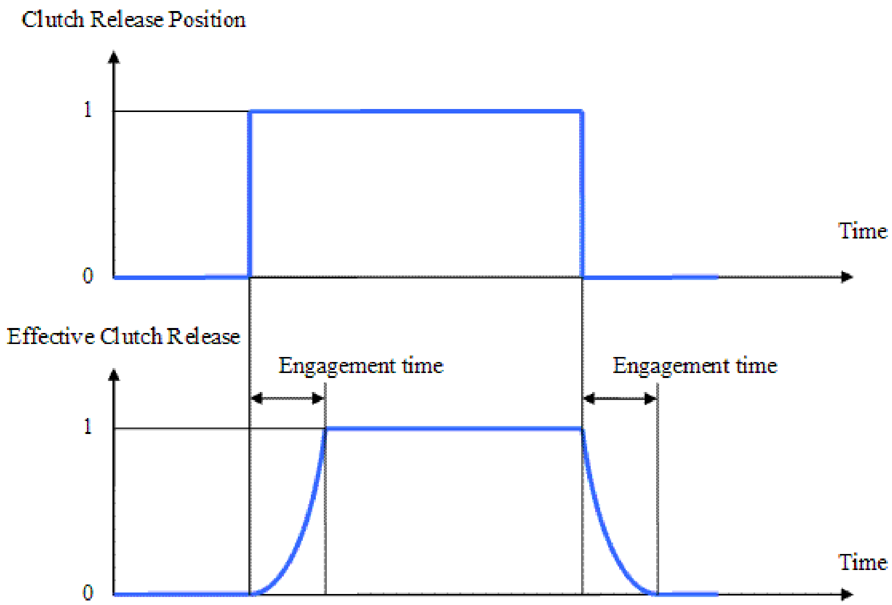


Figure 4-7: Engagement Time

- **Friction Coefficient Ratio** between slipping and sticking transmission
- **Maximum transferable Torque** for sticking transmission. If a constant value is specified it is assumed that this value decreases linear to 0 with increasing Clutch Release Position; a different dependency can be specified by means of a Table.

4.4. Cylinder

The specifications for the cylinders cover the basic dimensions of the cylinder and the cranktrain (bore, stroke, compression ratio, conrod length, piston pin offset, firing order), plus information on the combustion characteristics, heat transfer, scavenging process and the valve/port specifications for the attached pipes. Furthermore, initial conditions for the calculation in the cylinder must be specified.

If a standard cranktrain is used, the piston motion is calculated from the stroke, conrod length and piston pin offset. The direction of positive piston pin offset is defined as the direction of the rotation of the crankshaft at Top Dead Center (TDC).

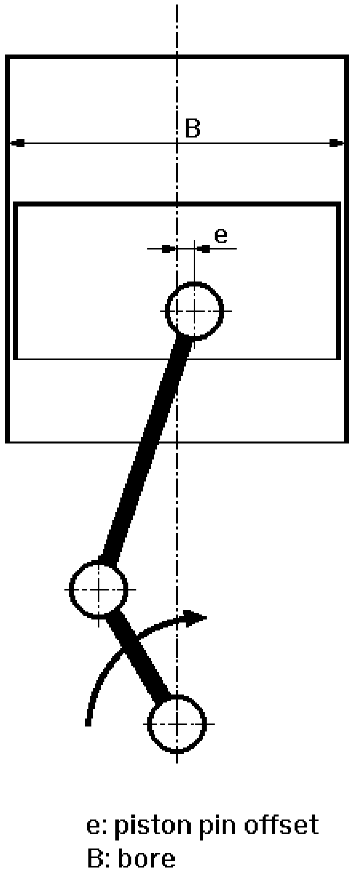


Figure 4-8: Standard Cranktrain

Alternatively, **BOOST** allows a user-defined piston motion to be specified. This gives the user freedom to simulate an unconventional powertrain. For a user-defined piston motion the relative piston position should be specified over crank angle.

The relative piston position is defined as the distance of the piston from the TDC position relative to the full stroke. Zero degree crank angle corresponds to the Firing TDC of the selected cylinder.

Considering blow-by from the cylinder, an equivalent effective blow-by gap must be specified as well as the average crankcase pressure. The actual blow-by mass flow is calculated from the conditions in the cylinder and the pressure in the crankcase, and from an effective flow area which is calculated from the circumference of the cylinder and the effective blow-by gap. The blow-by mass flow is lost. No recirculation to the intake may be considered.

4.4.1. General

Bore / Stroke / Compression Ratio / Con-rod Length / Firing Order	Basic dimensions of the cylinder and the cranktrain.
Piston Pin Offset	If a **standard cranktrain** is used, piston motion is calculated from the stroke, the con-rod length, and the piston pin offset. The direction of positive **Piston Pin Offset** is defined as the direction of the rotation of the crankshaft at TDC.
Effective Blow By Gap / Mean Crankcase Pressure	For the consideration of blow-by from the cylinder, an equivalent **Effective Blow-By Gap** and **Mean Crankcase Pressure** should be specified. The actual blow-by mass flow is calculated from the conditions in the cylinder, the pressure in the crankcase and the effective flow area calculated from the circumference of the cylinder and the effective blow-by gap. The blow-by mass flow is lost. No recirculation to the intake may be considered.
User Defined Piston Motion	A user-defined piston motion to be specified which allows the user to simulate an unconventional powertrain. For a user-defined piston motion the relative piston position should be specified over crank angle. The relative piston position is defined as the distance of the piston from the TDC position relative to the full stroke. Zero degree crank angle corresponds to the Firing TDC of the selected cylinder. The cylinder piston motion may be specified alternatively depending on degrees crank angle. The piston position is expressed relatively with 0 meaning piston in TDC and 1 piston in BDC.
Chamber Attachment	Select if an engine with divided combustion chamber is to be simulated. The pre-chamber data can be specified under the **Chamber** sub-group.
Scavenge Model	Three scavenging models are available (Figure 4-9 shows a comparison of the scavenging efficiency curves of the perfect displacement and the perfect mixing models.): **Perfect mixing:** The gas flowing into the cylinder is mixed immediately with the cylinder contents. The gas leaving the cylinder has the same composition as the mixture in the cylinder. The perfect mixing model is the standard scavenging model for the simulation of 4-stroke engines.

	Perfect displacement: A pipeline model is used to determine the exhaust gas composition. This means that all residual gases in the cylinder are exhausted first. Only when no more residual gases are left in the cylinder, is fresh charge lost to the exhaust. **User-defined scavenging model:** For the simulation of 2-stroke engines, the specification of the scavenging efficiency over scavenge ratio is required to define the quality of the port arrangement with respect to scavenging flow. This data are usually taken from literature or from the results of scavenging tests. The scavenging efficiency is defined as the volume of fresh air in the cylinder related to the total cylinder volume. The scavenge ratio is defined as the total volume of air which entered the cylinder related to the total cylinder volume.

Figure 4-9: Scavenging Models

4.4.2. Initialization

As initialization the cylinder conditions (pressure, temperature and gas composition) at the end of the high pressure at exhaust valve opening must be specified. The simulation of the in-cylinder conditions for each cylinder starts with the first exhaust opening and is not performed before.

4.4.2.1. SHP Condition Setting

In certain cases (i.e. identification of combustion model parameters) it can be useful to specific the cylinder state at each SHP event (all valves closed). This can be achieved by the **SHP Conditions Setting** option.

If activated, the following options are available:

Setting of **Mass**	The user specifies mass and pressure in the cylinder at SHP, the corresponding temperature is calculated.
Pressure at SHP	Specifies the pressure at SHP.
Air Massflow	Specifies the air massflow for the given cylinder.
Fuel Massflow	Specifies the fuel massflow for the given cylinder.
Trapping Efficiency Air	Multiplier to tune the actually trapped air mass (i.e. two stroke engines, large valve overlap in four stroke engines,...)
Trapping Efficiency Fuel	Multiplier to tune the actually trapped fuel mass (i.e. two stroke engines, large valve overlap in four stroke engines,...)
Mass Fraction of Residual Gas at SHP	Specifies the mass fraction of EGR at SHP
Setting of **Temperature**	The user specifies temperature and pressure in the cylinder at SHP, the corresponding mass is calculated.
Pressure at SHP	Specifies the pressure at SHP.
Temperature at SHP	Specifies the temperature at SHP.
SHP Gas Composition	Specifies the air composition at SHP.

4.4.3. Combustion Model

For the specification of the combustion characteristics, either a heat release approach, a theoretical combustion cycle, a user-written subroutine or a truly predictive model can be selected from the pull down menu.

For selected **Vibe Parameter Fitting** option Vibe Parameters for the calculated Rate of Heat Release (based on Combustion Models or Table input) are fitted and available as Transients results.

Thereby the total heat released during the combustion is calculated from the amount of fuel which is burned in the cylinder and the lower heating value of the fuel:

For engines with internal mixture preparation the fuel is injected directly into the cylinder and the fueling is therefore part of the cylinder specification. For convenience, the fueling may be specified as the fuel mass which is injected into the cylinder or as a target A/F ratio, where the actual fueling is calculated every cycle from the mass of air in the cylinder and the specified target air/fuel ratio.

In the case of external mixture preparation, the fuel is fed to the intake system and the total heat supply is calculated from the amount of fuel in the cylinder at intake valve closing. For modeling of gasoline direct injection engines, fuel may be added to the cylinder charge directly. In this case **In Cylinder Evaporation** (4.4.3.19) must be selected and the normalized rate of evaporation must be specified. The rate of evaporation defines the addition of fuel vapor to the cylinder charge.

The specified curve is normalized, so that the area beneath the curve is equal to one. The actual amount of fuel added is either defined directly or by the target A/F-Ratio.

As for engines with internal mixture preparation, the evaporating fuel mass or the target A/F-ratio can be set by the user. If the target A/F-ratio is selected, the injected fuel mass will be determined as the fuel mass required in addition to the aspirated fuel mass to achieve the desired A/F-ratio. If the A/F-ratio is already lower than the target A/F-ratio, no fuel will be added. The evaporation heat is used to calculate the cooling of the cylinder charge due to the evaporation of the fuel. The following table may be used to determine the evaporation heat of different fuels:

Table 4-3: Evaporation Heat – Standard Values

Fuel	**Evaporation Heat [kJ/kg]**
Methanol	1109
Ethanol	904
Gasoline	377-502
Gasoline (Premium)	419
Diesel	544-795

By specifying Heat from Wall greater than `0`, the amount of evaporation heat covered from the combustion chamber walls can be input.

For the definition of the heat release characteristics over crank angle, the following options are available:

- Single Vibe function
- Double Vibe function
- Single Zone Table
- Two Zone Table
- Woschni/Anisits (internal mixture preparation only)
- Hires et al. (external mixture preparation only)
- User Defined Model
- User-Defined High Pressure Cycle
- Constant Volume Combustion
- Constant Pressure Combustion
- Motored
- Vibe 2 Zone
- Target Pressure Curve
- Target Pressure Curve 2 Zone
- Fractal
- Single Zone HCCI

For the specification of the relevant parameters for the pollutant formation models, the following is available:

- Pollutants

For a General Species Transport calculation additional options are available:

For the **Single Zone HCCI** and **HCCI 6-Zone** combustion model the following chemistry sets can be defined:

- Single Zone Chemistry: The specified chemistry set is taken into account during the high pressure phase.
- Gas Exchange Phase Chemistry: The specified chemistry set is taken into account during the gas exchange phase.

For any **Two Zone** combustion model the following chemistry sets can be defined:

- Single Zone Chemistry: The specified chemistry set is taken into account during the high pressure phase except the two zone phase.
- Gas Exchange Phase Chemistry: The specified chemistry set is taken into account during the gas exchange phase.
- Two Zone Unburned Chemistry: The specified chemistry set is taken into account in the unburned zone during the two zone phase (i.e. knock chemistry).
- Two Zone Burned Chemistry: The specified chemistry set is taken into account in the burned zone during the two zone phase (i.e. pollutant formation chemistry).

If there are convergence problems, the relative and absolute tolerance of the cylinder solver can be specified. (Smaller values give higher accuracy and lead to higher run-times.)

4.4.3.1. Single Vibe Function

The Vibe function is a very convenient method for describing the heat release characteristics. It is defined by the start and duration of combustion, a shape parameter 'm' and the parameter 'a'. These values can be specified either as constant values or dependant on engine speed (in rpm) and engine load (expressed as BMEP in bar). Select **Map** ▼ to specify these values.

The heat release characteristic of gasoline engines, with essentially homogeneous mixture distribution in the cylinder, is mainly determined by the flame propagation speed and the shape of the combustion chamber. A high flame propagation speed can be achieved with high compression ratio and high turbulence levels in the cylinder. In diesel engines on the other hand, the combustion characteristic depends strongly on the capabilities of the fuel injection system, compression ratio and the charge air temperature.

For accurate engine simulations the actual heat release characteristic of the engine, (which can be obtained by an analysis of the measured cylinder pressure history), should be matched as accurately as possible. To obtain an estimate on the required combustion duration to achieve a certain crank angle interval between 10% and 90% mass fraction burned, the following chart may be used.

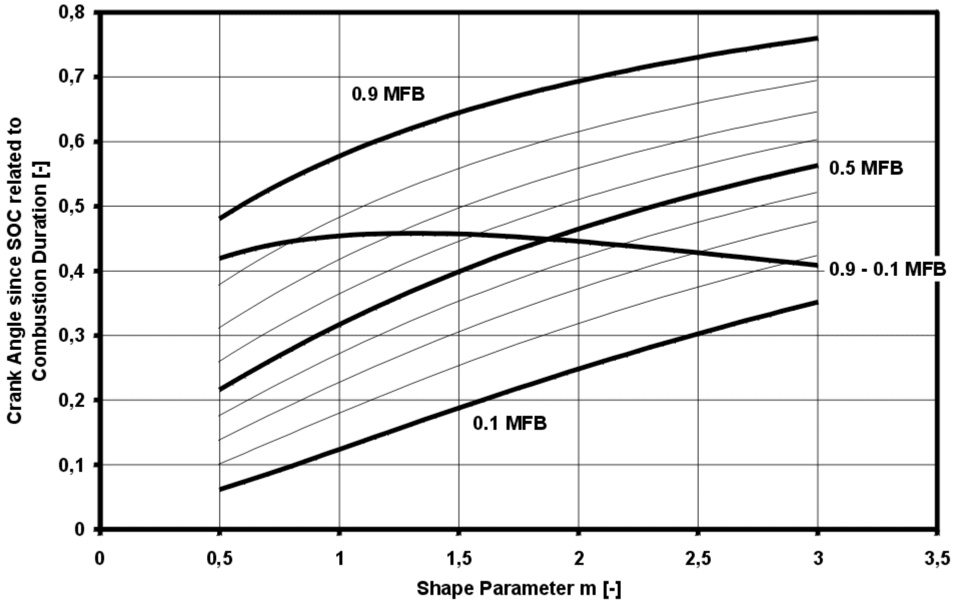


Figure 4-10: Crank Angle related to Combustion Duration

For example:

A shape parameter of 1.5 is selected and the duration between 10% and 90% MFB is 30 degrees CRA. The crankangle interval between 10% and 90% MFB related to the combustion duration is 0.46. (read from the graph). Hence the combustion duration is 30/0.46 = 65 degrees CRA. The point of 50% MFB is at 10 degrees CRA ATDC. According to the graph the location of 50 % MFB after combustion start related to the combustion duration is 0.4. Thus the combustion start is calculated from 10 – 65 * 0.4 = -16 = 16 degrees BTDC.

If measured heat release data is not available, the following standard values may be used to complete the engine model.

Table 4-4: VIBE Parameters – Standard Values

	Operating Point	Comb. Duration	Par. m
Gasoline Engine	**Standard Combustion System (2-Valve Engine)**		
	1500 rpm WOT	60 degrees CRA	2.3
	5000 rpm WOT	65 degrees CRA	1.9
	Standard Combustion System (4-Valve Engine)		
	1500 rpm WOT	50 degrees CRA	2.5
	5000 rpm WOT	55 degrees CRA	2.1
	Fast Burn Concepts		
	1500 rpm WOT	45 degrees CRA	2.6
	5000 rpm WOT	50 degrees CRA	2.6
Passenger Car	**Naturally Aspirated (Full Load)**		
Diesel Engine (IDI)	Rated Speed	90 degrees CRA	0.5
	30% Rated Speed	65 degrees CRA	0.5
	Turbocharged (Full Load)		
	Rated Speed	90 degrees CRA	1.0
	30% Rated Speed	65 degrees CRA	0.8
	Turbocharged Intercooled (Full Load)		
	Rated Speed	90 degrees CRA	1.1
	30% Rated Speed	65 degrees CRA	0.8
Passenger Car	**Naturally Aspirated (Full Load)**		
Diesel Engine (DI)	Rated Speed	80 degrees CRA	0.4
	30% Rated Speed	55 degrees CRA	0.4
	Turbocharged (Full Load)		
	Rated Speed	75 degrees CRA	0.9
	30% Rated Speed	55 degrees CRA	0.7
	Turbocharged Intercooled (Full Load)		
	Rated Speed	75 degrees CRA	1.0
	30% Rated Speed	55 degrees CRA	0.7

Heavy Duty Truck Engine (DI)	**Naturally Aspirated (Full Load)**		
	Rated Speed	70 degrees CRA	0.5
	50% Rated Speed	55 degrees CRA	0.6
	Turbocharged (Full Load)		
	Rated Speed	70 degrees CRA	1.1
	50% Rated Speed	55 degrees CRA	0.8
	Turbocharged Intercooled (Full Load)		
	Rated Speed	75 degrees CRA	0.9
	50% Rated Speed	60 degrees CRA	1.0
Medium Speed Engines (DI, TCI)	Rated Output	65 degrees CRA	1.0

The start of combustion must be defined considering fuel consumption, peak cylinder pressure limitation, or knocking characteristics for gasoline engines.

The Vibe parameter 'a' characterizes the completeness of the combustion. For complete combustion, a value of `6.9` is required.

Start of Combustion, Combustion Duration and Shape Parameter Maps: These values can be specified as map depending on engine speed and load (BMEP).

4.4.3.2. Double Vibe Function

For a good approximation of the double peak heat release characteristics of DI diesel engines (first peak due to premixed burning, second peak due to diffusion burning), **BOOST** allows two Vibe functions to be specified. These are superimposed during the calculation process. Besides the start of combustion, the fuel allotment must be specified. The fuel allotment is defined as the fraction of fuel burnt with the characteristics of Vibe 1.

For each Vibe function, the combustion duration and the shape parameter 'm' must also be specified.

4.4.3.3. Single Zone Table

For an optimum approximation of the actual heat release characteristics of an engine, **BOOST** allows reference points for the rate of heat release over crank angle to be specified. As the specified heat release characteristics will be normalized by the **BOOST** code (i.e. converted to percent of the total heat input per degree CRA), the dimension of the heat release values is of no importance.

4.4.3.4. Woschni/Anisits Model

The Woschni/Anisits Model predicts the Vibe parameter for engines with internal mixture preparation if the parameters for one operating point are known. This model should be used for transient simulations as the heat release characteristics will change with different operating conditions. In addition to the Vibe parameters, the following data must be specified to characterize the baseline operating point:

a) Engine speed
b) Dynamic injection nozzle opening
c) Ignition delay
d) A/F ratio
e) Cylinder conditions at intake valve closes

4.4.3.5. Hires et al. Model

For gasoline engines the Hires et al. Model may be used for transient simulations. Similar to the Woschni/Anisits model, the heat release characteristic is calculated from the Vibe parameters and some characteristic data of a baseline operating point.

The heat release characteristic of gasoline engines with essentially homogeneous mixture is mainly determined by the flame propagation speed and by the shape of the combustion chamber. A high flame propagation speed can be achieved with high compression ratio and high turbulence levels in the cylinder.

The **Piston to Head Clearance** which is the distance of the piston crown to the cylinder head with the piston at TDC-position completes the input for this model.

This model cannot predict knocking combustion.

4.4.3.6. User Defined Model

If the heat release characteristics are set to **User Defined Model,** the subroutine `UDCOMB_CALCULATE_TS()` is called for the calculation of the rate of heat release. The source code of this subroutine is available for the user and any model may be implemented provided it is translated into valid FORTRAN 90, compiled and linked to the rest of the code. For details please refer to the BOOST Interfaces Manual.

In the case of the selected **2 Zone Framework** option the Cylinder is performing a 2 Zone Combustion Model simulation (Burned/Unburned Zone). A precondition for this 2 Zone simulation is a proper related User Coding Template which can be requested from boost_support@avl.com.

The **User Model Parameters** input dialog allows the specification of data which can be accessed in the user written code (identification via the Parameter Key). In addition to single values (of type integer, double precision and character string) it is also possible to input an arbitrary number of two-column double- precision **User Model Tables** for the usage in the user written code (e.g.: RateOfInjection, ...).

4.4.3.7. User-Defined High Pressure Cycle

If the **User-Defined High Pressure Cycle** is selected, the complete high pressure cycle is replaced by the subroutine `UDHPC_CALCULATE_TS()`. For details please refer to the BOOST Interfaces Manual.

In the case of the selected **2 Zone Framework** option the Cylinder Environment is prepared to calculate a 2 Zone Combustion Model (Burned/Unburned Zone).

The **UD High Pressure Cycle Parameters** input dialog allows the specification of data which can be accessed in the user written code (identification via the Parameter Key). In addition to single values (of type integer, double precision and character string) it is also possible to input an arbitrary number of two-column double- precision **UD High Pressure Cycle Tables** for the usage in the user written code (e.g.: RateOfInjection, ...).

☞ **Note:** Only experienced users should add user-defined subroutines.

4.4.3.8. Constant Volume Combustion

If **Constant Volume Combustion** is selected, the entire combustion takes place at the crankangle specified by the user. In theory, constant volume combustion yields maximum efficiency at a certain compression ratio if no peak firing pressure limits have to be considered and the combustion timing is set to firing TDC.

4.4.3.9. Constant Pressure Combustion

If the combustion characteristics are set to Constant Pressure Combustion, **BOOST** determines the rate of heat release with the following strategy from the specified peak cylinder pressure:

- If the maximum cylinder pressure at the end of compression is lower than the specified peak cylinder pressure, the cylinder pressure is raised to the specified value by a constant volume combustion and the remaining fuel is burned in such a way that this pressure is kept constant. This combination of constant volume/constant pressure combustion is called the Seiliger process.
- If the maximum cylinder pressure at the end of compression exceeds the specified value, constant pressure combustion is initiated when the cylinder pressure drops below the specified value during the expansion stroke.

In theory constant pressure combustion yields maximum efficiency for a certain peak firing pressure if the compression ratio is selected to achieve the maximum sustainable peak firing pressure at the end of the compression stroke.

The Seiliger process yields maximum efficiency for a certain combination of peak firing pressure and compression ratio.

4.4.3.10. Motored

If the heat release characteristics are set to Motored, no combustion will take place irrespective of the amount of fuel aspirated or injected.

4.4.3.11. Vibe 2 Zone Combustion Model

For the Vibe 2 zone combustion model, the same input as for the single Vibe function is required. However, instead of one mass averaged temperature, two temperatures (burned and unburned zone) are calculated. This model also predicts the knocking characteristics of the engine, provided the actual rate of heat release is described properly by the Vibe function specified.

4.4.3.12. Empirically Based Combustion Models: EBCM and PBCM

☞ **Note:** From BOOST v5.0 on the EBCM and PBCM combustion models are replaced by the “Fractal Combustion Model”.

4.4.3.13. AVL MCC Model

The AVL MCC model predicts the rate of heat release and NOx production in DI-Diesel engines based on the amount of fuel in the cylinder and on the turbulent kinetic energy introduced by the fuel injection. The model requires the number of injector holes, the hole diameter, the discharge coefficient of the injector holes and the rail pressure to calculate with the effective hole area, the velocity and thus the kinetic energy of the fuel jet.

The table containing the rate of injection determines injection rate. The input is normalized and used with the fuel specified in the general cylinder box to determine the fuel injected each time step.

The ignition delay is calculated using the modified ignition delay model developed by Andree and Pachernegg. To fit the delay to measured data it can be influenced by the ignition delay calibration factor.

The model parameters are normalised, therefore with a value of 1 good results should be obtained. The following parameters control the rate of heat release and the NOx production.

1. The ignition delay calibration factor influences the ignition delay, higher values result in longer ignition delays.
2. The combustion parameter has the greatest influence on the **ROHR** shape. A higher value results in a faster combustion.
3. The turbulence parameter controls the influence of the kinetic energy density while the dissipation parameter influences the dissipation of the kinetic energy.
4. Dissipation parameter controls the turbulence dissipation.
5. The NOx production parameter has influence on the NOx result.
6. The EGR influence parameter controls the influence of EGR on combustion.
7. The premixed combustion parameter determines the fraction of fuel injected during ignition delay burned during premixed combustion, a value of 0.7 should be used as default.

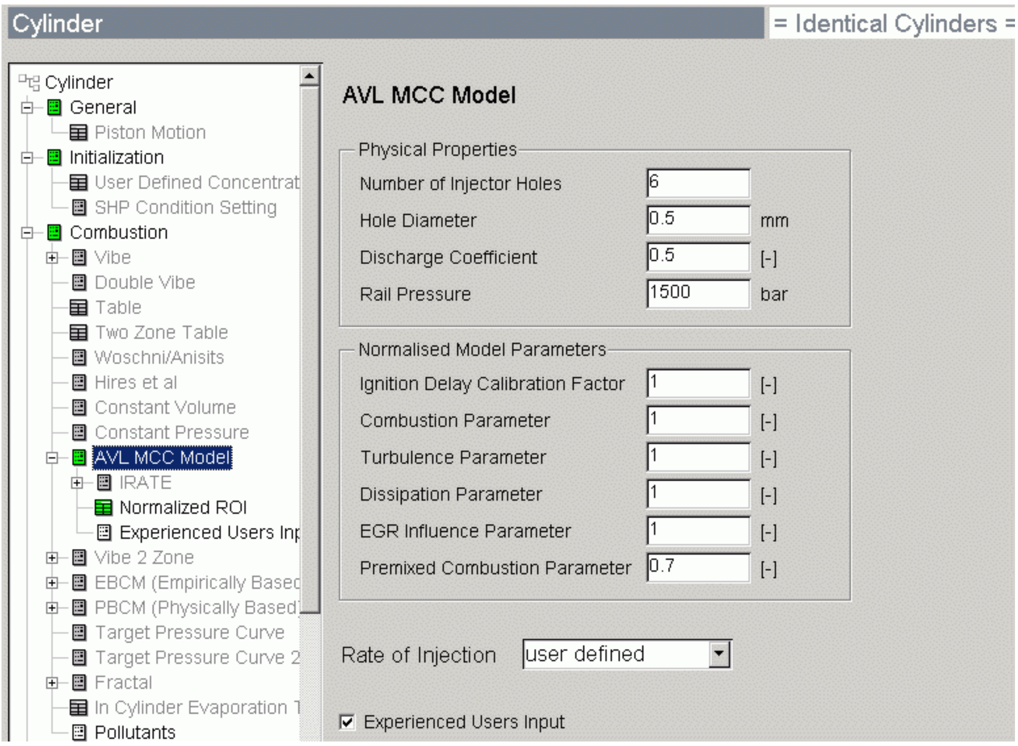


Figure 4-11: AVL MCC Combustion Model Window

8. Activate **Experienced Users Input** to access the following options.

PreMixed Combustion Duration Factor	Parameter to tune the duration of the pre-mixed combustion phase.
TKE Calculation	Specifies the type of TKE model used: **Standard**: makes former formulation of the TKE model available for compatibility reasons. **Revised**: default and recommended option.
Combustion Excess Air Ratio Development	Parameter to tune the excess air ratio development of the burned zone.
Evaporation Velocity Parameter	Parameter to tune the evaporation velocity.

AVL MCC Model / IRATE Calculation

The AVL MCC combustion model is extended to predict the Rate of Injection based on the nozzle flow calculation. This mode is activated in Figure 4-11 by selecting **calculated** from the **Rate of Injection** pull-down menu.

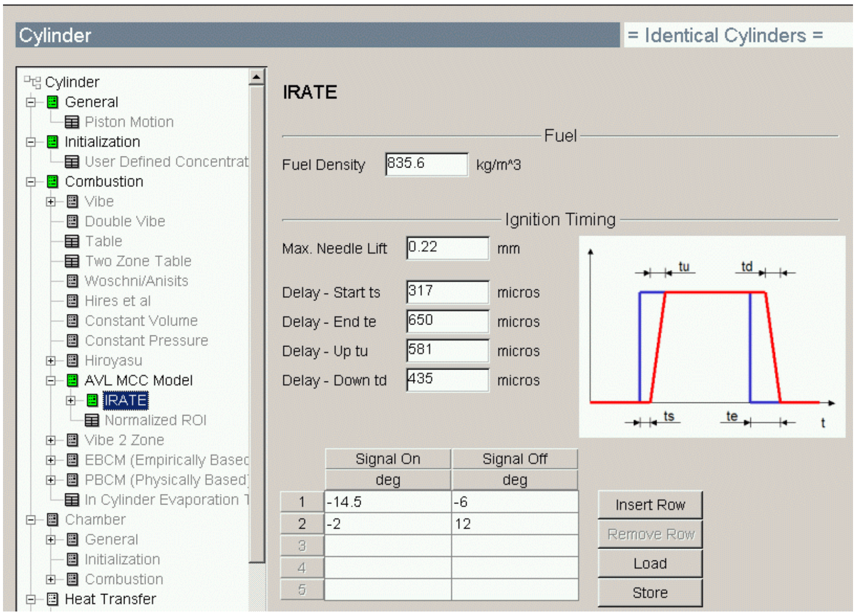


Figure 4-12: AVL MCC IRATE Tool

In addition to the density of the injected fuel data for the injection timing is required. It is controlled by pairs of Signal On/Off crank angles (usually two: pre and main injection) which are adapted according to the delay times of the signals.

The flow characteristics of the nozzle are specified by measured data for the volume flow as a function of needle lift which is usually based on a Steady State Flow Test Rig (constant test bed injection pressure and specific oil fluid).

An initial cylinder pressure trace input is required to calculate the Rate of Injection (displayed in **Calculated ROI**). During calculation the cyclic updated cylinder pressure is used to evaluate the ROI curve.

To check the input data, an Excel sheet evaluating an estimation for the injection fuel mass can be requested from boost_support@avl.com.

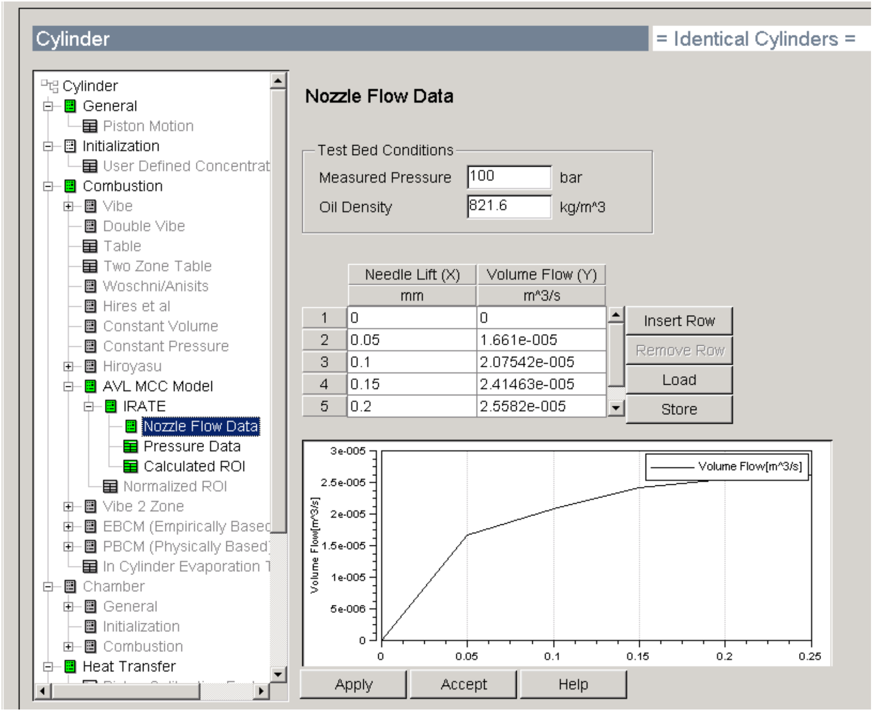


Figure 4-13: IRATE - Nozzle Flow Data Window

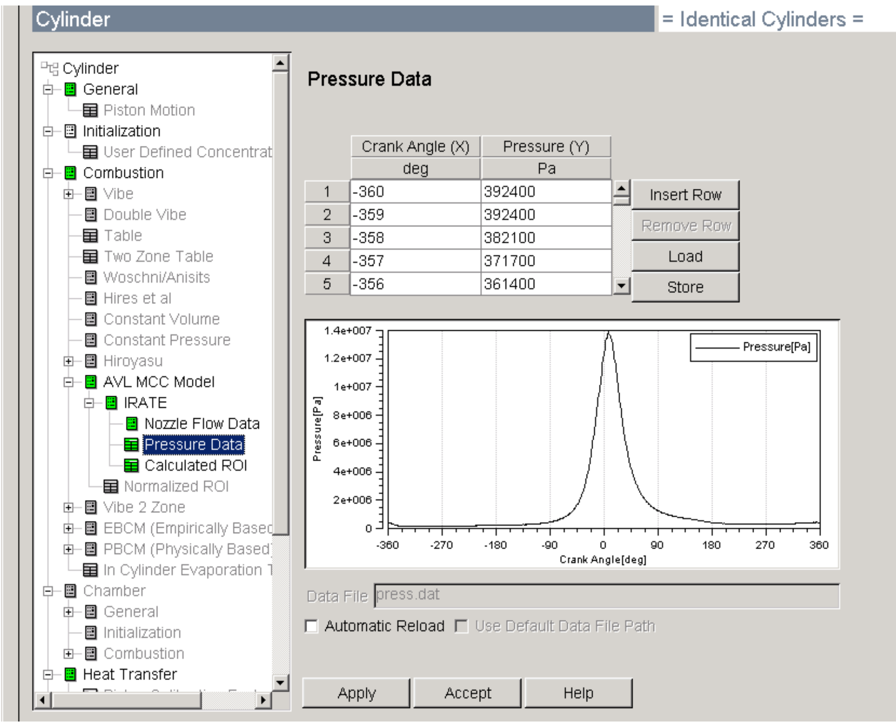


Figure 4-14: IRATE - Pressure Data Window

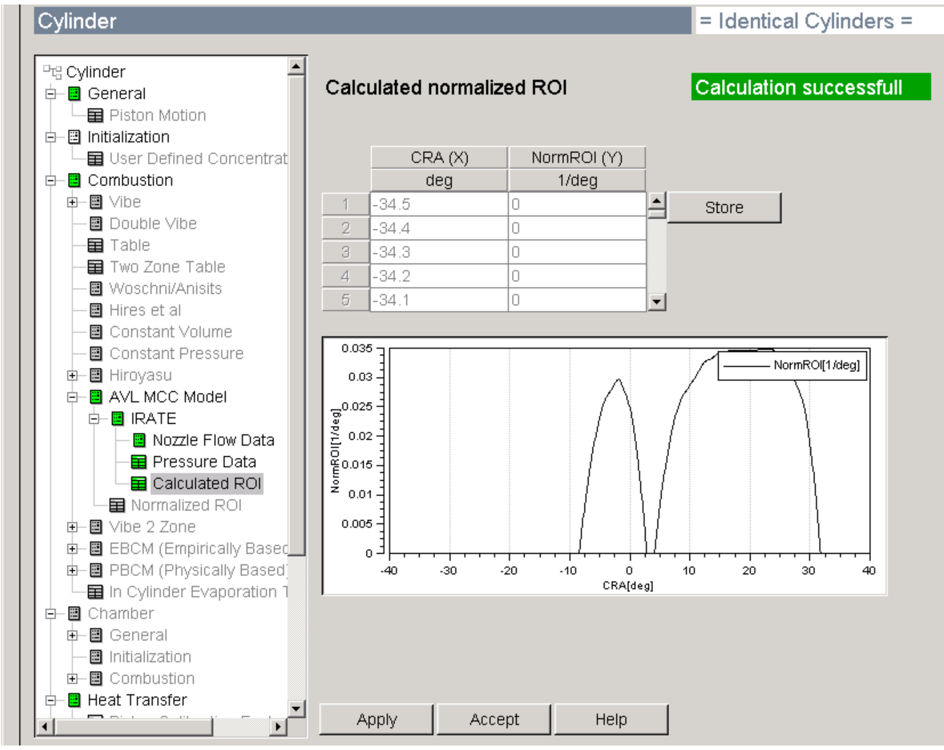


Figure 4-15: IRATE - Calculated ROI Window

4.4.3.14. Target Pressure Curve

In addition to the cylinder pressure trace this combustion model requires the following input:

Ignition Time / Start of Injection	Specifies the time when the algorithm starts to burn/inject fuel.
Adapted Value at SHP	Specifies the value that is adapted at SHP: • Pressure Curve (Shift) • Cylinder Mass • Cylinder Temperature

4.4.3.15. Target Pressure Curve 2 Zone

In addition to the cylinder pressure trace this combustion model requires the following input:

Ignition Time / Start of Injection	Specifies the time when the algorithm starts to burn/inject fuel.
Adapted Value at SHP	Specifies the value that is adapted at SHP: • Pressure Curve (Shift) • Cylinder Mass • Cylinder Temperature

4.4.3.16. Fractal Combustion Model

Refer to Combustion Models, section 2.2.2 of the Theory Manual for a detailed description and the corresponding parameters:

Ignition Timing	Specifies the start of the combustion simulation (spark deployment).
Ignition Formation Multiplier	Parameter to tune the ignition delay: c_{ign}
Ignition radius ratio	Parameter to tune the ignition delay: $r_{f,ref}$
Turbulence Production Constant	Parameter to tune the turbulence model: c_t
Turbulent Length Scale Parameter	Parameter to tune the turbulence model: c_l
Turbulence Length Scale Density Exponent	Parameter to tune the turbulence model: m allows the adaptation of Length Scale $\mathrm{L}_{\max}$ dependent on Unburned Zone Density: $\left(\frac{dm_b}{dt}\right)_{fractals} = \rho_u \left(\frac{L_I}{l_k}\left(\frac{\rho_{SOC}}{\rho_{UZ}}\right)^m\right)^{D_3-2} A_L\, S_L$ ρ_{SOZ} Density of Unburned Zone at Start of Combustion (entire cylinder content) ρ_{UZ} Density of Unburned Zone
Mass Fraction Burned at Wall Combustion Start	Determines when the model starts with the wall combustion phase: $\left(\frac{m_b}{m}\right)_{tr}$ transition time t_{tr} is determined when the specified Mass Fraction Burned $\left(\frac{m_b}{m}\right)_{tr}$ is achieved (instead of flame arrival at cylinder wall).
LFS Exponent	Determines when the model starts with the wall combustion phase: d allows the adaptation of Laminar Flames Speed S_L dependent on Residual Gas Mass Fraction mf_{RG} according to the following formula: $S_L = c_{lfs}\, S_{L,RG=0}\left(1 - mf_{RG}\right)^d$.

Guide to Tuning Fractal Combustion Parameters

The fractal combustion model assumes that combustion undergoes the following stages:

Stage 1: Ignition;

Stage 2: Turbulent flame development;

Stage 3: Turbulent flame propagation;

Stage 4: Wall combustion/Termination (determined by wall combustion).

These 4 stages are governed by 7 parameters characterizing, respectively,

Ignition delay (1 parameter);

Beginning and end of turbulent flame combustion (2 parameters);

Turbulence production and dissipation (2 parameters);

Turbulent-combustion interaction (1 parameter);

Influence of residual gas content on combustion (1 parameter).

The process of tuning the combustion parameters is as follows:

Step 1: Building the Boost model and setting initial values for all 7 combustion parameters.

After building the Boost model, set the following default valves for the 7 combustion parameters:

Ignition delay parameter:	$c_{ign} = 1.0$
Reference flame radius:	$R_{f,ref} = 0.01$
Mass fraction for wall combustion:	$w_2 = 0.2$
Residual gas content influence parameter:	$d = 2$
Turbulence-combustion interaction parameter:	$m = - 0.33$
Turbulence production constant:	$c_t = 0.5$
Turbulent length scale parameter:	$c_L = 0.5.$

In general, $R_{f,ref}$, w_2 and d should take their default values and no tunings are needed. Run the Boost model. Plot the calculated as well as the measured cylinder pressures and rates of heat release (ROHR).

Step 2: Tuning the ignition delay parameter c_{ign}

Compare the calculated and measured ROHR to see if the combustion starts at the same timing. If not, tune the ignition delay parameter c_{ign} by increasing it (>1) or decreasing it (<1). Figure 4-16 shows the comparison of the start of combustion (SOC). In the case (a), the predicted SOC is too early; thus, c_{ign} must be increased to increase the delay period. In the case (b), the predicted SOC is too late; therefore, c_{ign} must be decreased to reduce the delay period. After tuning, rerun the model. Repeat this process until a close start of combustion is reached.

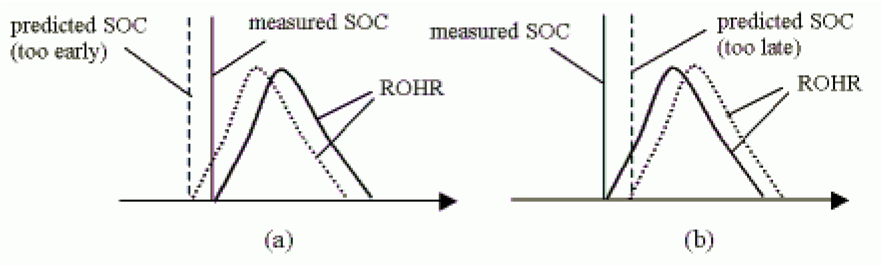


Figure 4-16: Comparison of Measured and Predicted SOC

Step 3: Tuning turbulent production constant c_t and turbulent length scale parameter c_L

Compare the calculated and measured cylinder pressures and ROHR; if they do not match then c_t and c_L need to be tuned.

The turbulent production constant c_t governs how rapidly the turbulent intensity u' grows during the intake stroke. A large value for c_t leads to that the peak for u' occurs in the early stage of the intake valve opening; a small value for c_t results in an occurrence of the peak for u' in the middle or late stage of the intake valve opening; and, if c_t is too low, the peak of u' may occur in the compression stroke due to contribution of the density term in the turbulent kinetic energy equation.

The turbulent length scale parameter c_L controls the decay rate of the turbulent intensity u': a large value for c_L leads to a slow decay during compression and thus a higher u' before combustion; a small value for c_L results in a rapid decay which tends to lower the value of u' before combustion.

Influence of c_t and c_L on u' is shown in Figure 4-17. In the case (a), a high c_t results in an early occurrence in the peak of u'; and the decay in u' depends on the value of c_L. In the case (b), a too low c_t gives a slow increase in u' and the peak of u' occurs in the early stage of the compression stroke; and, the high c_L leads to a slow decay in u', which may result in an overestimation of u' during combustion. For the case (b), although lowering c_L may make u' fall into the right range during combustion, this case is not physically correct.

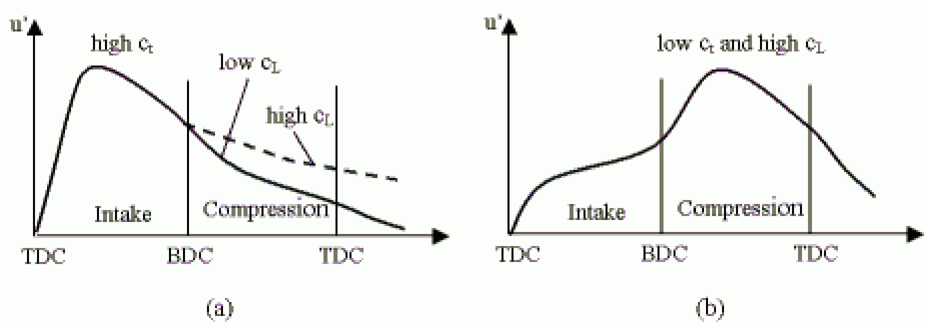


Figure 4-17: Influence of c_t and c_L on Turbulent Intensity

According to the CFD simulations conducted by AVL, the peak of u' occurs in the early stage of the intake valve opening for part load and it appears around the crank angle where the piston reaches its maximum speed for full load. Generally, during combustion, the value for u' is about 1 ~ 2 times of the mean piston speed. The locations for peak values of u' from CFD simulations and the values for u' during combustion should be used as a guide in tuning c_t and c_L. The recommended values for c_t and c_L are: for part load c_t = 0.6 ~ 0.7 and for full load c_t = 0.4 ~ 0.6; and for both full and part load, the input value of c_L should be adapted to give a simulation result value for u' at compression TDC being 1 ~ 2 times of the mean piston speed..

Step 4: Tuning turbulence-combustion interaction parameter m

The turbulence-combustion interaction parameter m is a fine tuning parameter to better match the cylinder pressures and ROHR. Because it works as a factor that corrects the turbulent length scale parameter c_L, depending on the value for c_L, the final value for m may be several times of its default value in either positive or negative direction.

Specification of Chamber Geometry

For simple geometries, the table can be generated by **BOOST**. Select the **Chamber** geometry calculation subgroup to input the main dimensions of the combustion chamber.

For the cylinder head, the following shapes can be considered (required input as shown in the sketches):

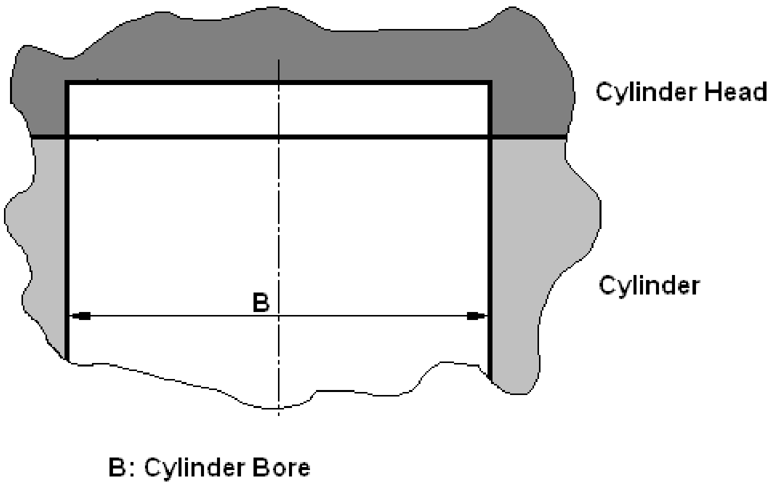


Figure 4-18: Flat Cylinder Head

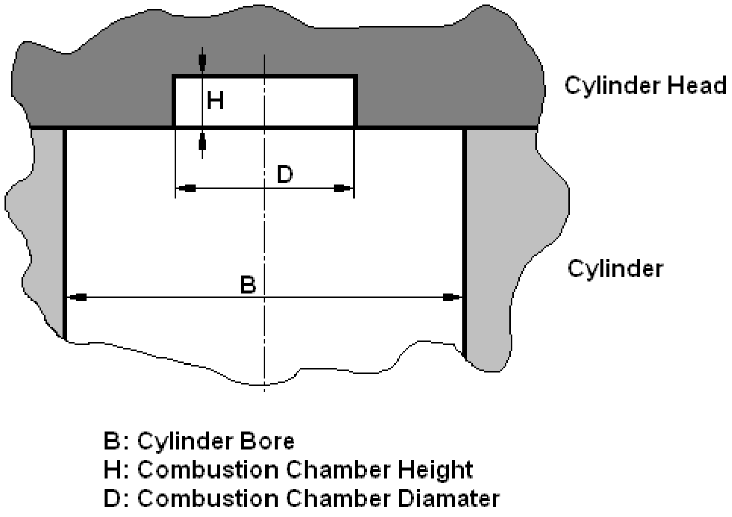


Figure 4-19: Disc Chamber Cylinder Head

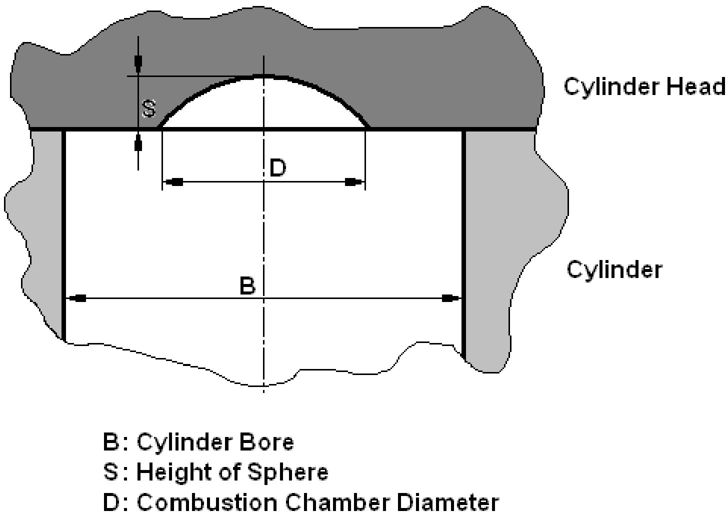


Figure 4-20: Spherical Cylinder Head

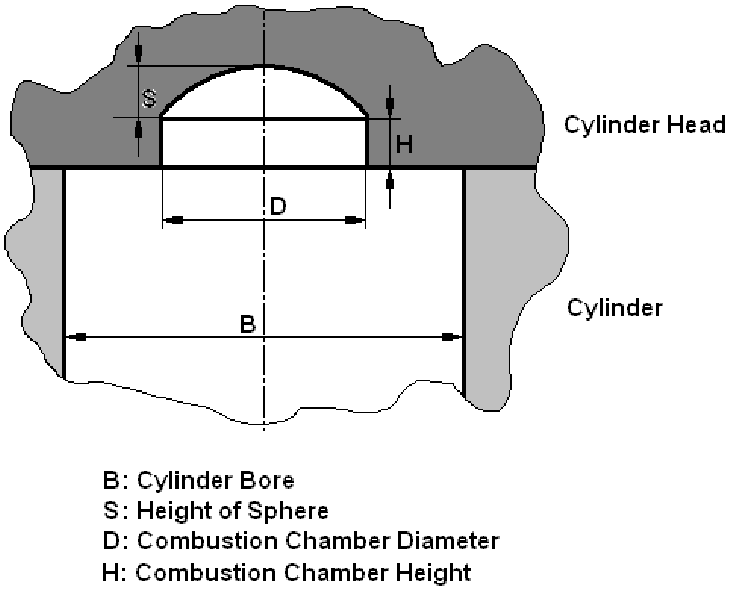


Figure 4-21: Backset Special Cylinder Head

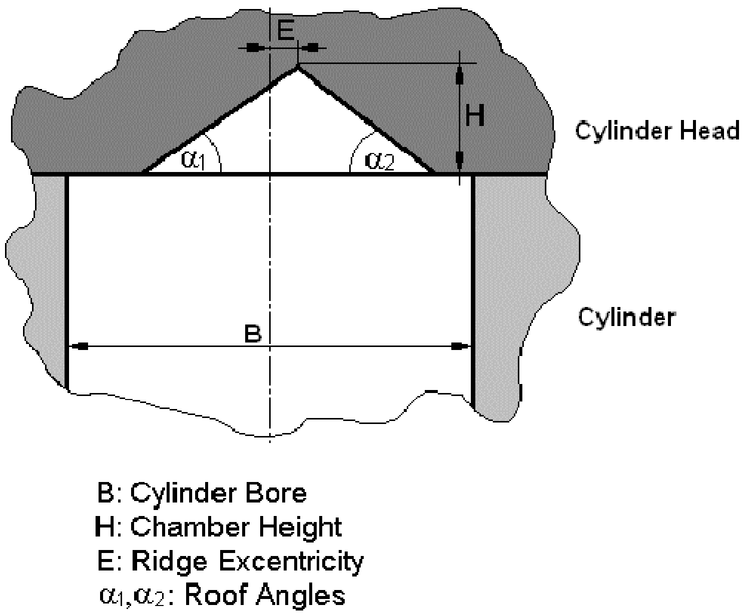


Figure 4-22: Pent Roof Cylinder Head

In addition, the user must select the shape of the piston top from the following list (required input as shown in the sketches):

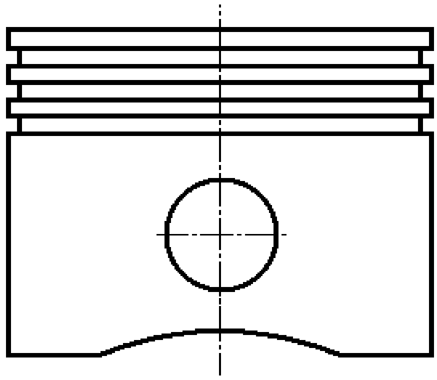
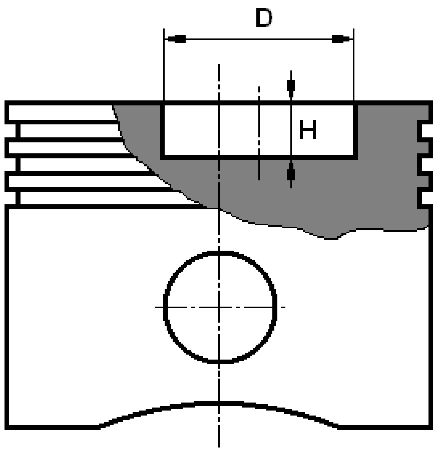
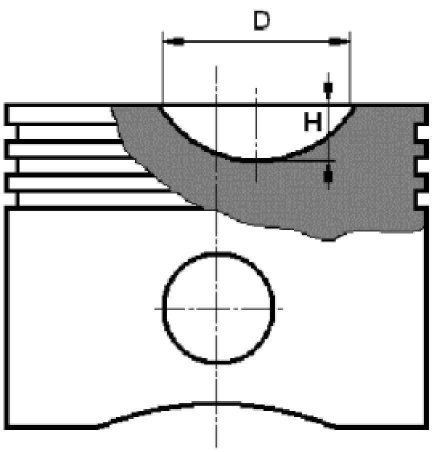


Figure 4-23: Flat Piston Top



D: Bowl Diameter
H: Bowl Depth

Figure 4-24: Heron Piston Top



D: Bowl Diameter
H: Bowl Depth

Figure 4-25: Spherical Bowl Piston Top

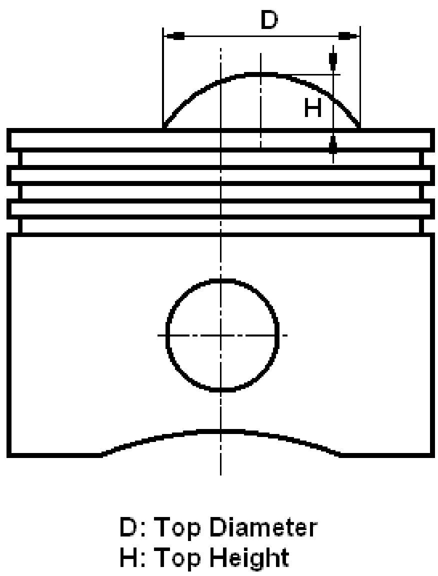


Figure 4-26: Spherical Piston Top

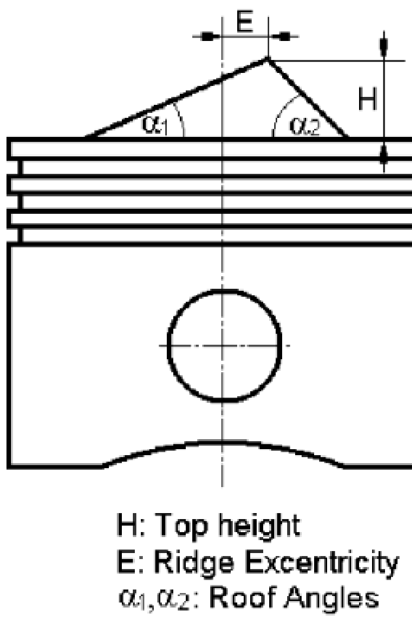


Figure 4-27: Pent Roof Piston Top

If there is an offset between spark plug location and the cylinder axis as well as an offset between the center of the piston bowl or top, the angle between spark plug and bowl or top center must be input according to the definition shown in the following sketch.

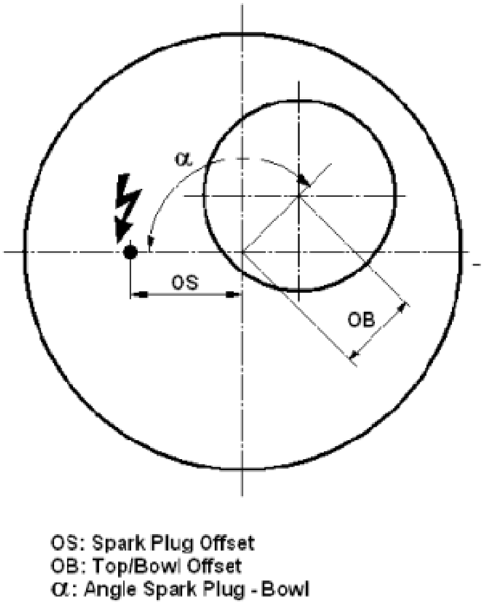


Figure 4-28: Definition of Angle between Spark Plug and Bowl/Top Center

For a pent roof head or a pent roof piston, the spark plug position must be defined by two rectangular coordinates as shown in Figure 4-28.

Alternatively, the table can be generated externally and the name of the file can be specified by the user. The file must be a sequential formatted ASCII file and may contain comment lines marked with a "#" in the first column.

☞ **Note:** The geometry file format has changed from version 3.2.

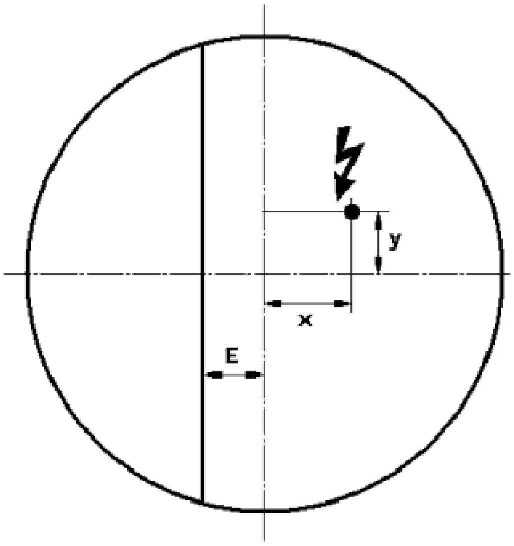


Figure 4-29: Definition of Spark Plug Position

The file format can be seen in the following example.

```
TYPE 2
#
# Bore =   84.0mm, Stroke =   90.0mm, Compression Ratio =   9.0
# Headtype: flat
# Spark Plug Position: x =    0.0mm, y =    0.0mm, z =    0.0mm
# (Position x=0, y=0, z=0 means center of bore at head bottom)
# Pistontype: flat
# Number of flame radii
NUMFLARAD        101
# Number of piston positions
NUMPISPOS        101
# total head area [mm2]
TOTHEADAREA    5541.77
# minimal liner area [mm2]
MINLINAREA    2968.81
# total piston area [mm2]
TOTPISAREA    5541.77
# volume in head [mm3]
HEADVOL       0.00
# volume in piston [mm3]
PISVOL       0.00
# minimum piston position [-]
PISPMIN       0.00
# maximum piston position [-]
PISPMAX      90.00
# increment of piston position [-]
PISPINC       0.03
```

```
# minimum flame radius [mm]
FRADMIN       0.00
# maximum flame radius [mm]
FRADMAX      99.32
# increment of flame radius [mm]
FRADINC       0.99
# minimum burned zone volume[mm3]
BVMIN       0.00
# maximum burned zone volume[mm3]
BVMAX  525001.01
# flame front radii:
FLAMERADII
   0.000000E+00   0.993177   ...
# contact area burned zone - cylinder head versus flame front radius [mm2]
HEADAREA
   0.000000E+00    3.09887   ...
# depending on piston position:
# contact area burned zone - liner versus flame front radius [mm2]
# contact area burned zone - piston versus flame front radius [mm2]
# contact area burned zone - unburned zone versus flame front radius [mm2]
# burned zone volume versus flame front radius [mm3]
# data for piston position:
PISPOS   0.000000
LINERAREA
   0.000000E+00   0.000000E+00  ...
PISTONAREA
   0.000000E+00   0.000000E+00  ...
FREEFLAMES
   0.000000E+00    6.19773      ...
BURNEDVOL
   0.000000E+00    2.05182      ...
# data for piston position:
PISPOS   0.027930
LINERAREA
   0.000000E+00   0.000000E+00  ...
PISTONAREA
   0.000000E+00   0.000000E+00  ...
FREEFLAMES
   0.000000E+00    6.19773      ...
BURNEDVOL
   0.000000E+00    2.05182      ...
             .
```

Stratification of Charge

The two options for the input of Stratification of Fuel and Residual Gas allows to specify the local Fuel and Residual Gas Concentration the Flame is propagating through during Combustion (usually a result available from 3D-CFD simulations).

The definition of the required Table Input for **Normalized Air-Equivalence-Ratio** and **Normalized Residual-Gas-Ratio** can be found in the related part of section 2.2.2 of the Theory Manual.

4.4.3.17. HCCI 6-Zone Combustion Model

Refer to Combustion Models, section 2.2.2 of the Theory Manual for a detailed description and the corresponding parameters:

Boundary Layer Thickness	Defines the thickness of all boundary layer zones (piston, liner, head). Recommended values are 0.5 – 2 mm.
Zone Heat Transfer Time Constant	Zone heat transfer time constant defines the heat flow rate between the zones. Its usage is shown in equation (6ZHCCI_4). Lower values give higher rates of heat flow which lowers a temperature difference between zones. Recommended values are 0.5 – 2 ms.
Crevice Zone Volume	Defines the volume which will be represented as a constant temperature crevice zone.
Solver Absolute Tolerance for Temperature	Absolute tolerance gives the actual amount of the error for each component of the solution vector. Since the values of temperature are significantly different to the values of the other components (which can be set optionally in the Cylinder/Combustion Dialog), the absolute tolerance has to be set separately for the temperature.
Mass Exchange Multiplication Factor	In mass exchange calculation a factor for multiplication of mass transfer is calculated. This factor speeds up the convergence of the solution. But if this factor is too large it can produce a oscillating problem which can lead to calculation error. Therefore a maximum value of this factor must be set. Larger values of this factor will give faster convergences, but in some cases will produce oscillations, while a lower value reduce the possibility of obtaining oscillations but with a cost of a greater number of iterations before convergence of the solution is obtained. Recommended values are 100 – 400 (300).
Number of Single Zone HCCI Pre-Cycles	Since for the convergence of results there is a need for calculation of several cycles, in order to make the calculation faster it is possible to use combined single zone – six zone calculation. If this option is used then a single zone HCCI calculation of in cylinder changes during high pressure cycle is used for a several cycles whose number is defined by the user, and after that a six zone calculation starts for the residual number of cycles. If this option is used than a number of single zone cycles must be defined. If the total number of calculation cycles is less than or equal to number of single zone cycles than only single zone calculation will be performed.

4.4.3.18. Open Chamber Gas Engine Combustion Model

Refer to Combustion Models, section 2.2.2 of the Theory Manual for a detailed description and the corresponding parameters:

Ignition Timing	Specifies the start of the combustion simulation (spark deployment).
Combustion Chamber Geometry	
Piston Bowl Diameter	Diameter of the piston bowl d_b

Piston Bowl Depth	Depth of the piston bowl h_b
TDC Piston to Head Distance	Distance from piston top to head at top dead center position of the piston $h_{cl,\min}$
Valve Seat Angle	Valve seat angle α_v
Turbulence	
Squish Constant	Squish constant C_{squish} Usual value range: 0.2 – 2
Swirl Constant	Swirl constant C_{swirl} Usual value range: 0.01 – 0.05
Swirl Friction Constant	Swirl friction constant C_{sf} Usual value range: 0.01 – 0.05
Dissipation Constant	Dissipation constant C_D Usual value range: 2.E-5 – 1.E-4
Compression Constant	Compression constant C_C Usual value range: 0.01 – 0.1
Turbulence Level Constant	Turbulence level constant C_{TL} Usual value range: 0.05 – 0.4
Ignition Delay	
Arrhenius Constant	Arrhenius constant A_{Arr} Usual value range: 2.E5 – 5.E5
Magnussen Constant	Magnussen constant A_{Mag} Usual value range: 0.02 – 0.05
Ignition Delay Constant	Ignition delay constant A_{Id} Usual value range: 0.5 – 2
Combustion	
ROHR Constant	Rate of heat release constant C_{ROHR} Usual value range: 10 – 30
Flame Thickness	Flame thickness s_F Usual value range: 0.5 – 2 mm
Mass Fraction Burned at Transition	Mass fraction burned at transition μ_T Usual value range: 0.3 – 0.7
Wall Transition Parameter	Wall transition parameter P_T Usual value range: 0.2 – 2

4.4.3.19. In Cylinder Evaporation

The **Rate of Evaporation** defines the addition of fuel vapor to the cylinder charge. The specified curve is normalized, so that the area beneath the curve is equal to one. The actual amount of fuel added is either defined directly or by the target A/F-Ratio.

4.4.3.20. Pollutants

NOx and CO:

For all two zone combustion models (internal and external mixture preparation) the NOx and CO production models are activated. The following parameters can be set:

NOx Kinetic Multiplier	Parameter to tune the NOx production model.
NOx Postprocessing Multiplier	Parameter to tune the result of NOx production model.
CO Kinetic Multiplier	Parameter to tune the CO production model.

For the NOx model the stratification of the burned zone can be considered. It is recommended to use 5-10 zones.

Soot:

The soot production model is available for all two zone combustion models in combination with internal mixture preparation (Diesel). The following parameters can be set:

Soot Production Constant	Parameter to tune the soot production.
Soot Consumption Constant	Parameter to tune the soot consumption.

Hydrocarbon emissions (HCs):

The HC production model is available for all two zone combustion models in combination with external mixture preparation (Gasoline). The following parameters can be set:

Crevice height	Height of the top land crevice; typically 5 mm
Crevice gap	Gap of the top land crevice; typically 0.1-0.2 mm
Oilfilm thickness	typically 5 microns
HC postoxidation multiplier	Parameter to tune the post-oxidation of the HCs in the burned gases; default = 1.0

HC postoxidation E	Activation temperature of the post-oxidation of the HCs in the burned gases; default = 18790K
HC postoxidation f	Scaling factor of the post-oxidation of the HCs in the burned gases; default = 0.3 mean that only in 30% of the burned zone the post-oxidation reactions can take place.
HC partial burn P	Scaling factor for the partial burn emissions model.

Knock

For gasoline engines (External Mixture Preparation) the knock model calculates the minimum octane number required for engine operation free of knock based on the Model constants input.

4.4.4. Chamber

If an engine with divided combustion chamber is to be simulated, the user may specify the pre-chamber data after selecting **Chamber Attachment** in the **General** folder of the Cylinder element. The basic input of the pre chamber is its volume and the initial conditions (pressure, temperature and gas composition) at exhaust value opens. The geometry of the connecting pipe is described by its length and diameter. In addition the turbulent wall friction coefficient, the wall temperature and a heat transfer amplification factor must be input.

In order to consider particular pressure losses resulting from multi dimensional flow phenomena at the connecting pipe orifice, **BOOST** requires the specification of flow coefficients for in-flow and out-flow at the connecting pipe. The flow coefficients are defined as the ratio between the actual mass flow and the loss-free isentropic mass flow for the same stagnation pressure and the same pressure ratio.

The flow coefficients may be specified either as constant values or in a **Table** as functions of time in seconds, time in degrees crank angle or pressure difference between cylinder and chamber.

For in-flow (flow into the chamber) the pressure difference is defined as the static pressure in the connecting pipe minus the pressure in the chamber. For out-flow it is defined as the pressure in the chamber minus the static pressure in the connecting pipe.

The flow coefficients for flow from the chamber into a pipe depend mainly on the protrusion of the pipe end through the wall in which it is installed and on its bellmouth characteristics. Refer to **Flow Coefficients** for details on standard values and directions.

To specify the heat release characteristics in the chamber, the user may use a Vibe-function, a double Vibe function or a single zone table.

If the wall heat transfer in the chamber is turned on, the box for the input of the required data is accessed. The data comprise the chamber geometry (spherical or user-defined), the friction coefficient for the calculation of the friction torque, the connecting pipe eccentricity, the chamber wall temperature and a calibration factor. For a user defined chamber geometry the surface area, the characteristic radius for the calculation of the heat transfer coefficient by the Nusselt equation, and the inertia radius of the chamber are to be defined by the user.

If a variable wall temperature is to be considered, the wall thickness of the pre chamber, the conductivity of the material and its heat capacity as well as the coolant temperature and the outer heat transfer coefficient must be input.

4.4.5. Heat Transfer

The following heat transfer models are available for the cylinder:

- Woschni 1978 and 1990
- Hohenberg
- Lorenz 1978 and 1990 (Cylinders with attached chamber only)
- AVL 2000

Alternatively, **None** can be selected.

In addition to the heat transfer coefficient provided by the heat transfer model, the surface areas and wall temperatures of the piston, cylinder head and liner must be specified.

The wall temperatures are defined as the mean temperature over the surface.

A calibration factor for each surface may be used to increase or to reduce the heat transfer.

For the surface areas the following guidelines may be used:

Piston:

DI diesel engines with a bowl:	Surface area is approximately 1.3 to 1.5 times the bore area.
SI engines:	Surface area is approximately equal to the bore area.

Cylinder Head:

DI diesel engines:	Surface area is approximately equal to the bore area.
SI engines:	Surface area is approximately 1.1 times the bore area.

Liner with Piston at TDC:

The area may be calculated from an estimated piston to head clearance times the circumference of the cylinder.

Wall temperature must be specified at the piston TDC and BDC positions. Between those positions a special temperature profile is assumed (refer to Section 2.1.1 of the Theory manual).

Refined Liner Layer Discretization:

If detailed information about the liner wall temperature distribution along the liner is available, the option “Layer Discretization” allows the User to input the wall temperature dependent on the distance from cylinder head.

This discretization can also be used in combination with an external link element (Liner Layer Wall Temperature Actuator, Liner Layer Wall Heat Flow Sensor).

For both Woschni formulae, the user must specify whether the engine features a divided combustion chamber.

Select **IDI** for IDI diesel engines (swirl chamber or pre-chamber combustion system).
Select **DI** for DI diesel engines and gasoline engines.

In order to consider the influence of the in-cylinder charge motion on the heat transfer coefficient, the in-cylinder swirl ratio (defined as the speed of the charge rotation relative to engine speed) must be specified.

Select **Variable Wall Temperature** to calculate the energy balance of the combustion chamber walls. For each wall (head, piston and liner) an effective wall thickness together with material data must be specified. Conductivity and heat capacity are required and the following list provides some typical materials:

Table 4-5: Heat Capacity and Conductivity – Standard Values

Material	Heat Capacity [kJ/m³K]	Conductivity [W/mK]	Specific Heat [kJ/kgK]	Density [kJ/m³]
Cast Iron	3900	53	0.545	7200
Steel	3600	48	0.460	7840
Aluminum	2460	221	0.910	2700
PVC (Plastics)	1360	0.17	0.980	1390
Ceramics	2940	5.5	0.840	3500

The mean effective **Thickness** of the **piston**, the **liner** and the fire deck of the **cylinder head** together with the **Heat Capacity** determine the thermal inertia of the combustion chamber walls. The **Conductivity** is required to calculate the temperature difference between the surface facing the combustion chamber and the surface facing the coolant.

The **Heat Capacity** is the product of the density and the specific heat of the material.

For the heat transfer to the coolant (head and liner) and engine oil (piston), an average heat transfer coefficient and the temperature of the medium must be specified.
For the heat transfer in the ports, a modified Zapf-model is used (refer to Section 2.1.2 of the Theory manual).

The **Lorenz Heat Transfer Model** for cylinders with divided combustion chamber similar to Woschni's equation. However the velocity term is modified to consider the velocities introduced by flow into or out of the chamber.

4.4.6. Valve / Port Data

For each pipe attached to a cylinder, the user must specify whether this port is controlled by a valve or by the piston (piston control is only feasible for 2-stroke engines). If the cylinder features a combustion chamber, the pipe may be also declared to be attached to the chamber. In this case, the port may be either controlled by a valve or with the standard definition of flow coefficients.

Click on the input field with the left mouse button to open the submenu shown in the following window.

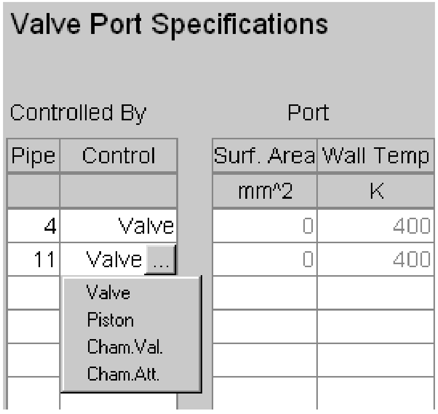


Figure 4-30: Valve Port Specifications Window

If the heat transfer in the intake and exhaust ports must be considered, the specification of the port surface area and the mean port wall temperature is required (valve controlled port only).

For the calculation of the energy balance of the port wall, similar data as for the combustion chamber walls (i.e. the average thickness, the heat capacity and the conductivity of the material) is required.

For the calculation of the summed up intake and exhaust mass flow characteristics, the user must specify whether the considered port is an intake or exhaust port. A pipe attached to the combustion chamber is considered as an intake.

For valve controlled ports the inner valve seat diameter is required for the calculation of the port wall heat transfer coefficient, as well as for the conversion of normalized valve lift to effective valve lift.

The valve lift is defined by the valve lift curve and by the valve clearance.

By specifying the crank angle of the first valve lift value and the cam length, the crank angle range in the table is defined. The number of reference points for the valve lift curve can be specified directly or by inputting a constant crank angle interval between two valve lift points.

After completing the input of reference points, the input is presented in the graphics window for immediate control purposes.

If a valve lift curve is already specified in the table, a new specification of the timing of the first valve lift shifts the entire valve lift curve.

If the cam length is changed, a shorter or longer valve lift curve will be calculated from the baseline valve lift curve under the assumption of similar valve velocities.

The actual valve lift at a certain crank angle is calculated from the valve lift, specified in the valve lift curve, minus the valve clearance, as shown in the figure below:

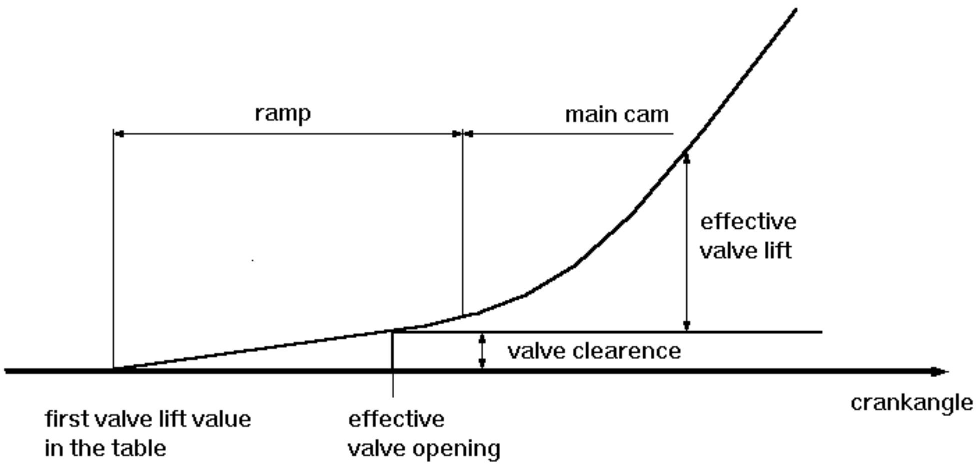


Figure 4-31: Calculation of Effective Valve Lift

For **Valve Controlled** valves a modification of the baseline valve lift curve can be specified in the **Modification of Valve Lift Timing**. This is possible for each individual valve connected to a cylinder so that different modifications can be applied to different intake (or exhaust) valves of a multiple valve model.

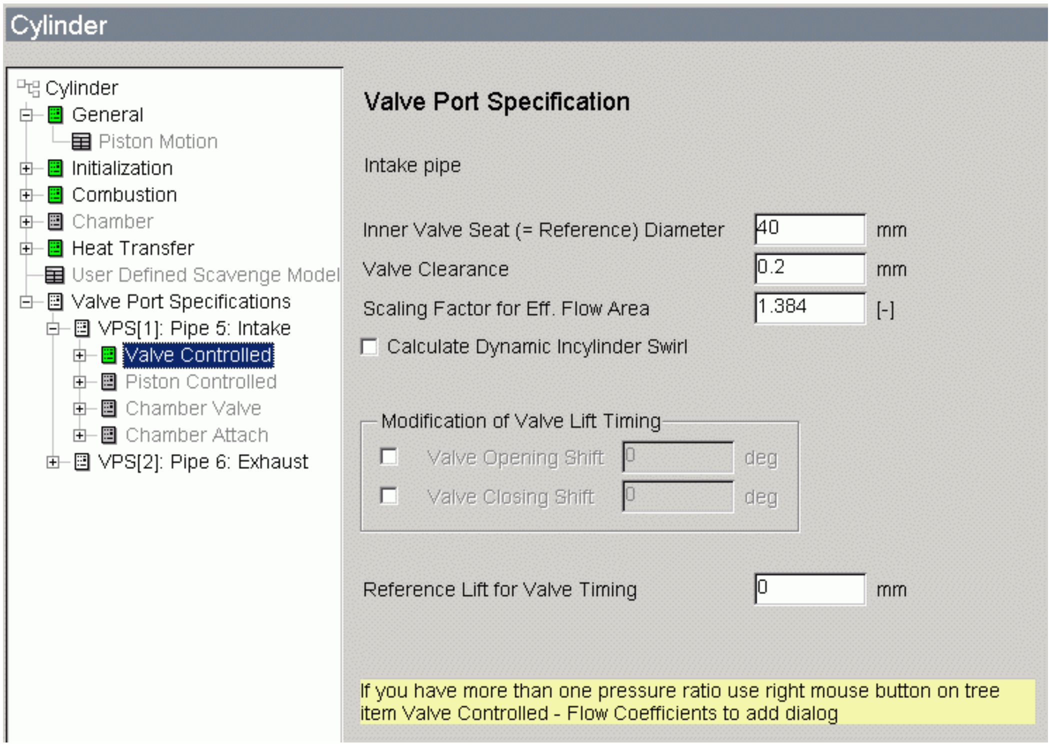


Figure 4-32: Modification of Valve Lift Timing

The possible modifications using these options are shown in the following figures (dashed lines are the baseline valve lift curves before modification).

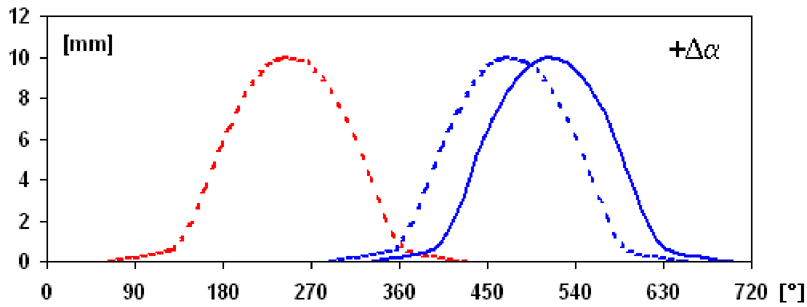


Figure 4-33: Positive intake valve opening and closing shift (same value)

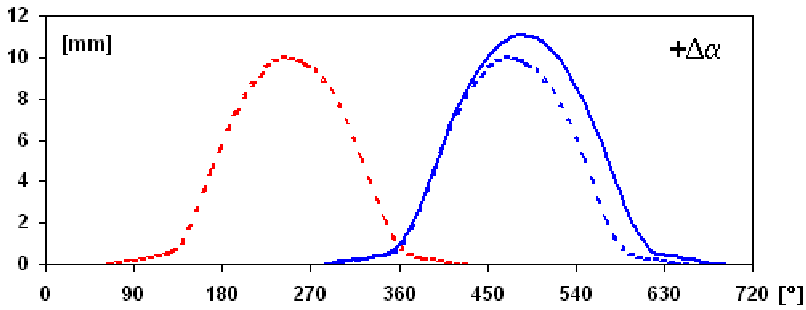


Figure 4-34: Positive intake valve closing shift only

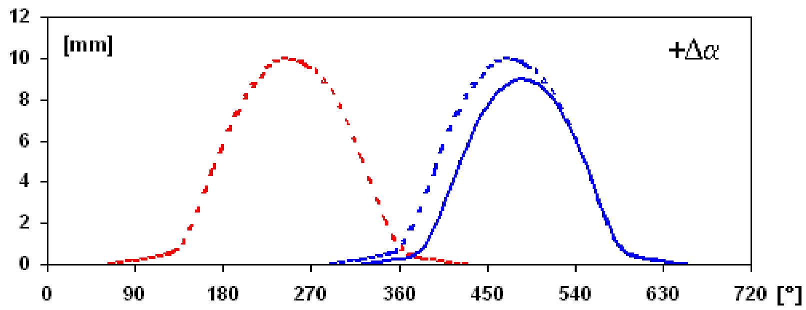


Figure 4-35: Positive intake valve opening shift only

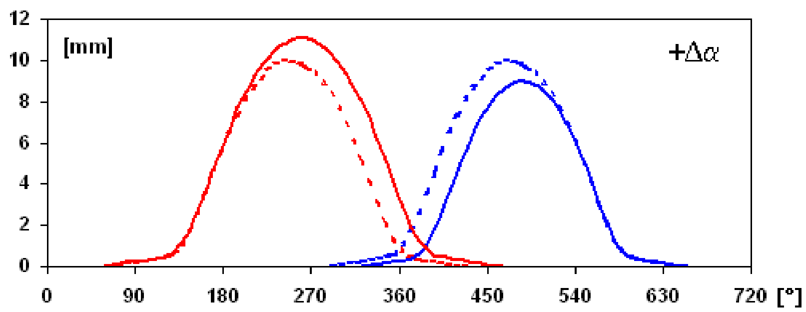


Figure 4-36: Positive exhaust closing shift and positive intake opening shift

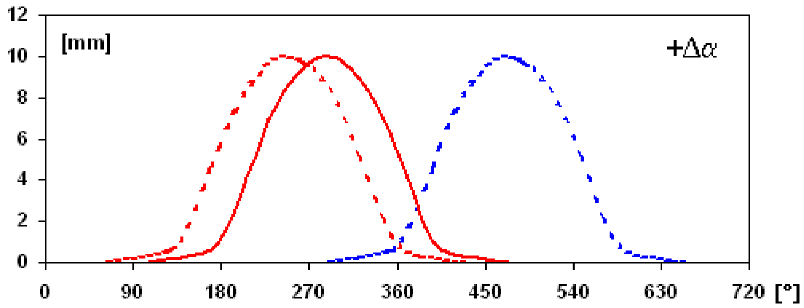


Figure 4-37: Positive exhaust opening and closing shift (same value)

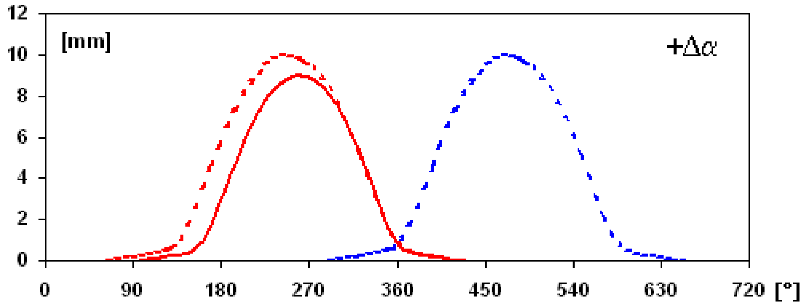


Figure 4-38: Positive exhaust opening shift only

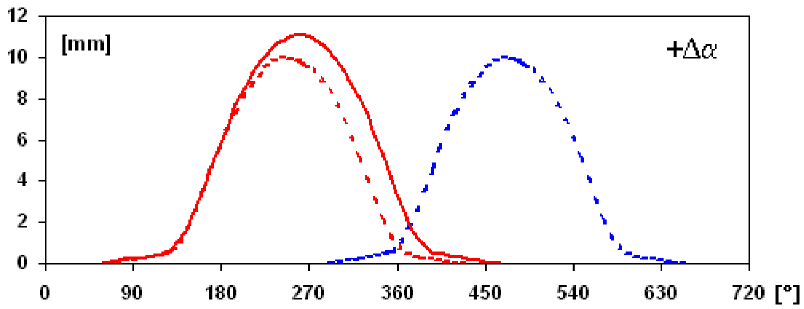


Figure 4-39: Positive exhaust valve closing shift only

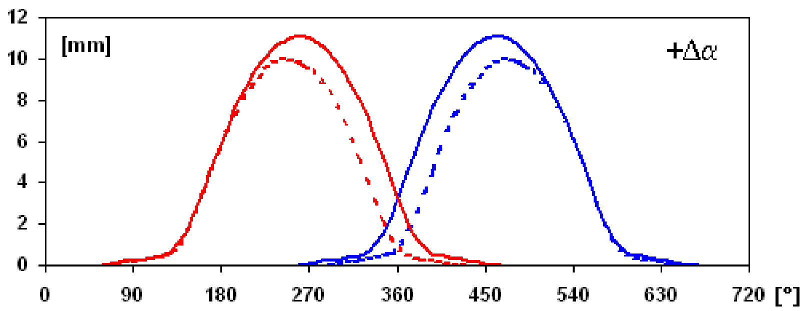


Figure 4-40: Positive exhaust valve closing shift and negative intake opening shift

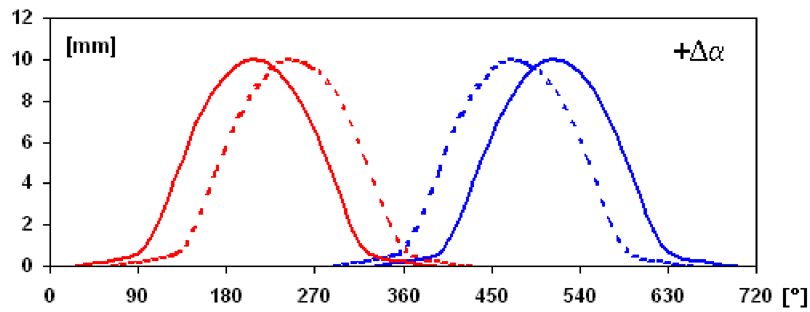


Figure 4-41: Negative exhaust shifts (same value) and positive intake shifts (same value)

To consider particular pressure losses resulting from multi dimensional flow phenomena which cannot be directly predicted by the program, **BOOST** requires the specification of flow coefficients of the ports. The flow coefficients are defined as the ratio between the actual mass flow and the loss-free isentropic mass flow for the same stagnation pressure and the same pressure ratio.

BOOST allows the specification of the flow coefficients of ports as a function of the pressure ratio at the port. For the flow into the cylinder, the pressure ratio is defined as the pressure in the cylinder divided by the stagnation pressure in the port (pressure ratio <1). For flow out of the cylinder, the pressure ratio is defined as the cylinder pressure divided by the static pressure in the port (pressure ratio > 1).

BOOST interpolates linearly the flow coefficients of pressure ratios which are less than and greater than one. It does not interpolate between the largest pressure ratio smaller than one and the smallest pressure ratio larger than one. Outside the defined range the value for the smallest/largest pressure ratio is taken. Figure 4-42 illustrates this procedure:

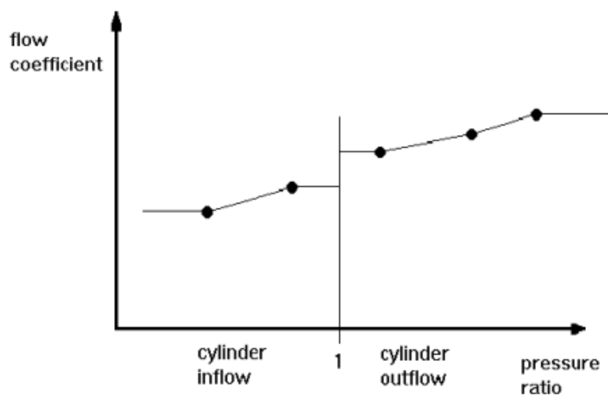


Figure 4-42: Interpolation of Flow Coefficients

The program interprets the specified flow coefficients of the ports are related to the cross-section of the pipe attached to the cylinder. If the measured flow coefficients of the ports are related to a different cross-section, the scaling factor for the effective flow area may be used to overcome this and achieve the correct effective flow areas.

Usually, the flow coefficients are related to the inner valve seat area. In this case, the scaling factor may be calculated easily from the following formula:

$$f_{sc} = \frac{n_v \cdot d_{vi}^{\ 2}}{d_{pi^2}} \tag{4.4.1}$$

f_{sc} scaling factor

n_v number of valves modeled with the port under consideration

d_{vi} inner valve seat (= reference) diameter

d_{pi} attached pipe diameter

The effective flow area is then calculated as:

$$A_{eff} = f_{sc} \cdot \alpha \cdot \frac{d_{pi}^{\ 2} \cdot \pi}{4} \tag{4.4.2}$$

α flow coefficient

The flow coefficients of the ports must be specified over valve lift. This can be done either by specifying the flow coefficients directly over valve lift or over the normalized valve lift. The latter is defined as valve lift related to the inner valve seat diameter (**AVL** definition). The advantage of using the normalized valve lift as a parameter is that the flow coefficients of similar ports can be used without modification.

For intake ports, the swirl characteristics versus valve lift may also be specified by the user. With this input, a dynamic in-cylinder swirl is calculated. In addition, a static swirl with **AVL**'s standard lift curve and the engines actual lift curve will be calculated for each port.

The following options are available to specify the flow characteristics and the opening characteristics of the ports of 2-stroke engines:

- **Specification of the effective flow area:** The user may specify the effective flow area over piston position or over crank angle. If, in addition to the effective flow area, the port geometry is specified, the pre-processor calculates the flow coefficients for the port automatically. They may be used to determine effective flow areas for slightly modified ports (e.g. modified timing).
- **Specification of port geometry and flow coefficients:** Instead of specifying the effective flow area directly, the user may specify the port geometry over piston position or crank angle, and the flow coefficients of the port depending on the port opening. The port geometry, i.e. the port width over piston position or crank angle must be specified for each port opening. In a BOOST model one port may feature more than one opening so the number of openings must be specified.

Similar to the valve controlled ports, **BOOST** allows the effective flow areas of the ports as a function of pressure ratio at the port to be specified. The definition of pressure ratio is the same as described for valve controlled ports.

The scaling factor may be used to increase or to decrease the specified flow areas by a constant factor.

The effective flow areas of the ports may be specified either as a function of the distance between the actual position of the piston and its TDC position, or on crank angle. If the effective flow area is specified over crank angle, the full crank angle range between port opening and port closing must be covered. It is the user's responsibility to ensure that the timing relative to BDC is symmetrical.

The flow coefficients are defined as the actual mass flow related to the specific mass flow rates calculated from the isentropic flow equations for the same stagnation pressure and temperature and for the same pressure ratio.

The definition of the port geometry consists of the specification of the port openings, the port width (either as chord or as developed length) over the distance from the upper port edge, and the minimum duct cross-section.

The port opening timing may be specified either in degrees crank angle after TDC or as the distance between the upper port edge and the TDC position of the piston top (location of upper port edge below TDC), Figure 4-43.

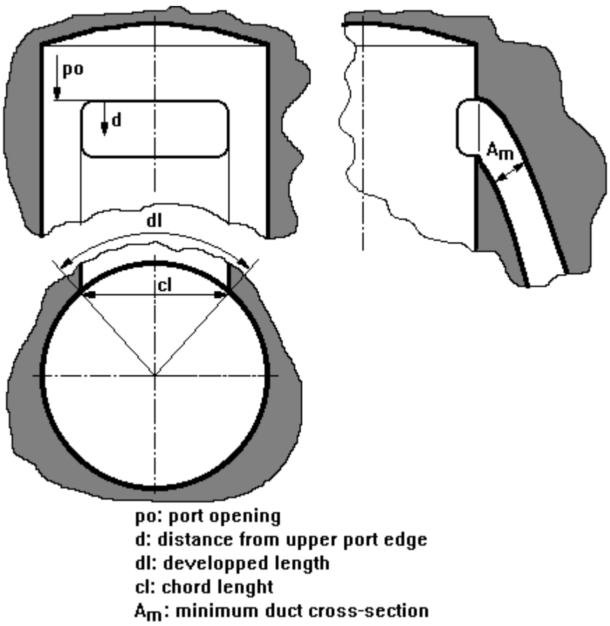


Figure 4-43: Definition of Window Geometry

The minimum duct cross-section is required to determine the upper limit for the geometric cross-section of the port. It may be specified directly or calculated from the port opening dimensions and the port angles (angles between the port centerline and the horizontal and radial planes), Figure 4-44. So it accounts for a situation where the flow direction of entering/leaving mass is not normal to the port opening area so that the entire effective flow area table is scaled according to that ratio A_{eff}/A.

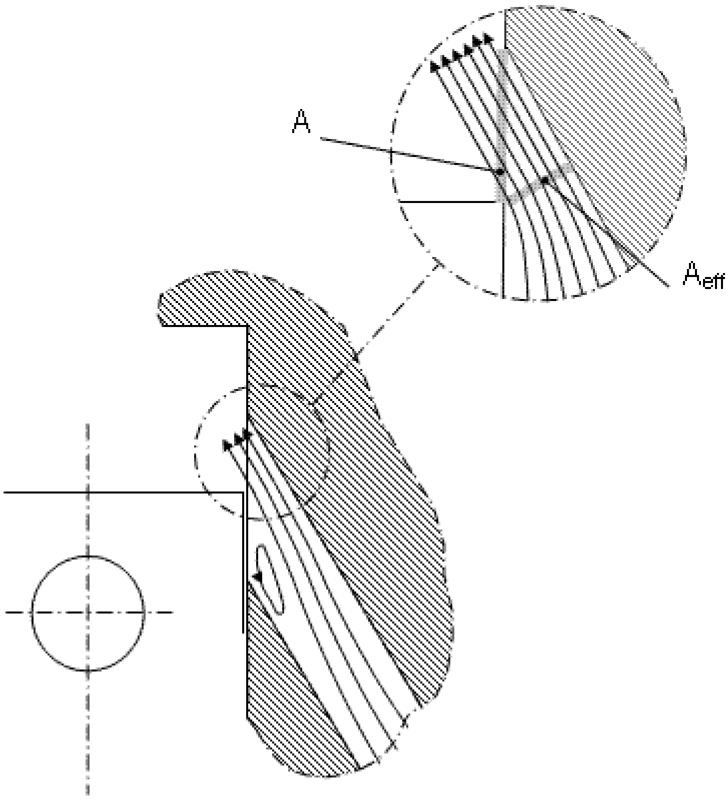


Figure 4-44: Calculation of Minimum Duct Cross Section

The flow coefficients of the ports of two-stroke engines are related to the actual port opening area which varies with piston position. They must be specified as a function of distance from the upper port edge.

4.5. Engine

4.5.1. General

Transient Engine Speed	Steady state simulations are default. **BOOST** can also simulate engine and vehicle acceleration or deceleration processes by selecting **Transient Calculation Speed**.
Engine Speed	The engine speed is the revolution speed of the crankshaft. For steady state simulations, it is kept constant. For transient simulations it is the starting value which is in the following calculated from solving the moment of momentum equation applied to the crankshaft at each time step.
Inertia Moment of Engine	Input the average moment of inertia for the crank train (plus all auxiliary drives and the inertia of the load reduced to engine speed if not modeled by separate elements connected via Mech. Connectors).
Cycle Type	2-Stroke (1 Crank Shaft Revolution per Cycle) 4-Stroke (2 Crank Shaft Revolutions per Cycle) Rotary Piston Engine (assumed to be a 4-Stroke Engine with 3 Eccentric/Crank Shaft Revolutions per Cycle)
BMEP Control	Select to activate the BMEP Control input fields described in section 4.5.4.

The engine inertia may depend on time or crank angle, therefore input the values in the **Table** ▼.

To convert the mass of a vehicle to a rotational inertia related to engine speed, the following formula may be used:

$$I = \frac{m_V \cdot r_T^{\;2}}{i^2} \tag{4.5.1}$$

I rotational inertia of the vehicle

r_T (dynamic) tire radius

i total gear ratio between engine and drive wheels, given:

$$i = \frac{n_e}{n_w} \tag{4.5.2}$$

n_e engine speed

n_w wheel speed

To convert the mass of a vehicle to a rotational inertia related to engine speed, the following formula may be used:

$$I = \frac{m_V \cdot r_T^{\,2}}{i^2} \qquad (4.5.3)$$

I rotational inertia of the vehicle

r_T (dynamic) tire radius

i total gear ratio between engine and drive wheels, given:

$$i = \frac{n_e}{n_w} \qquad (4.5.4)$$

n_e engine speed

n_w wheel speed

4.5.2. Cylinder Setup

Identical Cylinders	**BOOST** features individual cylinders which means that each cylinder can have its own specifications. If this feature is not required, it is recommended to select **identical cylinders** in order to simplify the input process. In this case, only the specifications for cylinder 1, the firing order and the firing intervals must be specified.
Firing Order	Input the firing order of each cylinder with reference to the absolute crankshaft start angle (0 deg).

4.5.3. Engine Friction

Engine friction adversely affects the maximum work output and fuel economy characteristics of an engine and directly accounts for much of the difference in fuel consumption between cold and full-warm engine operation. For the calculation of the brake mean effective pressure (BMEP) and the brake specific fuel consumption (BSFC), the specification of friction mean effective pressure (FMEP) over engine speed and engine load is required.

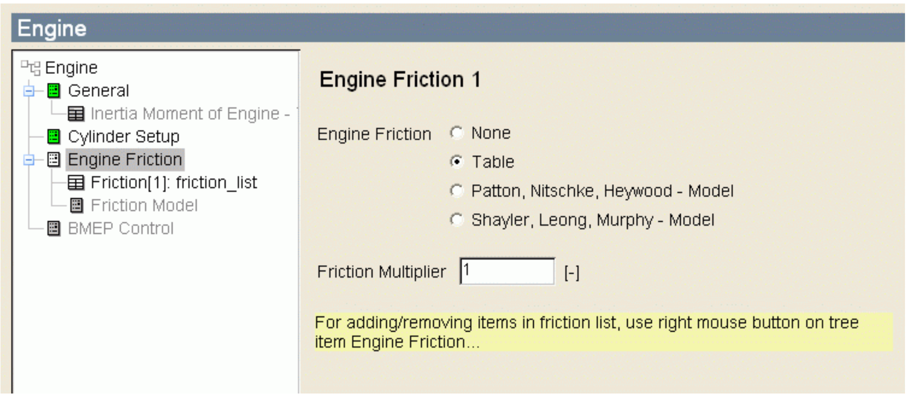


Figure 4-45: Engine Friction Window

Engine Friction	**BOOST** offers different methods to specify the FMEP: **None:** No losses due to engine friction are considered in the BOOST calculation
	Table: The FMEP can be specified as a function of engine load, represented by the BMEP, and the engine speed.
	Patton, Nitschke, Heywood –Model: This model calculates the FMEP based on a set of engine type and geometry related input data.
	Shayler, Leong, Murphy –Model: Similar to the above model the FMEP is calculated based on a set of engine type and geometry related input data.
Friction Multiplier	This can be used to scale the specified (Table) or calculated (PNH model and SLM model) FMEP.

4.5.3.1.1. FMEP Table Input

The engine friction may be defined versus engine speed for several loads expressed by BMEP.

In order to add data for various engine loads select the **Engine Friction** sub-group with the right mouse button and then select **Add**:

- Define the engine load (BMEP).
- Define the **Friction Mean Effective Pressure (FMEP)** versus engine speed in the **Table** ▼.

The following rules apply when evaluating the table during runtime:

- Values which are not specified explicitly in the table are obtained by interpolation with the actual speed and load.
- For operating points outside the defined range the values at the boundary of the defined range will be used by the program.

If no data is available for the friction as function of load, a difference of 0.2 bar in the FMEP between zero and full load may serve as a rough guide line.

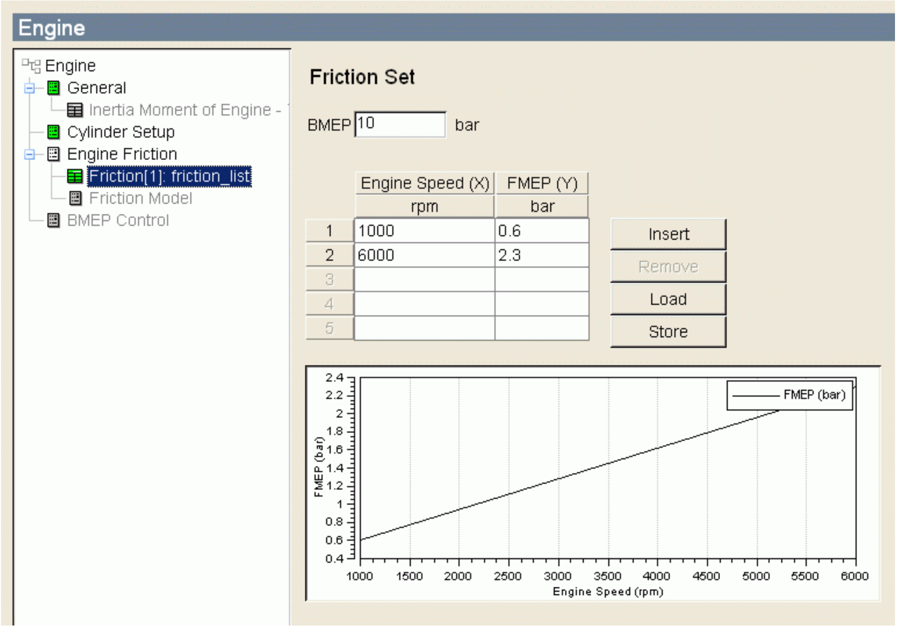


Figure 4-46: Engine Friction - Table Input Window

4.5.3.1.2. PNH and SLM –Models

Both the PNH and the SLM models calculate the friction losses associated with the main bearings, the valve train, piston group and auxiliary components.

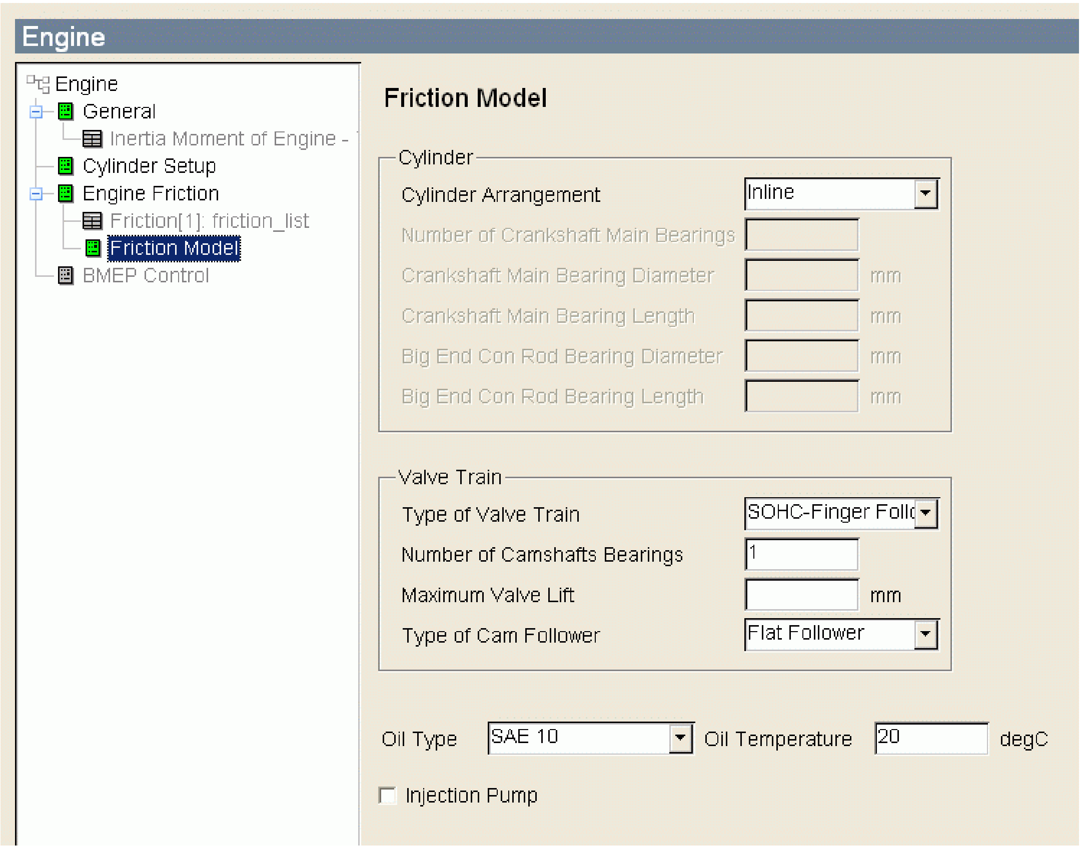


Figure 4-47: Engine Friction - Friction Model Window

Cylinder	
Cylinder Arrangement	Default values are available for **Inline**, **V6** and **V8** engines. If **User Defined** is selected, the following data must be specified: **Number of Crankshaft Main Bearings** **Crankshaft Main Bearing Diameter** **Crankshaft Main Bearing Length** **Big End Con Rod Bearing Diameter** **Big End Con Rod Bearing Length**
Valve Train	
Type of Valve Train	If **No Valve Train** is selected, the contribution of the valve train to engine friction is neglected. If **SOHC-Finger Follower**, **SOHC-Rocker Arm**, **SOHC-Direct Acting**, **DOHC- Direct Acting** or **OHV Push Rods** is selected, the following data must be specified: **Number of Camshaft Bearings** **Maximum Valve Lift** **Type of Cam Follower – Flat or Roller**
Oil Type	Select the oil type from the list.
Oil Temperature	Specify the oil temperature.
Injection Pump	Activates/Deactivates the Injection Pump.

4.5.4. BMEP Control

The BMEP Control offers a convenient way to reach a target BMEP value without using an ECU element. The controlled value is either the injected fuel mass (DI, GDI) of selected **Cylinders** or the flow-coefficient (throttle, turbine waste-gate) of selected **Restrictions**. In addition to the BMEP value, the controlled value and elements, the parameters of the **Integral Controller** have to be specified.

According to the following formula (4.5.5) either the injected fuel mass (DI, GDI) of selected cylinders or the flow-coefficient of selected restrictions (throttle, turbine waste-gate) is controlled.

$$vc = vc_{guess} + \left(vc_{upper} - vc_{lower}\right)\frac{i}{t_{CDUR}}\int_0^t \left(BMEP_{des} - BMEP\right)\cdot dt \qquad (4.5.5)$$

vc	controlled value (injected fuel mass [kg] or flow coefficient [1])
vc_{guess}	initial value for controlled value ([kg] or [1])
vc_{upper}, vc_{lower}	upper and lower limit for controlled value ([kg] or [1])
i	integral control gain [1/Pa]

t_{CDUR}	cycle duration [s]
$BMEP_{des}$	target BMEP [Pa]
$BMEP$	current BMEP[Pa]

Select **BMEP Control** in the **General** window to access the following options in the **BMEP Control** sub-group:

Desired BMEP	Target $BMEP_{des}$ [Pa] to be reached
Controlled	Controlled actuator value; one of: Fuel Mass [kg] Flow Coefficients [1] Throttle Angle [1]
Controlled Value Lower Limit	lower limit for controlled value vc_{lower} ([kg] or [1])
Controlled Value Upper Limit	upper and lower limit for controlled value vc_{upper} ([kg] or [1])
Controlled Value Guess	initial value for controlled value vc_{guess} ([kg] or [1])
Integral Control Gain	integral control gain i [1/Pa]
Element	List of elements to be controlled

4.6. Mechanical Consumer

4.6.1. General

Inertia of Mechanical Consumer	Input the average moment of inertia for the **Mechanical Consumer**.
Load Characteristic	Coefficient a Coefficient b Coefficient c Coefficient d
AMEP Consideration of Mech. Power	If the Mechanical Power supplied/consumed by the **Mechanical Consumer** should be considered in the Engine AMEP this Check Box has to be selected.

The **Load Characteristic** applied to the **Mechanical Consumer** is calculated according to the formula

$$M = \frac{a}{n_c} + b + cn_c + dn_c^{\,2} \qquad (4.6.1)$$

M load torque

a, b, c, d load coefficients

n_c rotational speed of the **Mechanical Consumer**

coefficients a, b, c and **d** specified as constant value or as a **Table** ▼.

A **Mechanical Consumer** has to be connected to another Mechanical Component by means of a **Mechanical Connection Full Model**.

4.7. Vehicle

4.7.1. General

Inertia of Drivetrain	Inertia considering the assembly between engine clutch and road wheels referenced to wheel speed.
Vehicle Mass	Inertia of translational moved masses.
Rolling Radius	(dynamic) tire radius.
Vehicle Load Characteristic	The vehicle load is calculated from the following formula:

$$F = \frac{a}{v} + b + c\,v + d\,v^2 \qquad (4.7.1)$$

F vehicle load [N]

v vehicle speed

a,b,c,d vehicle load coefficients

(in general determined by : b ... rolling resistance, uphill gradient;

c ... friction caused by laminar flow; d ... air resistance)

- Input a constant value for Coefficient a or a **Table** ▼ of time dependent values. Coefficients b, c, d are treated analogous.

4.7.2. Driver

The Driver transient calculation allows the user to simulate the dynamic behavior of the two-body system vehicle and engine which can be decoupled by a gear shift. The ECU (described in section 4.15.1), which has to be present when executing the driver model, tries to follow a specified speed course by calculating the load signal depending on the deviation of the actual vehicle speed from the desired one.

Select **Desired Engine Speed** for the ECU input (the value or table of the Desired Engine Speed is not taken into account).

In the **Engine** element the **Transient Engine Speed** option has to be selected. The **inertia** input field is activated. Input the inertia of the engine plus all auxiliary drives (not including mechanically driven supercharging devices, inertia of drivetrain and inertia of vehicle). Input can be a constant value or a **Table** of time or crank angle dependent values.

The crank angle dependent inertia caused by the translational moved masses of a standard crank train (no piston pin offset considered) can be calculated from:

$$I_t = \frac{m s^2}{4}\left(\sin(\alpha) + \frac{\frac{\sin(2\alpha)}{2}}{\sqrt{\left(2\frac{l}{s}\right)^2 - \sin^2(\alpha)}}\right)^2 \tag{4.7.2}$$

I_t inertia of translational moved masses [kgm²]

m translational moved masses [kg]

s stroke [m]

l conrod length [m]

The **Vehicle** Element has to be **Engine** Element by means of a **Mechanical Connection Full Model** with activated Clutch. Concerning the transferred torque the clutch has the following states:

a. The clutch does not slip (transferred torque is smaller than the maximum transferable torque)

b. The clutch slips (transferred torque is equal to the maximum transferable torque)

The maximum transferable torque is given by the formula

$$t_{tm} = t_{cm}\ p_{cc} \tag{4.7.3}$$

t_{tm} maximum transferable torque [Nm]

t_{cm} maximum clutch torque [Nm]

p_{cc} clutch-control position [1]

Specify the maximum clutch torque t_{cm} [Nm].

During the Shifting process (Figure 4-48) the load signal and clutch-control position are determined according to the following figure.

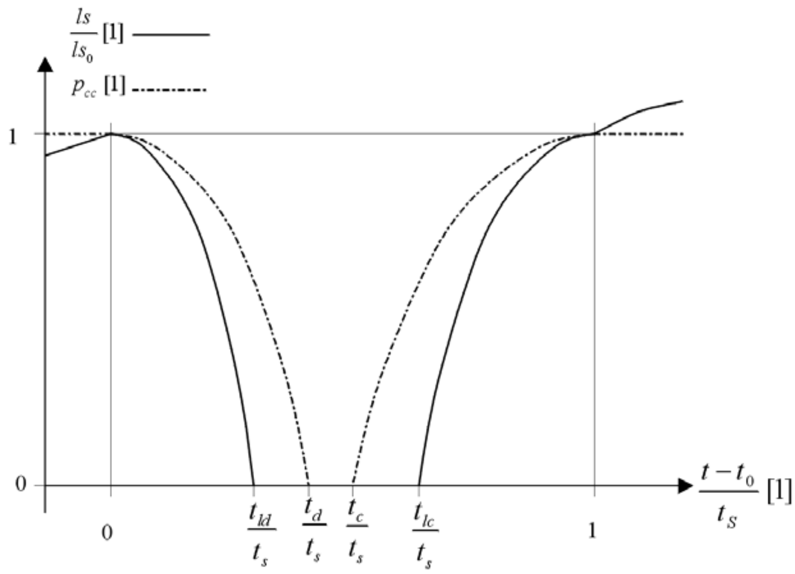


Figure 4-48: Shifting Process

ls	Load signal [1]
ls_0	Load signal at start of shifting process [1]
p_{cc}	Clutch-control position [1]
t_s	Period of shifting process [s]
$\frac{t_d}{t_s}$	End of decoupling period [1]
$\frac{t_c}{t_s}$	Start of coupling period [1]
$\frac{t_{ld}}{t_s}$	End of the load signal decreasing period [1]
$\frac{t_{lc}}{t_s}$	Start of the load signal increasing period [1]

Driver	
Shifting Time	Period of shifting process t_s [s]
Clutch Pedal On	End of decoupling period $\frac{t_d}{t_s}$ [1]
Acceleration Pedal Off	End of the load-signal decreasing period $\frac{t_{ld}}{t_s}$ [1]

Acceleration Pedal On	Start of the load-signal increasing period $\frac{t_{lc}}{t_s}$ [1]
Clutch Pedal Off	Start of coupling period $\frac{t_c}{t_s}$ [1]
Velocity	
Vehicle Velocity	Based on the deviation of the actual vehicle speed from the specified value(s), the ECU calculates the load signal according to the formula $$ls = p(n_{des} - n) + i\int_0^t (n_{des} - n)\mathrm{d}t + d\frac{\mathrm{d}}{\mathrm{d}t}(n_{des} - n) \quad (4.7.4)$$ ls load signal [1] p proportional control gain [1/rpm] i integral control gain [1/rpms] d differential control gain [s/rpm] n_{des} desired vehicle speed reduced to crank shaft speed [rpm] n engine speed [rpm] The desired vehicle speed is interpolated from a specified constant value or a **Table** of time dependent values.
Gear Shifting	
Min. Engine Speed	A gear shift downwards is initiated if the engine speed falls below the minimum engine speed [rpm].
Max. Engine Speed	A gear shift upwards appears by exceeding the maximum engine speed [rpm].
Gear Box	
Gear Step At Calculation Start	To initialize the gearbox, input the gear step which will calculate the vehicle speed at the start of the calculation (the corresponding engine speed is specified in the **Engine**). Input a table of corresponding gear ratios in ascending order [1]. Definition of the total gear ratio: $$i = \frac{n_e}{n_w} \quad (4.7.5)$$ i gear ratio [1] n_e engine speed [rpm] n_w driving wheel speed [rpm]

4.8. Measuring Point

Using measuring points, the user can access flow data and gas conditions over crank angle at a certain location in a pipe. The location of the measuring point must be specified as its distance from the upstream pipe end.

The user may select the output for a measuring point:

Standard	Pressure, flow velocity, temperature, Mach number and mass flow rates.
Extended	Additional output of stagnation pressure, stagnation temperature, enthalpy flow, fuel concentration, combustion products concentration, fuel flow, combustion products flow, forward and backward pressure and velocity waves. Additional acoustic data is also written to the acoustic folder for measuring points with extended output selected.

4.9. Boundaries

4.9.1. System Boundary

Click on **Linear Acoustics** for relevant information.

The system boundary element provides the connection of the calculation model to a user-definable ambient.

4.9.1.1. General

Saving of Energy and Mass for Backflow	Select to determine the temperature condition for Inflow by the accumulated Outflow.
Boundary Type	**Standard** is the default setting for a system boundary. No special features are used. **Anechoic Termination** suppresses backward pressure waves. This can be used for the termination of an acoustic model. **Acoustic Source** generates a varying pressure in the ambient. Used for generating source conditions for acoustic models.
End Correction	Select to include an acoustic end correction in order to account for multidimensional effects. This will increase the length of the attached pipe by the magnitude of the end correction (=0.6 * radius of the connected pipe). See Theory Manual for details.

4.9.1.2. Boundary Conditions

Both local or global boundary conditions can be set. In the later case one of the predefined global sets can be used to specify the boundary conditions.

The ambient conditions (pressure, temperature, air/fuel ratio, fuel vapor and combustion products) must be specified either as constant values or in a **Table** as functions of time or crank angle.

For General Species Transport the specification of mass fractions is possible either as a constant value (using the **Initialization Mass Fraction** window in **Simulation Control/Globals**) or as table (by activating the **Mass Fraction Input** option).

The input of user-defined concentrations is disabled if the number of user-defined concentrations was set to zero.

4.9.1.3. Flow Coefficients

The flow coefficients for flow from the ambient into a pipe depend mainly on the protrusion of the pipe end through the wall in which it is installed and on its bellmouth characteristics. Refer to **Flow Coefficients** for details on standard values and directions.

4.9.1.4. Acoustic Source

The numerical generation of an acoustic periodic signal (white noise) is carried out as the sum of N sinusoidal pressure oscillations with a fixed amplitude, Δp, and frequency multiple of the fundamental frequency, f.

$$p(t) = p_o + \sum_{n=1}^{N} \Delta p \sin\left(2\pi f t + \varphi_n\right)$$

p_o is a constant value representing the mean ambient pressure. A random phase is used for each sinusoidal component of the sum.

Minimum frequency: This is also the fundamental frequency for the pressure calculation.

Maximum frequency: Frequency is incremented from the minimum frequency in steps of the fundamental frequency (also the minimum frequency) until the maximum frequency is reached.

Mean Pressure, p_o: Base pressure about which the pressure is varied. This can be used to control the mean flow during the simulation depending on the termination conditions.

Delta Pressure, Δp: The acoustic pressure of the source.

Transmission Loss: The transmission loss between two measuring points can automatically be calculated when using an acoustic source system boundary and an anechoic termination (if a non anechoic termination is used the result will be the noise reduction and not the transmission loss). Simply activate the transmission loss checkbox and select the upstream and downstream measuring points in the model. The transmission loss is then calculated as follows (assuming MP1 is the upstream MP and MP2 is the downstream MP),

Transmission Loss = Sound Pressure @ MP1 – Sound Pressure @ MP2 – 10.log(A2/A1)

Where,

A1 = cross sectional area at MP1

A2 = cross sectional area at MP2

Note : When an acoustic source is used with an anechoic termination, the sound pressure levels at the measuring points are from the forward running pressure wave only.

After a successful calculation the Transmission Loss result can be found in the Acoustic folder of the Acoustic Source System Boundary.

4.9.2. Aftertreatment Boundary

Click on **Aftertreatment** for relevant information.

The aftertreatment boundary element provides the connection of the aftertreatment analysis model to a user-definable ambient. **Two** aftertreatment boundaries (one inlet and one outlet) can be connected to **one** catalytic converter model or **one** diesel particulate filter. The application of this type of boundary can only be used for aftertreatment analysis simulations. More detailed information can be found in the BOOST Aftertreatment Manual.

☞ **Note:** Input values for an aftertreatment boundary are considered to be periodic. This means the defined period is repeated until the end of the simulation.

4.9.3. Internal Boundary

The internal boundary element allows boundary conditions for the calculation model to be specified directly in the last cross section of a pipe where a model ends. It is extremely helpful if measured boundary conditions in the intake and exhaust pipe of a cylinder are available. In this case a simplified sub-model of the engine between the two measuring points is made. An internal boundary is placed at the location of the measuring point, and the measured pressure and temperature over crank angle are specified.

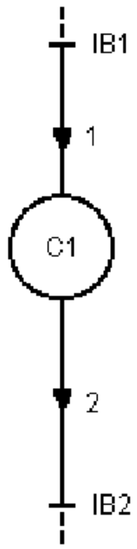


Figure 4-49: Engine Cylinder Sub-model

4.9.3.1. General

Select **Save Energy and Mass for Backflow** to determine the temperature boundary condition when flow is into the pipe from the accumulated flow out of the pipe into the boundary.

4.9.3.2. Boundary Conditions

Both local and global boundary conditions can be set. In the later case one of the predefined global sets can be used to specify the boundary conditions.

The gas conditions in the pipe (pressure, temperature, air/fuel ratio, fuel vapor and combustion products) must be specified either as constant values or in a **Table** as a function of time or crank angle.

The input of user-defined concentrations is disabled if the number of user-defined concentrations has been set to zero.

For General Species Transport the same options are available as for the **System Boundary**.

4.10. Transfer Elements

4.10.1. Flow Restriction

The flow restriction element is used to consider a distinct pressure loss at a certain location in the piping system. This pressure loss may be caused by a geometrical restriction of the pipe cross-section (e.g. a butterfly valve, an orifice plate, etc.), or by a flow separation at that location caused by a step in the diameter of the piping or by a narrow elbow.

For a flow restriction, flow coefficients must be specified for both possible flow directions. The flow coefficients are defined as the ratio between the actual mass flow and the loss-free isentropic mass flow for the same stagnation pressure and the same pressure ratio.

The flow coefficients of restrictions depend very much on the design details of the restriction (control valve, orifice, flow separation, sudden change of diameter etc.). Standard values for the flow coefficients can only be given for a sudden change of the diameter.

For a sudden expansion of the flow (flow direction from a smaller to a larger diameter pipe), the flow coefficients depend mainly on the cross-sectional area ratio. This influence is considered automatically by the **BOOST** program. The values specified in the input cover only the deterioration over the ideal geometry. Therefore, a value of 1.0 is recommended for a well manufactured diameter step.

For a sudden contraction of the flow (flow from a larger to a smaller diameter pipe), the flow coefficients depend again mainly on the cross-sectional area ratio and on the relative radius at the inlet to the smaller pipe. This is defined as the actual radius divided by the (hydraulic) diameter of the smaller pipe (refer to Figure 4-50).

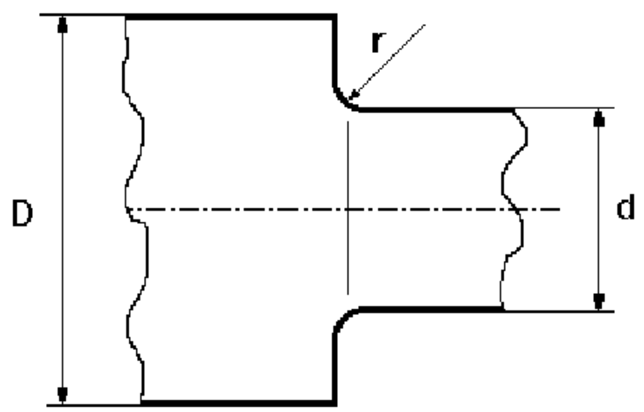


Figure 4-50: Sudden Diameter Change

Relative Radius (r/d)	Area Ratio $(d/D)^2$				
	0.0	**.4**	**.7**	**.9**	**1.0**
0.0	.815	.865	.915	.960	1.0
0.02	.855	.895	.935	.970	1.0
0.06	.910	.935	.960	.980	1.0
0.12	.955	.970	.980	.990	1.0
>0.20	.985	.990	.995	.998	1.0

Values between the specified points can be obtained by linear interpolation.

For all other types of restriction, the flow coefficients must be determined by steady state flow tests or estimated from the geometrical restriction of the pipe cross-section.

☞ **Note:** In **BOOST** the flow coefficients of restrictions are always related to the minimum attached pipe cross-section.

The restriction element can include a physical pipe extension from the smaller pipe into the larger pipe (**Inlet or Outlet Extension**) as well as an end correction (**Karal's End Correction**) to account for multidimensional effects. The combined length of the extension (physical + end correction) is used to adjust the length of the two connected pipes. The length is added to the smaller diameter pipe and subtracted from the larger diameter pipe. The length is also used to create a quarterwave resonator at the junction between the two pipes. If the length and applied corrections result in a negative pipe length or a quarter wave resonator length smaller than the model cell size the corrections are not applied and no resonator is created.

See Recommendations : Modelling Extensions for more details.

☞ **Note:** Flow coefficients of restrictions are fixed to 1.0 when the extension and or end correction result in quarter wave resonator.

4.10.2. Throttle

Click on **Linear Acoustics** for relevant information.

The throttle element is used to consider a distinct pressure loss over the throttle element. The implementation and the functionality of the throttle element is similar to the flow restriction element, except that the flow coefficients must be specified as a function of the throttle flow angle for both possible flow directions.

The flow coefficients are defined as the ratio between the actual mass flow and the loss-free isentropic mass flow for the same stagnation pressure and the same pressure ratio and are typically determined experimentally, where the reference diameter is the diameter that was used to calculate the flow coefficients.

4.10.3. Rotary Valve

Rotary valves are used to control the air flow in a pipe as a function of crank angle or time. A typical application is the control of the intake process of a two-stroke engine. In the **BOOST** system the rotary valve is treated in a similar way to the flow restriction.

For the rotary valve the flow coefficients must be specified for both possible flow directions depending on the time in seconds or on crank angle.

The flow coefficients are defined as the ratio between the actual mass flow in the loss-free isentropic mass flow for the same stagnation pressure and the same pressure ratio.

The total time interval for which the flow coefficient is specified may be less than, equal to, or greater than the cycle duration. If the time interval is shorter than the specified maximum calculation period, **BOOST** treats the flow coefficient over time function as a periodic function.

☞ **Note:** For the rotary valve, the flow coefficients are related to the minimum pipe cross-section attached.

4.10.4. Check Valve

A check valve is a pressure actuated valve used to prevent reverse flow. Two models are available:

1. **Simplified Check Valve Model**

   The flow resistance of the valve only depends on the pressure difference over the check valve. No inertia effects of the valve are considered. In this case **BOOST** requires the specification of flow coefficients for both possible flow directions as a function of the pressure difference over the check valve.

   The flow coefficients are defined as the ratio between the actual mass flow and the loss-free isentropic mass flow for the same pressure difference. In the case of the check valve, the flow coefficients are related to the minimum pipe cross-section attached.

   If the actual pressure difference in the engine model exceeds the maximum pressure difference for which a flow coefficient has been specified, the flow coefficient for the maximum specified pressure difference will be used.

2. **Full Check Valve Model**

   The dynamic valve lift is calculated using an equivalent spring-damper-mass system. The flow coefficients must be specified as a function of the valve lift.

   The moving masses, damping coefficient, valve spring pre-load and valve spring rate must be defined. Furthermore, the specification of reference areas is required in order to calculate the forces acting on the valve resulting from the pressure difference over the valve. **BOOST** allows different reference areas for the closed valve and opened valve to be specified.

   The maximum valve lift may be limited as is often the case in real check valve configurations.

   Flow coefficients as a function of valve lift must be specified for both possible flow directions.

4.10.5. Injector / Carburetor

The injector element is used to add fuel (classic species transport) or any other species (general species transport) into a pipe in the intake or exhaust system, although it is most often used for engines with external mixture preparation (PFI, MPFI, …) to add the fuel to the air in the intake system.

To consider the particular pressure losses resulting from multi-dimensional flow phenomena which cannot be predicted by the program, **BOOST** requires the specification of flow coefficients at the fuel injector. The flow coefficients are defined as the ratio between the actual mass flow and a loss-free isentropic mass flow for the same stagnation pressure and the same pressure ratio.

4.10.5.1. Injected species specification

BOOST requires the user to choose between the "Fuel" (default) and the "Local Species Definition" method.

For both approaches **BOOST** can take into account the heat needed for the evaporation and the heat needed for heating the injected mass flow from the reference temperature (298.15K) to the instantaneous temperature. Please refer to Table 4-3 for the evaporation heat of different fuels. By specifying Heat from Wall greater than `0`, the amount of evaporation heat covered from the combustion chamber walls can be input.

4.10.5.2. Injected mass flow specification

The injected mass flow can be specified either using the **Ratio Control** (default) or the **Direct Control** method.

For **Ratio Control** the fuel supply is specified by the A/F Ratio. If the **Carburettor Model** is used, the air flow at the carburettor position is used together with the specified A/F ratio to calculate the amount of fuel supplied. For the **Injection Nozzle** Model a measuring point at the position of the air flow meter has to be specified. In this case the fuelling is calculated from the mass flow at the air flow meter position and the specified A/F ratio. As the air flow meter usually serves more than one cylinder, the percentage of the total air flow served by each injector must be specified.

For **Direct Control** the mass flow can be specified either in kg/s or in kg/cycle.

4.10.5.3. Injection method specification

Using the **Continuous Injection** method (default) the mass is injected over the whole engine cycle. The **Intermittent Injection** option enables the user to model the injection event in a more detailed way. The following additional input is required:

- **Reference Cylinder**: Choose the cylinder which is targeted by this injector (defined FTDC for the definition of the Injection Angle).
- **Injection Angle**: Specify either the SOI or the EOI timing.
- **Rate/Duration Settings**: Choose from 'Rate', 'Duration' or 'Rate and Duration'.
- **Delivery Rate**: Specify the delivery rate for the injector. If the delivery ration is not known, the below formula can be used to estimate it.
- **Injection Duration**: Specify the duration of the injection.
- **Fuel Film Thickness**: Specify the thickness of the fuel film.
- **Fraction of Fuel in Wallfilm**: Specify the fraction of the injected fuel that is directly deposited in the wallfilm.
- **Film=Wall Temperature taken from**: Select the Measuring Point that will be used to determine the wallfilm temperature for the evaporation.
- **Evaporation Multiplier**: Can be used to tune the rate of evaporation (Sherwood number based part).
- **Shape Multiplier**: Can be used to tune the rate of evaporation (geometry based part).

If the injector **Delivery Rate** is not known, a realistic estimate can be made using the following formula:

$$\dot{m}_{delivery} = \eta_v \cdot \rho_{ref} \cdot n \cdot V_{disp} \cdot \frac{1}{(A/F)_{engine}} \cdot \frac{6}{N_{cyl} \cdot \Delta\alpha_{inj}} \qquad (4.10.1)$$

with:

$\dot{m}_{delivery}$	injector delivery rate [g/s]
η_v	volumetric efficiency [-]
n	engine speed [rpm]
V_{disp}	engine displacement [l]
$(A/F)_{engine}$	air/fuel ratio (mass based) [-]
N_{cyl}	no. of cylinders [-]
$\Delta\alpha_{inj}$	injection duration [degCA]

Typically an injector is designed such, that at the highest speed and at WOT the injection duration equals the duration of the intake valve opening (~200 degCA).

The evaporation characteristics of gasoline fuel are typically described by a **Distillation Curve** as shown for Gasoline in Figure 4-51. Components with higher volatility evaporate at lower temperatures (approx. 50 degC), components with lower volatility evaporate at higher temperatures (approx. 170 degC).

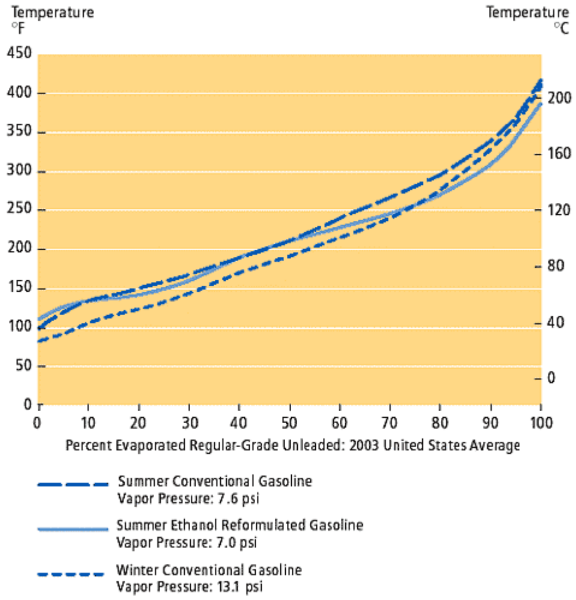


Figure 4-51: Distillation curves for different fuel types (Source: www.chevron.com)

BOOST requires the distillation curve (distillation temperature as f(fraction evaporated fuel)) as input and takes this effect into account by splitting the injected mass into three different packages:

- High Volatility: 0-25% evaporated
- Mean Volatility: 25-75% evaporated
- Low Volatility. 75-100% evaporated

For each of these three packages the rate of evaporation and the corresponding mass in the fuel puddle are balanced separately.

Fuel Injector Puddle mass-flow Chart

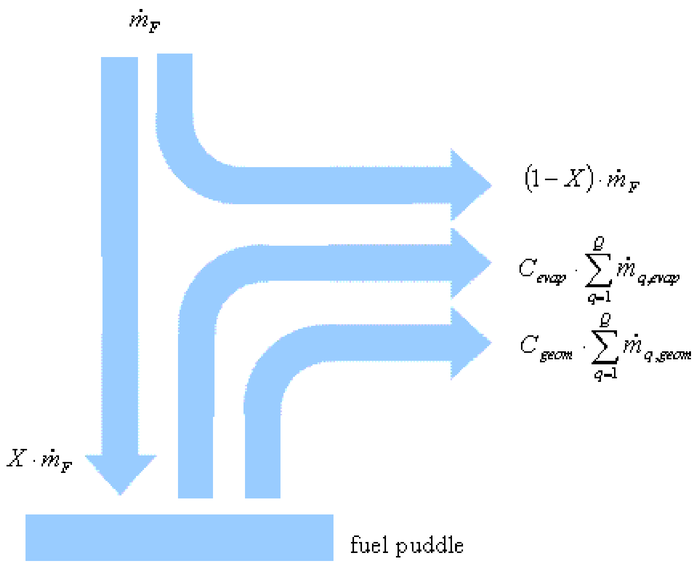


Figure 4-52: Fuel Injector Puddle mass-flow

$$\dot{m}_{F,eff} = \dot{m}_{F,inj} + \dot{m}_{F,puddle} \tag{4.10.2}$$

$$\dot{m}_{F,inj} = (1-X)\cdot\dot{m}_F \tag{4.10.3}$$

$$\dot{m}_{F,puddle} = \sum_{q=1}^{Q}\left(C_{evap}\cdot\dot{m}_{q,evap} + C_{geom}\cdot\dot{m}_{q,geom}\right) \tag{4.10.4}$$

$$\dot{m}_{q,evap} = k_q \cdot A_P \cdot \rho_g \cdot \left(\frac{y_{q,sat}-y_q}{1-y_{q,sat}}\right)\cdot MW_q \tag{4.10.5}$$

$$\dot{m}_{q,geom} = C_P \cdot m_{P,q} \tag{4.10.6}$$

$\dot{m}_{F,eff}$	effective fuel mass flow, [kg/s]
$\dot{m}_{F,inj}$	effective fuel mass flow, injected part [kg/s]
$\dot{m}_{F,puddle}$	effective fuel mass flow, puddle part [kg/s]
$\dot{m}_F$	total injected mass flow, [kg/s]
X	injected mass distribution factor, part injected into puddle [-]
Q	total number of fuel-type packages, [-]
$\dot{m}_{q,evap}$	puddle fuel mass flow, evaporation part [kg/s]
$\dot{m}_{q,geom}$	puddle fuel mass flow, geometry part [kg/s]

$m_{P,q}$	mass of package q in the puddle , [kg]
C_P	puddle geometry tuning factor (default=3.0), [1/s]
C_G	puddle geometry multiplier, [-]
C_{evap}	evaporation rate multiplier, [-]
k_q	mass transfer coefficient of package q, [m/s]
A_P	puddle area, [m2]
ρ_g	molar density of the gas , [kmole/m3]
y_q	bulk (cell value) mole fraction of package q, [-]
$y_{q,sat}$	saturation mole fraction of package q, [-]
MW_q	molecular weight of package q, [kg/kmole]

4.10.6. Pipe Junction

Click on **Linear Acoustics** for relevant information.

For the junction of pipes three sub-models are available:

1. **Constant Pressure Model**

   Flow coefficients for flow to the junction and flow out of the junction must be specified explicitly by the user for each pipe attachment. The flow coefficients for the pipe attachments may be specified either as constant values or as functions of time in seconds, time in degrees crank angle or on the pressure difference at the pipe attachment. For in-flow (flow into the junction), the pressure difference is defined as the static pressure in the pipe minus the pressure at the junction, and for out-flow as the pressure at the junction minus the static pressure in the pipe.

   Refer to **Flow Coefficients** for details on standard values and directions.

> ☞ **Note:** This model corresponds to a plenum with zero volume. The momentum of flow into the constant pressure junction is lost.

2. **Constant Static Pressure Model**

   This junction model enforces the same static pressure in all pipe cross sections attached to the junction.

3. **Refined Model (Three-way Pipe Junctions)**

An accurate calculation model based on the equations for orifice flow is available. This model requires flow coefficients for each flow path in each possible flow pattern, which adds up to two times six flow coefficients. Figure 4-53 shows the qualitative trend of these flow coefficients versus the ratio of the mass flow in a single branch to the mass flow in the common branch for a joining flow pattern.

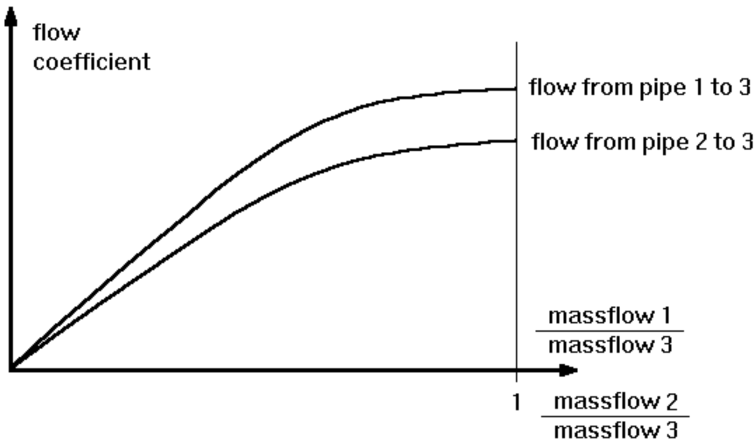


Figure 4-53: Flow Coefficients of a Junction

The actual values depend on the geometry of the junction, i.e. the area ratio and the angle between the pipes. **BOOST** interpolates suitable flow coefficients for the considered junction from a database (`RVALF.CAT`) delivered with the program.

The database contains the flow coefficients of six junctions, covering a wide range of area ratios and angles. The data was obtained from measurements on a steady state flow test rig. The file `RVALF.CAT` is a formatted ASCII file. The user may add measured flow coefficients for special junctions or for an extension of the catalogue.

The structure of the file is as follows:

```
MEASURED  0  30 1.3158 1.6900
11   0 0.7600 0.0000 0.2332 0.4385 0.6072 0.7400 0.8380 0.9032 0.9381 0.9462 0.9314 0.9029
12  30 0.5917 0.0000 0.1732 0.3530 0.5208 0.6624 0.7691 0.8375 0.8696 0.8727 0.8595 0.8490
21  30 1.6900 0.0000 0.0785 0.1517 0.2205 0.2859 0.3486 0.4087 0.4661 0.5202 0.5702 0.6192
22 150 1.2844 0.0000 0.0740 0.1430 0.2077 0.2690 0.3268 0.3807 0.4294 0.4712 0.5036 0.5418
31   0 1.3157 0.0000 0.1311 0.2565 0.3696 0.4696 0.5567 0.6315 0.6954 0.7507 0.8001 0.8241
33 150 0.7785 0.0000 0.1212 0.2297 0.3249 0.4061 0.4735 0.5271 0.5680 0.5972 0.6163 0.6351
41   0 1.3157 0.0000 0.1498 0.2997 0.4495 0.5133 0.5964 0.6811 0.7619 0.8453 0.9498 1.0800
42  30 1.6900 0.0000 0.1710 0.3420 0.5130 0.6099 0.7049 0.7894 0.8606 0.9216 0.9812 1.0400
51  30 0.5917 0.0000 0.0410 0.0831 0.1266 0.1720 0.2196 0.2698 0.3231 0.3795 0.4394 0.5023
52 150 0.7785 0.0000 0.0672 0.1290 0.1862 0.2394 0.2894 0.3366 0.3812 0.4234 0.4632 0.4944
61   0 0.7600 0.0000 0.0489 0.1006 0.1552 0.2135 0.2761 0.3439 0.4180 0.4995 0.5896 0.6862
62 150 1.2844 0.0000 0.1275 0.2319 0.3197 0.3952 0.4620 0.5226 0.5785 0.6304 0.6678 0.6959
S1   0 1.3157 0.6192 0.6892 0.7526 0.8059 0.8452 0.8687 0.8767 0.8720 0.8593 0.8456 0.8241
S2  30 1.6900 0.8241 0.8456 0.8593 0.8720 0.8767 0.8687 0.8452 0.8059 0.7526 0.6892 0.6192

CATALOGUE  0  90 1.6900 1.3158
11   0 0.5917 0.0000 0.2751 0.5096 0.6916 0.8227 0.9069 0.9510 0.9644 0.9643 0.9603 0.9496
12  90 0.7600 0.0000 0.1051 0.2158 0.3242 0.4236 0.5095 0.5796 0.6337 0.6739 0.7042 0.7380
21  90 1.3157 0.0000 0.0858 0.1615 0.2304 0.2943 0.3540 0.4098 0.4608 0.5055 0.5417 0.5715
```

```
22  90 0.7785 0.0000 0.1377 0.2595 0.3673 0.4626 0.5465 0.6196 0.6818 0.7328 0.7715 0.7985
31   0 1.3157 0.0000 0.0828 0.1701 0.2610 0.3545 0.4486 0.5403 0.6259 0.7006 0.7490 0.7705
32  90 0.7785 0.0000 0.0863 0.1697 0.2491 0.3241 0.3942 0.4589 0.5175 0.5691 0.6128 0.6575
41   0 1.6900 0.0000 0.1103 0.2298 0.3531 0.4760 0.5969 0.7167 0.8389 0.9698 1.1182 1.3000
42  90 1.3157 0.0000 0.1391 0.2488 0.3375 0.4121 0.4778 0.5385 0.5966 0.6532 0.7080 0.7520
51  90 0.7600 0.0000 0.0611 0.1255 0.1904 0.2538 0.3142 0.3708 0.4236 0.4730 0.5200 0.5609
52  90 1.2844 0.0000 0.1019 0.2085 0.3155 0.4192 0.5166 0.6054 0.6842 0.7523 0.8098 0.8446
61   0 0.5917 0.0000 0.0529 0.1057 0.1583 0.2112 0.2646 0.3193 0.3757 0.4349 0.4975 0.5619
62  90 0.7785 0.0000 0.0829 0.1565 0.2240 0.2874 0.3482 0.4075 0.4653 0.5213 0.5745 0.6217
S1   0 1.6900 0.5715 0.6028 0.6318 0.6617 0.6901 0.7149 0.7350 0.7501 0.7602 0.7665 0.7705
S2  90 1.3157 0.7705 0.7665 0.7602 0.7501 0.7350 0.7149 0.6901 0.6617 0.6318 0.6028 0.5715
```

The lines are described as follows:

1st line:

- **Measured**: The flow coefficients are used for a junction with the same area ratio and the same angle between the pipes.
- **Catalogue**: The flow coefficients are used for the interpolation of flow coefficients if no suitable measured flow coefficients are found. They are not used even if the specified junction in the data set exactly matches the junction from which the catalogue data was obtained.

Deflection angle for flow path 1 (a $\rightarrow$ c), flow pattern 1

Deflection angle for flow path 2 (a $\rightarrow$ b), flow pattern 1

Area ratio between pipe a and c

Area ratio between pipe b and c

2nd to 13th line:

The first two characters indicate the flow pattern and the flow path.

Deflection angle of the specific flow path

Area ratio between the pipe attachments upstream and downstream of the specific flow path

Flow coefficients for the mass flow ratio 0, 0.1, 0.2, 0.9, 1.0 between the flow in the specific flow path and the total mass flow through the junction.

14th and 15th line:

Additional flow coefficients for the special treatment of injector effects in flow pattern 4 (joining flow). These lines must be omitted if there is no flow against a pressure gradient.

4.11. Volume Elements

4.11.1. Plenum

Click on **Linear Acoustics** for relevant information.

A plenum is defined as an element in which spatial pressure and temperature differences are not considered. This means that the momentum of the flow in the plenum is neglected.

4.11.1.1. General

For **Geometry Definition** select **Volume** or **Diameter and Length**. Depending on the selection, specify the values respectively.

If a perforated pipe is contained in the plenum, the effective volume is calculated by subtracting the volume of the contained pipes from the specified one.

If **Wall Heat Transfer** is selected, input fields in the **Wall Heat Transfer** sub-group are activated (see section 4.11.1.5).

4.11.1.2. Connection Definition

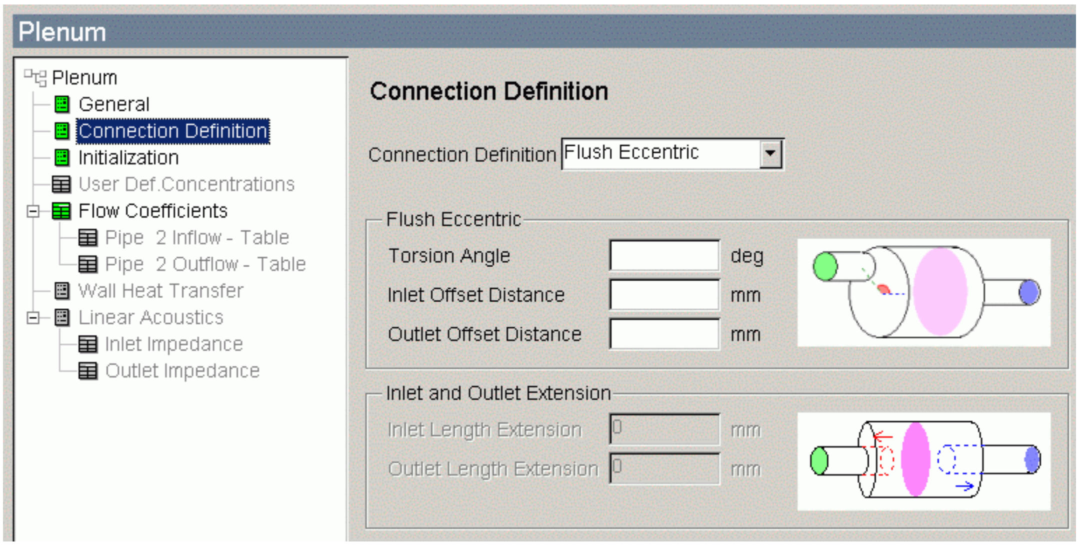


Figure 4-54: Plenum – Connection Definition Window

For **Connection Definition** select **Flush Eccentric**, **Inlet and Outlet Extension** or **None**. Depending on the selection, specify the values respectively.

4.11.1.3. Initialization

The initial conditions (pressure, temperature, gas composition and user-defined concentrations) must be specified for a plenum, as well as flow coefficients for each pipe attachment.

For General Species Transport the specification of mass fractions is possible by using the **Initialization Mass Fraction** window in **Simulation Control**.

4.11.1.4. Flow Coefficients

In order to consider particular pressure losses resulting from multi-dimensional flow phenomena which cannot be directly predicted by the program, **BOOST** requires the specification of flow coefficients for in-flow and out-flow at each pipe attachment. The flow coefficients are defined as the ratio between the actual mass flow and the loss-free isentropic mass flow for the same stagnation pressure and the same pressure ratio.

The flow coefficients for each pipe attachment may be specified either as constant values or in a **Table** as functions of time in seconds, time in degrees crank angle or pressure difference at the pipe attachment.

For in-flow (flow into the plenum) the pressure difference is defined as the static pressure in the pipe minus the pressure in the plenum. For out-flow as the pressure in the plenum minus the static pressure in the pipe. Refer to **Flow Coefficients** for details on standard values and directions.

4.11.1.5. Wall Heat Transfer

The specification of the plenum surface, the wall temperature and the heat transfer coefficient is required. The user may specify the heat transfer coefficient directly or use a simplified heat transfer model for plenums incorporated in **BOOST**. In this case, the calculated heat transfer coefficient may be increased or decreased by means of an **Amplification factor**.

In order to determine the transient wall temperature, the wall thickness of the plenums, its material properties and data describing the ambient of the plenum are required.

4.11.1.6. Chemistry

For a General Species Transport Calculation chemical reactions can be taken into account in the plenum. If activated, a chemistry set needs to be specified.

4.11.1.7. Perforated Pipe

Select to insert a perforated pipe in the plenum.

In addition to the standard input of the pipe, the perforation characteristics and those of the (automatically) generated transfer elements have to be specified. The effective flow area of the outer pipe is calculated from its cross section area by subtracting the area of the inner pipe.

Perforation Characteristics

Porosity and **Porosity Discharge Coefficient** for both flow directions, which determine the effective perforation flow area.

Perforation Hole Diameter and **Perforation Wall Thickness** which have influence on the inertia of the flow across the perforation. Porosity, Perforation Hole Diameter and Perforation Wall Thickness can be specified as functions of the location in the pipe in a **Table**:

They may be specified as a function of distance from the upstream pipe end. The first value must be specified at the upstream pipe end (Location = 0) and the last value at the downstream pipe end (Location = Length).

Transfer Elements

- **Plenum Boundary Anchors**
  If an outer pipe is attached to a perforated pipe in plenum a transfer element analogous to the **Flow Restriction** is created, otherwise one analogous to the **System Boundary** is attached.
- **Plenum Internal Anchors**
  If two perforated pipes are connected to the same internal anchor of the plenum a transfer element analogous to the **Flow Restriction** is created. A single perforated pipe connected to an internal anchor is a simple attachment to the plenum and only flow coefficients have to be specified. Refer to **Flow Coefficients** for details on standard values and directions.

In addition, input for the pipe ends is necessary. Four types of connection for a perforated pipe end are available as shown in the following figure:

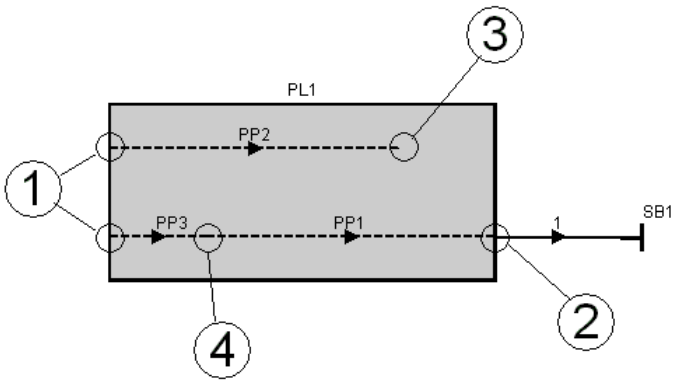


Figure 4-55: Perforated Pipes Contained in Plenum

1. If the pipe end is attached to the plenum boundary and there is no outside pipe connected to the same anchor: this results in the pipe end being connected to a system boundary. This system boundary will be automatically generated but not shown on the screen. Additional data for this system boundary has to be specified. The data for this system boundary can be input in the data window for the appropriate perforated pipe.
2. If the pipe end is attached to a plenum boundary and an outside pipe connects to the same anchor: This results in a connection via a restriction element between these two pipes. The restriction will be automatically generated but not shown on the screen. Additional data for this restriction has to be specified. The data for this restriction can be input in the data window for the appropriate perforated pipe.
3. If a single pipe end is attached to an anchor point inside the plenum: This results in a connection between the pipe end and the plenum. The flow coefficients for the inflow and outflow from this pipe have to be specified in the data window for the plenum.
4. If two pipe ends are attached to the same anchor point inside the plenum: This results in a connection via a restriction element between these two pipes. The restriction will be automatically generated but not shown. Additional data for this restriction has to be specified.

4.11.2. 3D Cell Elements

The required geometry input and the default Wall Heat Transfer surface for the different 3D Cell Types is:

General	Overall Volume	sum over all attachments of ((Attachment Circumference) *(Characteristic Length))
Sphere	Volume equivalent diameter	sum over all attachments of ((Attachment Circumference) *(3D Cell Diameter))
T-Right	Diameter and Length of the straight flow section	PI*Diameter*Length

Junction Type

The General 3D cell can also be sub divided into a pipe based junction model (Junction Type) or a volume based 3D cell intended for acoustic modeling (non Junction Type).

If the effective Wall Heat Transfer Surface differs from the Default Value the optional input can be enabled by selecting the related check box.

Friction

The laminar wall friction loss is calculated by means of the Laminar Friction Coefficient (Default Value according to Hagen-Poiseuille Law:64).

The turbulent wall friction loss is calculated by means of the Friction Coefficient. This can be either specified directly or via the specification of the Absolute Surface Roughness in combination with a Friction Multiplier. In this case the BOOST Solver calculates the Friction Coefficient based on Moody's diagram (see User Manual).

Heat Transfer

The calculation of the Gas/Wall Heat Transfer is based on a Nusselt number. For its definition BOOST offers several approaches. If Constant is chosen, the Heat Transfer Coefficient can be specified directly.

The Heat Transfer Factor enables the wall heat losses calculated from the wall and gas temperatures to be increased or reduced.

The Wall Temperature is either fixed or the initial one if Variable Wall Temperature is selected.

If Variable Wall Temperature is set, the wall temperature of the cell will change according to the heat balance between the heat flux from the gas-flow in the cell to the cell wall and the heat flux from the cell wall to the ambient. Additional information is required under the Variable Wall Temperature sub tree item.

For the detailed input requirement of the **Variable Wall Temperature** Functionality please refer to the section 4.2.6.

Initialization

The initial conditions (pressure, temperature, gas composition and user-defined concentrations) must be specified for a plenum, as well as flow coefficients for each pipe attachment.

For General Species Transport the specification of mass fractions is possible by using the **Initialization Mass Fraction** window in **Simulation Control**.

3D Cell General and Sphere Attachment Specification

For each 3D Cell Attachment the following input is required:

- **Angle X, Y and Z** between the Flow Attachment centerline and the Local X-, Y, and Z-Axis of the cell (see Figure below). The sign of the flow attachment centerline vector should be consistent (either towards the cell center or away from it) for all attachments.
- **Characteristic Flow Length** before a fluid particle entering the attachment hits the opposite cell wall or attachment opening (3D Cell General only).
- **Diameter** of characteristic flow cross-section to which fluid expands while entering the cell volume (3D Cell General only).

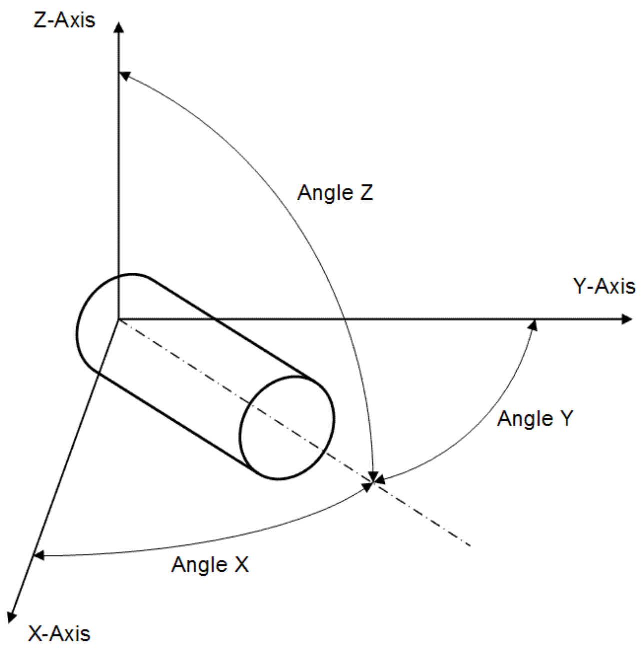


Figure 4-56: 3D Cell Attachment Angle specification

4.11.3. Variable Plenum

The variable plenum is similar to a standard plenum and in addition considers the change of the volume and surface area of the plenum over time. The user may specify the volume over time explicitly by selecting one of the following:

User-Defined	**BOOST** allows the volume and the surface area to be specified depending on time in seconds or on time in degrees crank angle. Zero volume is not allowed as input. If the Volume Work should be considered in the Engine AMEP the corresponding Check Box has to be selected.
Crankcase	The user must specify the number of the cylinder to which the defined crankcase is related. By specifying the geometrical crankcase compression ratio, which is defined as the volume of the crankcase with the piston at TDC divided by the volume of the crankcase with the piston at BDC, the geometrical definition of the crankcase is completed. For consideration of the wall heat transfer in a crankcase **BOOST** requires the specification of the minimum plenum surface area (piston at BDC), the wall temperature, and the heat transfer coefficient. Similar to the plenum data for the calculation of the energy balance of the variable plenum wall can be specified by the user. The heat transfer coefficient may be specified directly or a simplified heat transfer model for plenums incorporated in **BOOST** can be used.
Scavenging Pump	A scavenging pump is defined as a pumping cylinder which is directly actuated by the crankshaft. This means that the speed of the scavenging pump is equal to engine speed. For consideration of the power consumption of the scavenging pump the user must specify to which cylinder the scavenging pump is attached. The geometrical specifications of a scavenging pump cover the TDC delay relative to the attached cylinder, the bore and the stroke of the pumping cylinder as well as the con-rod length and the piston pin offset. The definition of the volume of the scavenging pump over crank angle is completed by the specification of the scavenging pump compression ratio, which is defined as the BDC volume divided by the TDC volume.

4.11.4. Perforated Pipe in Pipe

Click on **Linear Acoustics** for relevant information.

In addition to the standard pipe data for inner and outer **Pipe**, the following perforation data should be specified in the following window:

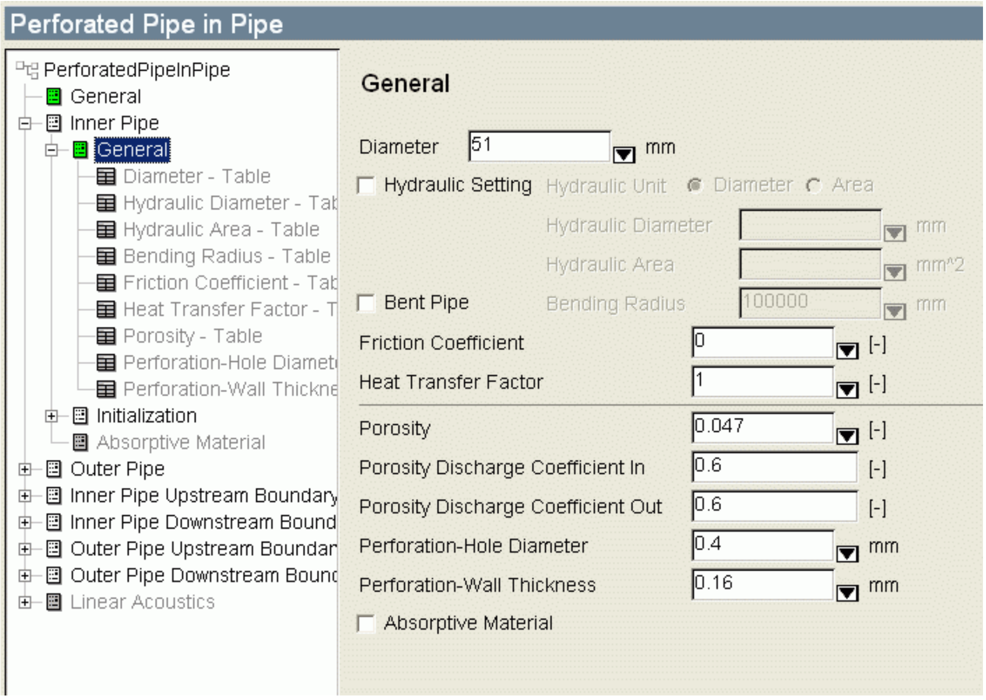


Figure 4-57: Perforated Pipe in Pipe Window

Porosity and Porosity Discharge Coefficient for both flow directions, which determine the effective perforation flow area.

Perforation Hole Diameter and Perforation Wall Thickness which have influence on the inertia of the flow across the perforation (Porosity, Perforation Hole Diameter and Perforation Wall Thickness can be specified pipe location dependent).

Heat transfer between the two pipes is not considered and the wall heat transfer dialog for the inner pipe is disabled.

Transfer Elements

If a pipe is attached to a perforated pipe anchor a transfer element analogous to the **Flow Restriction** is created, otherwise one analogous to the **System Boundary** is attached.

Note: The geometric outer pipe diameter (not the hydraulic one) should be input to give the effective flow area in the outer pipe. This is because the effective flow area of the outer pipe is calculated from its cross sectional area less the cross sectional area of the inner pipe.

4.12. Assembled Elements

4.12.1. Air Cleaner

BOOST automatically creates a more refined calculation model of a plenum-pipe-plenum type for the air cleaner. This is used to model the gas dynamic performance of the air cleaner as well as the pressure drop over the air cleaner depending on the actual flow conditions.

4.12.1.1. General

The input of the total air cleaner volume, the inlet and outlet collector volumes and the length of the filter element is required. It is important to note that the length of the cleaner pipe is also used to model the time a pressure wave needs to travel through the cleaner. The physical diameter of the cleaner pipe is calculated from the specified pipe volume ($V_{pipe} = V_{total} - V_{inlet\ collector} - V_{outlet\ collector}$) and the specified pipe length (length of filter element).

By default the hydraulic diameter in Equation 2.4.9 in the Theory Manual is identical with the physical diameter. By activating the **Hydraulic Settings** option the hydraulic diameter can be specified by the user directly or via the hydraulic area.

4.12.1.2. Friction

There are two options to specify the performance (pressure drop) of the air cleaner:

<u>Option 1: Target Pressure Drop</u>

The air cleaner pressure drop is specified by means of a reference mass flow, the target pressure drop (defined as the static pressure difference at the inlet and the outlet pipe attachment) at the reference mass flow and the inlet air conditions (temperature and pressure), Figure 4-58.

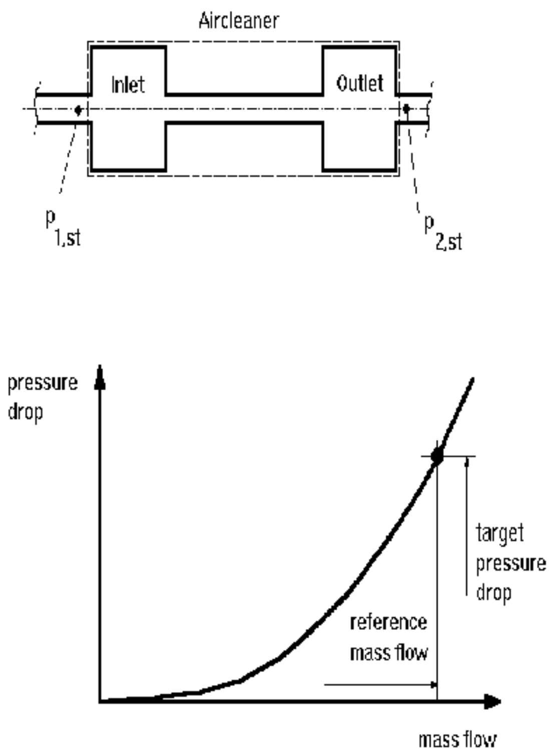


Figure 4-58: Steady State Air Cleaner Performance

On the basis of this information, the wall friction loss of the model is adjusted by the program.

<u>Option 2: Coefficient</u>

The pressure drop of the air cleaner is calculated using the specified values for laminar and turbulent friction coefficients and the specified hydraulic diameter of the pipe as described in section 2.4 of the Theory Manual.

4.12.1.3. Flow Coefficients

Particular flow resistances at the inlet to and at the outlet from the air cleaner can be considered. The flow coefficients for the pipe attachments may be specified as a function of time in seconds, time in degrees crank angle or pressure difference at the pipe attachment. For in-flow (flow into the air cleaner) the pressure difference is defined as the static pressure in the pipe minus the pressure in the air cleaner collector, and for out-flow as the pressure in the air cleaner collector minus the static pressure in the pipe. Refer to **Flow Coefficients** for details on standard values and directions.

4.12.2. Catalyst

Click on **Aftertreatment** or **Linear Acoustics** for relevant information.

As for the air-cleaner (refer to 4.12.1) **BOOST** automatically creates a more refined calculation model of the catalyst. This is used to model the gas dynamic performance of the catalyst as well as the pressure drop over the catalyst depending on the actual flow conditions.

4.12.2.1. General

☞ **Note:** The catalyst model in the **BOOST** cycle simulation can also be used in combination with chemical reactions. Please refer to the BOOST Aftertreatment Manual for additional information.

The input of the total catalyst volume (i.e. the monolith volume consisting of the gas and also the solid structure), the inlet and outlet collector volumes and the length of the monolith is required.

The specification of the honeycomb cell structure has a decisive effect on the pressure drop that is calculated for the catalyst:

- Square Cell Catalyst: The hydraulic diameter of the catalyst pipe is defined via a CPSI value and a wall and washcoat thickness.
- General Catalyst: The hydraulic diameter of the catalyst pipe is defined directly or via the hydraulic area of the catalyst front face (without solid part). The input of open frontal area (OFA) and geometric surface area (GSA) is relevant only if chemical reactions are active in this catalyst.

In order to simulate the chemical conversion behavior of the catalyst, activate the **Chemical Reactions** toggle switch in any case. Otherwise the catalyst is understood as flow element where only data about geometry and friction is required.

The basic geometry has to be defined by the following data:

		Typical Values and Ranges
Monolith Volume	Determines the volume of the monolith in comprising both, the volume of the gas phase and the solid substrate.	1–10 (dm^3)
Length of Monolith	Determines the length of the monolith.	1–0.5 (m)
Inlet Collector Volume	Determines the volume of the inlet cone. This information is only required for the Cycle Simulation task.	1 (dm^3)
Outlet Collector Volume	Determines the volume of the inlet cone. This information is only required for the Cycle Simulation task.	1 (dm^3)

4.12.2.2. Type Specification

The cell structure of the monolith can either be defined assuming **Squared Cell Catalysts** in a simplified way or within any geometrical assumptions for **General Catalysts**.

If **Square Cell Catalyst** is selected, the following input data has to be defined:

		Typical Values and Ranges
Cell density (CPSI)	Determines the type of monolith using the number of channels per in^2.	100–900(1/in²)
Wall Thickness	Determines the thickness of the monolith's walls.	0.006–0.015 (in)
Washcoat Thickness	Determines the thickness of the washcoat.	0–0.003 (in)

If **General Catalyst** is selected, the following input data has to be defined:

		Typical Values and Ranges
Open Frontal Area (OFA)	Determines the open frontal area (= fluid volume fraction) of monolith.	0.50–0.75 (-)
Hydraulic Diameter (Hydraulic Area)	Determines the hydraulic unit or (diameter or area) of the monolith channels.	0.001–0.005 (m)
Geometric Surface Area (GSA)	Determines the geometric surface area. This surface is used for heat and mass transfer between the gas and the solid phase.	1500–4000 (m^2/m^3)

4.12.2.3. Friction

The friction of the catalytic converter model can either be specified by **Target Pressure Drop** or by a friction **Coefficient**. If the catalyst is simulated in the aftertreatment analysis mode only the specification of a friction coefficient can be used. For the case of a standard BOOST cycle simulation both input variants can be used.

If **Target Pressure Drop** is selected, the following data is required:

		Typical Values and Ranges
Inlet Mass Flow	Determines the inlet mass flow, as reference value for the evaluation of a friction coefficient.	0 (kg/s) depends on the catalyst size
Inlet Temperature	Determines the inlet temperature, as reference value for the evaluation of a friction coefficient.	300 (K)

Inlet Pressure	Determines the inlet pressure, as reference value for the evaluation of a friction coefficient.	1 (bar)
Target Pressure Drop	Determines the pressure drop the element, as basis for the evaluation of a friction coefficient.	0.003 (bar)

If **Coefficient** is selected, the following input data is required:

		Typical Values and Ranges
Laminar Coefficient a	Determines a laminar friction coefficient according to Equation (23) in the Aftertreatment Manual.	64 (-)
Laminar Coefficient b	Determines a laminar friction coefficient according to Equation (23) in the Aftertreatment Manual.	-1 (-)
Turbulent (Friction Coefficient)	Determines a turbulent friction coefficient. The friction coefficient can be specified as constant or table value (see typical values below). The latter value is defined as a function of the monolith length.	0.01–0.04 (-)
Friction Multiplier **Channel Shape**	Determines a dimensionless factor that considers the influence of the channel shape in the case of laminar flow. The multiplier either can be chosen for different channel geometries (see section 3.4 of the Aftertreatment Manual) or setup completely free.	0.04–1 (-)

There are two options to specify the performance (pressure drop) of the catalyst:

<u>Option 1: Target Pressure Drop</u>

Please see section 4.12.1.1 for details.

<u>Option 2: Coefficient</u>

The pressure drop of the catalyst is calculated as described in section 2.4 of the Theory Manual using the specified values for

- laminar friction coefficients (Coefficient a only, Coefficient b cannot be changed in gas-exchange simulations),
- turbulent friction coefficient (Turbulent) and
- friction multiplier (Channel Shape)

in combination with the hydraulic diameter of the pipe.

4.12.2.4. Flow Coefficients

Please see section 4.12.1.3.

4.12.3. Air Cooler

BOOST automatically creates a more refined calculation model of the air cooler (plenum-pipe-plenum). This is used to model the gas dynamic performance of the air cooler as well as the pressure drop over the air cooler depending on the actual flow conditions. In addition, a model for the cooling performance of the air cooler is created based on the layout data.

4.12.3.1. General

Please refer to section 4.12.1.1.

4.12.3.2. Pressure Drop Performance

Please refer to section 4.12.1.2.

4.12.3.3. Cooling Performance

There are three options to specify the cooling performance:

Option 1: Target Efficiency

The cooling performance is specified by the coolant temperature and the target efficiency.

The cooler efficiency is defined as the achieved temperature difference related to the maximum possible temperature difference:

$$\eta_c = \frac{T_{in} - T_{out}}{T_{in} - T_{cool}} \tag{4.12.1}$$

η_c cooler efficiency

T_{in} inlet temperature

T_{out} outlet temperature

T_{cool} coolant temperature

On the basis of this information, the heat transfer in the pipe modeling the cooling core are adjusted by the program.

Option 2: Target Outlet Temperature

The cooling efficiency is calculated using by the specified coolant temperature and the target outlet temperature.

Option 3: Heat Transfer Factor

This option allows direct specification of the heat transfer multiplier in the cooler pipe.

4.12.3.4. Flow Coefficients

Please see section 4.12.1.3.

4.12.4. Diesel Particulate Filter (DPF)

Click on **Aftertreatment** or **Linear Acoustics** for relevant information.

As for the air cleaner (refer to 4.12.1) **BOOST** automatically creates a more refined calculation model of the DPF. This is used to model the gas dynamic performance of the DPF as well as the pressure drop over the DPF depending on the actual flow conditions.

> **Note:** The DPF model in the **BOOST** cycle simulation is a purely gas dynamic model and does not include chemical reactions. Chemical reactions can be simulated using the aftertreatment analysis mode (refer to the BOOST Aftertreatment Manual).

4.12.4.1. Geometrical Properties

The input of the total DPF volume consisting of the gas and the solid volume fraction, the inlet and outlet collector volumes in conjunction with the length of the monolith is required.

The specification of the cell structure has a decisive effect on the pressure drop that is calculated for the DPF:

- Square Cell DPF: The hydraulic diameter of the DPF pipe is defined via a CPSI value and a wall thickness. The asymmetrical channel diameters option is not available for gas-exchange simulations.
- General DPF: The hydraulic diameter of the DPF pipe is defined directly or via the hydraulic area of the DPF front face (without sold part). The input of open frontal area (OFA) and geometric surface area (GSA) is relevant only if chemical reactions are active in this DPF.

There are two options to specify the performance (pressure drop) of the DPF:

Option 1: Target Pressure Drop

Please see section 4.12.1.1 for details.

Option 2: Coefficient

The pressure drop of the catalyst is calculated as described in section 2.4 of the Theory Manual using the specified values for the turbulent friction coefficient and the friction multiplier (Channel Shape) in combination with the hydraulic diameter of the pipe.

For the simulation of particulate filters ( ) the same input procedure is required as described for the catalytic converter. This means that run information, definitions of the gas and also solid species and boundary conditions have to be supplied by the user. The specification of the particulate filter itself also follows the input concept of the catalytic converter presented in Section 4.12.2. Thus, in the following section, only filter specific input data is explained.

4.12.5. Type Specification

If **Square + Asymmetric Cell DPF** is selected, the following input data has to be defined:

		Typical Values and Ranges
Cell density (CPSI)	Determines the number of channels per in^2.	100–900(1/in²)
Wall Thickness	Determines the thickness of the monolith's walls.	0.006–0.015 (in)
Enable Asymmetrical Channel Diameters	Enable the specification of filters with different diameters for the inlet and outlet channel.	
Ratio of Channel Diameters	Determines the diameter ratio of inlet to outlet channel	1-1.4(-)

If **Simplified Square Cell DPF** is selected, the following input data has to be defined:

		Typical Values and Ranges
Open Frontal Area (OFA)	Determines the open frontal area (= fluid volume fraction) of monolith (ε).	0.50–0.75 (-)
Hydraulic Unit	Determines the hydraulic unit or (diameter or area) of the monolith channels.	0.001–0.005 (m)

4.12.5.1. Flow Coefficients

Please see section 4.12.1.3.

4.13. Charging Elements

4.13.1. Turbocharger

Two types of turbocharger models are available: Simplified Model and Full Model.

4.13.1.1. Simplified Model

This model is only suitable for steady state simulations. **BOOST** considers the mean compressor and turbine efficiencies over the cycle in order to calculate the turbocharger energy balance. The advantage of this model is that it only requires limited data to describe the turbocharger performance characteristics. Furthermore, this model provides three modes for the turbocharger simulation:

Boost pressure calculation	The boost pressure is calculated from the specified turbine size and turbocharger efficiency.
Turbine layout calculation	The required turbine size is calculated from the target pressure ratio across the compressor and the turbocharger efficiency by adopting the turbine size multiplier.
Waste-gate calculation	The waste-gate mass flow is calculated from the target pressure ratio across the compressor, the turbocharger efficiency and the specified turbine size. If the target pressure ratio cannot be achieved even with the waste-gate closed, the boost pressure which can be achieved will be calculated from the specified turbine size.

Input data and calculation result relative to the turbocharger mode are shown in the following table:

	Boost Pressure	Turbine Layout	Waste Gate
Turbine size multiplier	input	result	input
Compressor pressure ratio	result	input	input
Turbine to total mass flow rate	input	input	result

The **Calculation mode** is accessible by the case explorer via a parameter assignment. The **Mechanical Efficiency** account s for mechanical losses of the rotor.

Beside the **Pressure Ratio** the **Compressor Efficiency** needs to be input, which can be either a constant or dependent on Corrected Volume/Mass Flow. For this dependency the input of **Reference Conditions** is additionally required. The compressor efficiency can be taken from the compressor performance map using the expected pressure ratio and compressor mass flow data.

The following Flow Types are available to specify the swallowing capacity of the Turbine:

- **Discharge Coefficient**
- **Corrected Mass Flow**
- **Corrected Volume Flow**

I case of selected **Discharge Coefficient** Type the effective flow area of the turbine is calculated from the equivalent discharge coefficient (constant or function of turbine expansion ratio) and a turbine reference area The **Turbine Reference Area** can either be directly input or is calculated from the cross-section of the pipe representing the turbine outlet and the **Pipe Area Scaling Factor**.

I case of selected **Corrected Mass Flow** or **Corrected Volume Flow** Type the input **Reference Conditions** is required. If no expansion ratio dependency for Corr. Mass/Volume Flow is selected the constant input value is assumed to be at the Reference **Pressure Ratio**.

The conversion of the swallowing capacity taken from the turbine map at a certain pressure ratio to an effective flow area is done with Equation 4.13.1:

$$A_{eff} = \left(\frac{\dot{m}\sqrt{To}}{po} \right) \cdot \sqrt{\frac{R}{2}}\ \psi^{-1} \tag{4.13.1}$$

A_{eff}	effective flow area
$\frac{\dot{m}\sqrt{To}}{po}$	swallowing capacity
R	gas constant
ψ	pressure function

The pressure function ψ is evaluated at the pressure ratio at which the effective flow area is to be determined. Typical values for the gas constant R and the ratio of specific heats of combustion gases are 287 J/kgK and 1.36 respectively. When evaluating the pressure function ψ it must be observed whether the pressure ratio is supercritical. In this case, $\psi_{\max}$ must be used instead of ψ.

To determine the swallowing capacity from an effective turbine flow area obtained by a turbine layout calculation, Equation 4.13.1 must be solved for $\frac{\dot{m}\sqrt{To}}{po}$.

The **Turbine Size Multiplier** is applied to determine the final swallowing capacity.

The **Turbine Efficiency** can either be specified directly (constant or as a function of the turbine expansion ratio) or by means of the **Turbocharger Overall Efficiency** which is the product of compressor efficiency, turbine efficiency and mechanical efficiency. The turbine efficiency can be taken either from a full turbine operating map (if available), or from any equivalent information provided by the turbocharger supplier

For twin entry turbines and multiple entry turbines, the reduction of the turbine efficiency due to the unequal flow distribution at unequal pressure ratios across the flows is taken into account by a reduction of the turbine efficiency. Figure 4-59 shows the factor by which the turbine efficiency is multiplied depending on the pressure ratio between the flows.

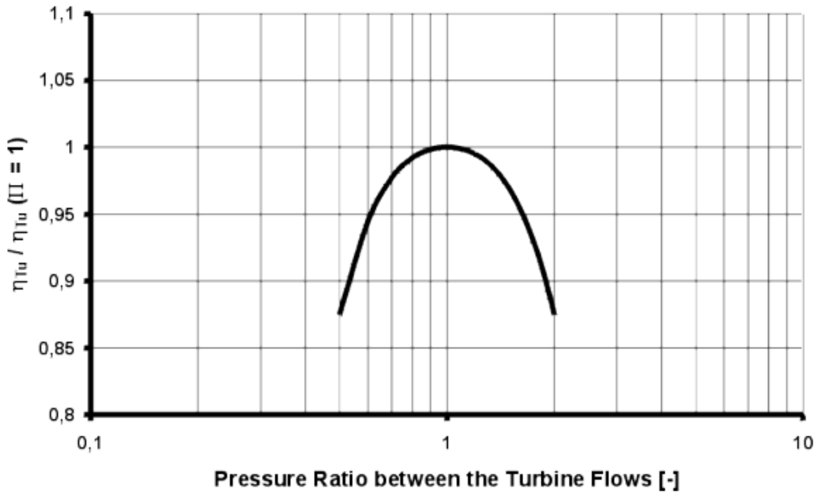


Figure 4-59: Deterioration Factor of a Twin Entry- or Multiple Entry Turbine

☞	**Note:** The turbine efficiency output in the global results or in the transients is the mass flow weighted average of the calculated efficiency over one cycle.

For the **BOOST Pressure Calculation** the **Pressure Ratio** at the compressor only represents an initial value for the start of the calculation. Similarly, the **Turbine Size Multiplier** only represents an initial value for the **Turbine Layout Calculation** and the **Turbine to Total Massflow** an initial value for the **Waste Gate Calculation**.

In the case of a **twin entry turbine** or a **multiple entry turbine**, an inlet flow coefficient must be specified in order to describe the interference between the attached pipes. The inlet interference flow coefficient is related to the cross-section of the pipe representing the turbine inlet. For radial type turbines, an inlet interference flow coefficient of `0.2` is recommended and for axial type turbines a value of `0.05` is recommended.

The attachment type of each pipe (compressor inlet/outlet, turbine inlet/outlet) is known from the sketch of the model and can be checked in the **Pipe Attachments** sub-group. If it needs to be changed, reattach the pipes to the correct side of the turbocharger.

4.13.1.2. Full Model

Mechanical Efficiency	The ratio between the torque available at the compressor end of the driveshaft related to the driving torque of the turbine. It may be defined as a function of the turbocharger wheel speed by means of a **Table** ▼.
Moment of Inertia	The MOI related to the compressor drive shaft may be specified in different units using the pull down menu.
Initial Speed	As an option the setting of the initial rotor speed is available. If not selected the intersection of initial compressor pressure ratio with the surge line is used for initialization.

This model requires the input of the entire compressor and the entire turbine map.

4.13.1.2.1. Compressor

For the specification of the compressor map points with the following data has to be input by the User:

Corrected compressor speed

Corrected mass flow or volume flow

Pressure ratio across the compressor (total to total)

Isentropic compressor efficiency (total to total)

Corrected Speed	The compressor speed related either to the square root of the inlet temperature (if **No Reference** is set) or related to the square root of the ratio of the reference temperature to the inlet temperature (if **Reference** is set). In any of the two cases the suitable unit has to be set with the pull down menu.
Corrected Mass Flow	The mass flow through the compressor times the square root of the entry temperature divided by the inlet pressure. If a reference condition is specified it is the ratio between the entry conditions and the reference conditions to which the mass flow is related.
Corrected Volume Flow	Similar to mass flow, the volume flow at the entry divided by the square root of the entry temperature.
Massflow Scaling Factor	The x-axis of the compressor map may be scaled.
Efficiency Offset	The compressor efficiencies specified may be modified additively.
Reference Conditions	In any case the pressure and temperature have to be defined together with the units by the User.

1. **Map Specification**

   There is no need to stick to a specific order although it is recommended that the points defined by the user cover the complete range of operating conditions during the planned simulation runs. If it turns out that the operating point of the compressor lies outside the defined range the values calculated by the interpolation algorithm should be checked carefully by the user.

   Different **Map Extrapolation** levels can be selected and for the identification of Iso Speed Lines an **Iso Speed Tolerance** greater than 0 can be specified.

   The “Iso_Speed_Bi_Linear” extrapolation method is intended for external prepared Map Data with should cover the entire operating range (no extrapolation performed). Because of the underlying bi-linear interpolation a high density of Iso-Speed Lines is recommended.

   A preview of the extrapolated maps is available by selecting **View Maps**. For control purposes of compressor map input the efficiency can be displayed versus massflow (or volume flow) and pressure ratio in **IMPRESS Chart**. In an additional layer input values are compared to the interpolated ones.

   Show Fringe displays the efficiency as waterfall plot, while the option **Show Isolines** adds iso-efficiency lines to the diagram. They can be tuned with **Efficiency minimum**, **Efficiency maximum** and **Efficiency increment**.

   The resolution of the map can be defined via the **Accuracy selector**, while the **Massflow Factor** and **Press Ratio Factor** multipliers enlarge the displayed map range.

   For already performed simulations related cases can be selected for visualization. Operating Line plots of the Compressor Performance (cycle resolved Traces and cycle averaged Series results) are then also available in separate layers of **IMPRESS Chart** which can be saved and used for reports afterwards.

   The **User Defined Map Parameters** can be used to supply the boost calculation kernel with additional input information. Therefore a Parameter Key and a corresponding Value has to be specified. For more information about this feature please contact boost_support@avl.com.

2. **Surge Line**

   This limits the stable operating range of the compressor to the left side. The operation of the compressor in the regime of the compressor map for longer durations should be avoided.

In the compressor map, iso speed lines (pressure ratio versus mass or volume flow) and lines of constant isentropic efficiency are plotted. The map is limited to the left side by the surge line. Beyond this line the mass flow through the compressor becomes unstable and the compressor will be destroyed if operated too often in this area.

On the right side the map is limited by choked flow either through the compressor wheel or the diffuser. This is indicated by the steep gradient of the iso speed lines, see the following figure.

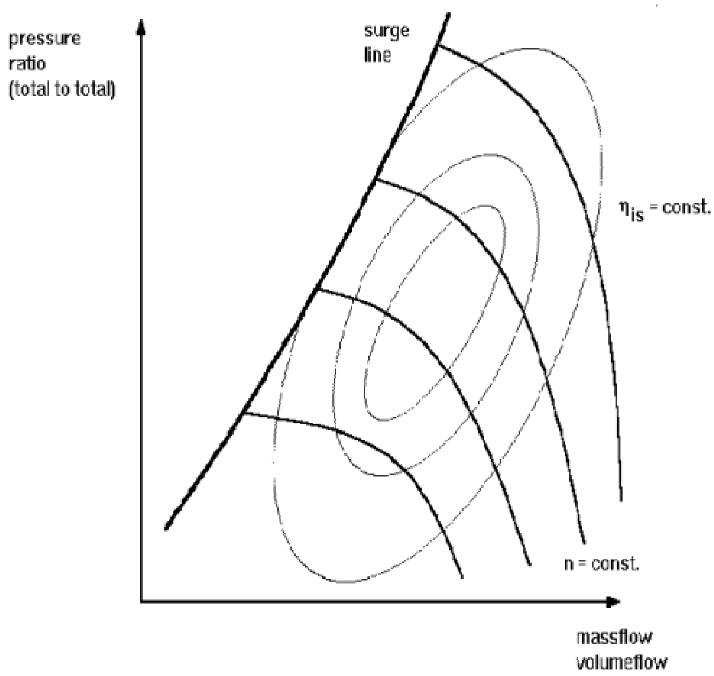


Figure 4-60: Compressor Map

Before the map can be input, the unit of the wheel speed and the x-axis of the map must be set. They may be related to a reference condition defined in the box. The suitable units may be selected from the list. For the specification of the compressor map points defined by the mass or volume flow, the pressure ratio, the wheel speed and the isentropic efficiency must be input by the user.

In addition the x-axis of the compressor map can be scaled with the mass flow scaling factor and the efficiencies modified additively by the efficiency offset.

4.13.1.2.2. Turbine

The following turbine types are available for defining the turbine performance map:

Single entry

Single entry - Variable Turbine Geometry (VTG): For each vane position a map must be defined.

Twin entry - simplified model: Only one map is specified. The map is measured with the same pressure ratio across both flows of the turbine. The interaction between the flows can be modeled by the definition of a suitable inlet interference coefficient.

Twin entry - full model: For each ratio of the total pressures at the turbine entry, a map containing the swallowing capacity of the two flows must be specified.

Twin entry – VTG - simplified model: For a twin entry VTG only the simplified model is available.

Multiple entry - simplified model: Only one map is specified. The map is measured with the same pressure ratio across all flows of the turbine. The interaction between the flows can be modeled by the definition of a suitable inlet interference coefficient.

Multiple entry – VTG - simplified model

The vane position must be set for VTG's.

For each position of the VTG a map is defined. In order to take into account the interaction of the two flows of the turbine an **Interference Coefficient** is input.

For the specification of the turbine map, points with the following data at each map point have to be input by the User:

Corrected turbine speed

Corrected mass flow or
Volume flow or
Discharge coefficient (together with the reference area in the unit selected by the pull down menu)

The Isentropic turbine efficiency (total to static) may be defined either versus the pressure ratio across the turbine together with the swallowing capacity or it may be defined separately versus the blade speed ratio. If it is defined versus blade speed ratio the outer wheel diameter has to be input as well together with its unit. The input windows of the maps are accessed in the 'Turbine->Performance Maps' sub-group (also if a Twin Entry Model is selected or a VTG Model is selected). The number of maps for a VTG Model is modified by pressing the buttons 'Insert Performance Map' and 'Remove Performance Map'.

In a turbine map (Figure 4-61) the swallowing capacity is plotted versus the pressure ratio across the turbine with the wheel speed as parameter. The isentropic efficiency can be plotted in the same way or it can be plotted versus the blade speed ratio. **BOOST** supports the input of both map types. The suitable units for the definition of the swallowing capacity and the reference conditions can be selected from predefined lists. Similar to the compressor map, the data for the definition of each point in the map must be input by the user. For each map a mass flow scaling factor allows the user to scale the swallowing capacities specified and an efficiency offset to modify the efficiencies additively.

For steady state simulations, an internal boost pressure control may be activated. For fixed geometry turbines an internal waste-gate is simulated, similar to the simplified model. For turbines with variable geometry, the vane position is determined. Select **Internal Wastegate Simulation / Determination of vane position** to activate the **BOOST** pressure control. The user must specify the target compressor pressure ratio and the initial value for the turbine to total massflow ratio (fixed geometry turbine only) in this case.

☞ **Note:** It is assumed that vane position 0 is the fully closed position and vane position 1 is the fully open position.

In addition to the maps, the total inertia of the turbocharger wheel together with the setting of the unit and the mechanical efficiency of the turbocharger must be defined.

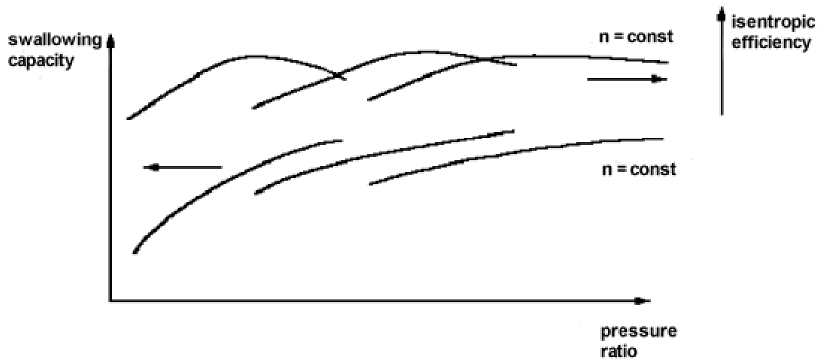


Figure 4-61: Turbine Map

Performance Maps

Different Map Extrapolation levels can be selected and for the identification of Iso Speed Lines a Iso Speed Tolerance greater than 0 can be specified.

The “Iso_Speed_Lines” extrapolation method allows input of optional Performance Map Fitting Coefficients. They are usually determined by an optimization algorithm and displayed in the info section of the **View Curves...** window. If this procedure does not lead to a sufficient result the values are made available for input by clicking on the Check Box.

The “Iso_Speed_Bi_Linear” extrapolation method is intended for external prepared Map Data with should cover the entire operating range (no extrapolation performed). Because of the underlying bi-linear interpolation a high density of Iso-Speed Lines is recommended.

For the Massflow Fit the following coefficients are available:

- Massflow-BSR Factor: This Factor influences the gradient of an iso speed line for pressure ratios above the one of efficiency optimum (Typical Range: 1.02-1.15).
- Massflow-BSR Exponent: This Exponent influences the massflow decrease for increasing turbine speed (Typical Range: 3.0-4.0).

For the Efficiency Fit the following coefficients are available:

- Efficiency-BSR Factor: This Factor influences the efficiency decrease for Pressure Ratios below the one of efficiency optimum (Typical Range: 1.2-2.0).
- Efficiency-BSR Exponent: This Exponent influences the efficiency decrease for Pressure Ratios above the one of efficiency optimum (Typical Range: 1.5-3.0).
- Efficiency-BSR Optimum Multiplier: This Multiplier shifts the Pressure Ratio of efficiency optimum (Typical Range: 0.8-1.2).
- Efficiency Correction Range: This value specifies the range for which a Correction Spline Function is introduced so that the efficiency Input values are perfectly matched (Typical Range: 5-10). This should be done after adapting the other coefficients first.

For control purposes of turbine map input the iso-speed lines for massflow (volume flow or discharge coefficient) and efficiency can be displayed in **IMPRESS Chart** by using the **View** button. In an additional layer input values are compared to the interpolated ones.

The resolution of the curves can be defined via the **Accuracy selector**, while the **Speed Factor** and **Press Ratio Factor** multipliers enlarge the displayed curve range.

For already performed simulations related cases can be selected for visualization. Operating Line plots of the Turbine Performance (cycle resolved Traces and cycle averaged Series results) are then also available in separate layers of **IMPRESS Chart** which can be saved and afterwards used for reports.

The **BOOST** pre-processor features an import filter for digital compressor and turbine maps as ASCII-files according to SAE standard J1826, Turbocharger Gas Stand Test Code, SAE – March 1995

The format of the files is:

Compressor:

Line 1:	Description (supplier, model name, compressor nomenclature, reference test number) A15, A10, A20, A10
Line 2:	Inlet diameter (mm), outlet diameter (mm), inlet type, outlet type, impeller inertia (N*m*s²) F10, F10, A15, A15, F10)
Line 3, 4, 5:	Additional comments (can be left blank) A80
Line 6 – N:	Corrected speed (rpm), corrected mass flow (kg/s), pressure ratio (T-S), efficiency (decimal) F10, F10, F10, F10

☞ **Note:** Corrected mass flow rates and speeds are listed in ascending order.

The following table shows an example

```
supplier     model     compressor name    ref. #
    30.000    40.000     inlet type    outlet type    0.0011
comment 1
comment 2
comment 3
20000         0.006         1.075         0.4
20000         0.025         1.05          0.42
40000         0.009         1.12          0.3
40000         0.05          1.02          0.5
80000         0.0368        1.3           0.65
80000         0.0515        1.26          0.7
80000         0.0632        1.233         0.7
80000         0.0794        1.15          0.65
100000        0.0368        1.5           0.65
100000        0.05          1.475         0.7
100000        0.1           1.26          0.65
120000        0.0441        1.74          0.65
120000        0.1           1.577         0.77
120000        0.125         1.38          0.65
140000        0.0574        2.04          0.65
140000        0.0735        2.01          0.7
```

Turbine:

Line 1:	Description (supplier, model name, turbine nomenclature, reference test number) A15, A10, A20, A10
Line 2:	Test compressor, housing type, discharge connection description A20, A20, A20
Line 3:	Inlet gas temperature (°C) or turbine inlet-to-compressor discharge temperature ratio (K/K), oil type, oil temperature (°C), rotor/shaft inertia ($N*m*s^2$) F10, A10, F10, F10
Line 4:	Cooling liquid description (if any), inlet temperature (°C), inlet pressure (kPa) A20, F10, F10
Line 5, 6, 7:	Additional comments (can be blank) A80
Line 8 – N:	Speed parameter (rpm/SQRT(K)), mass flow parameter (kg*SQRT(K)/(s*kPa)), expansion ratio (T-S), turbine x mechanical efficiency (decimal) F10, F10, F10, F10

☞ **Note:** Expansion ratios and speeds are listed in ascending order.

The following table shows an example

```
supplier     model        turbine name    ref. #
     test compressor        housing type   discharge connect.
    800.00   oiltype   100.000    0.0011
      cooling liquid   120.000   1500.00
comment 1
comment 2
comment 3
44000         4.33            1.5                 0.52
44000         4.47            1.54                0.53
44000         4.53            1.58                0.53
55000         4.8             1.71                0.52
55000         5               1.8                 0.54
55000         5.07            1.88                0.53
66000         5.2             2.02                0.52
66000         5.4             2.15                0.54
66000         5.53            2.28                0.55
```

The **User Defined Map Parameters** can be used to supply the boost calculation kernel with additional input information. Therefore a Parameter Key and a corresponding Value has to be specified. For more information about this feature please contact boost_support@avl.com.

The following table gives an overview about the usage of the different models and their modes together with the external waste gate element for steady state and transient simulations:

	Full model		simplified model		
			boost pressure	turbine layout	waste gate
	With internal boost pressure control	Without internal boost pressure control	calculation mode		
Steady state					
Without waste gate element	Yes	Yes	Yes	Yes	Yes
With waste gate element	No	Yes	Yes	No	No
Transient					
Without waste gate element	No	Yes	No	No	No
With waste gate element	No	Yes	No	No	No

4.13.2. Turbine

4.13.2.1. Simplified Model

The **Simplified Model** allows the user to specify an operating point, defined by the turbine massflow, volume flow, or Equivalent Discharge Coefficient, and the isentropic efficiency, irrespective of the actual conditions at the turbine. As an alternative an iso-speed line may be defined by the user. This model should be used for steady state simulations only.

For the simulation of a mechanically linked turbine, AVL BOOST requires the specification of the performance characteristics of the turbine along a line of constant turbine speed, the specification of the Mechanical Efficiency, which pipes are attached to the inlet and to the outlet of the turbine, and to which component the turbine is mechanically linked.

The Corrected Mass Flow, Corrected Volume Flow or Equivalent Turbine Discharge Coefficient and the Isentropic Efficiency may be specified versus Turbine Pressure Ratio for a line of constant turbine speed. For a simplified approach, also constant values for these values may be specified.

For the Flow Type Equivalent Turbine Discharge Coefficient a related Reference Area is required, while for Corrected Mass Flow and Corrected Volume Flow Reference Conditions have to be specified.

The Mechanical Efficiency covers mechanical friction losses of the turbine wheel.

In the case of a twin-entry turbine, an Inlet Interference Flow Coefficient has to be specified in order to describe the interference between the attached pipes. The inlet interference flow coefficient is related to the cross section of the actual pipe modeling the turbine inlet. For radial type turbines an inlet interference flow coefficient of 0.2 and for axial type turbines a value of 0.05 is recommended.

A simplified Waste Gate Calculation can be performed by specifying a Turbine Massflow to Total ratio less than 1.

4.13.2.2. Full Model

The **Full Model** allows the user to specify a full map of the turbine. The instantaneous operating point will be calculated from the turbine speed (determined from the mechanically linked component) and the conditions at the turbine in- and outlet.

The following turbine types are available for defining the turbine performance map:

Single entry

Single entry - Variable Turbine Geometry (VTG): For each vane position a map must be defined.

Twin entry - simplified model: Only one map is specified. The map is measured with the same pressure ratio across both flows of the turbine. The interaction between the flows can be modeled by the definition of a suitable inlet interference coefficient.

Twin entry - full model: For each ratio of the total pressures at the turbine entry, a map containing the swallowing capacity of the two flows must be specified.

Twin entry – VTG - simplified model: For a twin entry VTG only the simplified model is available.

Multiple entry - simplified model: Only one map is specified. The map is measured with the same pressure ratio across all flows of the turbine. The interaction between the flows can be modeled by the definition of a suitable inlet interference coefficient.

Multiple entry – VTG - simplified model

The vane position must be set for VTG's.

In a turbine map the swallowing capacity is plotted versus the pressure ratio across the turbine with the wheel speed as parameter. The isentropic efficiency can be plotted in the same way or it can be plotted versus the blade speed ratio. **BOOST** supports the input of both map types. The suitable units for the definition of the swallowing capacity and the reference conditions can be selected from predefined lists. Similar to the compressor map, the data for the definition of each point in the map must be input by the user. For each map a mass flow scaling factor allows the user to scale the swallowing capacities specified and an efficiency offset to modify the efficiencies additively.

Map Visualization

For details please refer to the corresponding section of the Turbocharger Turbine (section 4.13.1.2.2).

4.13.3. Turbo Compressor

For the simulation of a mechanically driven turbo-compressor, **BOOST** requires the specification of the mechanical efficiency, the specification of the performance characteristics of the turbocompressor along a line of constant compressor speed (**Simplified Model**) or the full map similar to the map of the compressor of a turbocharger (**Full Model**) refer to Figure 4-60.

4.13.3.1. Simplified Model

Using the Simplified Model the pressure ratio and the isentropic efficiency may be specified over the corrected mass flow or over the corrected volume flow for a line of constant turbo-compressor speed (**Table** ▼). For a simplified approach, constant values of pressure ratio and isentropic efficiency may also be specified.

The corrected volume flow is defined as the actual volume flow multiplied by the square root of the ratio between reference and actual air inlet temperature.

The corrected mass flow is defined as the actual mass flow multiplied by the square root of the ratio between inlet and reference inlet air temperature, and the ratio between reference and actual air inlet pressure.

To match the actual calculated flow characteristics to the corrected volume or mass flow data, **BOOST** requires the specification of the reference temperature and reference pressure related to the correct flow data. They must be taken from the performance maps provided by the supplier.

In order to facilitate the input of operating maps provided by various hardware suppliers, **BOOST** allows the selection of the most suitable dimensions.

The attachment type of each pipe (inlet/outlet) is known from the sketch of the model and can be checked in the **Pipe Attachments** sub-group.

4.13.4. Positive Displacement Compressors

For a mechanically driven positive displacement compressor, **BOOST** requires the specification of the performance characteristics along a line of constant compressor speed (**Simplified Model**) or the full performance map (**Full Model**).

4.13.4.1. Simplified Model

The full set of performance characteristics consists of the mass flow or volume flow characteristics, the temperature increase or isentropic efficiency and the power consumption or total efficiency as a function of pressure ratio.

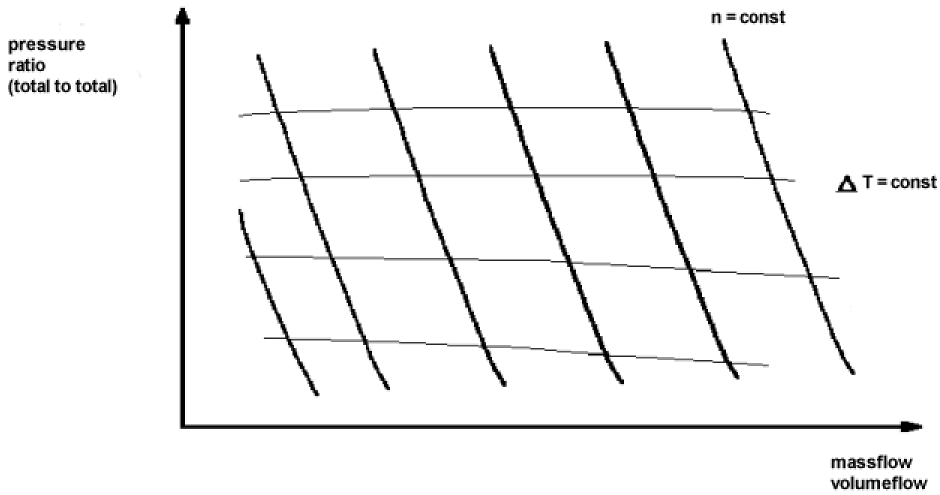


Figure 4-62: PD-Compressor Map

The flow characteristics of the compressor may be specified either as the corrected mass flow over pressure ratio (defined as the actual mass flow multiplied by the ratio between inlet air temperature and reference air temperature, and the ratio between reference inlet pressure and air inlet pressure), or by the volume flow over pressure ratio.

If the corrected mass flow is selected, the reference inlet pressure and the reference inlet temperature must be specified also.

For the specification of the internal efficiency of the compressor, either the temperature increase over pressure ratio for reference inlet conditions or the isentropic efficiency may be specified.

The information on the mechanical losses of the blower is obtained from the specification of the power consumption over pressure ratio at reference conditions or from the specification of the total efficiency.

Using the Simplified Model all performance characteristics may be specified in a **Table** as a function of pressure ratio at the compressor (iso-speed line) or in a simplified way as a constant value.

4.13.4.2. Full Model

Applying the Full Model all performance characteristics have to be specified in the compressor operating map.

In order to facilitate the input of operating maps provided by various hardware suppliers, **BOOST** allows the selection of the most suitable dimensions.

The attachment type of each pipe (inlet/outlet) is known from the sketch of the model. They can be checked by clicking **pipe attachments**.

4.13.5. Pressure Wave Supercharger (PWSC)

The BOOST PWSC Element covers the flow simulation inside the rotor channels and the interface between the casing and rotor channels. The intake and exhaust casing channels have to be modeled by means of BOOST pipes and restrictions. Allowing an arbitrary number of casing attachments this separation enables the setup of a wide range of possible geometry configurations (gas pockets and related valves).

If there is more than one charging cycle per rotor revolution the input of **Number of symmetric Cycles per Revolution** allows to reduce the amount of simulated rotor channels. In parallel the attachments have to be specified for the angle range of the first cycle only and the cross sections have to be enlarged according to this attachment unification.

Required input for the rotor is its rotational **Speed** and the effective flow **Length** of the rotor channels. In case of selected **Variable Wall Temperature** the solid material of the rotor is balanced according to the convection and conduction heat fluxes. Additional information concerning the solid material properties is required under the **Variable Wall Temperature** sub tree item.

The spatial discretization of the rotor channels can be specified by means of the **Cell Length**. For a sufficient resolution of gas-dynamic effects a minimum of 20 cells along the channel should be guaranteed.

The laminar wall friction loss is calculated by means of the **Laminar Friction Coefficient** (Default Value according to Hagen-Poiseuille Law:64).

The **Friction Multiplier** and the **Heat Transfer Factor** can be input as constant or function of the axial rotor position (X=0. corresponds to the intake side).

The **Wall Temperature** has to be specified as a function of the axial rotor position X (X=0. corresponds to the intake side) and it is only an initial condition in case of selected **Variable Wall Temperature**.

As a possible actuation target the angular **Casing Offset** between the intake and exhaust flange can be input. Specified angle values for the attachments of the exhaust side are shifted according to the offset in positive angle direction.

For considering the leakage flow from one channel to its neighbors directly and via the casing the Leakage Gap can be specified separately for the intake and exhaust side.

The Input of the **Rotor Friction Torque** (optional as function of rotor speed) allows to determine the required Rotor Brake/Drive Torque.

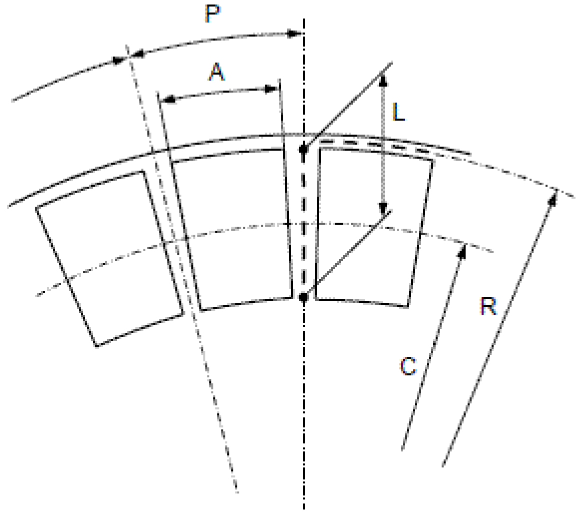
Rotor Specifications

Required Input for each Layer is the **Number of Channels** and the overall Flow Volume.

The **Pitch Offset** allows to specify a tangential shift of the different layers (+/- … positive /negative shift in angle direction).

The **Leakage Gap Length** L determines the effective area for the leakage flow direct into the neighbor channel while the effective leakage area per angular unit for the flow into the casing is proportional to the **Leakage Gap Ratio**. The **Leakage Gap Ratio** is the arc length of the gap per angular unit and for selected angular unit rad the value is equal to the radius

The tangential channel distribution of a single layer is specified by the **Opening Angle** A and the **Angular Pitch** P of the channel under consideration. This segment of the channel is multiplied according to the specified **Multiplier** M .The entire range of 360º is filled up by repeating the specified sequence: sum over all channel specification lines $\Sigma(P_i{*}M_i)$.



L ... Leakage Gap Length
R ... Leakage Gap Ratio
C ... Pitch Circle Radius
P ... Angular Pitch
A ... Opening Angle

Figure 4-63: Angle specification of Rotor Channels

The **Hydraulic Diameter** allows to consider non circular channel cross sections for calculating the friction.

Attachment Specification

For every attachment its tangential position has to input by means of the **Opening Position Angle** A and **Closing Position Angle** B.

To account for 3D effects of the flow casing channel ⇔ rotor channels the effective cross section can be adapted using the **Inflow** and **Outflow** Coefficients.

- **Inflow** ... flow into the rotor
- **Outflow** ... flow out of the rotor

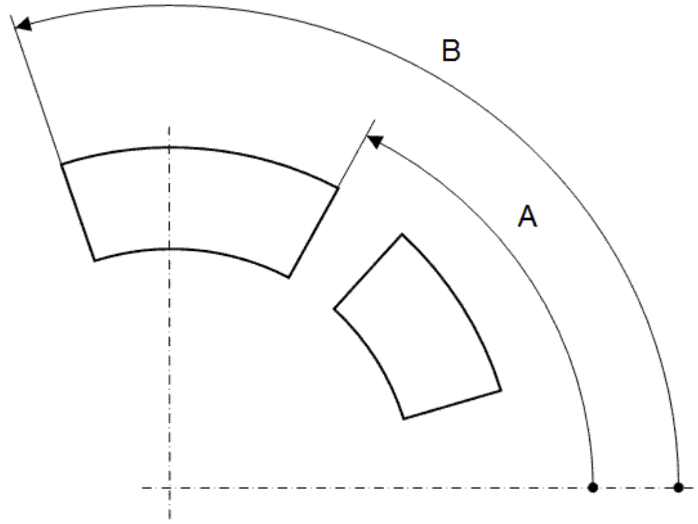


Figure 4-64: Angle specification of Attachments

The **Circumf. Angle** which is the one between the attachment channel flow direction and the rotor circumferential direction allows to consider the circumferential momentum flow entering the rotor (Rotor Brake/Drive Torque determination) and the accounting of incidence losses for the flow entering the rotor.

4.13.6. Waste Gate

A waste gate is a valve actuated by the pressure difference on the valve body plus the pressure difference on a diaphragm mechanically linked to the valve body.

The instantaneous valve lift is calculated using an equivalent spring-damper-mass system. The flow coefficients must be specified as a function of valve lift.

4.13.6.1. General

The areas on the high and low pressure side of the diaphragm are required in order to calculate the forces acting on the valve resulting from the respective pressures. The maximum lift of the valve may be limited.

Flow coefficients for flow must be specified. A leakage through the control diaphragm can be modeled by the input of a suitable flow coefficient for flow from the high to the low pressure side and vice versa. This flow is treated in the same way as the flow through a flow restriction.

4.13.6.2. Valves

The valve cross sections are the areas of the valve tulip exposed to the pressure on the respective side. For the high pressure side of the valve this area has to be input for **Wastegate closed** and **Wastegate opened.** For the low pressure side of the valve one area is input. The area of the valve body exposed to the high pressure with the valve closed and opened and the area of the valve body exposed to the low pressure are required. The moving masses, damping coefficient, valve spring pre-load and valve spring rate must be defined.

For the simulation of the movement of the wastegate valve the sum of all **Moving Masses** is required as well as the **Viscous Damping Coefficient**, the **Spring Preload** and the **Spring Rate** and finally the **Maximum Lift** of the valve.

4.13.6.3. Flow Coefficients

Flow coefficients as a function of valve lift must be specified in both possible flow directions.

The flow coefficients are defined as the ratio between the actual mass flow and the loss-free isentropic mass flow for the same stagnation pressure and pressure ratio.

If an electronically controlled waste gate is modeled, a flow restriction influenced by the engine control unit should be used.

4.13.7. Electrical Device

If the Mechanical Power supplied/consumed by the Electrical Device should be considered in the Engine AMEP the corresponding Check Box has to be selected. If the Electrical Device is not directly connected to the Engine Element the Electrical Power is considered for the Engine AMEP.

The **Simplified Model** allows the user to introduce a mechanical power source for the connected mechanical component (at current only Turbocharger allowed), while the **Full Model** also balances the rotational state (speed) of the electrical device.

For the power source of the mechanically linked component of the electrical device, the supplied electrical power (constant value or time dependent **Table**) and the electrical efficiency have to be specified. Required input for the **Full Model** is the moment of inertia and the mechanical torque can be specified instead of the electrical power.

As option the setting of initial speed is available. If this is not selected the linked mechanical component is used to determine the initial speed.

In case of an external control (by **Engine Control Unit**, **Monitor**, **MATLAB DLL** or **MATLAB API**), the electrical power can be limited by specifying a maximum electrical power.

4.14. External Elements

4.14.1. FIRE Link

BOOST offers the possibility of a 1D/3D Hybrid Calculation in conjunction with AVL's **FIRE** code for a time and cost effective simulation of three dimensional flow patterns within the thermodynamic engine simulation.

A one dimensional **BOOST** model must be designed using the **BOOST** preprocessor and a three dimensional **FIRE** model using the **FIRE** preprocessor.

The **Fire Link** element is located in the **BOOST** model to represent the interface between the 1D Boost domain and the 3D **FIRE** domain. The **Fire Link** element is similar to a flow restriction with two attached pipes, but with one explicit 1D-side and one explicit 3D-side. The **BOOST** sub-model at the 3D-side (shadow network) should be a 1D-approximation of the 3D **FIRE** domain. Pipes are attached to this **Fire Link** element in a similar way as is done for a restriction.

A three dimensional calculation mesh must be created with the **FIRE** preprocessor for the engine geometry between the 3D-sides of the **Fire Link** elements. The interface between the 1D and 3D domains should be located in a pipe section, where almost one dimensional flow occurs. By selecting a 1D-boundary on the interfaces in the boundary part of the **FIRE** preprocessor each interface is assigned the corresponding pipe.

For data exchange between the **BOOST** and **FIRE** codes it is necessary to model a part of the pipe (**Overlapping Pipe Section**) with **BOOST** and **FIRE**. The overlapping part is created internally by **BOOST**.

For the link to **FIRE** the User needs to specify the **Length of the Overlapping Pipe Section** and the **FIRE Passive Scalar** assigned to mass flow entering the **FIRE** calculation domain at each interface.

Please refer to the BOOST – FIRE 1D-3D Coupling Manual for further information.

4.14.2. User Defined Element

The User-Defined-Element (UDE) allows the user to include user-defined elements in the calculation model. The UDE is supported in both the pre and post-processor. Special subroutines allow user written code to simulate the element. The user written routines must be compiled and linked to create a new **BOOST** executable to run the model.

Data handling for all the pipe attachments is done by the UDE. The output generated by the user's algorithm may be analyzed with the **BOOST** post-processor provided that the BOOST interface routines are used.

In addition to the UDE Identifier (which allows to distinguish between different UDE implementations), the **UD Defined Element Parameters** input dialog allows the specification of data which can be accessed in the user written code (identification via the Parameter Key). In addition to single values (of type integer, double precision and character string) it is also possible to input an arbitrary number of two-column double-precision **UD Defined Element Tables** for the usage in the user written code (e.g.: variable volume table, ...).
For each pipe attachment the flow coefficients must be defined.

Similar to the system boundary or the plenum, different flow coefficients may be defined for inflow and outflow of the UDE. The flow coefficients may also depend on time in degree crank angles or seconds or on the pressure difference between the UDE and the attached pipe cross section. Refer to **Flow Coefficients** for details on standard values and directions.

For the template subroutines, compiling and linking BOOST please refer to the BOOST Interfaces Manual.

4.14.3. CFD Link

With the same functionality as the FIRE Link the CFD Link element offers the possibility to link **BOOST** to 3rd party CFD codes.

4.14.4. CRUISE Link

The **CRUISE Link** element can be used to specify optional channels for the exchange of information between elements in a **BOOST** model and **CRUISE**.

This can be done by connecting a Wire between the **CRUISE Link** element and the appropriate element. The wire is used to pass both sensor (**BOOST** to **CRUISE**) and actuator (**CRUISE** to **BOOST**) data.

The default channels, which can not be modified are greyed out.

4.15. Control Elements

There are two main types of engine control element available in BOOST:

Internal Control Element:	ECU, Engine Interface and PID
External Link Elements:	MATLAB API and MATLAB DLL

The link to an External Control Element Library is a complementary element to the Engine Control Unit (ECU) element. It may be used to incorporate complex models of engine control and management systems developed with MATLAB/SIMULINK (MATLAB-API Element, MATLAB-DLL Element) or any commercial software featuring C-code generation (MATLAB-DLL Element). All the important functions of an electronic engine control device can be simulated. Figure 4-65 shows a flowchart giving an overview of the interaction between BOOST and the External Link.

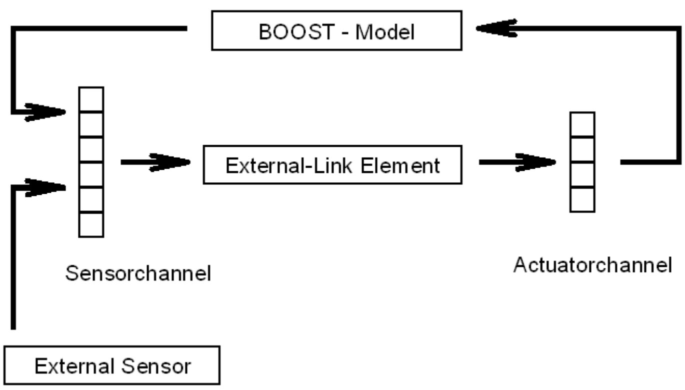


Figure 4-65: Interaction between BOOST and External-Link Element

4.15.1. Engine Control Unit

The Engine Control Unit (ECU) models all important functions of an electronic engine control device. Elements providing input to the ECU via Sensor Channels or which are controlled by the ECU via Actuator Channels need to be connected to the ECU by a connector.

4.15.1.1. General

Specify one of the following:

Load signal: The load signal is a fictive input to the ECU. It can be understood as the drivers' command in a drive-by-wire arrangement.

Desired Engine Speed: The engine control calculates the load signal using the control gains proportional, integral and differential together with the deviation of the actual engine speed from the desired engine speed:

$$ls = p \cdot (n_{des} - n) + i \int_0^t (n_{des} - n) \cdot dt + d \cdot \frac{d \cdot (n_{des} - n)}{dt} \qquad (4.15.1)$$

ls	load signal
p	proportional control gain
i	integral control gain
d	differential control gain
n	engine speed
n_{des}	desired engine speed

Both options may be specified in the **Table** dependent on time.

☞ **Note:** The user must ensure that the available load signal is used correctly to control the engine load, i.e. to influence the flow restriction(s) modeling the throttle(s) for mixture aspirating engines or to influence the fueling for engines with internal mixture preparation.

For the activation of dynamic functions thresholds for the maximum positive and the maximum negative load gradient are required.

The following Control Interaction Timesteps are available:

Cyclic

Every Timestep

Specified Timestep.

4.15.1.2. Map Specification

The selection of parameters to be controlled by the ECU is specified (elements connected by **Wire** and their possible actuator channels).

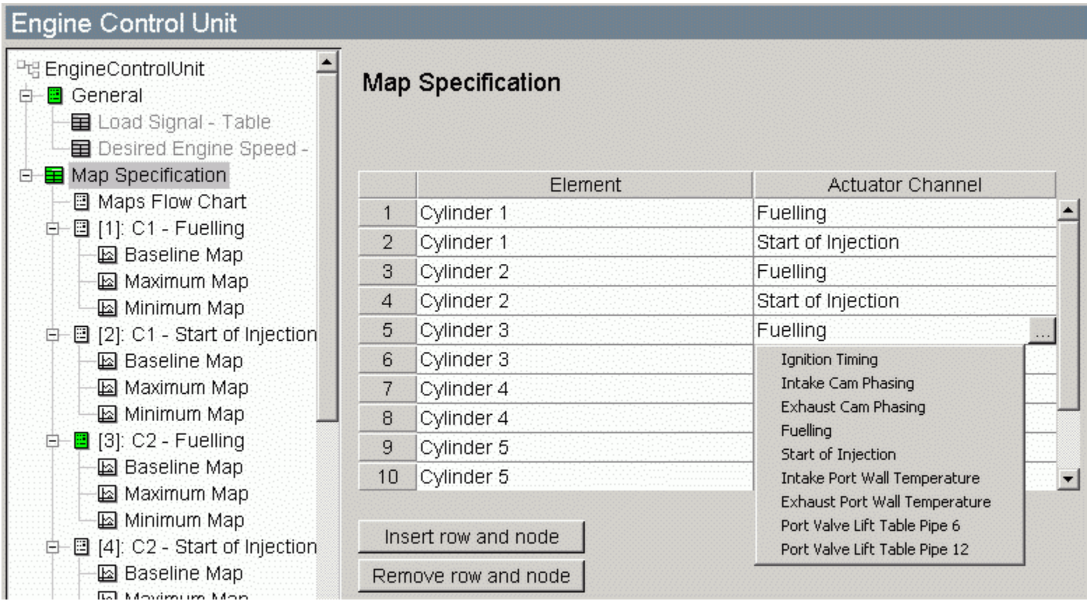


Figure 4-66: Selection of ECU Actuator Channels

If the cylinders have identical specifications, only cylinder one is listed and the data is transferred to all other cylinders.

The user must input maps for each actuator channel. First it must be determined whether a baseline map value or the last actual value should be used as starting value for the correction procedure. In the first case, the baseline map must be defined.

The value in a map can depend on up to two sensor channels which are selected in the pull down menu for the element (global or wire connected) and the respective sensor channel. If only a table is defined either x- or y-value keeps it's default setting **none**. If no dependency is specified this is equivalent to the specification of a constant value.

Please refer to section 8.2 for a list of available Actuator and Sensor Channels.

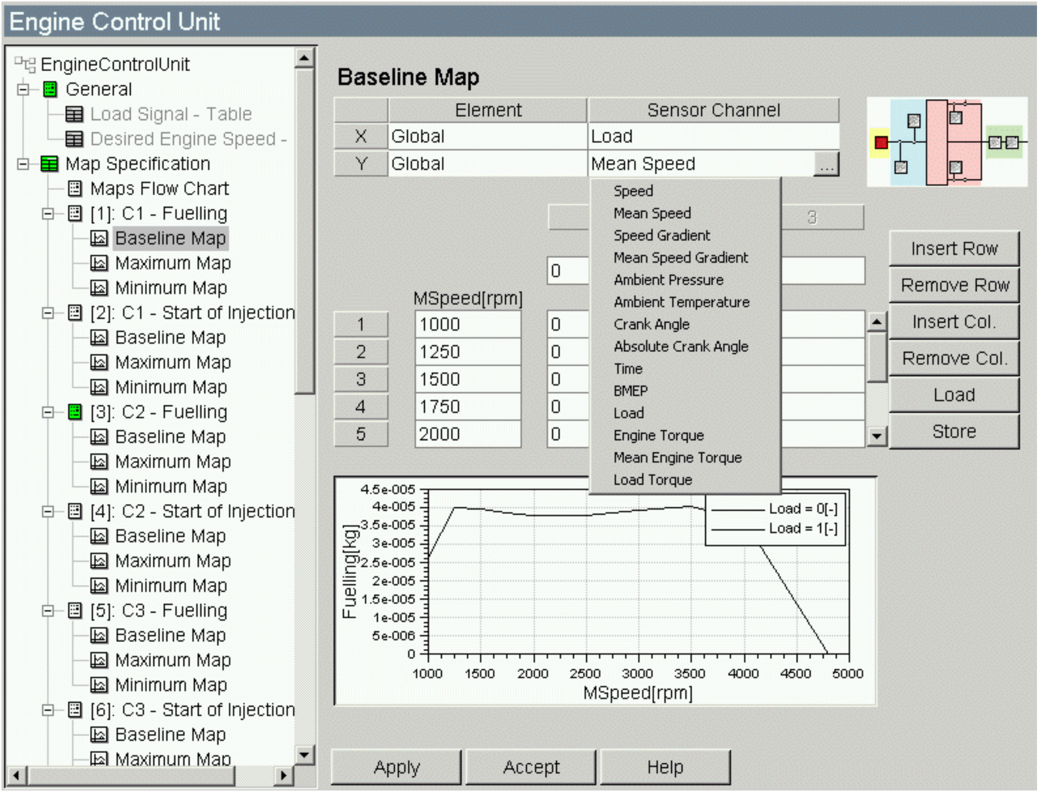


Figure 4-67: ECU Map Specification

Before inputting map values, the size should be customized using **Insert Row/Remove Row** and **Insert Col./Remove Col.** Maps can be written to a separate file using **Store** or they can be read in from an external file using **Load**.

Minimum and maximum maps are defined in the same way.

If the baseline value is to be corrected depending on other parameters (e.g. ambient temperature or pressure) correction maps can be added by pressing the left mouse button on the tree item. In addition to the specification of the map the type of correction (multiplication or addition) must be defined.

> ☞ **Note:** Corrections are done in the same sequence as they are specified, i.e. a correction value added to the baseline value followed by a multiplicative correction will produce a different output than the same corrections done in the reverse order.

If the positive gradient of the load signal exceeds the threshold specified in the first box, the corrections for acceleration become active. Their number, the maps themselves and the type of correction are specified in the same way as for the steady state corrections.

A time lag for the activation and deactivation of the correction and the respective time constant (the time between 0 % and 99 % correction or 100 % and 1 % correction) complete the input of the acceleration corrections. Figure 4-68 shows the definition of the time intervals:

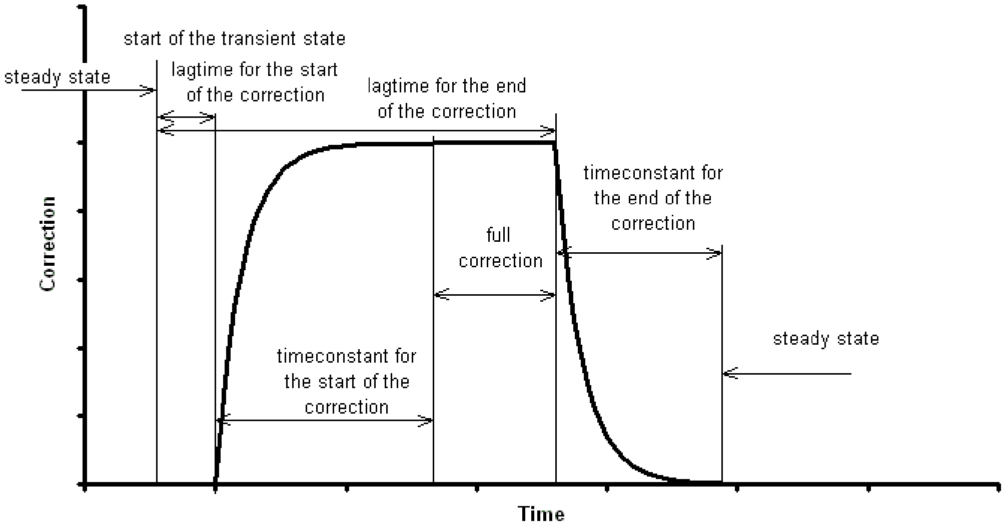


Figure 4-68: Time Constants for Transient ECU Functions

The procedure for the definition of the deceleration corrections is the same as for the acceleration corrections.

4.15.2. MATLAB DLL Element

The MATLAB DLL junction can be used to exchange information between elements in a **BOOST** model and MATLAB/Simulink from Mathworks. This can be done by connecting the MATLAB DLL junction and the appropriate element. The wire is used to pass both sensor (BOOST to MATLAB) and actuator (MATLAB to BOOST) data.

4.15.2.1. General

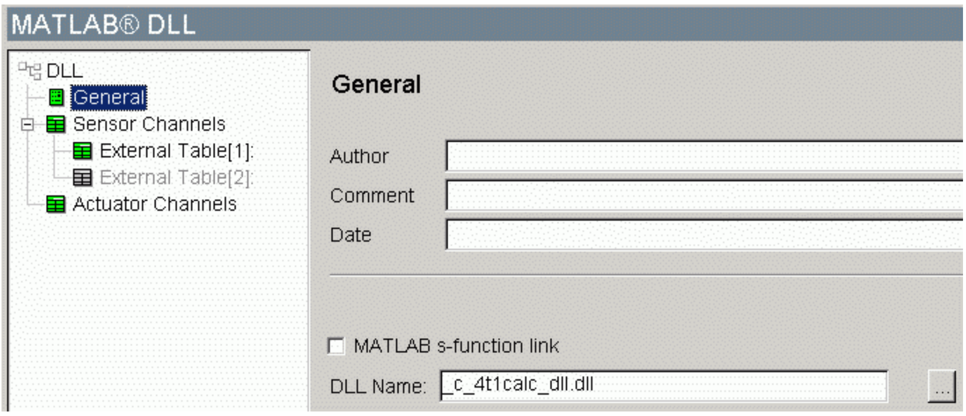


Figure 4-69: MATLAB DLL Element Input

There are two ways of using this element:

1. MATLAB DLL

BOOST can be run from the graphical user interface and dynamically loads a shared object created by MATLAB/Simulink. The full name and absolute path of this shared object must be given in the DLL Name input box (if the shared object isn't located in the *.bst input-file directory the name has to contain the absolute path).

- Feature supported for MATLAB V.5.3, V.6.0 and later versions.
- Simulation should be run using the GUI (**Simulation|Run**)
- The shared object must be created on the same operating system/platform on which **BOOST** is being run.
- The **MATLAB s-function link** should **not** be selected.

2. MATLAB s-function

The **BOOST** model is run from MATLAB/Simulink via a system function.

- Feature supported for MATLAB V.6.0 and later versions only.
- The **BOOST** model should be created but not run by the **BOOST** GUI. The **BOOST** input file (*.bst) created should be specified as the **BOOST** input file name in the s-function mask.
- Select the **MATLAB s-function link**. No DLL Name is required and will be grayed out when the check box is selected.

4.15.2.2. Sensor Channels

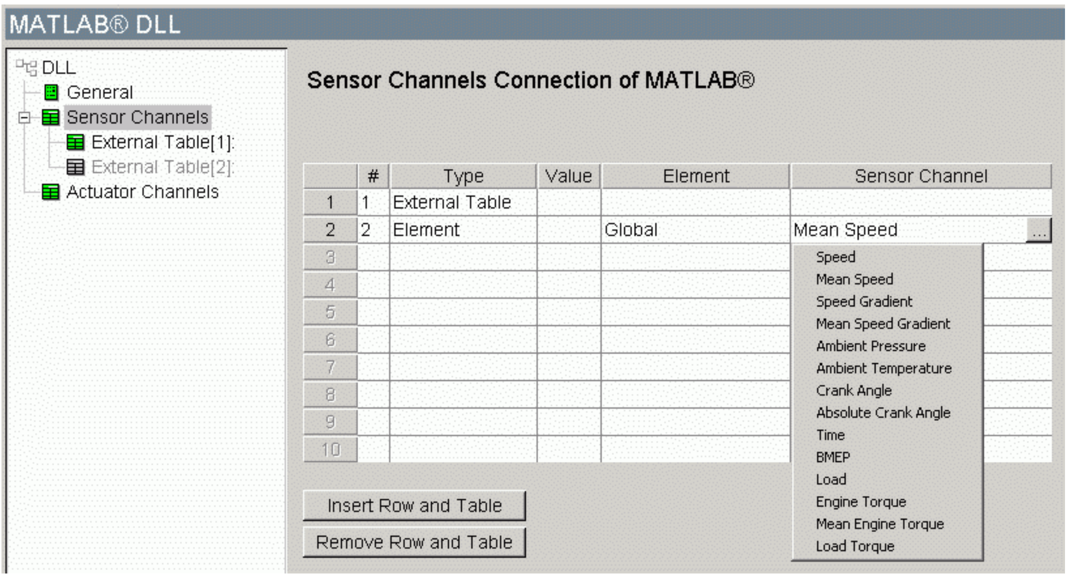


Figure 4-70: Sensor Channel Selection

For the definition of the index of a Sensor value in the vector the channel numbers must be specified. This vector is passed to the External Link Element as input. If a type value is set to **external** (the External Link Element only), the user must supply its value either as a constant or in a **Table** as a function of time in seconds. Possible applications of an external input are gain coefficients of a control or an input.

4.15.2.3. Actuator Channels

After inserting a row and clicking on the element input field, a list of all elements connected to the DLL element is shown, which can have at least one parameter controlled by the DLL element. An example of this input is shown in the following figure:

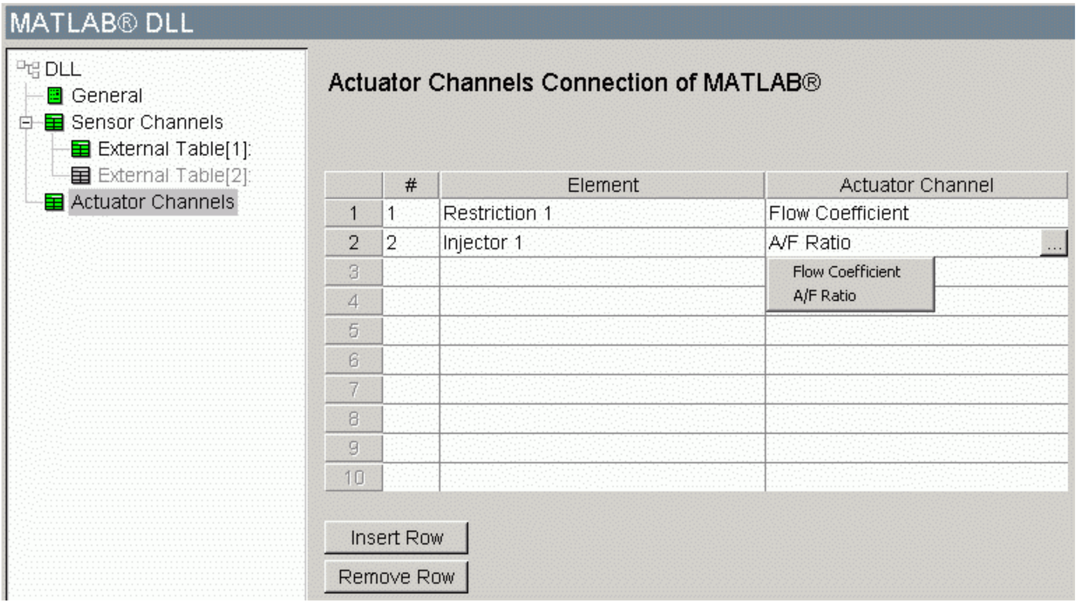


Figure 4-71: Actuator Channel Selection

If the cylinders have identical specifications, only cylinder one is listed and the data is transferred to all other cylinders.

Similar to the sensor channels, the channel number defines the index of the Actuator value in the Actuator vector.

Please refer to section 8.2 for a list of currently available Actuator and Sensor Channels.

4.15.3. MATLAB API Element

This element should be used when the model is to be run using the link to MATLAB using the API.

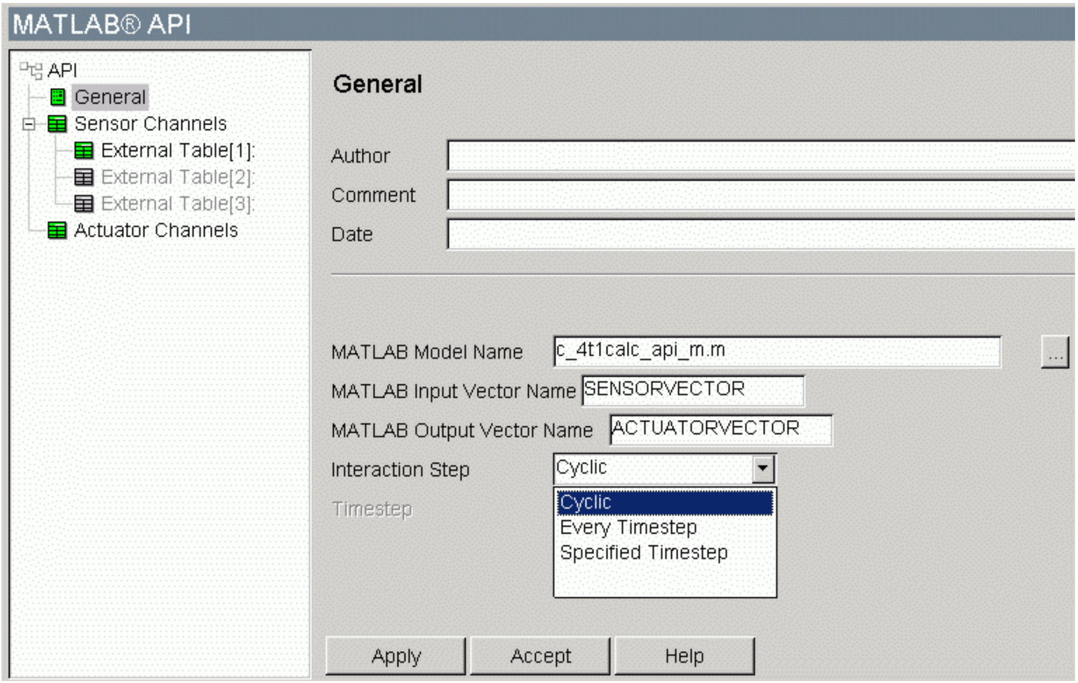


Figure 4-72: MATLAB API Element Input

In addition to the input of the Simulink-model (or m-Function) name, which performs the control algorithm, the name of the Sensor-channel and Actuator-channel vector must be specified (if the model is not located in the *.bst input-file directory the model name has to contain the absolute path). These vectors are introduced as members of the MATLAB Workspace and the Simulink-model (or m-Function).

Then the Interaction Step (Cyclic / Every Timestep / Specified Timestep) must be specified.

The Channel Specifications are done analogous to the MATLAB DLL element.

4.15.4. Engine Interface

The Engine Interface Element is used to supply data to elements in a BOOST model which are connected by wires. In the current BOOST version the link to external applications via the Engine Interface is not available. Actuators are served with data from Data Sets only.

Required input for a Data Set definition is its name, the unit of the evaluated value(s) and the type of the Data Base which can be either a Constant Value or one of the following:

- Table
- List Of Tables
- Regular Map
- Cyclic updated Table
- Map of Tables

Actuator Channels of the Type 'Crankangle dependent Table' (e.g.: RateOfHeatReleaseTable, RateOfInjectionTable,...) require the Data Set Type **Cyclic Updated Table** or **Map of Tables** while for the other Actuator Channels ('Single Value') the following Data Set Types are allowed: **Constant Value**, **Table**, **List Of Tables** and **Regular Map**.

The **Table** allows to specify a (1-dimensional) dependency from one of the available Sensor Channels.

A **List of Tables** allows the specification of a 2-dimensional dependency of an actuated Value. After selecting the Main- and Side Dependency Sensor Channels the Values for the Main Dependency Channel have to be specified by using **Insert**.

For every Main Dependency Channel Value an Input Dialog for the Side Dependency Channel appears, where a Table for the related Actuator Channel versus Side Dependency channel has to be specified.

The content of the specified file is read from AVL BOOST every cycle. It is intended for Control Purposes of an External Slave (Matlab API/Dll)- or Master(Matlab S-Function)-Process which supplies Data of the Type Table (RateOfHeatReleaseTable,ValveLiftCurveTable). The Table is evaluated with the fixed Dependency on Relative Crank angle.

A **Regular Map** allows the specification of a 2-dimensional dependency of the actuated Value on X- and Y Sensor Channels. Before specifying a map the size of the map should be customized. This is done by using the **buttons Insert Row/ Remove Row** and **Insert Col./ Remove Col**.

A **Map of Tables** allows the specification of a 3-dimensional dependency (e.g. rate of heat Release dependent on crank angle, speed and load signal). After selecting the main and side dependency sensor channels, the values for the main dependency channel have to be specified using **Insert**.

For every main dependency channel value an input dialog for the side dependency channel appears. For every side dependency channel value an input dialog for a **Table** appears, where the crank angle dependency of the Actuator Channel value has to be specified.

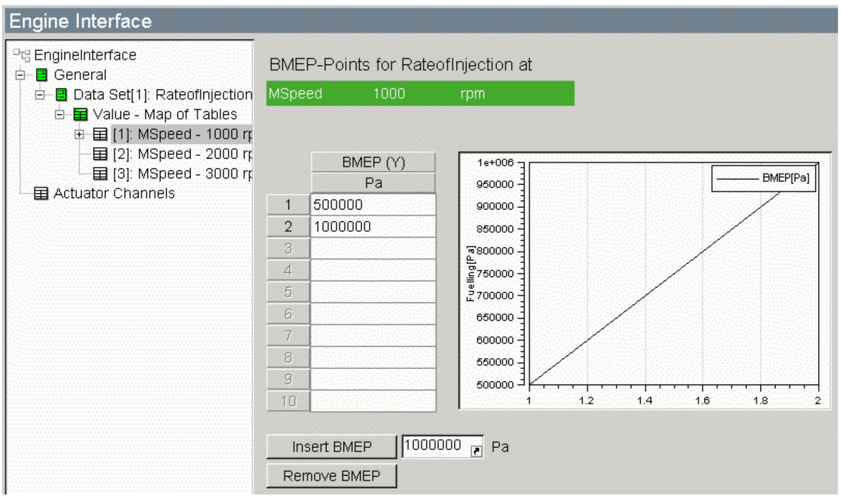


Figure 4-73: Engine Interface - Data Set Main Dependency Window

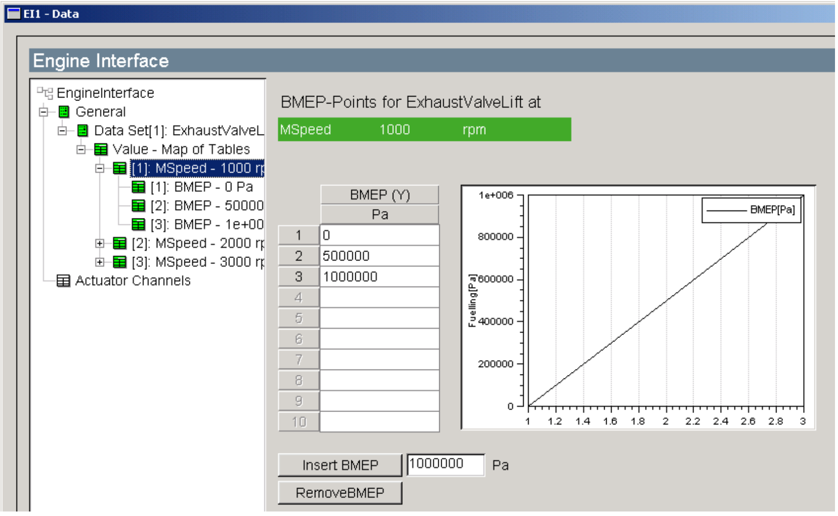


Figure 4-74: Engine Interface - Data Set Side Dependency Window

For every Main Dependency Sensor Value an arbitrary number of Side Dependency Sensor Values with it's related Table can be specified.

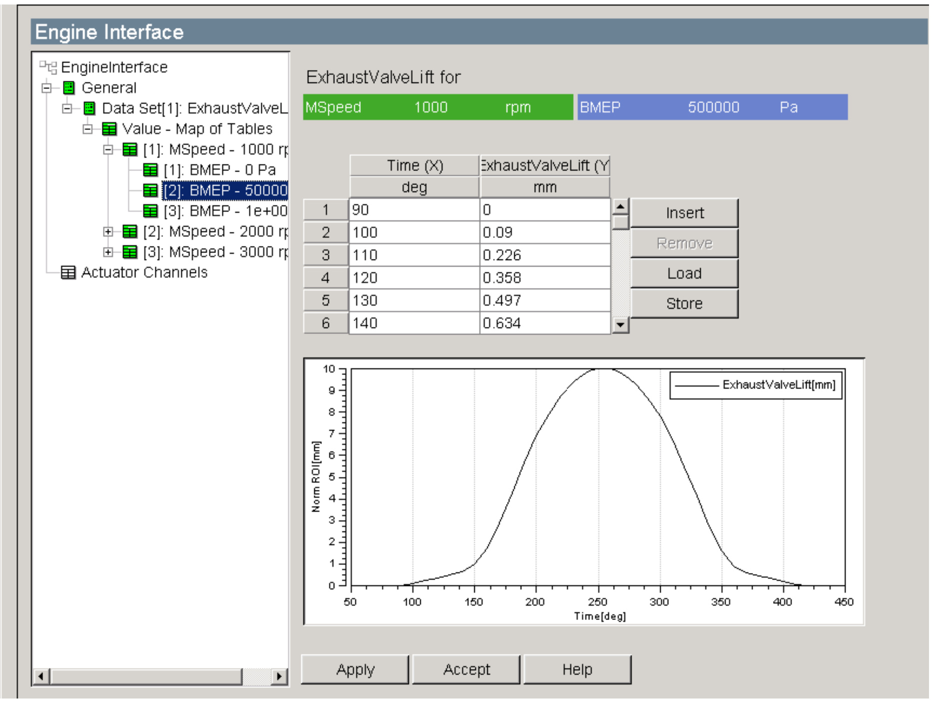


Figure 4-75: Engine Interface - Data Set Table Input Window

In the actuator input dialog table the assignment of Actuators (Number, Element and Channel) to their related Data Sets is done.

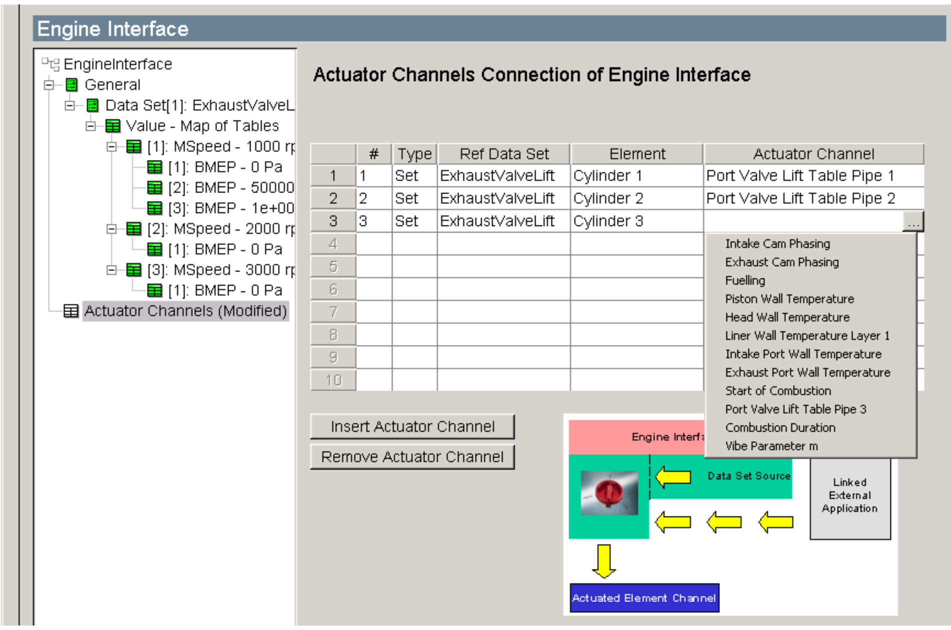


Figure 4-76: Engine Interface - Actuator Input Window

4.15.5. PID Controller

PID stands for Proportional-Integral-Derivative. This is a type of feedback controller whose output, an actuator control variable (AV), is generally based on the error (e) between a guiding value (GV) and some sensor value (SV). Each element of the PID controller refers to a particular action taken on the error:

If a positive change in the PID actuator output causes a positive change to the sensor value the controller gains should be positive. If a positive change to the actuator causes a negative change to the sensor then the controller gains should be negative.

- Proportional: error multiplied by a gain, Kp. This is an adjustable amplifier. In many systems Kp is responsible for process stability: too low and the SV can drift away; too high and the SV can oscillate.
- Integral: the integral of error multiplied by a gain, Ki. In many systems Ki is responsible for driving error to zero, but to set Ki too high is to invite oscillation or instability or integrator windup or actuator saturation.
- Derivative: the rate of change of error multiplied by a gain, Kd. In many systems Kd is responsible for system response: too high and the SV will oscillate; too low and the SV will respond sluggishly. The designer should also note that derivative action amplifies any noise in the error signal.

Tuning of a PID involves the adjustment of Kp, Ki, and Kd to achieve some user-defined "optimal" character of system response.

Although many architectures exist for control systems, the PID controller is mature and well-understood by practitioners. For these reasons, it is often the first choice for new controller design. It satisfies Occam’s Razor in being the simplest solution for most cases.

The PID controller is implemented as follows

$$
\begin{aligned}
P_i &= K_p . e_i \\
I_i &= K_i . \int_0^t e_k . dt \\
D_i &= \frac{K_d}{\Delta t} . (e_i - e_{i-1}) \\
AV_i &= P_i + I_i + D_i
\end{aligned}
\tag{4.15.2}
$$

where ei = GVi – SVi, and dt is the sampling interval.

AVMax. > AVi > AVMin.

When the output signal is at the limit the integral term does not continue to grow to prevent integral wind up of the controller.

☞	**Note:** Multiple PID controllers can be used in a single model. However, interfering controllers may render the control unstable even if each controller is stable by itself.

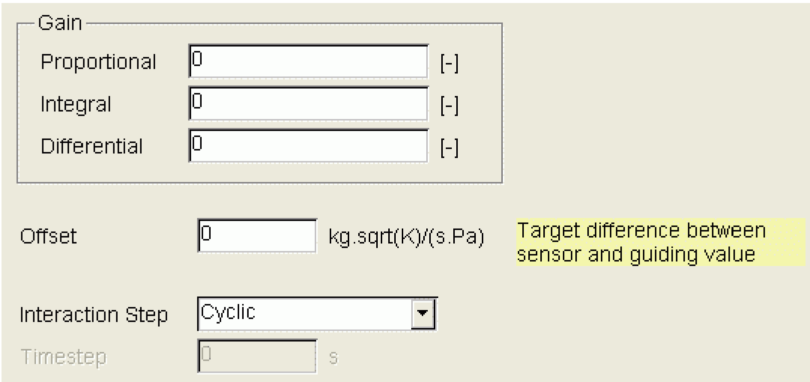


Figure 4-77: PID - General Input Window

The **Gain** values (Proportional, Integral, Differential) used by the controller are entered in the appropriate boxes on the general input page of the PID controller. Note that the gains are available as actuator channels for other control elements such as the engine interface.

An **Offset** between the sensor and the guiding value can be used. This should have the same units as the sensor and guiding channels

difference = guide value – sensor_value + offset

The offset is also available as an actuator channel for other control elements. This could be used for example to define a pressure difference versus time as the PID target.

☞	**Note:** A temperature offset should always be input in K. This is because the value is translated into SI units. Therefore a 0.0 degC offset will be translated as 273.15K !

The **Interaction Step** can be set to **Cyclic, Every Timestep** or **Specified Timestep**. If a specified timestep is used this has to be entered in the **Timestep** input field.

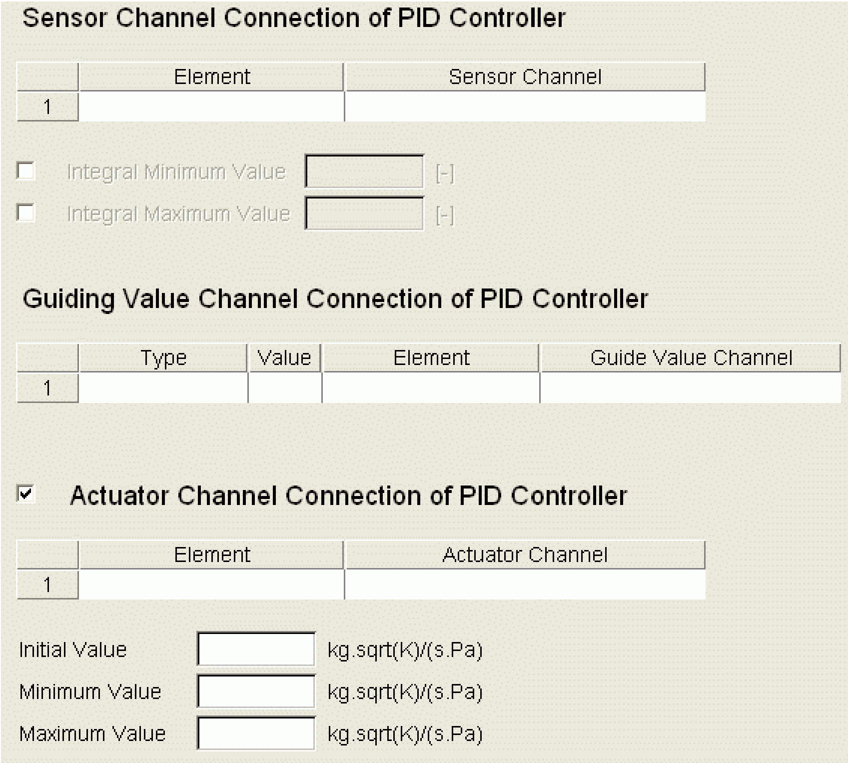


Figure 4-78: PID - Channels Input Window

The **Sensor Channel** is the measured value of the PID controller whose value should change based on the changes to the actuator channel until the guiding value plus offset is reached. The PID controller does not directly change the sensor channel. The sensor channel value is only indirectly changed by the output of the PID (e.g. BMEP increases and fuelling increases). Optional **Integral Minimum Value** and **Integral Maximum Value** can be set.

The **Guiding Value** is the target for the sensor channel value taking into account any offset entered on the general input page. In additional to other channels an external value or external table can be used for the target.

The **Actuator Channel** is optional as it can be used as the input to another PID controller or another control element able to set the PID output as a sensor channel. The **Actuator Channel** is the channel actually changed by the output of the PID controller and should be specified when the output of the PID is to be used directly. For example, to control a restriction flow coefficient, an **Initial Value** for the actuator as well as a **Minimum Value** and **Maximum Value** should be entered in the units matching the actuator channel.

4.15.6. Formula Interpreter

4.15.6.1. Background

A formula is basically a function that returns a desired value (OUTPUT) as a function of other variables (INPUT):

- INPUT: constant values and/or all **Sensor Channels** available in BOOST
- OUTPUT: all **Actuator Channels** available in BOOST
- BOOST evaluates the formula during runtime at each time step.
- The function may contain loops, conditional statements and local variables.
- The formula language syntax is very close to the well known C-programming language.

☞ **Note:** With formulae it is your responsibility to avoid divisions by zero, taking square roots of negative numbers, non-terminating loops or other numerical catastrophes. Such operations might crash the solver or trap it in your formula.

4.15.6.2. Formula Editor Syntax

The syntax of the formula source code is based on C (ANSI C). Some fundamentals and particularities of the C syntax are listed below.

4.15.6.2.1. Supported Data Types

```
char      one byte;
int       integer value, usually 4 bytes
float     floating point value, usually 4 bytes
double    floating point value, usually 8 bytes
```

4.15.6.2.2. General Features

Variable and function names are case sensitive.

Every statement has to be terminated by a SEMICOLON ';'.

There may be more than one statement per line.

One statement may extend over several lines (char terms between "" must be on one line, however).

All variables MUST be DECLARED EXPLICITLY before the first executable statements.

ARRAY ELEMENTS are accessed by the operator “[]”. Note that arrays start with index 0.

Example:

```
double a[3];
a[0] = 1; // assign 1 to first element in array
a[2] = 2; // assign 2 to last element in array
a[3] = 3; // ERROR!!! beyond array bounds!
```

LOOPS over arrays thus are typically written like this

```
int i;
double a[3];
for(i = 0; i < 3; i++){
   a[i] = 10*i+0.3;
}
```

The BUILT-IN MATH-FUNCTIONS include (returning double and taking one double argument; argument in radiants for trigonometric functions):

```
sqrt, sin, cos, tan, asin, acos, atan, log, log10, exp
```

and taking two double arguments:

```
pow(x, exponent), atan2(y, x), fmod(x, div)
```

Note that the integer-modulo function is provided by the “%” operator, e.g.:

```
int remainder;
remainder = 100 % 11;
```

Integer random numbers in the range [0,RAND_MAX] are returned by `rand()`. RAND_MAX is in general the largest 4 Byte integer, i.e. 2147483647. A new seed can be set by `srand(int seed)`. A floating point (double) random value in the range [0,1) is returned by `drand()`.

Output to the log file is done using the `printf` function, input by `scanf`, output/input to char-array by `sprintf` and `sscanf`, output/input to file by `fprintf`, `fscanf` (and also `fputs`, `fgets`).

For more information on the C-Language see the rich literature on the Internet (search e.g. for "C Tutorial" or "ANSI C"). Note however the differences between ANSI C and AST_SCI C listed below.

4.15.6.2.3. Extensions to the C-Syntax

C++ style comments "//" are allowed.

Function arguments are PASSED BY REFERENCE! E.g., the interpreter code

```
double f(int i, float[] f) { f[i] = i; i = 3; }
```

would be written in C:

```
double f(int *i, float[] f) { f[*i] = *i; *i = 3; }
```

A SIMPLIFIED PRINT STATEMENT is supported, eg:

```
double d =3.14;
int i = 123;
print "d is ", d, ", and 2 times i is ", 2*i;
```

DYNAMIC ALLOCATION to arrays, e.g.:

```
int n = 20;
int dynArr[10*n][3];
```

Dynamic reallocation of arrays:

```
int resize(array[], int newSize);    // returns number of bytes allocated  //
```

`newSize` is number of elements allocated (number of char's, int's, double's etc.), not number of bytes! `resize(array, 0)` frees memory. ATTENTION: after resizing to zero it can not be resized again! use `resize(array, 1)` instead!

DYNAMIC INITILIZATIONS supported, e.g.:

```
double pi = acos(-1.0);
double pi2 = 2.0*pi;
```

VECTOR OPERATIONS supported for `char, int, float and double []`, e.g. (vectors of different length are handled by wrapping around indices, length of result vector will be length of longer vector, except for assignments of course):

```
double a[3] = {1, 2, 3.7e-5}; // list initialization
double b[3] = a + 1.0;// b[i] = a[i] + 1.0; (i=0,1,2)
double c[3] = a * b;  // c[i] = a[i] * b[i]; (i=0,1,2)
double d[3] = 2.7;    // d[i] = 2.7; (i=0,1,2)
double e[3] = {2.7};  // e[0] = 2.7;
double m;
e = {-1, 2, 3.2};     // list assignment is allowed
print "vector e:", e; // print supports vector output! (printf does not!)
```

Additional operator for CROSS AND DOT PRODUCT and vector magnitude, e.g. continuing above code:

```
c = a^b;       // vector cross product, definition:
               // c[i] = a[(i+1)%sa]*b[(i+2)%sb] - a[(i+2)%sa]*b[(i+1)%sb]
               // is sa and sb are length of vectors a and b;
m = a.b;       // vector dot product, returns double
m = |a|;       // vector magnitude (same as sqrt(a.a))
```

Note that the ^ operator is the cross product for vectors of length three.

For vectors of length 2 the usual cross product will be the second component:

```
double a[2] = {1, -2};
double b[2] = {-1, 5};
double c[2] = a^b;
double crossp2 = c[1];// 2D cross product; (c[0] will be -c[1]);
```

For vectors of other length the ^ operator will probably not be useful.

A FLOATING POINT (double) RANDOM VALUE in the range [0,1) is returned by `drand()`.

4.15.6.2.4. Limitations

No pointers except FILE*.

No call by value.

No structs.

No typedefs.

No block scope variables. Only global scope and function scope.

No goto or labels.

No switch/case statements.

Only one declaration per statement., i.e.

```
int i, j = 2;   // will generate syntax error!!!
```

is not allowed, but

```
int i; int j = 2;
```

is.

No short, long, unsigned.

Argument names must be provided in function declarations.

Empty argument list must be used instead of "void".

Max 10 arguments in calls to external functions.

Only call by reference in external functions.

Recursion not supported yet.

Can't print the character " (neither with \" nor "").

strchr, strrchr, strstr not available, substituted by istrchr, istrrchr and istrstr;

istrchr, istrrchr and istrstr return int instead of pointer, which is index of corresponding position in char-array.

Casting (explicit or implicit) of vectors not supported, e.g.

```
double a[3] = {1, 2, 3}; // OK: scalars cast to double components
int b[3] = {1, 2.0, 3};  // OK: scalars cast to int components
a += b;                  // not supported because b would have to be cast to double[]
                         // first!
b += 1;        // supported: same effect as "for(i=0;i<3;i++) b[i] += 1;"
b += 1.0;      // supported (1.0 would be cast to scalar int), otherwise as
               // above
b = b + 1.0;   // not supported because term (b+1.0) would have to be cast to
               // float[]!
b = b + 1;     // supported, no cast needed
```

4.15.6.2.5. Hints and Tricks

Loop overhead: avoid short loops. Better use e.g.

```
a[i][0] = x[0];
a[i][1] = x[1];
a[i][2] = x[2];
```

instead of

```
for(j = 0; j < 3; j++) a[i][j] = x[j];
```

or even better use vector assignment:

```
a[i] = x;
```

Arrays are allocated dynamically at run time if the dimension is not a constant integer but any integer expression. Otherwise memory is allocated at parse time.

Use dynamic allocation for large arrays:

```
double a[1*1000];     // dynamic allocation
double a[1000];       // allocation at parse time!
```

or

```
double a[1];          // allocation of 1
resize(a, 1000);      // reallocation at run time;

resize(a, 1);        // reallocation to 1 at end of function; if reallocation
                      // to 0, it can not be reallocated again!
```

4.15.6.2.6. Known Bugs

A few syntax errors may not be reported correctly at parse time.

4.15.6.2.7. List of Keywords / tokens

<table>
<tr><th>Control</th><th>Functions</th><th>Math functions</th><th>Data types, constants operators</th></tr>
<tr>
<td>while
for
break
continue
return
if
else</td>
<td>fprintf
sprintf
printf
fscanf
sscanf
scanf
print
fopen
fclose
fgetc
fputc
fgets
fputs
ferror
feof
exit
system

resize
strcpy
strncpy
strcat
strncat
strcmp
strncmp
strlen
istrchr
istrrchr
istrstr</td>
<td>sqrt
exp
log10
log
asin
acos
atan
sinh
cosh
tanh
sin
cos
tan
ceil
fabs
floor
atan2
pow
fmod</td>
<td>extern

void
char
int
float
double

FILE

NULL
EOF

{letter}[A-Za-z_0-9]*
variable/function name

+ plus
- minus
* multiply
/ divide
= assignment
++ unary increment (postfix or prefix)
-- unary decrement (postfix or prefix)
< comparator less than
> comparator greater than
>= comparator greater equal
<= comparator less equal
== comparator equal
!= comparator
+= binary add
-= binary substract
*= binary multiplication
/= binary division
&& logical AND
|| logical OR
! logical NOT

[] array element access
|var| vector length operator
. vector dot product
^ vector cross product</td>
</tr>
</table>

4.15.6.3. Formula Interpreter Input Windows

In this section the Formula Interpreter input windows are explained using a simple example, where the FMEP is calculated as a function of engine speed and peak firing pressure.

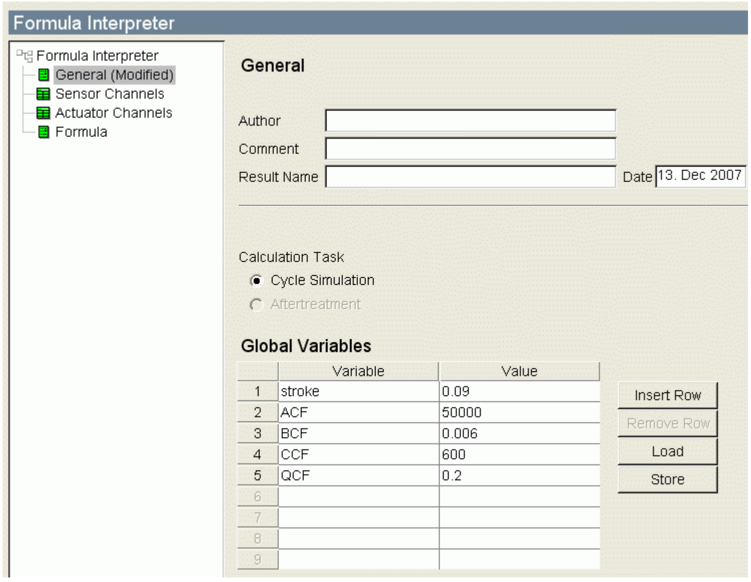


Figure 4-79: Formula Interpreter – General, Global Variables

In the General Window the user can specify the name and the value (can be a parameter) of an arbitrary number of **Global Variables** (*double*), which can be used in the formula (see below).
The selection of **Lock functionality modifications by disabling input fields of this element** allows a comfortable handling for exporting the element as module and the re-usage of the functionality in other models.

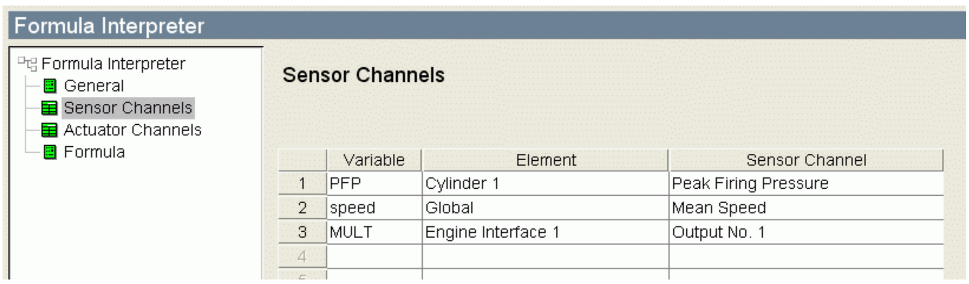


Figure 4-80: Formula Interpreter – Sensor Channels

The number of **Sensor Channels** is arbitrary. In this example the peak firing pressure of cylinder no. 1 is sensed and assigned to the variable “PFP”. This variable can be used in the formula (see below).

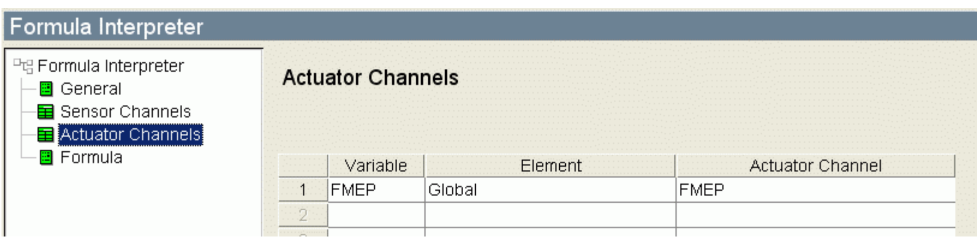


Figure 4-81: Formula Interpreter – Actuator Channels

The number of **Actuator Channels** is arbitrary. In this example the engine FMEP (element “Global”) is actuated. It needs to be defined in the formula (see below). (If no value is assigned to an actuated variable its value will be 0.0.)

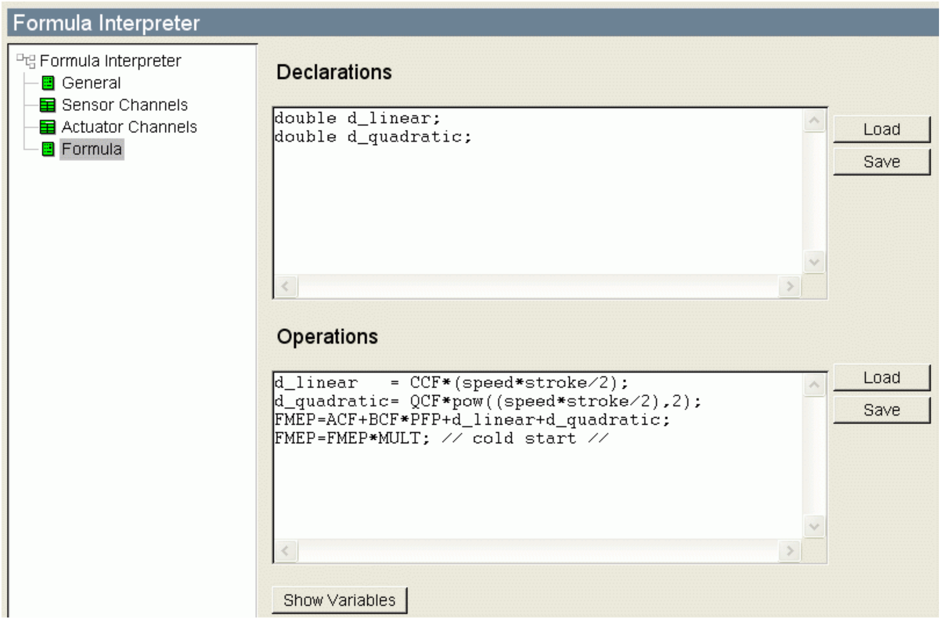


Figure 4-82: Formula Interpreter – Declarations and Formula

In this simple example two variables (“d_linear” and “d_quadratic”) are declared. Please refer to section 4.15.6.2.1 for more information on the extended data types.

The actual formula is defined in the **Operations** input field. In this simple example the variables “d_linear” and “d_quadratic” hold the linear and quadratic terms of the FMEP model (line 1 and 2). In line 3 the FMEP is calculated using a constant value and a linear dependency of the peak firing pressure. In line 4 the final value for the FMEP is obtained by multiplying a factor that was defined in **Engine Interface 1.** “// cold start //” is a comment.

4.15.6.4. Formula Interpreter Error Handling

When running a **BOOST** model that contains a Formula Editor element the **BOOST** solver checks the syntax of the model. If an error is found the calculation is stopped and an error message is written to the log file. For example, if the name of the variable “d_quadratic” is misspelled in the above example, the error message is:

```
FATALERROR 298024 FORMULA_INTERPRETER      1 READ_INDIVIDUAL_FORMULA_INTR       0.00
DEGCRA
  Syntax Error detected for Formula Interpreter No.   1
  Please check the following syntax:

           12:    CCF__1 = 600;
           13:    QCF__1 = 0.2;
           14:    return 0;}
           15:  //--------
           16:  int read_global_variables__1(
           17:   double global_values[]
           18:  ){
           19:    global_values[  0] = stroke__1;
           20:    global_values[  1] = ACF__1;
           21:    global_values[  2] = BCF__1;
           22:    global_values[  3] = CCF__1;
           23:    global_values[  4] = QCF__1;
           24:    return 0;}
           25:  //--------
           26:  int evaluate_formula__1(
           27:   double sensor[],
           28:   double actuator[]
           29:  ){
           30:    double PFP;
           31:    double speed;
           32:    double MULT;
           33:    double FMEP;
           34:    double d_linear;
           35:    double d_quadratic;
           36:    PFP = sensor[  0];
           37:    speed = sensor[  1];
           38:    MULT = sensor[  2];
           39:    d_linear   = CCF__1*(speed*stroke__1/2);
           40:    d_quadratic= QCF__1*pow((speed*stroke__1/2),2);
        X  41:    FMEP=ACF__1+BCF__1*PFP+d_linear+d_quadratic1;
           42:    FMEP=FMEP*MULT; // cold start //;
           43:    actuator[  0] = FMEP;
           44:    return 0;}
        line 41: '  FMEP=ACF__1+BCF__1*PFP+d_linear+d_quadratic1;'
        line 41, before ';': symbol 'd_quadratic1' not declared
        1 errors
 The calculation has been stopped.
```

4.15.7. Monitor

The **Monitor** element is used to produce <u>transient results</u> in the results folder and in the **Online Monitor** for an arbitrary number of **Actuator** and **Sensor Channels**.

Typical applications are:

- Check the value of a particular channel in a model that contains a large number of linked control elements.
- Visualize additional results that are calculated in a **Formula Interpreter** element.
- …

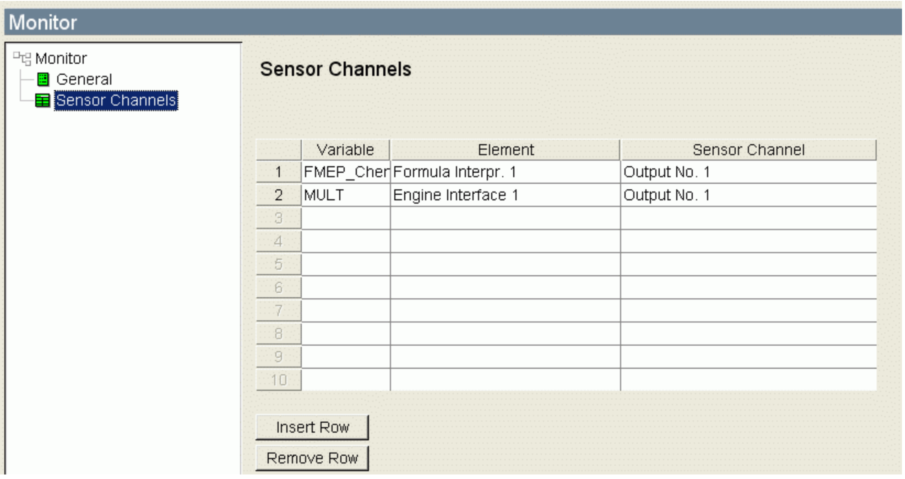


Figure 4-83: Formula Interpreter – Declarations and Formula

The number of **Sensor Channels** is arbitrary. In this example the output no. 1 of the **Formula Interpreter 1** is written to the transient results and to the **Online Monitoring** using the name "FMEP_Chen".

4.16. Acoustic Elements

4.16.1. Microphone

Click on **Linear Acoustics** for relevant information.

A microphone element can be added to any BOOST model in order to extract acoustic data such as overall dB(A) levels or order plots. The microphone is not attached to any pipe but linked in the input for the microphone to one or more system boundaries.

Figure 4-84: Microphone Input Window

Ground reflection can be included. In this case the height of the system boundary (orifice) above ground must be input.

The position of each system boundary relative to the microphone is defined as shown in the following figure.

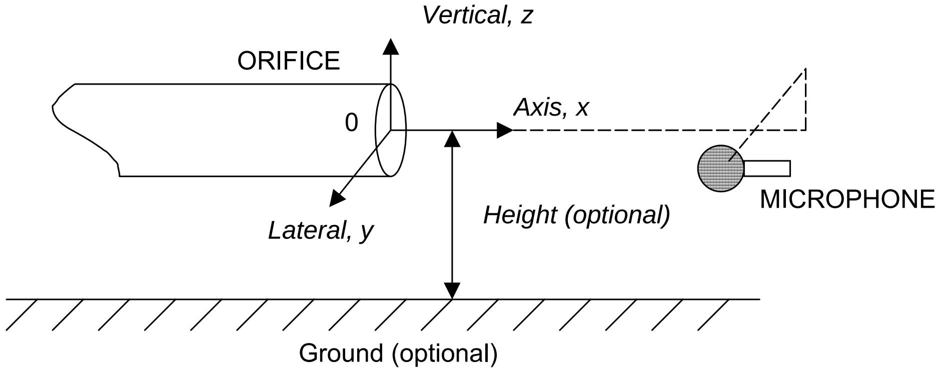


Figure 4-85: Microphone Position

Results from each microphone in a model can be found in the Acoustics folder and the Transients folder.

4.16.1.1. WAV file output

A steady state sound file (WAV) can be generated from the predicted sound pressure level at the microphone. This is based on the results from the last completed cycle of the simulation.

Simply select the **Sampling Rate**, **Low Pass Filter** frequency and the **Duration** of the sound file to be created. The WAV file will then be created in the results folder for the case with the name of the microphone (e.g. MIC1.wav).

The WAV file creation for microphones uses an automatic reference value. However, if the signal is too low (or too high) this value may not be appropriate. It can also be useful to compare WAV files with the same reference dB level. Therefore, the option to define a **Reference dB level** for the wav file creation is available.

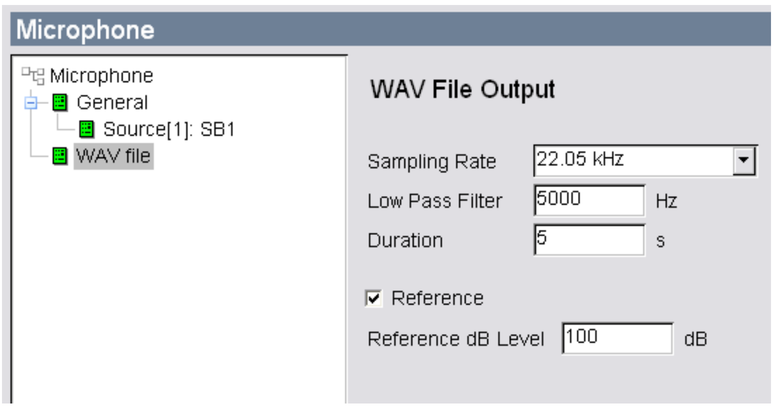


Figure 4-86: Microphone WAV File Input Data

4.16.2. Perforate

Click on **Linear Acoustics** for relevant information.

The perforate element is simply handled as a flow restriction with a flow coefficient that reflects the open area of the perforate as a function of the total surface area. The geometry of the perforate element is required as follows:

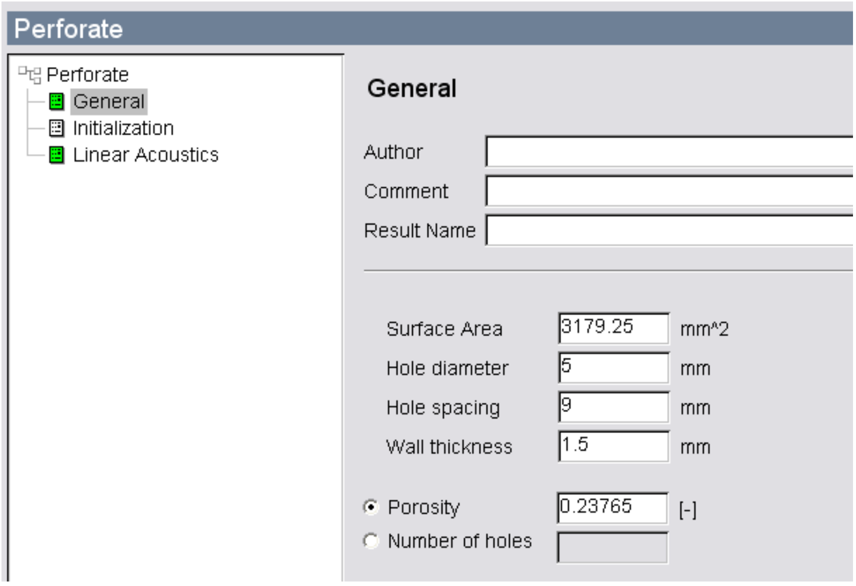


Figure 4-87: Perforate General Input Window

Surface Area

The total surface area of the perforate to be modeled. This should include the area of the holes and the wall. If using a segmentation approach for a perforated pipe then only the surface are of the segment being modeled should be entered (not the entire perforated section).

Hole Diameter

The diameter of the individual perforation holes.

Hole Spacing

The distance between the centers of the perforate holes.

Wall Thickness

The wall thickness of the perforated pipe or baffle.

Porosity or Number of Holes

The porosity of the perforated section can be defined directly or calculated from the surface area and the total number of holes.

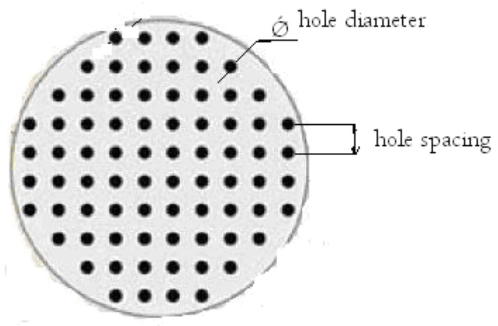


Figure 4-88: Perforate Geometry

4.16.3. Open Gap Chamber

Click on **Linear Acoustics** for relevant information.

The open gap chamber element is a super element. That is, it is not an element by itself but consists of a number of more fundamental acoustic elements. The input geometry required for the open gap chamber is shown.

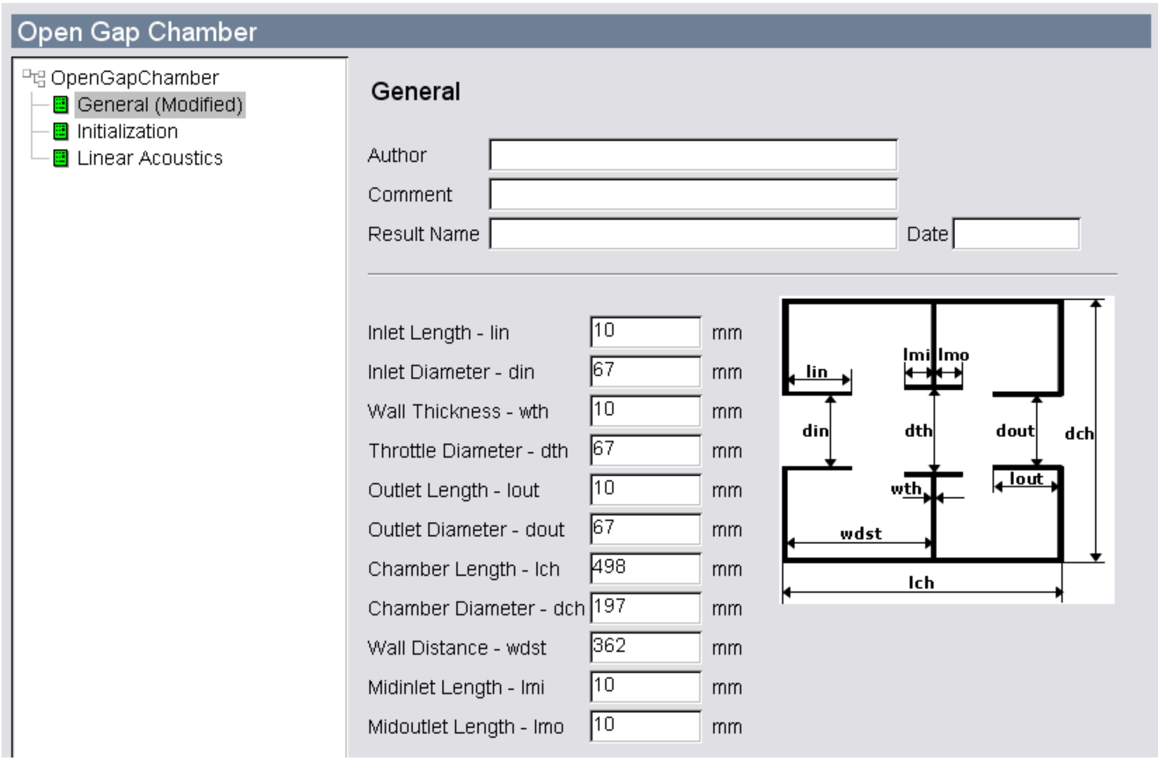


Figure 4-89: Open Gap Chamber General Input Window

This geometry is translated into a number of elements connected in series. The series starts with a pipe for the inlet followed by an inlet expansion into a pipe representing the main part of the inlet chamber. The mid section follows with a contraction element into the mid pipe and then an expansion into the outlet chamber. The outlet chamber is modeled as a pipe followed by a contraction into the out pipe.

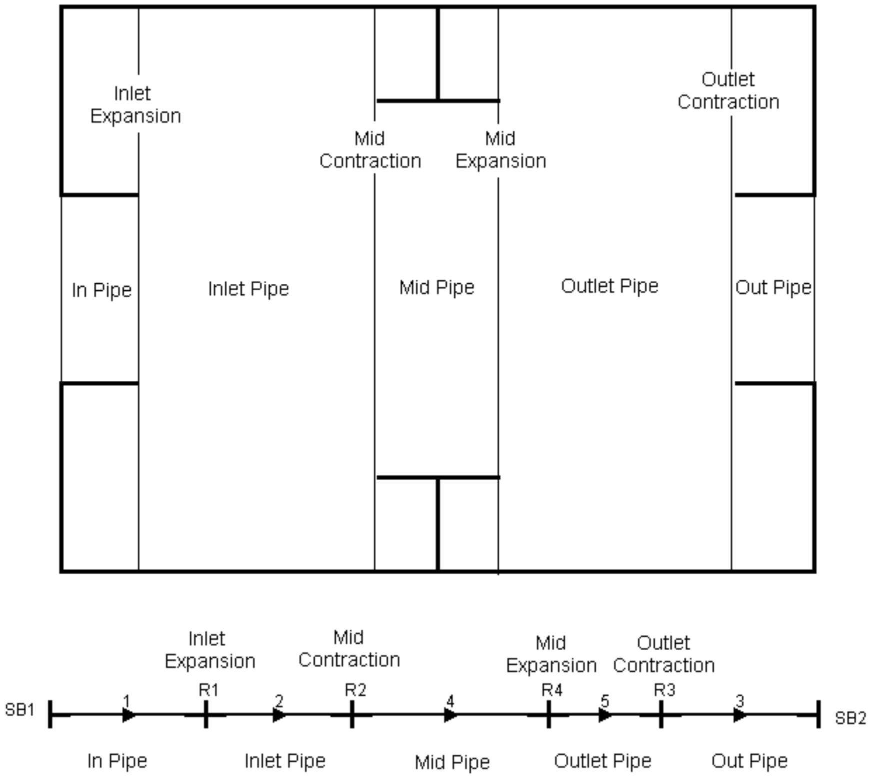


Figure 4-90: Open Gap Chamber Modeling

The open gap chamber element does not include automatic end corrections.

4.16.4. Overlapping Pipes

Click on **Linear Acoustics** for relevant information.

The overlapping pipes element is a super element. That is, it is not an element by itself but consists of a number of more fundamental acoustic elements. The input geometry required for the overlapping pipes element is shown

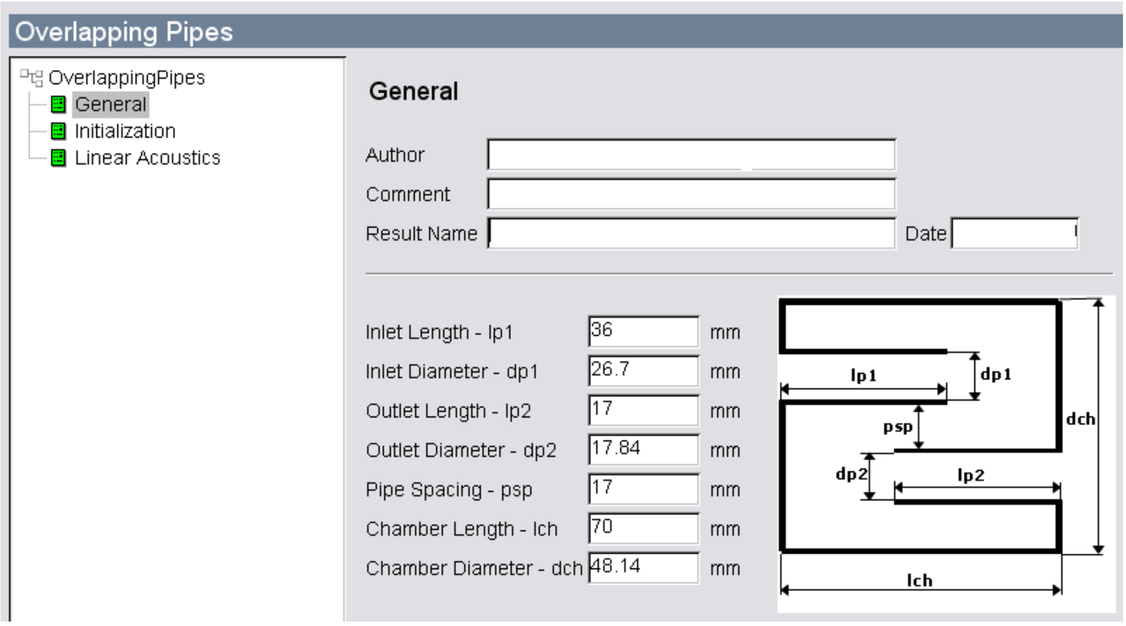


Figure 4-91: Overlapping Pipes General Input Window

This geometry is translated into a pipe-quarterwave-pipe-quarterwave-pipe set of elements connected in series.

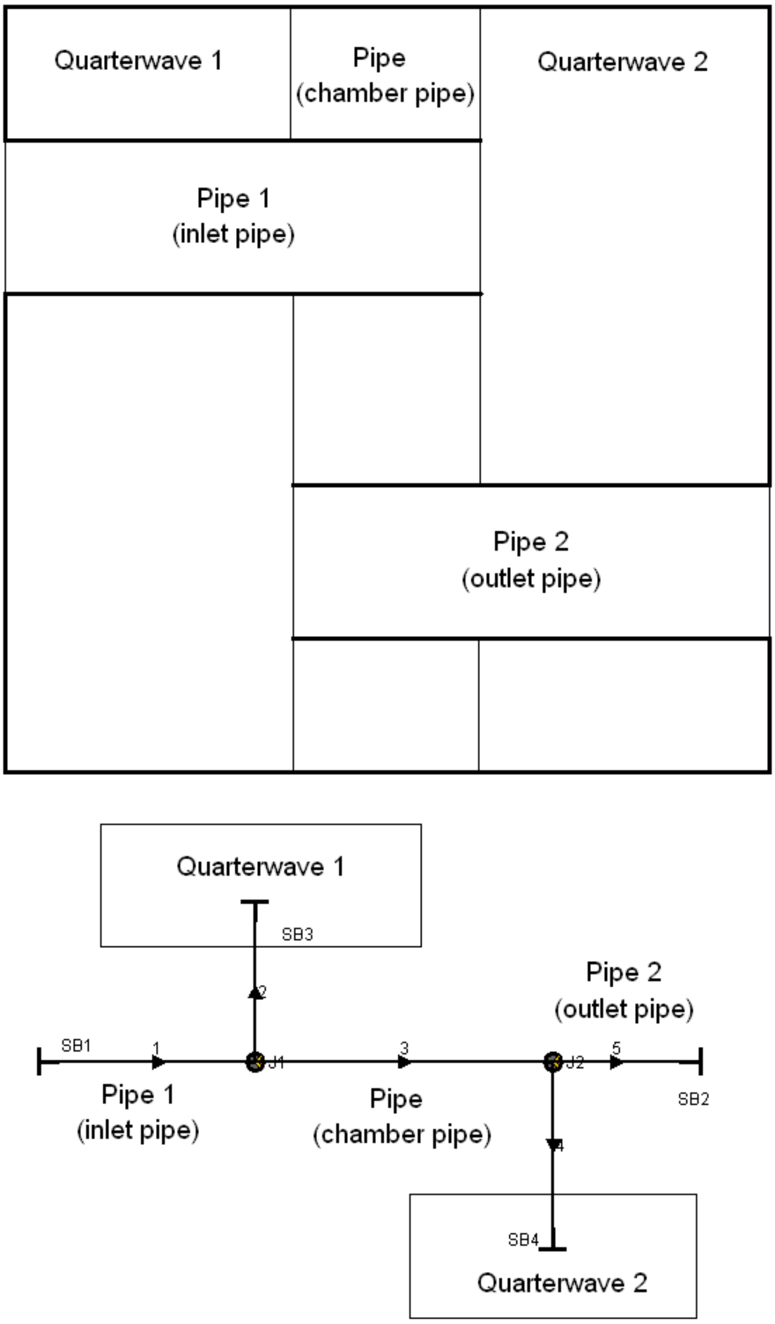


Figure 4-92: Overlapping Pipes Model

The overlapping pipes element does not include automatic end corrections.

4.16.5. Folded Boundary Resonator

Click on **Linear Acoustics** for relevant information.

The folded boundary resonator element is a super element. That is, it is not an element by itself but consists of a number of more fundamental acoustic elements. The input geometry required for the folded boundary resonator element is shown

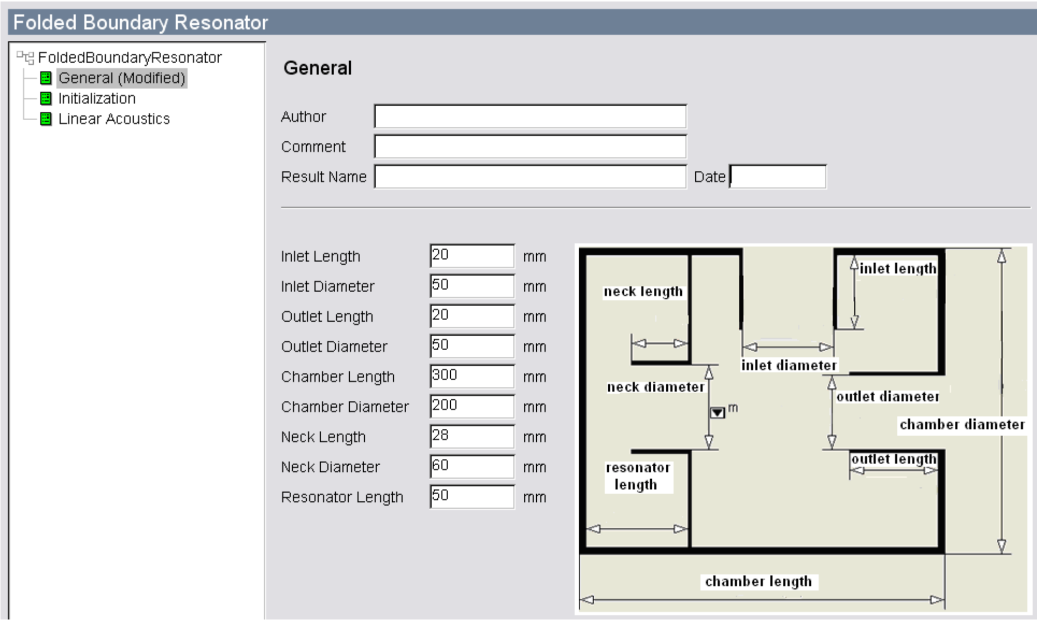


Figure 4-93: Folded Boundary Resonator General Input Window

The folded boundary resonator is translated as a series of pipes reflecting the geometry of the super element as well as a Helmholtz resonator for the end chamber.

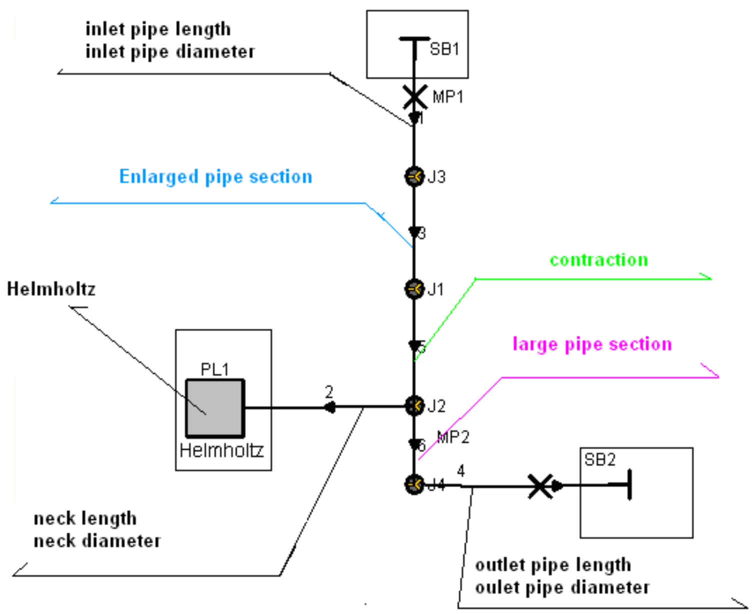


Figure 4-94: Folded Boundary Resonator Modeling

The Helmholtz element inside the folded boundary resonator super element includes an automatic end correction.

5. BOOST POST-PROCESSING

The **IMPRESS Chart** post-processing tool is used to display Traces, Transients, Acoustic and Series results and the **PP3** post-processing tool is used for Animation results. For the general handling of the **IMPRESS Chart** and **PP3** post-processing tools please refer to the GUI Users Guide.

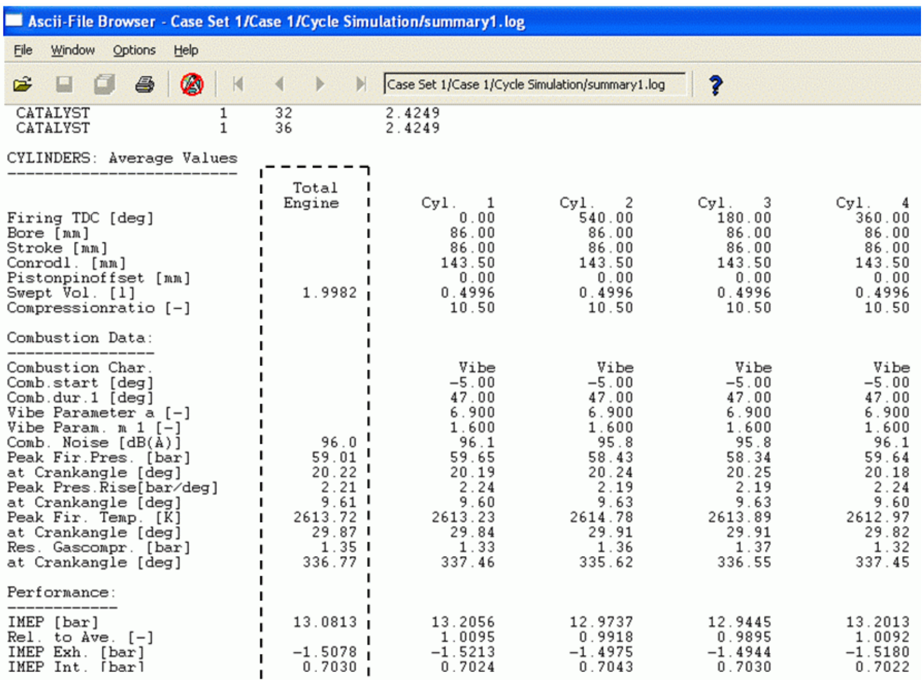
To accelerate the analysis process and to support the understanding of the complex flow phenomena in an internal combustion engine, the following result types are available:

- **SUMMARY** – Analysis of global engine performance data
- **TRANSIENTS** – Analysis of global calculation results over the cycles calculated
- **TRACES** – Analysis of calculation results over crank angle
- **ACOUSTIC** – Analysis of orifice noise
- **CASE SERIES** – Analysis of the results of a case-series calculation
- **ANIMATION** – Analysis of animated results
- **MESSAGES** – Analysis of messages from the main calculation program

Before starting a detailed analysis of the calculation run (Traces, Acoustic, Series, Animation, Summary), it is recommended to check **MESSAGES** for convergence failure and **TRANSIENTS** for achieved steady-state conditions.

5.1. Analysis of Summary Results

Select **Simulation | Show Summary** to display the summary results of the calculation together with detailed information of the calculation model and the important boundary conditions for the calculation. An example of summary results displayed in the Ascii File Browser window is shown in the following figure:




```
 CATALYST               1     32          2.4249
 CATALYST               1     36          2.4249

CYLINDERS: Average Values
-------------------------
                            Total
                            Engine      Cyl.   1     Cyl.   2     Cyl.   3     Cyl.   4
Firing TDC [deg]                           0.00        540.00        180.00        360.00
Bore [mm]                                 86.00         86.00         86.00         86.00
Stroke [mm]                               86.00         86.00         86.00         86.00
Conrodl. [mm]                            143.50        143.50        143.50        143.50
Pistonpinoffset [mm]                       0.00          0.00          0.00          0.00
Swept Vol. [l]              1.9982       0.4996        0.4996        0.4996        0.4996
Compressionratio [-]                      10.50         10.50         10.50         10.50

Combustion Data:
----------------
Combustion Char.                           Vibe          Vibe          Vibe          Vibe
Comb.start [deg]                          -5.00         -5.00         -5.00         -5.00
Comb.dur.1 [deg]                          47.00         47.00         47.00         47.00
Vibe Parameter a [-]                      6.900         6.900         6.900         6.900
Vibe Param. m 1 [-]                       1.600         1.600         1.600         1.600
Comb. Noise [dB(A)]           96.0         96.1          95.8          95.8          96.1
Peak Fir.Pres. [bar]         59.01        59.65         58.43         58.34         59.64
at Crankangle [deg]          20.22        20.19         20.24         20.25         20.18
Peak Pres.Rise[bar/deg]       2.21         2.24          2.19          2.19          2.24
at Crankangle [deg]           9.61         9.60          9.63          9.63          9.60
Peak Fir. Temp. [K]        2613.72      2613.23       2614.78       2613.89       2612.97
at Crankangle [deg]          29.87        29.84         29.91         29.91         29.82
Res. Gascompr. [bar]          1.35         1.33          1.36          1.37          1.32
at Crankangle [deg]         336.77       337.46        335.62        336.55        337.45

Performance:
------------
IMEP [bar]                 13.0813      13.2056       12.9737       12.9445       13.2013
Rel. to Ave. [-]                         1.0095        0.9918        0.9895        1.0092
IMEP Exh. [bar]            -1.5078      -1.5213       -1.4975       -1.4944       -1.5180
IMEP Int. [bar]             0.7030       0.7024        0.7043        0.7030        0.7022
```

Figure 5-1: Summary Analysis Window

To access additional features for manipulating files select **File** from the menu bar of the Ascii File Browser.

In the section the “CYLINDERS: Average Values” all relevant summary results are available for each cylinder separately. In addition to that, as marked in Figure 5-1, engine relevant results (typically averaged values or sums) are printed in the first column. All results in this section are described in detail below in the sections 5.1.1.1 through 5.1.1.14.

☞ **Note:** Most of the results in the “CYLINDERS: Average Values” and in the “TURBOCHARGERS: Average Values” sections are available also as transient (cycle averaged) data in the post-processor. All definitions in the transient results are identical with the global/summary results.

5.1.1. Definition of Global Engine Data (SI-Units)

Average (mean) values over the cycle duration CD:

$$\overline{y} = \frac{1}{CD} \cdot \int_{CD} y(\alpha) \cdot d\alpha$$

$y(\alpha)$	variable depending on α
α	crank angle
$\overline{y}$	average value of y
CD	cycle duration

Mass flow weighted temperature:

$$T_{MS} = \frac{\int_{CD} T(\alpha) \cdot \dot{m}(\alpha) \cdot d\alpha}{\int_{CD} \dot{m}(\alpha) \cdot d\alpha}$$

T_{MS}	mass flow weighted temperature
$T(\alpha)$	temperature depending on α
$\dot{m}(\alpha)$	mass flow rate depending on α

Number of cycles per second:

$n_{cycle} = n$	for two-stroke engines
$n_{cycle} = \frac{n}{2}$	for four-stroke engines
n	crankshaft-revolutions per second

5.1.1.1. Geometry Data

Firing TDC	deg	
Bore	mm	
Stroke	mm	
Conrodl.	mm	length of connecting rod
Pistonpinoffset	mm	
Swept Vol.	l	
Compressionratio	-	$\varepsilon = \frac{V_C + V_D}{V_C}$ $V_C + V_D$ maximum cylinder volume V_C minimum cylinder volume V_D displacement Note: The same definition is used for two and four stroke engines.
Dyn. Comp. ratio	-	$\frac{\text{Cylinder Volume at StartOfHighPressure}}{\text{Cylinder Volume at TopDeadCenter}}$

5.1.1.2. Combustion Data

Combustion Char.	-	Identifier for the applied combustion model: (Motored, Vibe, DbleVibe, Table, cnst.vol, cnst.pre., Wo/Ani, Hires/Tab, 2Z-Table, 2Z-Vibe, Quadim, AVL-MCC, Usr.hipr, GS_HCCI, TrgtPre1Z, TrgtPre2Z)
Comb.start	deg	start of combustion
Comb.dur.1	deg	duration of combustion (first peak in case of a double vibe combustion)
Vibe Parameter a	-	
Vibe Param. m 1	-	vibe parameter m (first peak in case of a double vibe combustion)
Comb.dur.2	deg	duration of combustion (second peak in case of a double vibe combustion)
Vibe Param. m 2	-	vibe parameter m (second peak in case of a double vibe combustion)
Ign. Delay	deg	ignition delay
Comb. Noise	dB(A)	
Peak Fir.Pres.	bar	maximum pressure
at Crankangle	deg	
Peak Pres.Rise	bar/deg	maximum pressure increase

at Crankangle	deg	
Peak Fir. Temp.	K	maximum temperature
at Crankangle	deg	
Peak T_burned	K	maximum temperature in the burned zone (two zone calculation only)
at Crankangle	deg	
Evaporation Energy	kJ	heat sink due to fuel evaporation
Required O.N.	-	Required Octane Number (see section 2.2.2.1.1 of the Theory Manual.; for two-zone combustion models with external mixture preparation only)
Res. Gascompr.	bar	Maximum Pressure during Exhaust Scavenging Stroke

5.1.1.3. Emissions (Classic Species Transport)

NOX	g/kWh	accumulated emissions of NOx
NOX	g/h	
NOX	ppm	
CO	g/kWh	accumulated emissions of CO
CO	g/h	
CO	ppm	
HC	g/kWh	accumulated emissions of HC (external mixture preparation only)
HC	g/h	(external mixture preparation only)
HC	ppm	(external mixture preparation only)
Soot	g/kWh	accumulated Emissions of soot (internal mixture preparation only)

5.1.1.4. Performance

IMEP	bar	$IMEP = \frac{1}{V_D} \cdot \int_{CD} p_c \cdot dV$ p_c cylinder pressure V cylinder displacement
Rel. to Ave.	-	cylinder IMEP relative to the engine IMEP
IMEP Exh.	bar	IMEP exhaust stroke (only four-stroke): $IMEP_{ex} = \frac{1}{V_D} \cdot \int_{\alpha=180}^{360} p_c \cdot dV$

IMEP Int.	bar	IMEP intake stroke (only four-stroke): $IMEP_{in} = \frac{1}{V_D} \cdot \int_{\alpha=360}^{540} p_c \cdot dV$
IMEP Gasex.	bar	IMEP gas exchange (= pumping mean effective pressure PMEP; only four-stroke): $PMEP = \frac{1}{V_D} \cdot \int_{\alpha=180}^{540} p_c \cdot dV$
IMEP-HP	bar	IMEP high pressure: $IMEP_{hp} = \frac{1}{V_D} \cdot \int_{\alpha=IVC}^{EVO} p_c \cdot dV$
FMEP	bar	friction mean effective pressure: $FMEP = \frac{P_{fr}}{V_D \cdot n_{cycle}}$ P_{fr} friction power FMEP does not contain the work caused by scavenging pumps, crankcase scavenging or mechanically driven supercharging devices,
BMEP	bar	brake mean effective pressure (individual cylinder): $BMEP_C = IMEP - FMEP - SMEP$ brake mean effective pressure (overall engine): $BMEP_E = IMEP - FMEP - AMEP$
AMEP; SMEP	bar	scavenging mean effective pressure (for the individual cylinder): $SMEP = \frac{P_S}{V_D \cdot n_{cycle}}$ P_S required power of related scavenging pump or crankcase scavenging auxiliary drives mean effective pressure (for the overall engine): $AMEP = \frac{P_{SP} + P_{CS} + P_{MC}}{V_{DE} \cdot n_{cycle}}$ P_{CS} required power of scavenging pumps P_{CS} required power of crankcase scavenging P_{CS} required power of mechanically driven supercharging devices V_{DE} engine displacement
ISFC	g/kWh	indicated fuel consumption (total fuel mass): $ISFC_{tt} = \frac{m_{t,FV} \cdot n_{cycle}}{P_i}$
Rel. to Ave.	-	cylinder ISFC relative to the engine ISFC

ISFC (tr.f.)	g/kWh	indicated fuel consumption (trapped fuel mass): $ISFC_{tr} = \frac{m_{c,FV} \cdot n_{cycle}}{P_i}$
ISFC (high p.)	g/kWh	$ISFC_{hp} = ISFC \frac{IMEP}{IMEP_{hp}}$
BSFC	g/kWh	brake specific fuel consumption: $BSFC = ISFC \frac{BMEP}{IMEP}$
Indicated Eff.	-	indicated efficiency: $\eta_T = \frac{\int_{CD} p_c \cdot dV}{m_{c,FV} \cdot H_u}$ H_u lower heating value
Iso vol. comb. Eff	-	isovolumetric combustion efficiency : $\eta_{gl\alpha}$ $\eta_{gl\alpha} = \frac{\left(\frac{dQ}{d\alpha}\right)}{Q} \cdot \frac{1 - 1/\varepsilon_\alpha^{\kappa-1}}{1 - 1/\varepsilon^{\kappa-1}} \cdot d\alpha$ $\varepsilon_\alpha = \frac{V_D}{V_\alpha}$ $\frac{dQ}{d\alpha}$ rate of heat release Q total released energy κ ratio of specific heats ε compression ratio $\varepsilon_\alpha = \frac{V_D}{V_\alpha}$ compression ratio at α V_D displaced volume V_α cylinder volume at α
Polytropic Coeff.	-	polytropic exponent evaluated for the compression change of in-cylinder state between StartOfHighPressure and StartOfCombustion

5.1.1.5. Fuel Mass Balance

Inj. Fuelmass	g	$m_{inj,FV}$ total mass of fuel directly injected
Asp.Trap. Fuelmass	g	$m_{astr,FV} = m_{c,FV} - m_{inj,FV}$ $m_{astr,FV}$ mass of fuel aspirated trapped

Fuelmassfl.(A+I)	g/s	flow of Asp.Trap. Fuelmass
Fuelmass tot.trap.	g	$\dot{m}_{astr,FV} = m_{astr,FV} \cdot n$ n engine cycle frequency [1/s]
Trapped Fuelm.fl.	g/s	flow of Fuelmass tot.trap.
Trapp. Eff. Fuel	-	trapping Efficiency Fuel: $\eta_{tr,F} = \frac{m_{c,FV}}{m_{t,FV}}$ $m_{t,FV}$ total mass of fuel added

5.1.1.6. Energy Balance

Fuel Energy	kJ	$Q_F = m_{c,FV} \cdot H_u$ $m_{c,FV}$ total mass of fuel trapped in the cylinder H_u lower heating value
Released Energy	kJ	$Q_{released} = Q_F \cdot FCV$ FCV fuel conversion factor as specified in Figure 5-2
Eff. Rel. Energy	kJ	$Q_{released,eff} = Q_{released} - Q_{CP}$ Q_{CP} amount of fuel energy that is not effectively released in the cylinder but is going into the combustion products: $Q_{CP} = f(\lambda)$ λ Excess air ratio. for stoichiometric and lean conditions ($\lambda \geq 1$) Q_{CP} goes to zero, for rich conditions it increases with decreasing λ. Chemically this reflects the fact that under rich conditions more and more energy is stored in species like CO, H2,…
Gross Rel. Energy	kJ	$Q_{released,gross} = Q_{released} + Q_{art}$
Eff.Gross Rel.Ener.	kJ	$Q_{released,gross,eff} = Q_{released,eff} + Q_{art}$ Q_{art} artificial source of fuel energy; this term applies for calculations running in the BOOST Analysis Mode (Burn, GCA) only, the term is 0.0 for all “standard” BOOST gas exchange simulations.

Energy Balance	-	$X_{energy} = \frac{Q_{released,gross}}{Q_F}$
Eff. Energy Balance	-	$X_{energy,eff} = \frac{Q_{released,gross,eff}}{Q_F}$

BOOST uses a fuel conversion factor to correct the lower heating value. The conversion factor is a function of the excess air ratio:

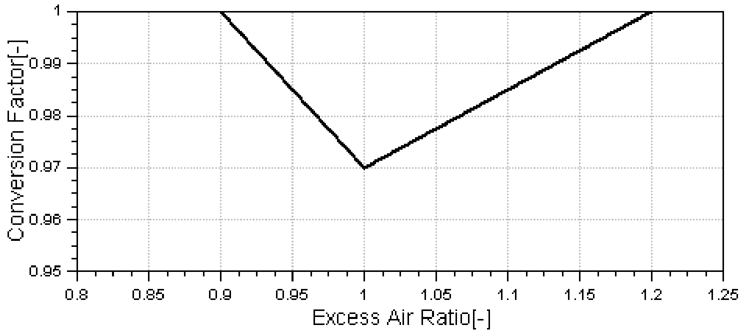


Figure 5-2: Fuel conversion factor

5.1.1.7. Blowby

Blowbymass	g	total mass lost by blowby
Blowbymassfl.	g/s	blowby mass flow
Blowby Heat Flow	kJ	Heat lost by blowby

5.1.1.8. Reference Values at Start of High Pressure (SHP)

Pressure at SHP	Bar	
Temperature	K	
Air Massfl.	g/s	$\dot{m}_{as,A} = m_{as,A} \cdot n$ $m_{as,A}$ mass of air aspirated n engine cycle frequency [1/s]
Fuel Massfl.	g/s	fuelmass tot.trap. (see above for definition)
Trapp. Eff. Air	-	(see below for definition)
Trapp. Eff. Fuel	-	(see above for definition)

A/F-Ratio (Cmb.)	-	air fuel ratio of combustion: $$AF_{Cmb} = \frac{m_{c,At}}{m_{c,FV}}$$ $m_{c,At}$ total mass of air in the cylinder
Excess Air Ratio	-	excess air ratio: $$\lambda = \frac{AF_{Cmb}}{AF_{Stc}}$$ λ excess air coefficient AF_{Stc} stoichiometric A/F-ratio

5.1.1.9. Residual Gas

Res.gas content	-	The residual gas content is the mass fraction of combustion products in the cylinder at the start of the high pressure phase (IVC).
Res.gas content	-	residual gas content: $$RG = \frac{m_{c,CP}}{m_{c,SHP}}$$ $m_{c,CP}$ mass of combustion products in the cylinder at SHP recirculated exhaust gas is added to the residuals.
Com.Prod.Mass. @ EO	g	The mass of combustion products inside the cylinder at the end of the high pressure phase (EVO). This is used as the reference value to determine the fractions of combustion products flowing through the intake and exhaust valves.
Res.gas mass @ SHP	g	The mass of combustion products inside the cylinder at the start of the high pressure phase (IVC).
Res.gas aspirated IN	g	This is the mass of combustion products that is aspirated through the intake valve(s). This is calculated by continually integrating the mass flow of combustion products through the intake(s).
Res.gas from intake	g	This is the mass of combustion products that flowed through the intake valve(s) into the cylinder. This is calculated by continually integrating the pure inflow of combustion products through the intake(s) (backflow is only considered when re-aspirated).
Rel. to Total	-	This is the fraction of the residual gas made up of the flow through the intake valve(s). This is calculated as follows, $$\frac{\text{Residual\_Mass\_Intake}}{\text{Residual\_Gas\_Mass}}$$

Res.gas flow EX	g	This is the mass of combustion products that flowed through the exhaust valve(s). This is calculated by continually integrating the mass flow of combustion products through the exhaust(s).
Res.gas from exhaust	g	This is the mass of combustion products that flowed through the exhaust valve(s) into the cylinder. This is calculated by continually integrating the pure inflow of combustion products through the exhaust(s).
Rel. to Total	-	This is the fraction of the residual gas that followed through the exhaust. This is calculated as follows, $\frac{\text{Residual\_Mass\_Exhaust}}{\text{Residual\_Gas\_Mass}}$

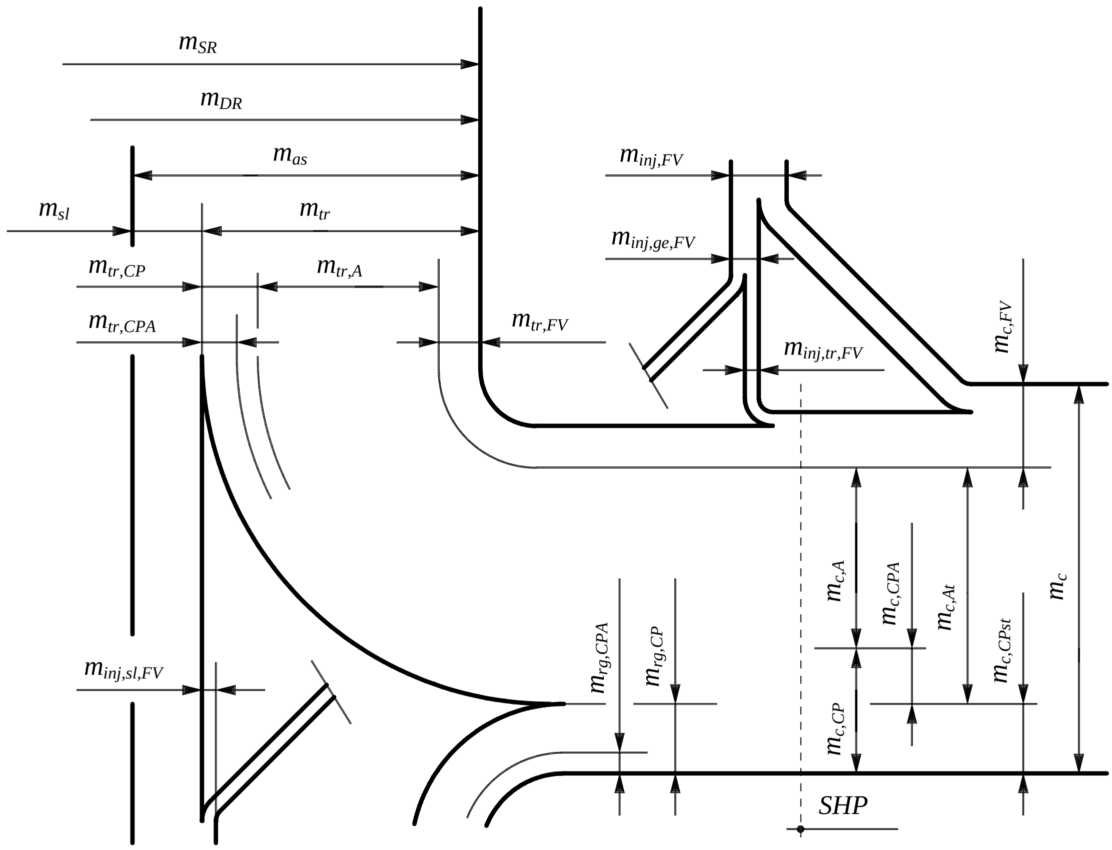
5.1.1.10. Gas Exchange

Volumetric Eff.	-	volumetric efficiency rel. to ambient conditions: $\eta_{V,a} = \frac{\dot{m}_{tr,A}}{\rho_a \cdot V_D \cdot n_{cycle}} = \frac{m_{tr,A}}{m_{DR,a}}$ $\dot{m}_{tr,A}$ mass flow of air trapped
Rel. to Ave.	-	relative to the average value
Rel. To	-	volumetric eff. rel. to intake manifold conditions (specified measuring point): $\eta_{V,m} = \frac{\dot{m}_{tr,A}}{\rho_m \cdot V_D \cdot n_{cycle}} = \frac{m_{tr,A}}{m_{DR,m}}$
Total Mass at SHP	g	$m_{c,SHP}$ total in-cylinder mass at SHP (all ports closed)
Mass Delivered	g	m_{as} mass of fresh charge aspirated
Mass Delivered	g/s	$\dot{m}_{as}$ Flow of Mass Delivered
Delivery Ratio	-	delivery ratio related to ambient conditions: $\lambda_{D,a} = \frac{m_{as}}{V_D \cdot \rho_a}$ ρ_a ambient air density
Rel. to Ave.	-	delivery ratio relative to the average value
Rel. To	-	delivery ratio related to intake manifold conditions (specified measuring point): $\lambda_{D,m} = \frac{m_{as}}{\rho_m \cdot V_D}$ ρ_m air density in the intake manifold (specified measuring point or plenum)

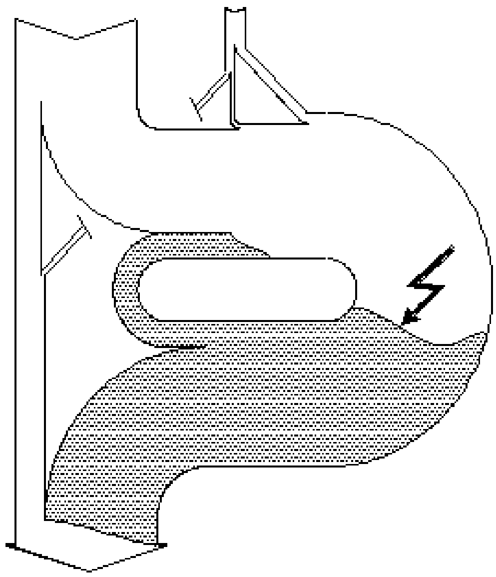
Av. Airmass at SHP	g	$m_{c,At}$ total mass of air in the cylinder at SHP
Air Delivered	g	$m_{as,A}$ mass of air aspirated
Air Delivered	g/s	flow of air delivered
Airdeliveryratio	-	air delivery ratio related to ambient conditions: $\lambda_{D,A,a} = \dfrac{\dot{m}_{as,A}}{\rho_a \cdot V_D \cdot n_{cycle}} = \dfrac{m_{as,A}}{m_{DR,a}}$ $\dot{m}_{as,A}$ mass flow of air aspirated $m_{DR,a}$ reference mass (ambient conditions) ρ_a ambient air density
Rel. to Ave.	-	air delivery ratio relative to the average value
Rel. To	-	air delivery ratio related to intake manifold conditions (specified measuring point): $\lambda_{D,A,m} = \dfrac{\dot{m}_{as,A}}{\rho_m \cdot V_D \cdot n_{cycle}} = \dfrac{m_{as,A}}{m_{DR,m}}$ $m_{DR,m}$ reference mass (manifold conditions) ρ_m air density in the intake manifold (specified measuring point or plenum)
Airmass Trapped	g	$m_{tr,A}$ mass of air trapped
Airmass Trapped	g/s	flow of airmass trapped
Trapp. Eff. Air	-	$\eta_{tr} = \dfrac{m_{tr,A}}{m_{as,A}}$
Rel. to Ave.	-	trapp. eff. air relative to the average value
Airpurity	-	$AP = \dfrac{m_{c,At}}{m_{c,SHP}}$
Dyn. Swirl [-]	-	dynamic swirl according to section 2.2.5 of the Theory Manual.
Dyn. Tumble [-]	-	dynamic tumble according to section 2.2.5 of the Theory Manual.

☞ **Note:** Gas Exchange data is defined in accordance with SAE standard J604 (Engine Terminology and Nomenclature – General, NN, June 1995).

The relation between the different data characterizing the gas exchange can be seen in the following figure:



m_{SR} reference mass for scavenge ratio
m_{DR} reference mass for delivery ratio
m_{as} mass of fresh charge aspirated
$m_{as,A}$ mass of air aspirated
$m_{as,CP}$ mass of combustion products aspirated (= $m_{as,CPst}$ for IMP)
m_{tr} mass of fresh charge trapped
m_{sl} mass lost during scavenging
$m_{tr,CP}$ mass of combustion products trapped (= $m_{tr,CPst}$ for IMP)
$m_{tr,CPA}$ mass of air included in trapped combustion products (= 0 for IMP)
$m_{tr,A}$ mass of air trapped
$m_{tr,FV}$ mass of fuel trapped (= 0 IMP)
$m_{inj,FV}$ total mass of fuel directly injected
$m_{inj,ge,FV}$ mass of fuel injected during gas exchange
$m_{inj,tr,FV}$ mass of injected fuel trapped during gas exchange (= 0 for IMP)
$m_{inj,sl,FV}$ mass of injected fuel lost during gas exchange (= 0 for IMP)
$m_{rg,CP}$ mass of residual gas
$m_{rg,CPA}$ mass of air included in residual gas
m_c total in-cylinder mass
$m_{c,A}$ mass of air in the cylinder (= $m_{c,At}$ for IMP)



$m_{c,At}$ total mass of air in the cylinder
$m_{c,CP}$ mass of combustion products in the cylinder at SHP (=$m_{c,CPst}$ for IMP)
$m_{c,CPA}$ mass of air included in combustion products,cylinder (= 0 for IMP)
$m_{c,CPst}$ mass of stoichiometric combustion products, cylinder
$m_{c,FV}$ total mass of fuel trapped in the cylinder (= $m_{inj,FV}$ for IMP)

Figure 5-3: Relation of Gas Exchange Data

5.1.1.11. Wall Heat Losses

Piston	kJ	
Cylinderhead	kJ	
Cylinderliner	kJ	
Sum of Wallheat	kJ	
Piston HP	kJ	during high pressure phase only
Cylinderhead HP	kJ	during high pressure phase only
Cylinderliner HP	kJ	during high pressure phase only
Sum of Wallheat HP	kJ	during high pressure phase only
Piston	-	relative to heat input
Cylinderhead	-	relative to heat input
Cylinderliner	-	relative to heat input
Sum of Wallheat	-	relative to heat input
M. Eff. HTC	W/m2/K	mean wall heat transfer coefficient in the cylinder $\overline{h_w} = \frac{1}{CD} \cdot \int_{CD} h_w(\alpha) \cdot d\alpha$ $h_w(\alpha)$ wall heat transfer coefficient depending on crank angle $\overline{h_w}$ mean wall heat transfer coefficient
M. Eff. Temp.	K	effective mean gas temperature for wall heat transfer in the cylinder. $T_{g,eff} = \frac{1}{CD \cdot \overline{h_w}} \cdot \int_{CD} T_G(\alpha) \cdot h(\alpha) \cdot d\alpha$ T_G gas temperature

5.1.1.12. Reference Values at EO

Pressure	bar	
Temperature	K	
A/F-Ratio	-	$AF_{EO} = \frac{m_{c,\ CP,\ EVO} - m_{c,\ FB,\ EVO}}{m_{c,\ FB,\ EVO}}$ $m_{c,\ CP,\ EVO}$ mass of combustion products in the cylinder at Exhaust Valve Opening $m_{c,\ FB,\ EVO}$ mass of burned fuel in the cylinder at EVO
Com.Prod.Conc.	-	mass fraction of combustion products
Fuel Concentr.	-	mass fraction of fuel

5.1.1.13. Average Values of Pipe Attachments

Vlv/Prt.Op.Clr.0mm	deg	valve opening: timing at 0 mm clearance, effective valve opening
Vlv/Prt.Op.Eff.0mm	deg	valve opening: timing at 0 mm effective lift (=specified valve clearance)
Vlv/Prt.Op.Eff.1mm	deg	valve opening: timing at 1 mm effective lift (=specified valve clearance)
Vlv/Prt.Op.Udef.mm	deg	valve opening: timing at user defined specification
Vlv/Prt.Cl.Clr.0mm	deg	valve closing: timing at 0 mm clearance, effective valve opening
Vlv/Prt.Cl.Eff.0mm	deg	valve closing: timing at 0 mm effective lift (=specified valve clearance)
Vlv/Prt.Cl.Eff.1mm	deg	valve closing: timing at 1 mm effective lift (=specified valve clearance)
Vlv/Prt.Cl.Udef.mm	deg	valve closing: timing at user defined specification
Cam Phasing	deg	shift of cam for this attachment
Massflow	g/cycle	massflow through this attachment
Wallheat	kJ/cycle	wall heatflow for this attachment
rel.to Heatinp.	-	
Swirl Entry	-	dynamic swirl according to section 2.2.5 of the Theory Manual.
Tumble Entry	-	dynamic tumble according to section 2.2.5 of the Theory Manual.

5.1.1.14. Engine Results

Indicated torque	Nm	$T_i = \frac{IMEP \cdot V_D}{k_{cycle}\pi}$ T_i indicated torque k_{cycle} cycle parameter: 2 for two-stroke engines 4 for four-stroke engines
Indicated specific torque	Nm/l	$T_{is} = \frac{T_i}{V_D}$
Indicated power	kW	$P_i = IMEP \cdot V_D \cdot n_{cycle}$
Indicated specific power	kW/l	$P_{is} = \frac{P_i}{V_D}$

Auxiliary Drives Torque	Nm	$T_A = \dfrac{AMEP \cdot V_D}{k_{cycle}\pi}$
Auxiliary Drives Power	kW	$P_A = AMEP \cdot V_D \cdot n_{cycle}$
Friction Torque	Nm	$T_F = \dfrac{FMEP \cdot V_D}{k_{cycle}\pi}$
Friction Power	kW	$P_F = FMEP \cdot V_D \cdot n_{cycle}$
Effective Torque	Nm	$T_{eff} = \dfrac{BMEP \cdot V_D}{k_{cycle}\pi}$
Effective Specific Torque	Nm/l	$T_{eff,s} = \dfrac{T_{eff}}{V_D}$
Effective Power	kW	$P_{eff} = BMEP \cdot V_D \cdot n_{cycle}$
Effective Specific Power	kW/l	$P_{eff,s} = \dfrac{P_B}{V_D}$

5.1.1.15. Compressor Results

Cycle averaged Isentropic Compressor Efficiency (Total to Total; Summary and Transient Results)	-	$\overline{\eta_{CTT}} = \dfrac{\int\limits_{CDUR} c_p T_{01}\left(\left(\dfrac{p_{02}}{p_{01}}\right)^{\frac{\kappa-1}{\kappa}} - 1\right)\dot{m}_1 dt}{\int\limits_{CDUR} (h_{02} - h_{01})\dot{m}_1 dt}$
Cycle averaged Compressor Pressure Ratio (Summary and Transient Results)	-	$\overline{\dfrac{p_{02}}{p_{01}}} = \dfrac{\int\limits_{CDUR}\left(\dot{m}_1 \dfrac{p_{02}}{p_{01}}\right)dt}{\int\limits_{CDUR} \dot{m}_1\, dt}$
Cycle averaged Compressor Total Inlet Pressure	Pa	$\overline{p_{01}} = \dfrac{\int\limits_{CDUR} (\dot{m}_1 p_{01})dt}{\int\limits_{CDUR} \dot{m}_1\, dt}$
Cycle averaged Compressor Total Inlet Temperature	K	$\overline{T_{01}} = \dfrac{\int\limits_{CDUR} (\dot{m}_1 T_{01})dt}{\int\limits_{CDUR} \dot{m}_1\, dt}$
Cycle averaged Compressor Total Outlet Temperature	K	$\overline{T_{02}} = \dfrac{\int\limits_{CDUR} (\dot{m}_2 T_{02})dt}{\int\limits_{CDUR} \dot{m}_2\, dt}$

Cycle averaged, Temperature based Compressor Efficiency	K	$\overline{\eta_{CTT,temp}} = \dfrac{\overline{\left(\dfrac{p_{02}}{p_{01}}\right)}^{\overline{\left(\frac{\kappa-1}{\kappa}\right)}} - 1}{\dfrac{\overline{T_{02}}}{\overline{T_{01}}} - 1}$
Cycle averaged Compressor Corrected Massflow	$\dfrac{kg\sqrt{K}}{sPa}$ or $\dfrac{kg}{s}$	unreferenced: $\overline{\dot{m}_{C,cor}} = \dfrac{\sqrt{\overline{T_{01}}}}{\overline{p_{01}}} \dfrac{\int_{CDUR} \dot{m}_1 dt}{t_{CDUR}}$ referenced: $\overline{\dot{m}_{C,cor}} = \dfrac{\sqrt{\overline{T_{01}}}}{\overline{p_{01}}} \dfrac{\int_{CDUR} \dot{m}_1 dt}{t_{CDUR}} \dfrac{p_{ref}}{\sqrt{\overline{T_{ref}}}}$
Cycle averaged Compressor Corrected Speed	$\dfrac{rpm}{\sqrt{K}}$ or rpm	unreferenced: $\overline{n_{C,cor}} = \dfrac{n}{\sqrt{\overline{T_{01}}}}$ referenced: $\overline{n_{C,cor}} = \dfrac{n}{\sqrt{\overline{T_{01}}}} \cdot \sqrt{T_{ref}}$

5.1.1.16. Turbine Results

Cycle averaged Isentropic Turbine Efficiency (Total to Static; Summary and Transient Results)	-	$\overline{\eta_{TTS}} = \dfrac{\sum_{i_{Entries}}\left(\int_{CDUR} h_{03,i}\dot{m}_{3,i}dt\right) - \int_{CDUR} h_{04}\dot{m}_4 dt}{\int_{CDUR} T_{03,i} \sum_{i_{Entries}}(\dot{m}_{3,i}) c_p \left(1 - \left(\dfrac{p_4}{\frac{1}{n_{Entries}} \sum_{i_{Entries}}(p_{03,i})}\right)^{\frac{\kappa-1}{\kappa}}\right) dt}$
Cycle averaged Turbine Pressure Ratio (Summary and Transient Results)	-	$\overline{\dfrac{p_{03}}{p_4}} = \dfrac{\int_{CDUR}\left(\left(\dfrac{1}{n_{Entries}} \sum_{i_{Entries}} \dfrac{p_{03,i}}{p_4}\right)\left(\sum_{i_{Entries}} \dot{m}_{3,i}\right)\right)dt}{\int_{CDUR} \sum_{i_{Entries}} \dot{m}_{3,i} dt}$
Cycle averaged Turbine Total Inlet Pressure	P	$\overline{p_{03}} = \dfrac{\int_{CDUR}\left(\left(\dfrac{1}{n_{Entries}} \sum_{i_{Entries}} p_{03,i}\right)\left(\sum_{i_{Entries}} \dot{m}_{3,i}\right)\right)dt}{\int_{CDUR} \sum_{i_{Entries}} \dot{m}_{3,i} dt}$

Cycle averaged Turbine Total Inlet Temperature	T	$\overline{T_{03}} = \dfrac{\int\limits_{CDUR} \left(\left(\dfrac{1}{n_{Entries}} \sum\limits_{i_{Entries}} T_{03,i} \right) \left(\sum\limits_{i_{Entries}} \dot{m}_{3,i} \right) \right) dt}{\int\limits_{CDUR} \sum\limits_{i_{Entries}} \dot{m}_{3,i}\, dt}$
Cycle averaged Turbine Static Outlet Temperature	T	$\overline{T_4} = \dfrac{\int\limits_{CDUR} \left(\dot{m}_4 \sum\limits_{i_{Entries}} T_4 \right) dt}{\int\limits_{CDUR} \dot{m}_4\, dt}$
Cycle averaged, Temperature based Turbine Efficiency	-	$\overline{\eta_{TTS,temp}} = \dfrac{1 - \dfrac{\overline{T_{04}}}{\overline{T_{03}}}}{1 - \overline{\left(\dfrac{p_4}{p_{03}} \right)}^{\left(\frac{\kappa - 1}{\kappa} \right)}}$
Cycle averaged Turbine Corrected Massflow	$\dfrac{kg\sqrt{K}}{sPa}$ or $\dfrac{kg}{s}$	unreferenced: $\overline{\dot{m}_{T,cor}} = \dfrac{\sqrt{\overline{T_{03}}}}{\overline{p_{03}}} \dfrac{\int\limits_{CDUR} \dot{m}_4\, dt}{t_{CDUR}}$ referenced: $\overline{\dot{m}_{T,cor}} = \dfrac{\sqrt{\overline{T_{03}}}}{\overline{p_{03}}} \dfrac{\int\limits_{CDUR} \dot{m}_4\, dt}{t_{CDUR}} \cdot \dfrac{p_{ref}}{\sqrt{T_{ref}}}$
Cycle averaged Turbine Corrected Speed	$\dfrac{rpm}{\sqrt{K}}$ or rpm	unreferenced: $\overline{n_{T,cor}} = \dfrac{n}{\sqrt{\overline{T_{03}}}}$ referenced: $\overline{n_{T,cor}} = \dfrac{n}{\sqrt{\overline{T_{03}}}} \cdot \sqrt{T_{ref}}$
Cycle averaged Turbine Blade Speed Ratio	-	$\overline{BSR} = \sqrt{\dfrac{1}{2R} \left(\dfrac{\kappa - 1}{\kappa} \right)} \cdot \dfrac{d_t \pi \overline{n_{T,cor}}}{\sqrt{1 - \overline{\left(\dfrac{p_{03}}{p_4} \right)}^{-\left(\frac{\kappa - 1}{\kappa} \right)}}}$

5.2. Analysis of Cycle Dependent Results

TRANSIENTS: The transient results show the development of the solution over all calculated engine cycles. These results are typically integral values (average mass flow at a measuring point, IMEP…) or distinct values (peak firing pressure,…) for each cycle.

Select **Simulation | Show Results** to open the **IMPRESS Chart**. Please refer to the IMPRESS Chart Users Guide for details on its usage. The following data is available in the **Transients** subfolder:

Element Data	Unit	Comment
ENGINE and CYLINDER:		Refer to section 5.1.1 for detailed information.
PIPE:		
WALLHEATFLOW	J/cycle	integral wall heat losses
MAXIMUM TEMPERATURE	K	integral wall heat losses
WALLHEATFLOW	J/cycle	integral wall heat losses
PIPE with VARIABLE WALL TEMPERATURE activated:		
MAXIMUM TEMPERATURE	K	maximum wall temperature
MINIMUM TEMPERATURE	K	maximum wall temperature
MEAN TEMPERATURE	K	maximum wall temperature
MAXIMUM GAS TEMPERATURE	K	maximum gas temperature
MINIMUM GAS TEMPERATURE	K	maximum gas temperature
MEAN GAS TEMPERATURE	K	maximum gas temperature
AMBIENT TEMPERATURE	K	ambient temperature (convection)
RADIATION SINK TEMPERATURE	K	ambient temperature (radiation)
GAS-WALL HEATFLOW	J/cycle	gas/wall integral heat flow
GAS-WALL NUSSELT	-	gas/wall Nusselt number
GAS-WALL HEAT-TRANS COEFF	W/m2K	gas/wall heat transfer coefficient
GAS-WALL HEATFLOWPERS	W	gas/wall integral heat flow
WALL-AMBIENT NUSSELT	-	wall/ambient Nusselt number
WALL-AMBIENT HEAT-TRANS COEFF	W/m2K	wall/ambient heat transfer coefficient
RADIATIVE WALL-AMBIENT HEATFLOWPERS	W	wall/ambient integral heat flow due to radiation
CONVECTIVE WALL-AMBIENT HEATFLOWPERS	W	wall/ambient integral heat flow due to convection
GAS TEMPERATURE	K	at all axial positions
WALL TEMPERATURE X	K	wall temperature of layer X at all axial positions
MEASURINGPOINT:		
PRESSURE	Pa	
VELOCITY	m/s	
TEMPERATURE	K	
MASSFLOWAVERAGED TEMP	K	
MACHNUMBER	-	
MASSFLOW	kg/cycle	
MASSFLOWPERS	kg/s	
ENTHALPYFLOW	J/cycle	
STAGPRESSURE	Pa	
STAGTEMP	K	
REYNOLDSNUMBER	-	
WALLTEMPERATURE	K	
CONVERGENCE	-	sum of pressure temperature and velocity deviation between cycles
A/F_RATIO	-	of the combustion products
FUELVAPOURCONCENTRATION	-	
COMBPRODCONCENTRATION	-	
FUELFLOW	kg/s	
COMBPRODFLOW	kg/s	
SPECIES MASSFRACTIONS	-	general species transport
SPECIES MOLEFRACTIONS	-	general species transport
DENSITY	kg/m3	
SPECIFIC HEAT (CP)	J/kgK	
MEAN KAPPA	-	
MEAN GAS CONSTANT	J/kgK	
FRICTION COEFFICIENT	-	

PLENUM:		
PRESSURE	Pa	
TEMPERATURE	K	
MASS	kg	
WALLHEATFLOW	J/cycle	
WALLTEMPERATURE	K	
SPECIES MASSFRACTIONS	-	general species transport

VARPLENUM = PLENUM plus:		
VOLUME	m3	
VOLUMEWORK	J/cycle	

FUELINJECTOR:		
ADDEDFUEL	kg/cycle	
ADDEDFUEL-PUDDLING	kg/cycle	puddling: effective value
PUDDLE-FUELMASS-XXX	kg	fuel mass in the puddle for range XXX
PUDDLE-ACCUMULATED RATEEVAP-XXX	kg	accumulated (per cycle) evaporation rate from puddle for range XXX

THROTTLE:		
THROTTLE-ANGLE	deg	

AIRCOOLER		
WALLHEATFLOW	J/cycle	
for the inlet and the outlet plenums:		
PRESSURE	Pa	
TEMPERATURE	K	
MASS	kg	
A/F_RATIO	-	of the combustion products
FUELVAPOURCONCENTRATION	-	
COMBPRODCONCENTRATION	-	

AIRCLEANER:		see **AIRCOOLER**
CATALYST		see **AIRCOOLER**
DPF		see **AIRCOOLER**

TURBOCHARGER:		
for the compressor		
ROTATIONALSPEED	rpm	
COMPRESSORWORK	J/cycle	
COMPRESSORRATIO	-	see section 5.1.1.15
COMPRESSOREFFICIENCY	-	see section 5.1.1.15
BOOSTPRESSURE	Pa	
MECHANICALEFFICIENCY	-	
INLETTOTPRESSURE	Pa	
INLETTOTTEMP	K	
OUTLETTOTTEMP	K	
ISENTROPICEXPONENT	-	
COMPRESSOREFFICIENCY	-	
COMPRESSOREFFICIENCY	-	
COMPRESCORRMASSFLOWREF	-	compressor corrected massflow in input units
COMPRESCORRSPEEDREF	-	compressor corrected speed in input units
for the turbine		
TURBINEWORK	J/cycle	
TURBINERATIO	-	see section 5.1.1.16
TURBINEEFFICIENCY	-	see section 5.1.1.16
TURBINETOTOTAL	-	
EFFECTIVEFLOWAREA	-	
DISCHARGECOEFFICIENT	-	
VANEPOSITION	-	
INLETTOTPRESSURE	Pa	
INLETTOTTEMP	K	
OUTLETSTATTEMP	K	
ISENTROPICEXPONENT	-	
TURBINECORRMASSFLOWREF	-	turbine corrected massflow in input units
TURBINECORRSPEEDREF	-	turbine corrected speed in input units

PD-COMPRESSOR:		
COMPRESSORWORK	J/cycle	
COMPRESSORRATIO	-	mass flow averaged
ROTATIONALSPEED	rpm	
COMPRESSOREFFICIENCY	-	

ELECTRICAL DEVICE		
ROTATIONALSPEED	rpm	full model only
MECHWORKELMOTOR	J/cycle	
ELWORKELMOTOR	J/cycle	
ELMOTOREFFICIENCY	-	

TEST BED REFERENCE		
P_0_A	bar	Barometric Pressure (absolute)
P11	bar	Pressure at Test Bed Reference Location 11 (relative to P_0_A)
P21	bar	Pressure at Test Bed Reference Location 21 (relative to P_0_A)
P2_1	bar	Pressure at Test Bed Reference Location 2_1 (relative to P_0_A)
P31	bar	Pressure at Test Bed Reference Location 31 (relative to P_0_A)
P41	bar	Pressure at Test Bed Reference Location 41 (relative to P_0_A)
T11	degC	Temperature at Test Bed Reference Location 11
T21	degC	Temperature at Test Bed Reference Location 21
T_21	degC	Temperature at Test Bed Reference Location 2_1
T31	degC	Temperature at Test Bed Reference Location 31
T41	degC	Temperature at Test Bed Reference Location 41

ECU:		
LOAD SIGNAL	-	

various ELEMENTS:		
for each ATTACHEDPIPE		
MASSFLOW	kg/cycle	
VELOCITY	m/s	
FLOWCOEFFICIENT	-	

5.3. Analysis of Crank Angle Dependent Results

TRACES: The traces results show the solution over the last calculated engine cycle (720 degCA for four stroke, 360 degCA for two stroke engines.

Select **Simulation | Control | Output Control** in order to extend the “Traces - Saving Interval” to an arbitrary number of cycles.

Select **Simulation | Show Results** to open the **IMPRESS Chart** post-processor. The following data is available for each element in the **Traces** subfolder:

Element Data	Unit	Comment
ENGINE:		Refer to section 5.1.1 for detailed information.
TIME	s	time
ENGINESPEED	rpm	instantaneous revolution speed of the crank shaft
TORQUE	Nm	instantaneous torque at the crank shaft

SYSTEMBOUNDARY = INTERNALBOUNDARY		
TEMPERATURE	K	
PRESSURE	Pa	
for the ATTACHEDPIPE		
MASSFLOW	kg/s	
VELOCITY	m/s	
FLOWCOEFFICIENTS	-	

MEASURINGPOINT:		
PRESSURE	Pa	
VELOCITY	m/s	
FORWARDPRESSURE	Pa	forward moving wave
BACKWARDPRESSURE	Pa	backward moving wave
FORWARDVELOCITY	m/s	forward moving wave
BACKWARDVELOCITY	m/s	backward moving wave
TEMPERATURE	K	
MACHNUMBER	-	
STAGNATIONPRESSURE	Pa	
STAGNATIONTEMPERATURE	K	
MASSFLOW	kg/s	
ENTHALPYFLOW	J/s	
REYNOLDSNUMBER	-	
A/F_RATIO	-	of the combustion products
FUELCONCENTRATION	-	
COMBUSTIONPRODUCTCONCENTRATION	-	
FUELFLOW	kg/s	
COMBUSTIONPRODUCTFLOW	kg/s	
SPECIES MASSFRACTIONS	-	general species only
SPECIES MOLEFRACTIONS	-	general species only
DENSITY	kg/m3	
SPECIFIC HEAT (CP)	J/kg/k	
FRICTION COEFFICIENT	-	

PLENUM:		
PRESSURE	Pa	
TEMPERATURE	K	
MASS	Kg	
WALLHEATFLOW	J/s	
A/F_RATIO	-	see measuring point
FUELCONCENTRATION	-	
COMBUSTIONPRODUCTCONCENTRATION	-	
SPECIES MASSFRACTIONS	-	general species only

VARPLENUM = PLENUM plus		
VOLUME	m3	
VOLUMEWORK	Nm	

CYLINDER		
PRESSURE	Pa	
TEMPERATURE	K	
MASS	kg	
VOLUME	m^3	
VOLUMEWORK	J/deg	
PRESSURERISE	Pa/deg	
TEMPERATURERISE	K/deg	
RATEOFHEATRELEASE	J/deg	
RATEOFHEATRELEASE-EFF	J/deg	
BURNEDVOLUMEFRACTION	-	
TEMPERATURE-BURNEDZONE	K	
TEMPERATURE-UNBURNEDZONE	K	
MASS-BURNEDZONE	kg	
A/F-RATIO-BURNEDZONE	-	

HEATTRANSFERCOEFF-BURNEDZONE	W/(m^2.K)	
HEATTRANSFERCOEFF-UNBURNEDZONE	W/(m^2.K)	
ACCUMULATEDNOX	kg	
ACCUMULATEDCO	kg	
ACCHC-TOTAL	kg	
NOXFORMATION	kg/s	
COFORMATION	kg/s	
HCFORMATION-TOT	kg/s	
ACCHC-CREV	kg	
ACCHC-OIL	kg	
ACCHC-OXI	kg	
HCFORMATION-CREV	kg/s	
HCFORMATION-OIL	kg/s	
HCOXIDATION	kg/s	
ACCUMULATEDSOOT	kg	
SOOTFORMATION	kg/s	
TOTALWALLHEATFLOW	J/deg	
PISTONWALLHEATFLOW	J/deg	
HEADWALLHEATFLOW	J/deg	
LINERWALLHEATFLOW	J/deg	
HEATTRANSFERCOEFFICIENT	W/(m^2.K)	
INTAKEMASSFLOW	kg/s	
EXHAUSTMASSFLOW	kg/s	
BLOWBY	kg/s	
BLOWBYENTHALPYFLOW	J/deg	
FUELBURNEDCONCENTRATION	-	
COMBUSTIONPRODUCTCONCENTRATION	-	
FUELVAPOURCONCENTRATION	-	
A/F-RATIO	-	
MASSASPIRATED	kg	
RATEOFINJECTION	kg/deg	
EVAPORATIONRATE	kg/deg	
EVAPORATIONENERGY	J/deg	
SPECIESMASSFRACTION	-	general species transport only
SPECIESMASSFRACTION_UNBRND	-	general species transport / two zone only
SPECIESMASSFRACTION_BRND	-	general species transport / two zone only
SPECIESMOLEFRACTION	-	general species transport only
TURBULENT-KINETIC-VELOCITY	m/s	fractal combustion model
MEAN-KINETIC-VELOCITY	m/s	fractal combustion model
LAMINAR-FLAME-SURFACE	m^2	fractal combustion model
LAMINAR-FLAME-SPEED	m/s	fractal combustion model
FRACTAL-DIMENSION	-	fractal combustion model
ENTHALPY	J/kg	
ENTROPY	J/kg/K	
SPECHEATCV	J/kg/K	

SPECHEATCP	J/kg/K	
RGASMIX	J/kg/K	

FUELINJECTOR: ADDEDFUEL	kg/s	puddling: target value
ADDEDFUEL-PUDDLING	kg/s	puddling: effective value
PUDDLE-FUELMASS-XXX	kg	fuel mass in the puddle for range XXX
PUDDLE-RATEEVAP-XXX	kg/s	evaporation rate from puddle for range XXX
PUDDLE-X	-	effective distribution factor X

WASTEGATE: VALVELIFT	m	

AIRCOOLER, AIRCLEANER and CATALYST		see Transient results

TURBOCHARGER:		
ROTATIONALSPEED	rpm	
COMPRESSORPOWER	J/s	
COMPRESSOREFFICIENCY: INSTANTANEOUS ISENTROPIC COMPRESSOR EFFICIENCY (TOTAL TO TOTAL)	-	$\eta_{CTT} = \frac{h_{02,S} - h_{01}}{h_{02} - h_{01}} = \frac{c_p T_{01}\left(\left(\frac{p_{02}}{p_{01}}\right)^{\frac{\kappa-1}{\kappa}} - 1\right)}{h_{02} - h_{01}}$
COMPRESPRESSURERATIO	-	
COMPRESCORRMASSFLOWRREF	-	Compressor corrected massflow in input units
COMPRESCORRSPEEDREF	-	Compressor corrected speed in input units
TURBINEPOWER	J/s	
TURBINEEFFICIENCY: INSTANTANEOUS ISENTROPIC TURBINE EFFICIENCY	-	$\eta_{TTS} = \frac{h_{03} - h_{04}}{h_{03} - h_{4,S}} = \frac{h_{03} - h_{04}}{c_p T_{03}\left(1 - \left(\frac{p_4}{p_{03}}\right)^{\frac{\kappa-1}{\kappa}}\right)}$
TURBINEPRESSURERATIO	-	
TURBINECORRECTEDMASSFLOW	-	compressor corrected massflow in input units
TURBINECORRECTEDSPEED	-	compressor corrected speed in input units
for each ATTACHEDPIPE		
MASSFLOW	kg/s	
VELOCITY	m/s	
FLOWCOEFFICIENTS	-	
PD-COMPRESSOR:		
COMPRESSORPOWER	J/s	
MECHPOWER	J/s	
ROTATIONALSPEED	rpm	
COMPRESSOREFFICIENCY	-	

ELECTRICAL DEVICE:		
ROTATIONALSPEED	rpm	full model only
MECHPOWERELMOTOR	J/s	
ELPOWERELMOTOR	J/s	
ELMOTOREFFICIENCY	-	

JUNCTION:		
PRESSURE	Pa	
TEMPERATURE	K	
FLOWPATTERN	-	

various ELEMENTS: for each ATTACHEDPIPE		

MASSFLOW	kg/s	
MASSFLOW	kg/cycle	
VELOCITY	m/s	
FLOWCOEFFICIENT	-	

5.4. Analysis of Pressure Wave Motion

An important parameter for the analysis of gas dynamic pressure wave motion is the crank angle interval, which is required by a pressure wave to propagate over a certain distance. The speed of the pressure wave propagation is determined by the speed of sound and the flow velocity (a ± u). Mostly the Mach number of the flow in the pipe is relatively low, which allows the influence of the flow velocity to be neglected. In this case, the crank angle interval required for the propagation of a pressure wave over one meter distance can be calculated from the following formula:

$$v_W = \frac{6 \cdot n}{a} \tag{5.4.1}$$

v_w pressure wave propagation speed [degrees CRA/m]

n engine speed [rpm]

a speed of sound [m/s]

The speed of sound can be calculated from the gas temperature in the pipe. A typical value for the intake system is 345 m/s. In the exhaust system, the speed of sound varies typically between 550 m/s (diesel engines) and 650 m/s (gasoline engines).

When using the Equation 5.4.1, it should be noted that the influence of the flow velocity is neglected.

Another important effect in the analysis of gas dynamic calculation results is the characteristics of the pressure wave reflection:

- At an open pipe end (α ~1.0), a pressure wave is reflected as a depression wave, and a depression wave as a pressure wave.
- At a closed pipe end (α ~0), a pressure wave is reflected as a pressure wave, and a depression wave as a depression wave.
- The reflection of pressure waves at a plenum is more complex, as normally the pressure in the plenum varies over time. For that reason, the characteristics of the pressure wave reflection depend on the volume of the plenum:
- If the plenum is very large, the pressure in the plenum remains almost constant and the reflection characteristics are similar to those of a pipe open to the ambient as discussed above.
- If the plenum volume approaches zero, the variation of the pressure in the plenum is similar to the pressure variation inside the pipe.
- The behavior of diffusers and cones is also of special interest. A pressure wave propagating into a diffuser is weakened due to the expansion resulting from the increasing cross-section. As a consequence, depression waves are reflected by the diffuser:
- If a depression wave propagates into a diffuser, the depression wave is also weakened and pressure waves are reflected.

- If a pressure wave propagates into a cone, the pressure wave becomes stronger and pressure waves are reflected.
- If a depression wave propagates into a cone, the depression wave becomes stronger and depression waves are reflected.

5.5. Analysis of Composite Elements

Some elements are displayed on the screen as composite elements but consist of more fundamental components in the actual input file. Examples of such elements are:

- Perforated pipe in pipe
- Perforated pipe in plenum.

Some junctions are also not displayed on the screen and the perforated pipes use the same numbering scheme as the standard pipes although this is not shown. This effects:

- Perforated pipe numbers
- Pipe end junctions for perforated pipes in plenum (restriction or system boundary).
- Pipe end junctions for pipes of perforated pipe in pipe elements (restriction or system boundary).

To assist in post-processing data from such hidden elements, the fundamental contents of composite elements can be displayed by selecting **Simulation|Show Elements** to open the elements window. This information can then be used to post-process the data from the required location of composite elements.

Note: This is only possible after completing a successful simulation.

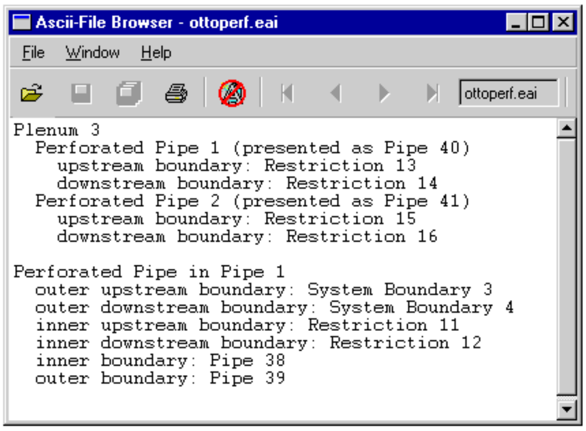


Figure 5-4: Show Elements Window

5.6. Analysis of Frequency Dependent Results and Orifice Noise

ACOUSTIC: The acoustic folder contains the simulation results against frequency. These results are only generated when at least one of the following conditions is met:

- Model contains at least one acoustic source (System Boundary).
- Model contains at least one microphone.
- Simulation Control > Output Control > Traces : Acoustic Cycles is activated
- User parameter "`ACOUSTIC_RESULTS`" is set to TRUE.

The frequency resolution of the results is determined by the cycle frequency.

$$\Delta f = \frac{RPM}{n.60}$$

Where,

Δf = frequency resolution [Hz]

n = 2 for a 4-stroke cycle or 1 for a 2-stroke cycle

RPM = engine speed [rev/min]

For example,

A 4-stroke engine running at 1400rpm will provide acoustic results with a frequency resolution of 11.66Hz (=1400/60x2). That is, results at 11.66Hz, 23.33Hz, 35Hz, etc.

The frequency resolution can be improved by increasing the number of stored acoustic cycles using the "Acoustic Cycles" input (Simulation Control > Output Control). The new frequency resolution will be the base resolution divided by the number of stored acoustic cycles.

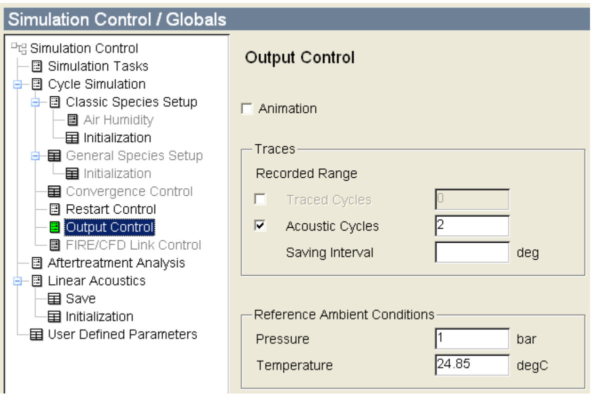


Figure 5-5: Acoustic Storage Cycles

For example,

A 4-stroke engine running at 1400rpm and with 10 stored acoustic cycles ("Acoustic Cycles"=10) will provide acoustic results with a frequency resolution of 1.166Hz (=1400/60x2/10). That is, results at 1.166Hz, 2.333Hz, 3.5Hz, etc.

Element Data	Unit	Comment
ENGINE: `EngineOrder`	-	Engine order versus frequency. Can be used as the x-axis to generate plots versus engine order
SYSTEMBOUNDARY: `SpecificMassflow`	kg/s/m2	For use with the orifice noise post processing operation described below

MEASURING POINT:
`PhaseAngle`
`RealPressure`
	
	Deg
	Pa	

`ImagPressure`	Pa	
`Linear : SoundPressure`	dB	In duct sound pressure level

MICROPHONE:
`PhaseAngle`
`Pressure`
`A-weighted : SoundPressure`
`Linear : SoundPressure`
	
	Deg
	Pa
	dB(A)
	dB
		
		A-weighted sound pressure level
		Linear sound pressure level

5.6.1. Sound Pressure Operation

The microphone element described in section 4.16.1 is recommended for determining orifice noise although the post processing operation described here is still supported.

However, note that the post processing operation only supports single source data to a microphone whereas the microphone element can handle multiple sources.

The orifice noise is determined from the calculated mass flow characteristics at the system boundaries. This is described in the BOOST Theory Guide.

Select **Simulation|Show Results** to open the **IMPRESS Chart** main window. Click on the **Operations** tab and the acoustic operations are available in the **Data Analysis** folder.

Click on the **Results** tab and select the **Acoustic** folder in **Results.ppd** to plot the Amplitude curve at the required system boundary.

Additional input of the microphone position relative to the location of the orifice in Cartesian coordinates is required.

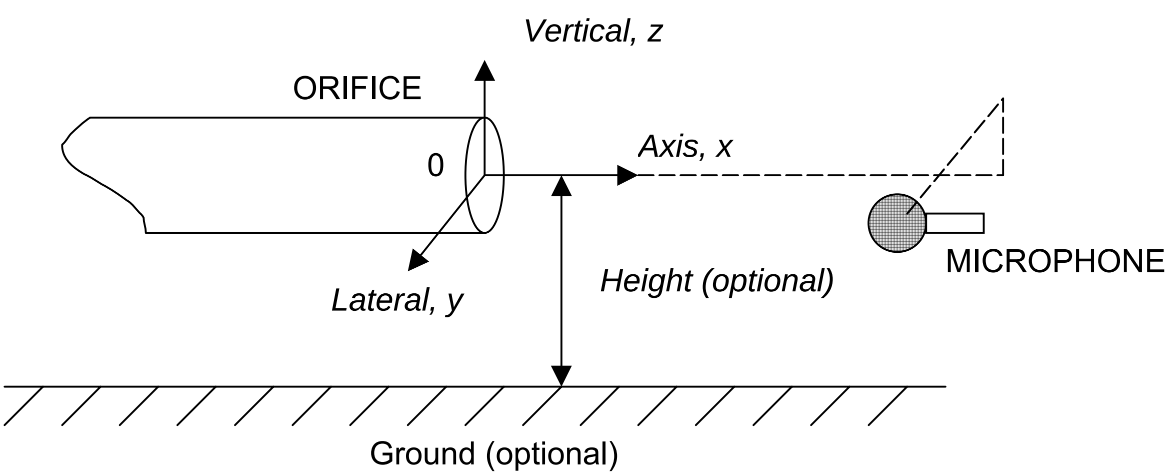


Figure 5-6: Microphone position

From this information the sound pressure levels in dB are calculated and displayed over frequency in a graphics window. In addition, the orifice noise in dB(A) is calculated and displayed in the acoustics window.

5.6.2. WAV Files

To play any WAV files from the microphone element select **Simulation | Show Audio.** Then navigate to the Case Set, Case and Microphone of interest. Right click on the WAV file and select Play. The default media player will then be used to play the WAV file. The media player can be changed using the environment variable AWS_AUDIO_PLAYER. (e.g. "C:\Program Files\Windows Media Player\wmplayer.exe")

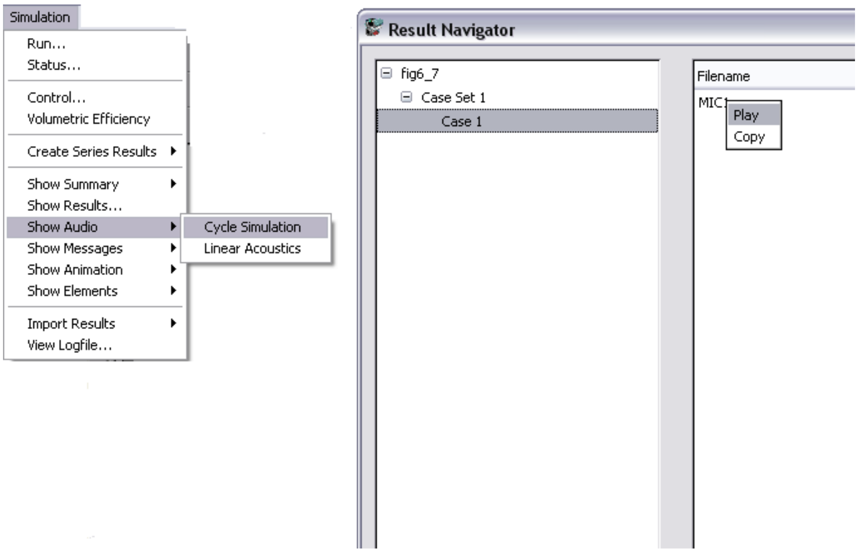


Figure 5-7: Show & Play Audio Results

5.7. Analysis of Case Series Results

For the Analysis of case series applications the full range of Transients result types (listed in 5.2) are available

Select **Simulation | Create Series Results**.

A one step solution for creating series results for all case sets is available. For each case set the main variation parameter can be freely chosen.

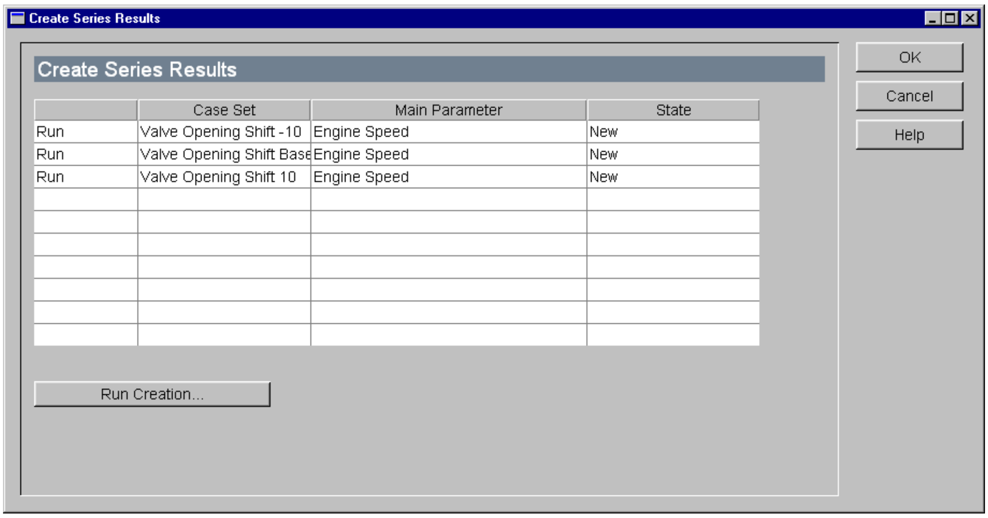


Figure 5-8: Create Series Results Window

- First column: defines if the results should be created
- Second column: shows all available case sets
- Third column: allows the definition of the main parameter for the results creation, this will be x-axis in IMPRESS Chart.
- Last column: shows the state of the creation process

Select **Run Creation** to start the processes of result creation.

Then select **Simulation | Show Results** to open the **IMPRESS Chart** main window which shows one folder for each case set (`name.case_set.case_no`) and an additional folder containing the series related results (`name.case_set`).

5.8. Analysis of Animated Results

ANIMATION: The display of animated results helps the user to comprehend the interaction of flow phenomena within the pipe system of an engine.

Spatial Plots

Depending on the specified output interval of Traces results, spatial plots for each pipe and time step can be accessed by selecting **Simulation|Show Results** (`working_directory/bwf_file_name.Case_Set_X.CaseY/simulation.dir/Results.ppd`).

Animated Results

An animated view on the whole system can be performed by selecting **Simulation|Show Animation** to open the **PP3** main window.

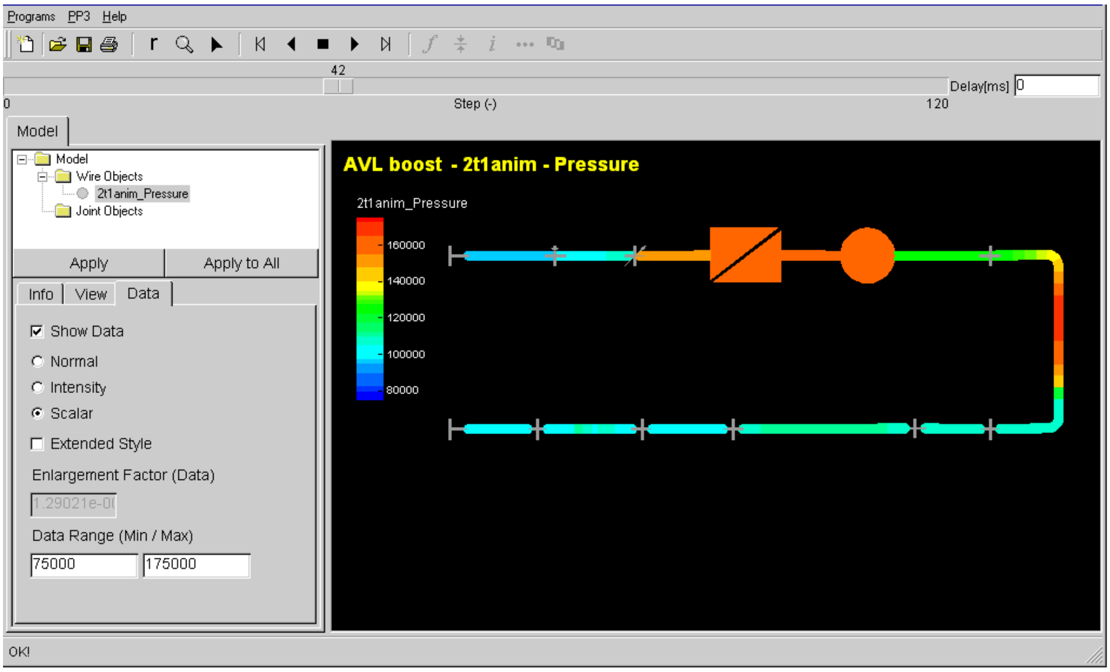


Figure 5-9: PP3 Main Window

The available animation data is:

- Pressure
- Gas velocity
- Gas Temperature
- A/F ratio of the combustion products
- Fuel vapor
- Combustion products

5.9. Message Analysis

MESSAGES: Displaying messages after the calculation process allows the user to check for information, warnings and errors generated by the solver.

Select **Simulation|Show Messages** to open the Message Browser as shown in the following window:

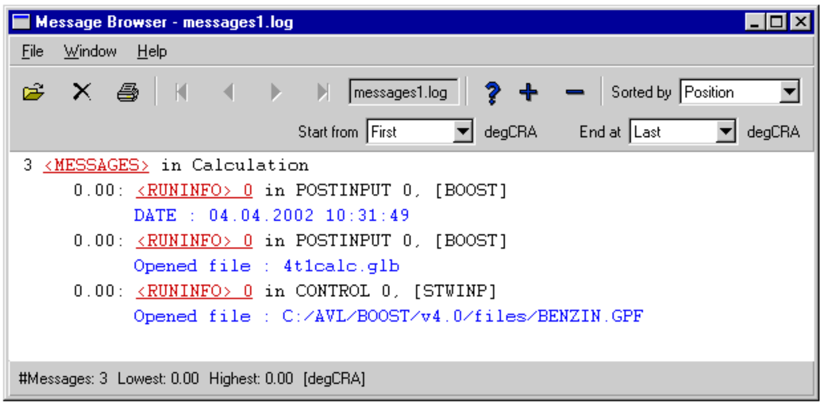


Figure 5-10: Message Analysis Window

From the **Sorted by** pull down menu, select **Message Type**, **Message ID**, **Element Name** or **Position** for the desired display. Select the respective values in the **Start from** and **End at** pull down menus to display messages occurring within a certain crank angle interval.

The global information is shown and more detailed information can be shown by clicking **<RUNINFO>** with the mouse. Click the expand button **+** to show the detailed information in the folder.

In a steady-state engine simulation it is strongly recommended to check the messages from the main calculation program displayed during the last calculated cycle. If major irregularities have occurred, it is essential to check whether the calculation results are plausible.

5.9.1. Message Description

Messages generated by the **BOOST** solver consist of a message header followed by text giving more detailed information. The format and components of the message header are described as follows:

<TYPE> <CODE> <ELEMENT> <NUMBER> <ROUTINE> <CRANK ANGLE> DEGCRA

1. **Type**

   The first part of the message header is the basic type of the message. The possible types and a brief description are given in the following table.

Message Type	Description
FATALERROR	A fatal error that causes the simulation to stop.
READERROR	An error occurred reading a value. This usually causes the simulation to stop.
INVALIDINPUT	The value has been read correctly but the value or string is invalid in this context. This also causes the simulation to stop.
CONVERGENCEFAIL	An iteration loop has reached the maximum number of iterations without converging. The loop will be exited and the simulation will continue. This message is not fatal.
RUNINFO	Contains useful information about the simulation. This includes the names and paths of loaded files and changes in default values.
WARNING	A warning about values or conditions in the current simulation. The simulation will continue to run.
OUTOFRANGE	A value is out of the permitted range. The accepted range is typically given in the body of the text. This is usually not fatal.
FILEERROR	An error occurred in reading or writing to files used by BOOST. This is a fatal error.
MEMORYERROR	A memory allocation error has occurred. Typically caused by insufficient memory available on the current host. This is a fatal error.

2. **Code**

   A number associated with the message which is useful for tracking the exact location in the code that generated the message.

3. **Element**

   If the message is generated by a specific **BOOST** element such as a cylinder or junction, this will be displayed at this location. Otherwise, a character string describing the current process, such as ‘INPUT’ or ‘CONTROL’, will be displayed.

4. **Number**

   The element number that generated the message. If the message is not associated with a particular element number then a zero will be displayed.

5. **Routine**

   The **BOOST** routine which generated the message.

6. **Crank Angle**

   The simulation crank angle when the message was generated. This will be in degrees.

5.9.2. Message Examples

```
RUNINFO      0 CONTROL      0 STWINP       0.00 DEGCRA
Opened file : C:/Program Files/avl/BOOST/v4.0/files/BENZIN.GPF
```

The message states the name and path of a file that has been loaded by **BOOST** during the simulation. In this case it is the gas property file (`.gpf`) for benzin. The message was issued at `0.00` degrees crank angle by the routine STWINP (i.e. at the beginning of the simulation).

```
WARNING 183658 TURBOCHARGER      1 TLVOLL    2880.22 DEGCRA
 The operating point of the compressor
 crossed the surge line of the performance map.
 Massflow: 0.036kg/s, Pressure ratio:  1.60
```

Warning number 183658 concerning the compressor operating point was issued by turbocharger number 1 at 2880.22 degrees crank angle in the routine TLVOLL.

```
CONVERGENCEFAIL 143302 JUNCTION      3 PSTP0    6336.58 DEGCRA
 The iteration of the junction massflow failed to
 converge at flowpattern 6.
 calculated values:   type 1      type 2 difference in % of total massflow
 attached pipe 1:    0.000609    0.000609    0.000000
 attached pipe 2:    0.007190    0.007366    2.206129
 attached pipe 3:    0.007970    0.007800    2.133474
```

5.9.3. Fatal Errors

5.9.3.1. MATLAB API

```
FATALERROR 121901 DLL      1 INIDLL     106.00 DEGCRA
 MATLAB-ENGINE run error
  - Check that matlab executable directory is in PATH.
  - Check that a valid license is available.
 The calculation has been stopped.
```

This message is generated when running with the MATLAB API option. There are several reasons this message is generated. MATLAB is not found in the directories listed in the PATH environment variable, a valid license is not available or there is a clash of MATLAB versions. For the last case this can happen when the version of the MATLAB mdl file does not match the version of MATLAB that BOOST is attempting to load. This can happen when there is more than one MATLAB version is installed on the computer. The following dialog box will be generated in such a case.

Figure 5-11: MATLAB API Error - version mismatch

The solution is to make sure the version of the MATLAB model (mdl file) matches the MATLAB version listed first in the PATH.

5.10. Analysis of Aftertreatment Analysis Results

All data from the aftertreatment analysis simulations is given as transient values at different spatial positions of the element. The spatial position (can be defined by the user) is part of the folder and curve name respectively. The following data is available in **Catalyst Analysis** and **Particle Filter Analysis** subfolder:

Element Data	Unit	Comment
CATALYST:		
SOLID TEMPERATURE	K	Temperature of the solid substrate. This temperature is used for all conversion reactions.
GAS TEMPERATURE	K	Temperature of the gas phase.
PRESSURE	Pa	The pressure data are relative values related to the pressure at the catalyst.
VELOCITY	m/s	The velocity is a interstitial velocity inside the catalyst channels. For the evaluation of the superficial velocity the open frontal area of the catalyst has to be applied.
MASS FRACTION <<XX>>	kg/kg	<<XX>> represents any species defined in Globals/Aftertreatment Analysis, e.g. CO, CO2, C3H6, NO2,...

PARTICULATE FILTER : SOLID TEMPERATURE	K	Temperature of the solid substrate. This temperature is used for all regeneration reactions.
GAS TEMPERATURE	K	Temperature of the gas phase.
PRESSURE	Pa	The pressure is given as relative value. A pressure difference is calculated between the pressure at the end of the filter outlet channel and the pressure at the corresponding axial position in the filter inlet channel.
VELOCITY	m/s	The velocity is an interstitial velocity inside an 'theoretically' combined channel, where the inlet and outlet channel are put together.
MASS FRACTION <<XX>>	kg/kg	<<XX>> represents any species defined in Globals/Aftertreatment Analysis, e.g. CO, CO2, C3H6, NO2,... This gas composition can be understood as part of the outlet channel.
SOOT MASS	kg/m^3_{Filter}	The soot mass is given as volume specific value, where the overall volume of the filter is used as reference.
SOOT HEIGHT	m	The soot height is evaluated assuming that soot is equally distributed over the entire inlet channel cross section.
WALL VELOCITY	-	The wall velocity is given by normalized values.
INLET CHANNEL VELOCITY	m/s	The inlet channel velocity is the interstitial velocity inside the filter inlet channel.
OUTLET CHANNEL VELOCITY	m/s	The outlet channel velocity is the interstitial velocity inside the filter outlet channel.
INLET CHANNEL PRESSURE	Pa	Absolute pressure in the inlet channel.
OUTLET CHANNEL PRESSURE	Pa	Absolute pressure in the outlet channel.

6. THE BOOST FILES

6.1. The .bwf Files

The BOOSTFILENAME.bwf files contains all graphics and input data of the **BOOST** model.

6.2. The .bst Files

The BOOSTFILENAME.bst file is the input file of the calculation kernel. It is generated by selecting **Simulation | Run | Model Creation** and is written into the subfolder BOOSTFILENAME.Case_X (*X...* Index of the Case Set).

As it is an ASCII formatted file, it can be transferred to and executed on every platform or computer where a **BOOST** calculation kernel is available.

The BOOSTFILENAME.bst file consists of the following sections:

- **SECTION HEADER**: Contains the total number of elements for each type in a calculation model.
- **SECTION INPUT**: Contains all input data.
- **SECTION MESSAGES**: Summary of the messages from the main calculation program.
- **SECTION TRANSIENTS**: Average results of each element over each cycle calculated (GIDAS format).
- **SECTION TRACES**: Covers the crank angle dependent calculation results from the last calculated cycle (GIDAS format). In an animation calculation this section is not available.
- **SECTION ANIMATION**: Summary of the results of an animation calculation (GIDAS format). In a single calculation this section is not available.
- **SECTION SUMMARY**: Contains the global calculation results. In a series calculation, this section is available for each of the calculated operating points or engine variants.

6.3. The .atm Files

The BOOSTFILENAME.atm is similar to the BOOSTFILENAME.bst but it is used to run the BOOST calculation kernel in aftertreatment analysis mode.

The BOOSTFILENAME.atm file consists of the following sections:

- **SECTION HEADER**: Contains the total number of elements for each type in a calculation model.
- **SECTION INPUT**: Contains all input data.
- **SECTION MESSAGES**: Summary of the messages from the main calculation program.
- **SECTION CAT_ANALYSIS**: Transient results of catalyst analysis simulations (GIDAS format).

- **SECTION DPF_ANALYSIS**: Transient results of diesel particulate filter analysis simulations (GIDAS format).
- **SECTION SUMMARY**: Contains the global calculation results and additional simulation data.

6.4. The .rs0 and .rs1 Files

The `BOOSTFILENAME.rs0` and `BOOSTFILENAME.rs1` files are restart files. As they are ASCII formatted files, a data set can be transferred together with the restart files to a different platform and the calculation continued with a restart.

6.5. The .uit File

This file is written by the main calculation program. It is used for writing debug information during the development of the code and can be deleted after a simulation run without any consequence.

6.6. The .gpf File

These files contain the tables of gas properties in dependence on pressure, temperature and excess air ratio (located in `$BOOST_HOME\..\..\files`).

6.7. The rvalf.cat File

This file contains the catalogue of flow coefficients for three-way junctions. It should be located in the directory `$BOOST_HOME\..\..\files`.

7. RECOMMENDATIONS

7.1. Turbocharger Matching

Another application of **BOOST** is to determine a suitable compressor and turbine size for a turbocharged engine. The simplified turbocharger model with its three calculation modes (turbine layout, boost pressure and waste gate calculation) supports the user in this task.

The following steps outline the procedure for the layout of a conventional waste gate turbocharger:

1. The first step is to estimate the air flow requirement for engine full load at the engine speed when the waste gate starts to open. A common layout is around maximum torque speed. The air flow can be calculated from the target Brake Mean Effective Pressure (BMEP), Brake Specific Fuel Consumption (BSFC) and the required Air/Fuel Ratio. The latter is estimated from emission targets considerations.

$$\dot{m}_{air} = AFR \cdot \frac{BMEP \cdot V_D \cdot n \cdot BSFC}{n_c \cdot 2.16 \cdot 10^9} \tag{7.1.1}$$

$\dot{m}_{air}$	air flow [kg/s]
AFR	air fuel ratio [-]
$BMEP$	brake mean effective pressure [bar]
V_D	displacement [l]
n	engine speed [rpm]
n_c	1 for two stroke engines
	2 for four stroke engines
$BSFC$	brake specific fuel consumption [g/kWh]

2. With another estimate of the intake manifold temperature and the volumetric efficiency of the engine, the target **BOOST** pressure is calculated from

$$P_m = \frac{\dot{m}_{air} \cdot R \cdot T_m \cdot n_c \cdot 6}{\eta_V \cdot V_D \cdot n \cdot 10} \tag{7.1.2}$$

P_m	intake manifold pressure [bar]
R	gas constant of air, 287 J/kg K
T_m	intake manifold temperature [K]
η_V	volumetric efficiency related to intake manifold conditions [-]

3. Substituting Equation 7.1.1 into Equation 7.1.2 yields

$$P_m = \frac{AFR \cdot BMEP \cdot BSFC \cdot R \cdot T_m}{\eta_V \cdot 3.6 \cdot 10^9} \tag{7.1.3}$$

4. With the pressure loss of the inter cooler and air cleaner, the compressor pressure ratio is known

$$\Pi_{co} = \frac{P_m + \Delta P_{cooler}}{P_{amb} - \Delta P_{cleaner}}$$

Π_{co} compressor pressure ratio [-]

ΔP_{cooler} inter cooler pressure loss [bar]

P_{amb} ambient pressure [bar]

$\Delta P_{cleaner}$ air cleaner pressure loss [bar]

5. Using a turbine layout calculation, an equivalent turbine discharge coefficient and an operating point of the engine in the compressor map is obtained. Making two additional calculations with the first turbine discharge coefficient at the lowest engine full load speed in the **BOOST** pressure calculation mode and at the highest full load speed in the waste gate calculation mode, yields another two operating points of the engine in the compressor map. The compressor pressure ratio for the waste gate calculation can be determined again from Equation 7.1.3. Figure 7-1 shows the three operating points in the compressor map.

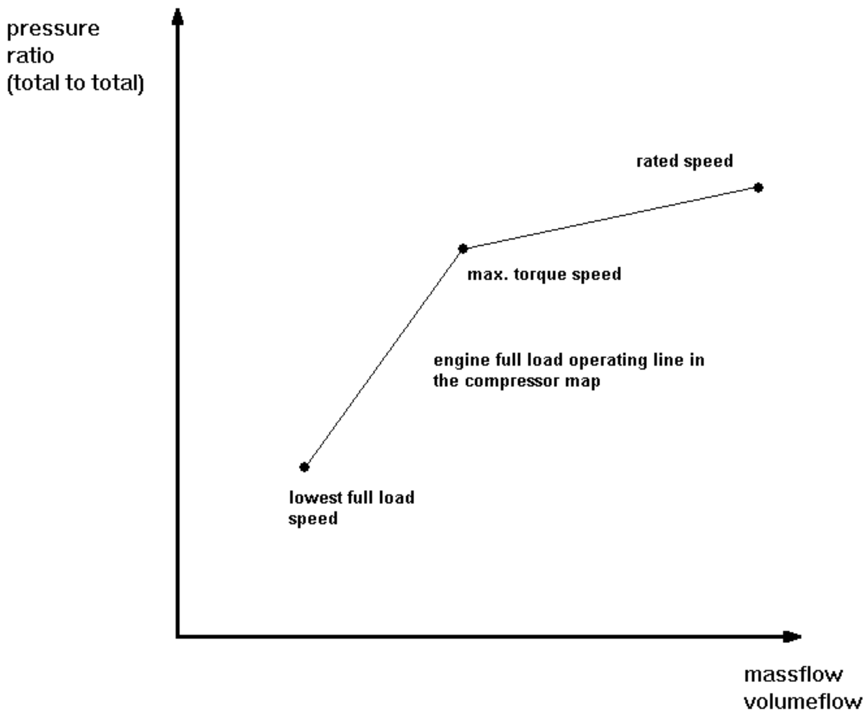


Figure 7-1: Engine Operating Line in the Compressor Map

6. With this information a suitable compressor can be selected. If the compressor is too small, the rated speed operating point is beyond the speed limit of the compressor or in the choked flow region, Figure 7-2.

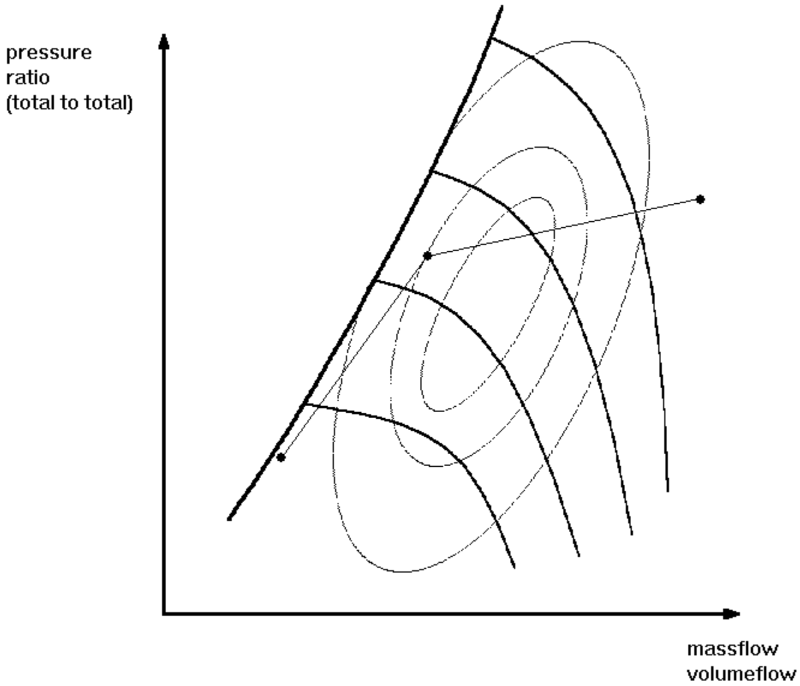


Figure 7-2: Engine Operating Line in the Compressor Map (compressor too small)

If the compressor is too large, low and/or mid speed operating points are located left of the surge line in Figure 7-3.

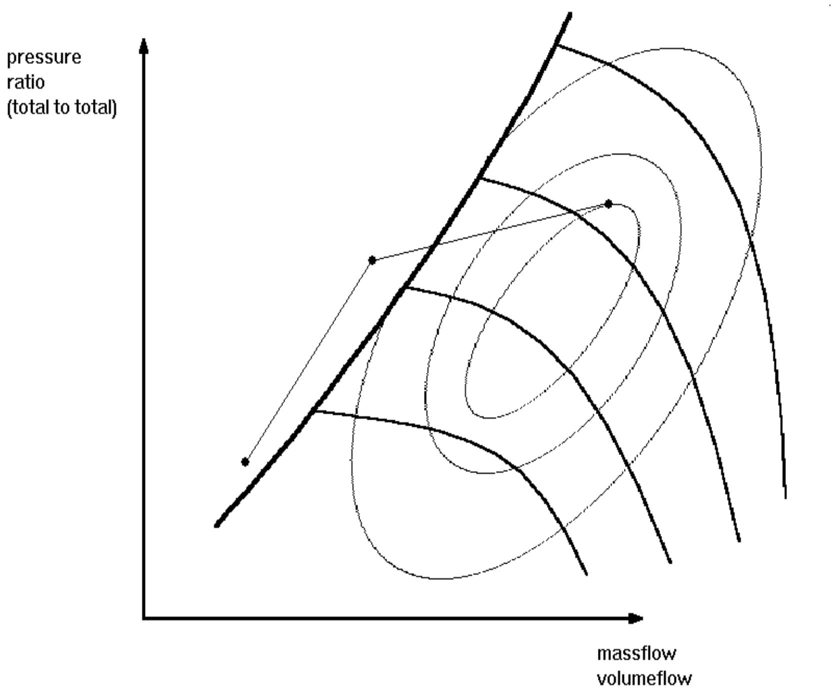


Figure 7-3: Engine Operating Line in the Compressor Map (compressor too large)

If the correct compressor is selected, the entire engine operating line is located within the map, Figure 7-4.

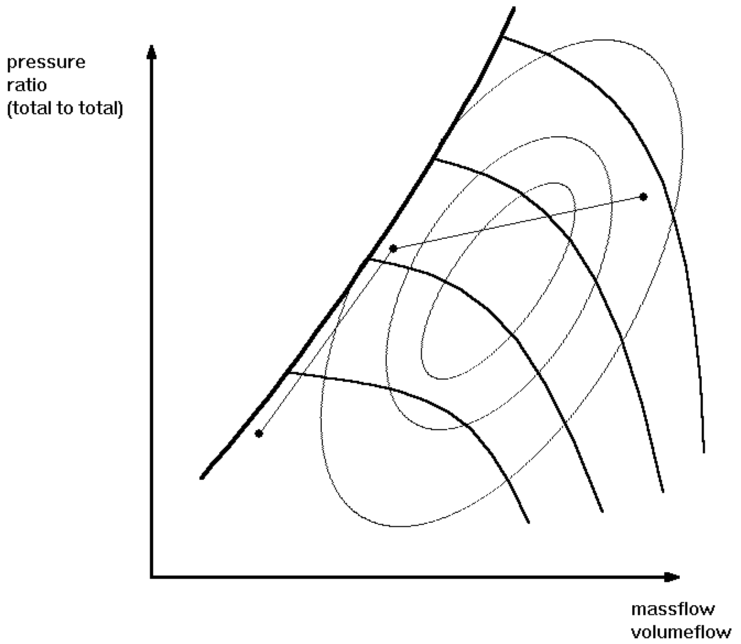


Figure 7-4: Engine Operating Line in the Compressor Map (correct compressor)

7. To determine the necessary turbine, the equivalent turbine discharge coefficient must be converted to a swallowing capacity and plotted in the turbine map, Figure 7-5.

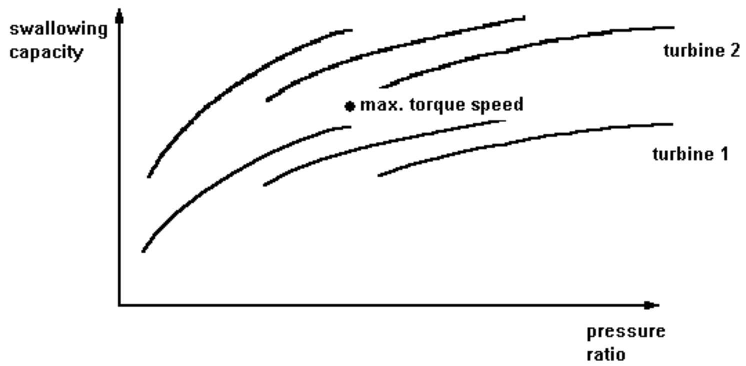


Figure 7-5: Engine Operating Point in the Turbine Map

8. After selecting possible turbines and compressors, the calculations must be repeated in the **BOOST** pressure and waste gate calculation modes to consider the actual efficiencies and swallowing capacities from the maps.

   For turbochargers with variable turbine geometry, the turbine layout calculation mode may be used at all engine speeds. The location of the engine operating point in the compressor and turbine map must be checked and the actual efficiencies compared to the assumed efficiencies of the calculation. If a larger difference between the efficiencies is detected, the calculation must be repeated with updated efficiencies.

7.2. Important Trends

This section summarizes some typical influences of important parameters on engine performance. They may be used to get an overview of required parameter modifications in an engine model to obtain calculated performance characteristics closer to the target engine performance.

The example figures shown in this chapter reflect the general trend. They were obtained from a simplified model of a 4-cylinder SI engine. The actual influence of the parameter varied may be different on other engines due to the presence of other effects.

The influence of heat transfer is two-fold. It influences the heating of the fresh charge during the gas exchange and thus the volumetric efficiency. This effect is more pronounced from low to mid-engine speeds as more time is available for the heat transfer to take place.

Secondly, the heat transfer influences the efficiency of the high pressure cycle by influencing the wall heat losses. Figure 7-6 shows the effect of the variation of the in-cylinder heat transfer on the engine performance.

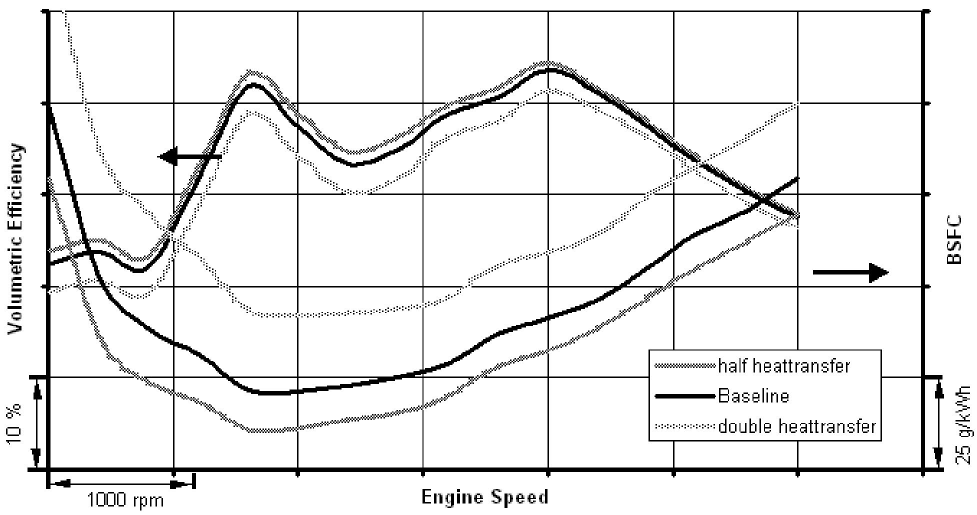


Figure 7-6: Influence of In-Cylinder Heat Transfer on Engine Performance

The influences of the flow coefficients and wall friction losses are more pronounced at high engine speeds, where the flow velocities in the system are relatively high. They have little influence on engine performance in the low and mid-speed range.

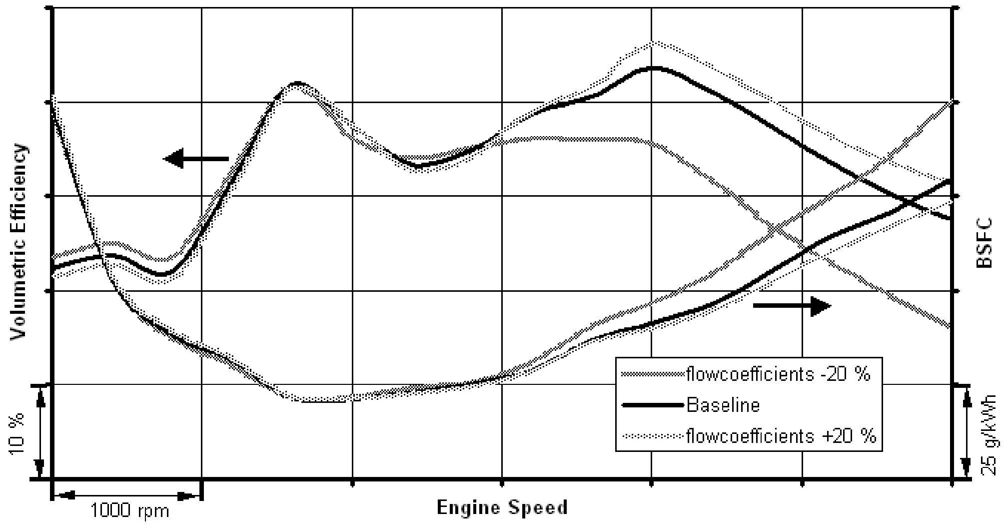


Figure 7-7: Influence of Port Flow Coefficients on Engine Performance

Intake valve closing mainly influences the volumetric efficiency of the engine. Advanced intake valve closing improves the engine air flow at low engine speeds and retarded intake valve closing favors high engine speeds.

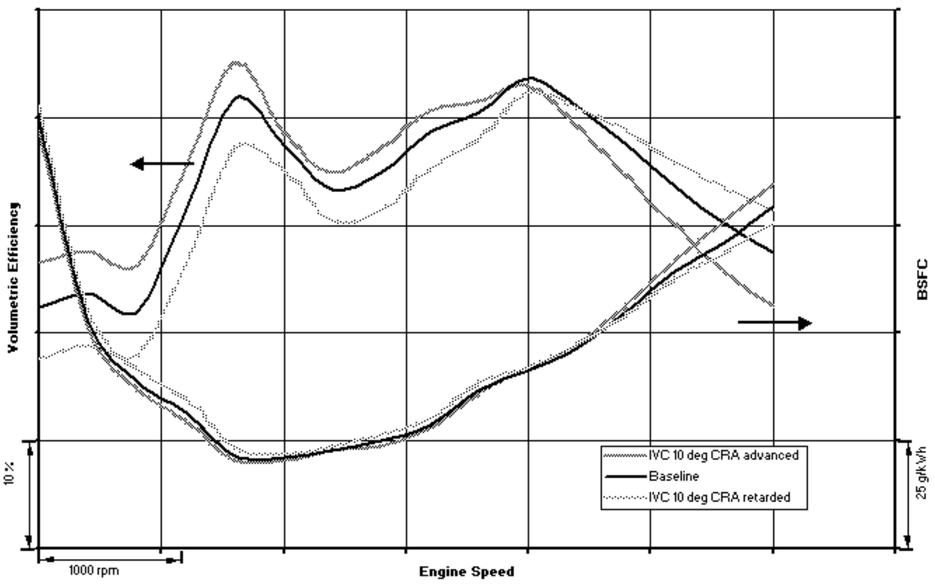


Figure 7-8: Influence of IVC on Engine Performance

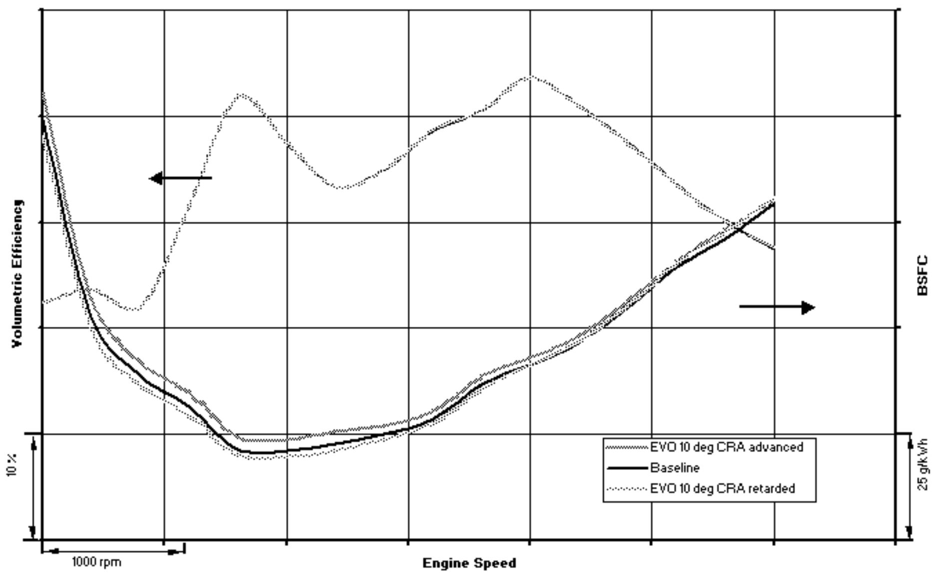


Figure 7-9: Influence of EVO on the Engine Performance

There may be a significant influence of the valve train dynamics and/or of the differences between the valve clearances between a cold and hot engine on the engine air flow characteristics. This depends on valve train design.

Inertia effects in the intake system may be used for a gas dynamic supercharging of the engine. This effect is important at higher engine speeds because the inertia of the gas in the intake runner becomes significant only at high velocities.

Another possibility of gas dynamic supercharging is the use of resonance effects in the intake system. The resonance frequency of such system can be determined roughly from the Helmholtz formula:

$$f = \frac{a}{2 \cdot \pi} \cdot \sqrt{\frac{A}{l \cdot V}} \tag{7.2.1}$$

f resonance frequency [Hz]

a speed of sound [m/s]

A pipe cross-section [m^2]

l tuning pipe length [m]

V plenum volume [m^3]

By selecting the dimensions, a resonance system may be tuned to low or high speeds. A tuning for low speeds can be achieved with a long tuning pipe, a large plenum volume and a small pipe cross-section. However, the plenum is usually located between the tuning pipe and the cylinders, which provide the excitation of the resonance system. For this reason, a large plenum volume lowers the resonance frequency but also increases the damping of the excitation, which is detrimental to gas dynamic tuning.

The effects of these two tuning strategies can be seen in the following figures. If the length of the air feed pipe to the intake receiver is varied, as defined in the following sketch, it mainly influences the low frequency resonance peak in the volumetric efficiency curve.

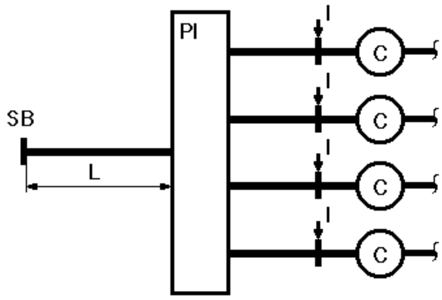


Figure 7-10: Air Feed to Intake Receiver

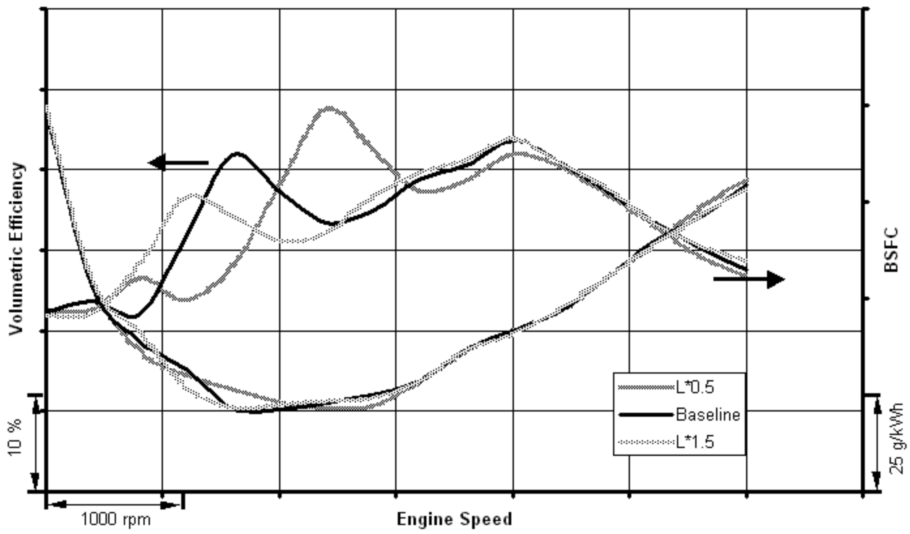


Figure 7-11: Influence of Air Feed Pipe Length on Engine Performance

Using the dimensions of the air feed pipe for tuning purposes depends on the number of cylinders. The excitation of the low frequency system decreases when the number of cylinders is increased.

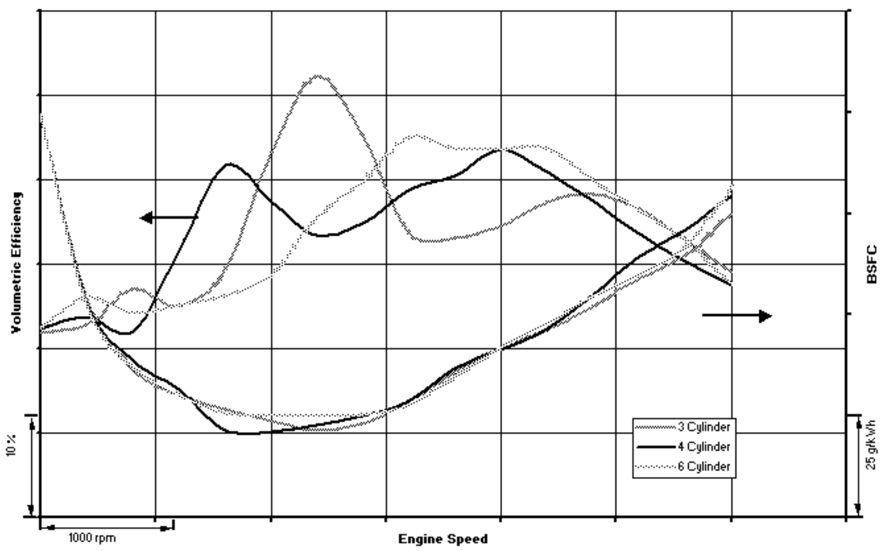


Figure 7-12: Influence of Number of Cylinders on Engine Performance

Although the intake runner length as shown in the next sketch, determines the high frequency resonance, it has also a certain influence on the low frequency peak.

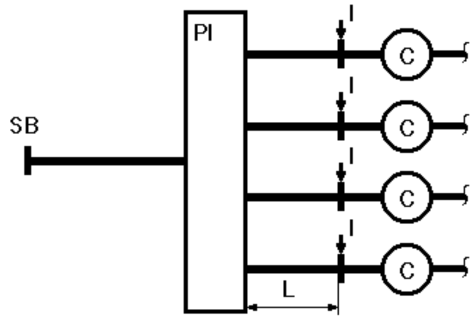


Figure 7-13: Intake Running Length

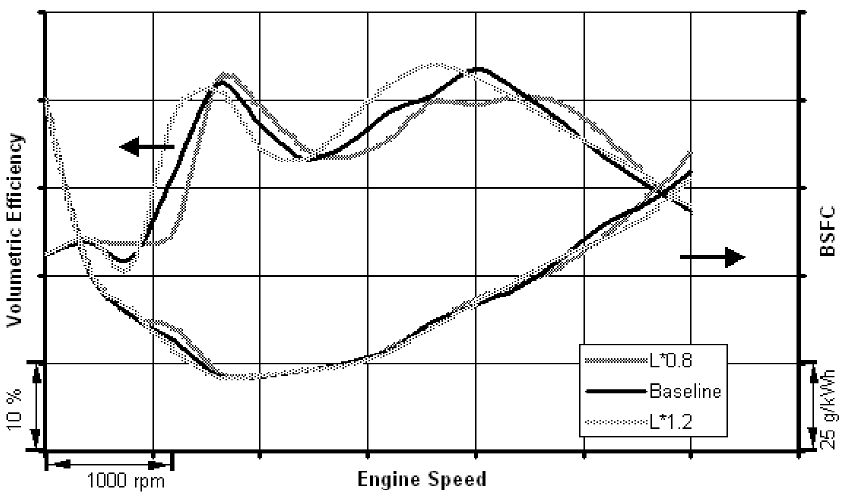


Figure 7-14: Influence of Intake Runner Length on Engine Performance

The performance characteristics of two-stroke engines are more unstable than four-stroke engines. This is caused by the strong interference between the intake and exhaust systems during the scavenging period. As a consequence, a large number of cycles must be calculated until steady conditions are achieved. Minor inaccuracies in the engine model or minor modifications to an engine configuration may result in large differences in the engine performance.

The tuning of a two-stroke engine with symmetrical port timing can almost be achieved via the exhaust system alone, as the conditions in the cylinder at the beginning of the high pressure cycle are determined by exhaust port closing. For this reason, the influence of combustion on the gas exchange process is also relatively strong (via the exhaust gas temperature and the speed of sound in the exhaust system). This is not the case for four-stroke engines.

7.3. Altitude Operation

For altitude operation of an engine the ambient temperature and pressure can be defined according to the ISO 2533:1975 (see also http://en.wikipedia.org/wiki/International_Standard_Atmosphere). The following table can be obtained by linearly interpolating the specified data between 0 and 11 km.

Geopotential Height **m**	Pressure **bar**	Temperature **°C**
0	1.013	15
1000	0.942	8.5
2000	0.870	2
3000	0.799	-4.5
4000	0.727	-11
5000	0.656	-17.5
6000	0.584	-24
7000	0.512	-30.5
8000	0.441	-37
9000	0.369	-43.5
10000	0.298	-50
11000	0.226	-56.5

7.4. Modeling Extensions

Pipe extensions into chambers are quite common in intake and exhaust systems. These extensions act acoustically as quarter wave resonators and can be modeled using BOOST in more than one way. The recommended way is to use restrictions elements. The alternative is to manually construct quarterwave resonators using pipes and system boundaries. However, this means that the pipe lengths and diameters have to be manually corrected. This is especially true for end corrections. The main advantage of using restriction elements is that the actual geometry can be used. For the main chamber the overall length and diameter should be input regardless of internal pipe extensions. For the attached pipes only the length of the pipe outside the chamber should be input. The extension length of the pipe inside the chamber will be automatically handled by the simulation.

For example, to model a 178.4mm diameter and 1.0m length chamber with extended inlet of 0.5m and an extended outlet length of 0.25m as shown below

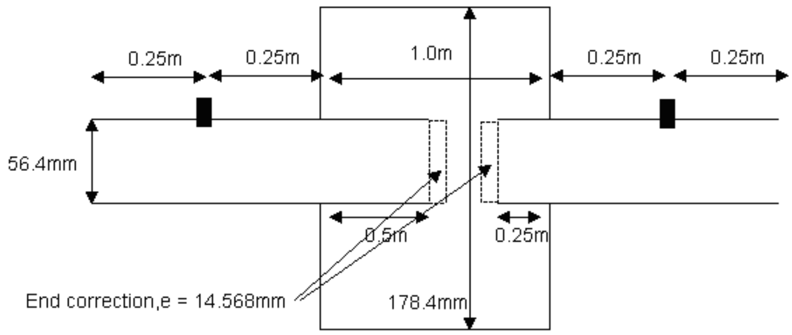


Figure 7-15: Chamber with Inlet and outlet pipe extensions

For a restriction based model all the lengths and diameters should be entered directly from the geometry.

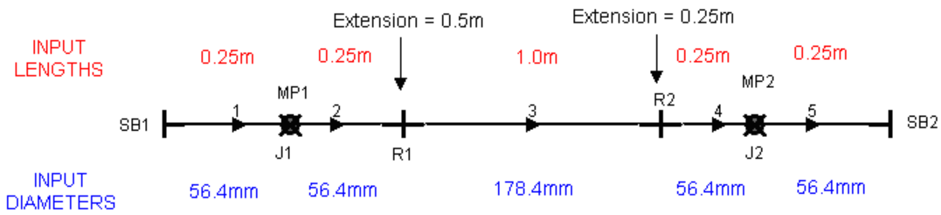


Figure 7-16: Model using restriction elements for extensions

The end correction of 14.568mm (in this case) is automatically handled to correct the lengths of the attached pipes and the length of the quarter wave resonator created by the pipe extension. Note that the lengths of PIPE 2 and PIPE 4 are only the length of the pipe outside the main chamber. The inlet and outlet pipes have been split in half with a junction so that linear acoustic data can be extracted from this point (e.g. to calculate a transfer function). This data can be extracted from the Measuring Point as the same location for a non linear simulation as this model is valid and identical for linear and non linear simulation.

The same system modeled using quarter wave is more complicated as the correct lengths have to be manually calculated. The input lengths and diameters for a quarterwave based model are shown in the figure below.

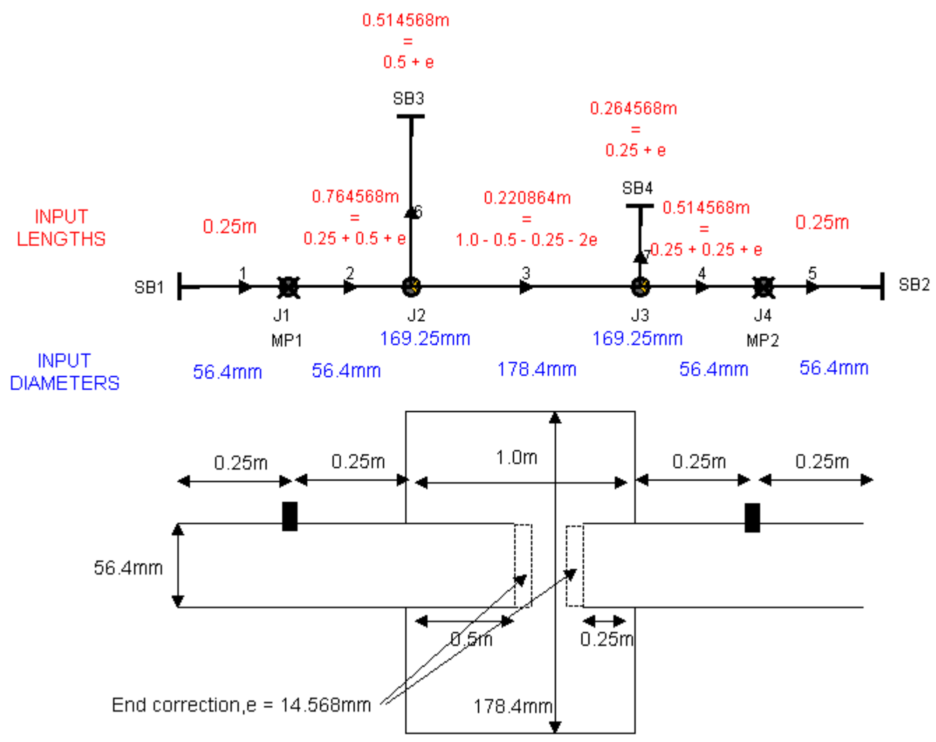


Figure 7-17: Model using quarter wave elements for extensions

For example, the main chamber is modeled using PIPE 3. The main chamber is 1.0m in length. However, due to the inlet extension of 0.5m this has to be reduced by 0.5m plus the end correction of 14.568mm.

Due to the outlet extension the length has to be further reduced by 0.25m plus the end correction. This gives a final value for the length of about 0.22m. Also note that the diameters of the quarter wave resonators have to be adjusted. The cross sectional area of the quarter wave resonators is the chamber cross sectional area minus the cross sectional area of the pipe extension.

Both models are valid and give the same results. However, as can be seen, the restrictions based model is easier to construct.

8. APPENDIX

8.1. Running The Executable

8.1.1. Command Line

It is recommended to run the **BOOST** executable from the graphical user interface (**Simulation | Run**). However, it is also possible to run the **BOOST** executable (calculation kernel) on its own from a shell or command prompt. This executable (`boost` or `boost.exe`) can be found in the platform dependent bin directory of the **BOOST** installation. It is also possible to use command line arguments and input file specification for this executable. Running the executable without any command line arguments will result in a command prompt requesting the input file name.

For a proper setup of the runtime environment for the execution of **BOOST** please refer to the script files **set_environment_BOOST_SIMULINK_win.bat** (for windows) and **set_environment_BOOST_SIMULINK_unix.csh** (for linux). These can be found in the files directory of the **BOOST** installation directory, e.g.: ./AVL/BOOST/v2010/files.

Please modify the script files according to the instruction comments in it. After execution of this modified script in a shell the **BOOST** executable can be started.

8.1.1.1. Options

Command line arguments are specified using a preceding dash (-). For some options only a single command line option or input files will be processed. That is, in some cases if multiple command line options are used followed by a **BOOST** input file (e.g. `boost -help -v 4t1cal.bst`) only the first command line option is processed before termination. See details on each option for more information.

1. **Version (-vers)**

This displays the current version number of the **BOOST** executable to screen.

```
> ./boost -vers
v2010
```

2. **Help (-hlp)**

This is used display some information on the executable, how to use it and a support contact.

```
M:\>D:\boost.exe -hlp

    A V L
    B O O S T

    Version:  v2010
    Platform: ia32-unknown-winnt
    Build:    Dec 21 2010 09:59:54

    Usage: boost [-vers|-hlp|-dirs|-plat|-what|-lic]
           or
           boost [-verbose] [-debug<number>] [-gca] [-atm|-awsburn] [-
stop] <fil
ename(s)>

    Options: -vers  Print version number
             -hlp  Print this help information
             -dirs  Print directory information
             -plat  Print platform type
             -what  Print executable information
             -lic   Print license information
             -astflex Print extended license information

             -verbose       Run in verbose mode
             -debug<number> Run in debug level <number> mode
                            Debug level from 0 (min) to 5 (max)
             -stop          Stop on error (multiple bst only)

             Run modes: (default is cycle simulation)

             -gca   GCA analysis
             -atm   Aftertreatment analysis
             -awsburn AWS combustion analysis

    Examples: boost 4t1calc.bst
              boost -atm aftertreatment.atm
              boost -awsburn burn.brn

    Support: boost_support@avl.com
```

This message will also be displayed for any unrecognized options.

3. **Directories (-dirs)**

This option displays the directories used by **BOOST** when executed on input files in the same manner.

```
> ./boost -dirs
   A V L
   B O O S T

   Version:  v2010
   Platform: ia32-unknown-linux
   Build:    Dec 21 2010 09:59:54

   Executable directory:    /XXX/BOOST/v2010/bin/bin.ia32-unknown-linux
   Working directory:    /XXX/boost/MODEL_A.Case_Set_1.Case_6
   BOOST_HOME:    /XXX/BOOST/v2010/bin/bin.ia32-unknown-linux
```

If `BOOST_HOME` has not been set then a message stating this will be displayed rather than a blank following the `BOOST_HOME`.

4. **Platform (-plat)**

This displays the build platform for the executable.

```
> ./boost -plat
ia32-unknown-linux
```

5. **What (-what)**

This displays more detailed information on the executable. The information displayed is similar to the UNIX 'what' command.

```
> ./boost -what
 AVL BOOST v2010 ia32-unknown-linux (Dec 21 2010 09:59:54)
```

6. **License (-lic)**

This displays information on the available licenses.

```
M:\>D:\AVL\BOOST\v2010 \bin\bin.ia32-unknown-winnt\boost.exe -lic

 AVL BOOST v2010 checking licenses....

   $Id: @(#) astflex v11.6 (Apr 27 2009 17:14:12) ia32-unknown-winnt  $

   Searching for feature "boost_main" version: "2010" .... found

      This license is available

   Searching for feature "boost_main_acoustic" version: "2010" .... found

      This license is available

   Searching for feature "boost_main_hpa" version: "2010" .... not found

   Searching for feature "boost_gca" version: "2010" .... not found

   Searching for feature "boost_main_egat" version: "2010" .... found
```

```
    This license is available
  Searching for feature "boost_main_charging" version: "2010" .... found
    This license is available
  Searching for feature "boost_main_interface" version: "2010" .... found
    This license is available
AVL BOOST v2010 finished checking licenses
```

7. **Verbose (-verbose)**

This option also runs the input file(s) through the solver. All messages that are written to the input file are also sent to the screen.

8. **Debug (-debug<number>)**

This option also runs the input file(s) through the solver. A number must also be given from 0 (minimum) to 5 (maximum). This selects debug options for certain features so that more checks are done. This typically causes a longer run time and an earlier exit due to errors.

9. **Stop (-stop)**

This option stops a multiple simulation run (e.g. ./boost *.bst) whenever a fatal error occurs.

8.1.1.2. File Search Paths

BOOST uses a number of auxiliary input files such as the gas property files. These files are opened by **BOOST** from the following directories, listed in order of priority:

1. Same directory as the **BOOST** input file.
2. `BOOST_HOME` files directory (`$BOOST_HOME/../files`)
3. `BOOST_HOME` files directory (`$BOOST_HOME/../../files`)
4. Same directory as the **BOOST** executable.
5. Current working directory. This is usually the same as 1 or 4 but can be different.
6. Parent directory of the **BOOST** input file.

As soon as the particular file is successfully opened from any of these directories **BOOST** will stop searching and continue. If it fails to open the file from any of these directories the run will fail unless the file has been specified as optional. Optional files are sometimes used for developmental features. No message is generated for failing to open an optional file. The error message includes the list of the directories specified above. The command line argument for directories (`-dirs`) can be used if **BOOST** has problems opening these files.

If a file exists in more than one of the allowed locations, the first successfully opened file will be used and the other(s) ignored. A RUNINFO message type specifying the name and path of the file loaded will be written. This is true for optional files also.

8.2. Available Channel Data

8.2.1. Sensor Channels

8.2.1.1. Element "Global"

Label	since Version	Unit
Sensor Channels		
Speed	4.0	ang_vel [rpm]
Ambient Pressure	4.0	pressure [Pa]
Ambient Temperature	4.0	temperature [K]
Crank Angle	4.0	angle [deg]
Absolute Crank Angle	4.0	angle [deg]
Time	4.0	time [s]
Cycle Frequency	5.1	frequency [Hz]

8.2.1.2. Element "Engine"

Label	since Version	Unit
Sensor Channels		
Speed	4.0	ang_vel [rpm]
Mean Speed	4.0	ang_vel [rpm]
Speed Gradient	4.0	speed_gradient [rpm_s]
Mean Speed Gradient	4.0	speed_gradient [rpm_s]
Ambient Pressure	4.0	pressure [Pa]
Ambient Temperature	4.0	temperature [K]
BMEP	4.0	pressure [Pa]
IMEP	5.1	pressure [Pa]
BSFC	5.1	spec_mass_flow [g_kWh]
Power	5.1	power [W]
Engine Torque	4.0	moment [Nm]
Mean Engine Torque	4.0	moment [Nm]
Load Torque	4.0	moment [Nm]
Sliding Averaged Engine Torque	5.1.1	moment [Nm]
Engine Fuel Consumption	5.1.1	massflow [kg_s]
Engine NOX Production	5.1.1	massflow [kg_s]
Engine CO Production	2009	massflow [kg_s]
Engine HC Production	2009	massflow [kg_s]
Engine Soot Production	2009	massflow [kg_s]
Overall Piston Wall Heatflow	5.1.1	heat_flow [J_s]
Overall Head Wall Heatflow	5.1.1	heat_flow [J_s]

Overall Liner Wall Heatflow	5.1.1	heat_flow [J_s]
Overall Intake Port Wall Heatflow	5.1.1	heat_flow [J_s]
Overall Exhaust Port Wall Heatflow	5.1.1	heat_flow [J_s]
Oil Temp. Friction	5.1.1	temperature [K]
Friction Power Crankshaft	5.1.1	power [W]
Friction Power Piston	5.1.1	power [W]
Friction Power Valvetrain	5.1.1	power [W]
Friction Power Auxiliaries	5.1.1	power [W]

8.2.1.3. Element "Mechanical Consumer"

Label	since Version	Unit
Sensor Channels		
Mean Device Speed	2010	ang_vel [rpm]
Mean Mechanical Torque	2010	moment [Nm]
Mean Speed Gradient	2010	speed_gradient [rpm_s]

8.2.1.4. Element "Vehicle"

Label	since Version	Unit
Sensor Channels		
Vehicle Speed	4.0	velocity [m_s]
Clutch Torque	5.0	moment [Nm]

8.2.1.5. Element "Cylinder"

Label	since Version	Unit
Sensor Channels		
FTDC CrankAngle	v2008	angle [deg]
A/F-Ratio	4.0	dimensionless [no]
Octane Number	4.0	dimensionless [no]
Pressure	4.0.1	pressure [Pa]
Temperature	4.0.1	temperature [K]
Piston Wall Heatflow	4.0.4	heat_flow [J_s]
Head Wall Heatflow	4.0.4	heat_flow [J_s]
Liner Wall Heatflow	4.0.4	heat_flow [J_s]
Liner S. Wall Heatflow	4.0.4	heat_flow [J_s]
Intake Port Wall Heatflow	4.0.4	heat_flow [J_s]
Exhaust Port Wall Heatflow	4.0.4	heat_flow [J_s]
Piston to Oil Heatflow	5.0	heat_flow [J_s]
Head to Coolant Heatflow	5.0	heat_flow [J_s]
Liner to Coolant Heatflow	5.0	heat_flow [J_s]

In-Port to Coolant Heatflow	5.0	heat_flow [J_s]
Ex-Port to Coolant Heatflow	5.0	heat_flow [J_s]
Piston Wall Temperature	5.0	temperature [K]
Head Wall Temperature	5.0	temperature [K]
Liner TDC Wall Temperature	5.0	temperature [K]
Liner BDC Wall Temperature	5.0	temperature [K]
Liner S. Wall Temper.	5.0	temperature [K]
Intake Port Wall Temperature	5.0	temperature [K]
Exhaust Port Wall Temperature	5.0	temperature [K]
Coolant Temperature	5.0	temperature [K]
Oil Temperature	5.0	temperature [K]
Piston Position	5.0	length [m]
Start of Combustion	4.0.5	angle [deg]
Rate of Heat Release	4.0.5	heat_flow [J_s]
Rate of Evaporation	4.0.5	massflow [kg_s]
Rate of Injection	4.0.5	massflow [kg_s]
Port Valve Lift	4.0.5	length [m]
Injection Rail Pressure	4.0.5	pressure [Pa]
AVLMCC Combustion Parameter	5.0.2	dimensionless [no]
AVLMCC Turbulence Parameter	5.0.2	dimensionless [no]
AVLMCC Dissipation Parameter	5.0.2	dimensionless [no]
Injection-On Signal	4.0.5	angle [deg]
Injection-Off Signal	4.0.5	angle [deg]
Combustion Duration	4.0.5	angle [deg]
Vibe Parameter m	4.0.5	dimensionless [no]
Fuelling	4.1	mass [kg]
Peak Firing Pressure	5.0.2	pressure [Pa]
Peak Firing Press CrAngle	2009	angle [deg]
IMEP	5.1	pressure [Pa]
BSFC	5.1	spec_mass_flow [g_kWh]
Total Fuel Mass	5.1	mass [kg]
Residual Gas Concentration	5.1	dimensionless [no]
NOX Production	5.1	massflow [kg_s]
CO Production	5.1	massflow [kg_s]
HC Production	5.1	massflow [kg_s]
Soot Production	2009	massflow [kg_s]
Acc Blowby	5.1	massflow [kg_s]
CrAngleMsFrcBrnd_50	2009.1	dimensionless [no]
CylinderMass	2010	mass [kg]

8.2.1.6. Element "Cooler"

Label	**since Version**	**Unit**

Sensor Channels		
Coolant Temperature	4.0	temperature [K]
Heat Flow	4.0	heat_flow [J_s]
Core Friction Coefficient	4.0.5	dimensionless [no]
Core Heat Transfer Factor	4.0.5	dimensionless [no]
Laminar Friction Coefficient	5.0	dimensionless [no]

8.2.1.7. Element "Air Cleaner"

Label	since Version	Unit
Sensor Channels		
Core Friction Coefficient	4.0.5	dimensionless [no]
Laminar Friction Coefficient	5.0	dimensionless [no]

8.2.1.8. Element "Catalyst"

Label	since Version	Unit
Sensor Channels		
Core Friction Coefficient	4.1	dimensionless [no]
Core Heat Transfer Factor	4.1	dimensionless [no]
Laminar Friction Coefficient	5.0	dimensionless [no]
Mean Temperature	5.0	temperature [K]
Max Temperature	5.0	temperature [K]
Min Temperature	5.0	temperature [K]
Max Temperature Gradient	5.0	dtda [K_deg]
Outlet Massflow	5.0	massflow [kg_s]
Outlet Temperature	5.0	temperature [K]
Overall Pressure Drop	5.0	pressure [Pa]
Outlet Gas Species Mole Fraction	5.0	dimensionless [no]
Gas Species Mole Fraction Pnt1	5.1	dimensionless [no]
Gas Species Mole Fraction Pnt2	5.1	dimensionless [no]
Gas Species Mole Fraction Pnt3	5.1	dimensionless [no]
Gas Species Mole Fraction Pnt4	5.1	dimensionless [no]
Gas Species Mole Fraction Pnt5	5.1	dimensionless [no]
Outlet Gas Species Mass Fraction	5.0	dimensionless [no]
Overall Gas Species Conversion	5.0	dimensionless [no]
Cumulative Outlet Species Massflow	5.0	mass [kg]
Mean GHSV	5.0	dimensionless [no]
Inlet Pressure	5.0	pressure [Pa]
Mean Surface Fraction Ce2O3(S)	5.0	dimensionless [no]
Mean Surface Fraction CeO2(S)	5.0	dimensionless [no]

Mean Surface Fraction Rh(S)	5.0	dimensionless [no]
Mean Surface Fraction RhO(S)	5.0	dimensionless [no]
Mean Surface Fraction BaCO3(S)	5.0	dimensionless [no]
Mean Surface Fraction Ba(NO3)2(S)	5.0	dimensionless [no]
Mean Surface Fraction Me(S)	5.0	dimensionless [no]
Mean Surface Fraction Me-NH3(S)	5.0	dimensionless [no]
Mean Surface Fraction User1	5.0	dimensionless [no]
Mean Surface Fraction User2	5.0	dimensionless [no]
Mean Surface Fraction User3	5.0	dimensionless [no]
Mean Surface Fraction User4	5.0	dimensionless [no]
Mean Surface Fraction User5	5.0	dimensionless [no]
Mean Surface Fraction User6	5.0	dimensionless [no]
Mean Surface Fraction User7	5.0	dimensionless [no]
Mean Surface Fraction User8	5.0	dimensionless [no]
Mean Surface Fraction User9	5.0	dimensionless [no]
Mean Surface Fraction User10	5.0	dimensionless [no]
Mean Reaction Rate 1	5.1	vol_spec_mol_rate [kmol_m3s]
Mean Reaction Rate 2	5.1	vol_spec_mol_rate [kmol_m3s]
Mean Reaction Rate 3	5.1	vol_spec_mol_rate [kmol_m3s]
Mean Reaction Rate 4	5.1	vol_spec_mol_rate [kmol_m3s]
Mean Reaction Rate 5	5.1	vol_spec_mol_rate [kmol_m3s]
Mean Reaction Rate 6	5.1	vol_spec_mol_rate [kmol_m3s]
Mean Reaction Rate 7	5.1	vol_spec_mol_rate [kmol_m3s]
Mean Reaction Rate 8	5.1	vol_spec_mol_rate [kmol_m3s]
Mean Reaction Rate 9	5.1	vol_spec_mol_rate [kmol_m3s]
Mean Reaction Rate 10	5.1	vol_spec_mol_rate [kmol_m3s]
Surface Fraction Me-NH3(S) Pnt1	5.1	dimensionless [no]
Surface Fraction Me-NH3(S) Pnt2	5.1	dimensionless [no]
Surface Fraction Me-NH3(S) Pnt3	5.1	dimensionless [no]
Surface Fraction Me-NH3(S) Pnt4	5.1	dimensionless [no]
Surface Fraction Me-NH3(S) Pnt5	5.1	dimensionless [no]
Gas Temperature Pnt1	5.1.1	temperature [K]
Gas Temperature Pnt2	5.1.1	temperature [K]
Gas Temperature Pnt3	5.1.1	temperature [K]
Gas Temperature Pnt4	5.1.1	temperature [K]
Gas Temperature Pnt5	5.1.1	temperature [K]
Solid Temperature Pnt1	5.1.1	temperature [K]
Solid Temperature Pnt2	5.1.1	temperature [K]
Solid Temperature Pnt3	5.1.1	temperature [K]
Solid Temperature Pnt4	5.1.1	temperature [K]
Solid Temperature Pnt5	5.1.1	temperature [K]

8.2.1.9. Element "DPF"

Label	since Version	Unit
Sensor Channels		
Core Friction Coefficient	4.1	dimensionless [no]
Core Heat Transfer Factor	4.1	dimensionless [no]
Laminar Friction Coefficient	5.0	dimensionless [no]
Mean Temperature	5.0	temperature [K]
Max Temperature	5.0	temperature [K]
Min Temperature	5.0	temperature [K]
Max Temperature Gradient	5.0	dtda [K_deg]
Outlet Massflow	5.0	massflow [kg_s]
Outlet Temperature	5.0	temperature [K]
Overall Pressure Drop	5.0	pressure [Pa]
Outlet Gas Species Mole Fraction	5.0	dimensionless [no]
Outlet Gas Species Mass Fraction	5.0	dimensionless [no]
Overall Gas Species Conversion	5.0	dimensionless [no]
Cumulative Outlet Species Massflow	5.0	mass [kg]
Mean GHSV	5.0	dimensionless [no]
Inlet Pressure	5.0	pressure [Pa]
Soot Mass	5.0	density [kg_m3]

8.2.1.10. Element "ATPipe"

Label	since Version	Unit
Sensor Channels		
Mean Temperature	5.1	temperature [K]
Max Temperature	5.1	temperature [K]
Min Temperature	5.1	temperature [K]

8.2.1.11. Element "Pipe"

Label	since Version	Unit
Sensor Channels		
Friction Coefficient	5.0	dimensionless [no]
Heat Transfer Factor	5,0	dimensionless [no]
Wall Temperature	5.0	temperature [K]
Wall Heat Flow	5.0	heat_flow [J_s]
Laminar Friction Coefficient	5.0	dimensionless [no]

8.2.1.12. Element "Turbocharger"

Label	since Version	Unit

Sensor Channels		
Rotational Speed	4.0	ang_vel [rpm]
Mean Rotational Speed	4.0	ang_vel [rpm]
Compressor Pressure Ratio	4.1	dimensionless [no]
Energy Balance	5.0	dimensionless [no]
Turbine WHFlow	5.1	heat_flow [J_s]

8.2.1.13. Element "Turbine"

Label	since Version	Unit
Sensor Channels		
Turbine Speed	4.1	ang_vel [rpm]
Mean Turbine Speed	4.1	ang_vel [rpm]
VTG Position	4.1	dimensionless [no]
Turbine to total Massflow	4.1	dimensionless [no]
Turbine Work	5.0	volumework [J_cycle]
Turbine WHFlow	5.1	heat_flow [J_s]

8.2.1.14. Element "PWSC"

Label	since Version	Unit
Sensor Channels		
Rotor Speed	5.0.2	ang_vel [rpm]
Casing Offset	5.0.2	angle [deg]
Channel Friction Coeff	5.0.2	dimensionless [no]
Channel Lam Fric Coeff	5.0.2	dimensionless [no]
Channel Heat Trans Factor	5.0.2	dimensionless [no]
Rotor Drive Torque	2009	moment [Nm]

8.2.1.15. Element "Electrical Device"

Label	since Version	Unit
Sensor Channels		
Mean Device Speed	4.1	ang_vel [rpm]
Mean Electric Power	4.1	power [W]
Mean Mechanical Torque	4.1	moment [Nm]
Mean Speed Gradient	5.0	speed_gradient [rpm_s]

8.2.1.16. Element "Measuring Point"

Label	since Version	Unit
Sensor Channels		
Pressure	4.0	pressure [Pa]
Mean Pressure	4.0	pressure [Pa]
Mean Stagnation Pressure	5.1	pressure [Pa]
Temperature	4.0	temperature [K]
Mean Temperature	4.0	temperature [K]
Mean Stagnation Temperature	5.1	temperature [K]
Mean H Based Temperature	5.1	temperature [K]
Mass Flow	4.0	massflow [kg_s]
Mean Mass Flow	4.0	massflow [kg_s]
Density	5.1	density [kg_m3]
Isent. Exponent	5.1	dimensionless [no]
Mean Isent. Exp.	5.1	dimensionless [no]
Gas Constant	5.1	spec_heat [J_kgK]
Mean Gas Const.	5.1	spec_heat [J_kgK]
Residual Gas Concentration	4.0	dimensionless [no]
Fuel Concentration	4.0	dimensionless [no]
Fuel Burned Conc.	2009	dimensionless [no]
A/F-Ratio	4.0	dimensionless [no]
Gas Species Mass Fraction	5.1	dimensionless [no]
Gas Species Mole Fraction	5.1	dimensionless [no]
Mean Residual Gas Conc.	2009	dimensionless [no]
Mean Fuel Conc.	2009	dimensionless [no]
Mean Fuel Burned Conc.	2009	dimensionless [no]
Mean A/F-Ratio	2009	dimensionless [no]
Mean Gas Spec. Mass Frac.	2009	dimensionless [no]
Mean Gas Spec. Mole Frac.	2009	dimensionless [no]

8.2.1.17. Element "Plenum"

Label	since Version	Unit
Sensor Channels		
Pressure	4.0	pressure [Pa]
Mean Pressure	4.0	pressure [Pa]
Temperature	4.0	temperature [K]
Mean Temperature	4.0	temperature [K]
Residual Gas Concentration	4.0	dimensionless [no]
Fuel Concentration	4.0	dimensionless [no]
A/F-Ratio	4.0	dimensionless [no]

Fuel Burned Conc.	2009	dimensionless [no]
Gas Species Mass Fraction	2009	dimensionless [no]
Gas Species Mole Fraction	2009	dimensionless [no]
Mean Residual Gas Conc.	2009	dimensionless [no]
Mean Fuel Conc.	2009	dimensionless [no]
Mean Fuel Burned Conc.	2009	dimensionless [no]
Mean A/F-Ratio	2009	dimensionless [no]
Mean Gas Spec. Mass Frac.	2009	dimensionless [no]
Mean Gas Spec. Mole Frac.	2009	dimensionless [no]
Volume	2009	volume [m3]

8.2.1.18. Element "Turbocompressor"

Label	since Version	Unit
Sensor Channels		
Compressor Speed	5.0	ang_vel [rpm]
Mean Compressor Speed	5.0	ang_vel [rpm]
Compressor Pressure Ratio	5.0	dimensionless [no]
Compressor Work	5.0	volumework [J_cycle]

8.2.1.19. Element "Injector"

Label	since Version	Unit
Sensor Channels		
Injection Angle	5.1	angle [deg]
Delivery Rate	5.1	massflow [kg_s]
Injection Duration	5.1	time [s]
Evaporation Multiplier	5.1	dimensionless [no]
Fuel Film Thickness	5.1	length [m]
Fraction of Fuel in Wallfilm	5.1	dimensionless [no]
A/F-Ratio	4.0	dimensionless [no]
Fuel Mass/Cycle	5.1	massflow_cycle [kg_cycle]
Fuel Mass/Time	5.1	massflow [kg_s]
Flow Coefficient	4.0	dimensionless [no]

8.2.1.20. Element "System Boundary"

Label	since Version	Unit
Sensor Channels		
Pressure	4.0	pressure [Pa]
Temperature	4.0	temperature [K]
Flow Coefficient	4.0	dimensionless [no]

Residual Gas Concentration	4.0	dimensionless [no]
A/F-Ratio	4.0	dimensionless [no]
Fuel Concentration	4.0	dimensionless [no]

8.2.1.21. Element "Internal Boundary"

Label	since Version	Unit
Sensor Channels		
Pressure	4.0	pressure [Pa]
Temperature	4.0	temperature [K]
Residual Gas Concentration	4.0	dimensionless [no]
A/F-Ratio	4.0	dimensionless [no]
Fuel Concentration	4.0	dimensionless [no]

8.2.1.22. Element "Mechanical Link"

Label	since Version	Unit
Sensor Channels		
Clutch Release Position	5.0	dimensionless [no]
Gear Ratio	5.0	dimensionless [no]
Clutch Torque	5.0	moment [Nm]
Gear Efficiency	5.0	dimensionless [no]

8.2.1.23. Element "PID Controller"

Label	since Version	Unit
Sensor Channels		
Output	5.0	dimensionless [no]

8.2.1.24. Element "Microphone"

Label	since Version	Unit
Sensor Channels		
Overall Linear Sound Pressure Level	5.0	soundpressure [dB]
Overall 'A' Sound Pressure Level	5.0	soundpressure [dB]

8.2.1.25. Element "Throttle"

Label	since Version	Unit
Sensor Channels		
Throttle Angle	5.0.2	angle [deg]

8.2.1.26. Element "ECU"

Label	since Version	Unit
Sensor Channels		
Output	5.1	dimensionless [no]
Load_Signal	4.0	dimensionless [no]

8.2.1.27. Element "DLL"

Label	since Version	Unit
Sensor Channels		
Output	5.1	dimensionless [no]

8.2.1.28. Element "API"

Label	since Version	Unit
Sensor Channels		
Output	5.1	dimensionless [no]

8.2.1.29. Element "Engine Interface"

Label	since Version	Unit
Sensor Channels		
Output	5.1	dimensionless [no]

8.2.1.30. Element "Formula Interpr."

Label	since Version	Unit
Sensor Channels		
Output	5.1	dimensionless [no]

8.2.1.31. Element "Cruise Link"

Label	since Version	Unit
Sensor Channels		
Output	5.1.1	dimensionless [no]

8.2.1.32. Element "ATM Injector"

Label	since Version	Unit
Sensor Channels		

Inj. Massflow	2009	massflow [kg_s]

8.2.2. Actuator Channels

8.2.2.1. Element "Engine"

Label	since Version	Unit
Actuator Channels		
Speed	5.0	ang_vel [rpm]
FMEP	5.0	pressure [Pa]
Distr. Piston Wall Temperature	5.1.1	temperature [K]
Distr. Head Wall Temperature	5.1.1	temperature [K]
Distr. Liner TDC Wall Temperature	5.1.1	temperature [K]
Distr. Liner BDC Wall Temperature	5.1.1	temperature [K]
Distr. Intake Port Wall Temperature	5.1.1	temperature [K]
Distr. Exhaust Port Wall Temperature	5.1.1	temperature [K]
Oil Temp. Friction	5.1.1	temperature [K]

8.2.2.2. Element "Mechanical Consumer"

Label	since Version	Unit
Actuator Channels		
Mechanical Torque	2010	moment [Nm]

8.2.2.3. Element "Vehicle"

Label	since Version	Unit
Actuator Channels		
Vehicle Load	5.0	force [N]
Clutch Release Position	5.0	dimensionless [no]
Gear Ratio	5.0	dimensionless [no]
Gear Step	5.0	dimensionless [no]
Gear Efficiency	5.0	dimensionless [no]

8.2.2.4. Element "Cylinder"

Label	since Version	Unit
Actuator Channels		
Ignition Timing	4.0.4	angle [deg]
Intake Cam Phasing	4.0	angle [deg]

Exhaust Cam Phasing	4.0	angle [deg]
Fuelling	4.0.4	mass [kg]
A2F Ratio Fuelling	2009.1	dimensionless [no]
Start of Injection	4.0.4	angle [deg]
Piston Wall Temperature	4.0.4	temperature [K]
Head Wall Temperature	4.0.4	temperature [K]
Liner Wall Temperature	4.0.4	temperature [K]
Intake Port Wall Temperature	4.0.4	temperature [K]
Exhaust Port Wall Temperature	4.0.4	temperature [K]
Liner TDC Wall Temperature	5.0	temperature [K]
Liner BDC Wall Temperature	5.0	temperature [K]
Coolant Temperature	5.0	temperature [K]
Oil Temperature	5.0	temperature [K]
Start of Combustion	4.0.5	angle [deg]
Start of Comb Offset	5.1	angle [deg]
Piston Position Derivative	5.0	rel_velocity [m_deg]
Rate of Heat Release Table	4.0.5	norm_roi [1_deg]
Rate of Evaporation Table	4.0.5	norm_roi [1_deg]
Rate of Injection Table	4.0.5	norm_roi [1_deg]
Port Valve Lift Table	4.0.5	length [m]
Port Valve Lift	5.0	length [m]
Injection Rail Pressure	4.0.5	pressure [Pa]
AVLMCC Combustion Parameter	5.0.2	pressure [Pa]
AVLMCC Turbulence Parameter	5.0.2	pressure [Pa]
AVLMCC Dissipation Parameter	5.0.2	pressure [Pa]
Fractal Ign. Timing	5.1.0	angle [deg]
Fractal Ign. Form. Mult.	5.1.0	dimensionless [no]
Fractal Ign. Rad. Ratio.	5.1.0	dimensionless [no]
Fractal Turb. Prod. Const.	5.1.0	dimensionless [no]
Fractal Turb. LS Parameter	5.1.0	dimensionless [no]
Injection-On Signal	4.0.5	angle [deg]
Injection-Off Signal	4.0.5	angle [deg]
Combustion Duration	4.0.5	angle [deg]
Vibe Parameter m	4.0.5	dimensionless [no]
Blowby Gap	5.1	length [m]
WHT Piston Calib. Factor	5.1	dimensionless [no]
WHT Head Calib. Factor	5.1	dimensionless [no]
WHT Liner Calib. Factor	5.1	dimensionless [no]
Piston Position Offset	2009	length [m]
CylinderWHT Coeff.	2010	heat_transf_coeff [W/(m^2.K)]

8.2.2.5. Element "Cooler"

Label	since Version	Unit
Actuator Channels		
Coolant Temperature	4.0	temperature [K]
Core Friction Coefficient	4.0.5	dimensionless [no]
Core Heat Transfer Factor	4.0.5	dimensionless [no]
Laminar Friction Coefficient	5.0	dimensionless [no]
Cooler Efficiency	5.1	dimensionless [no]

8.2.2.6. Element "Air Cleaner"

Label	since Version	Unit
Actuator Channels		
Core Friction Coefficient	4.0.5	dimensionless [no]
Laminar Friction Coefficient	5.0	dimensionless [no]

8.2.2.7. Element "Catalyst"

Label	since Version	Unit
Actuator Channels		
Core Friction Coefficient	4.1	dimensionless [no]
Core Heat Transfer Factor	4.1	dimensionless [no]
Laminar Friction Coefficient	5.0	dimensionless [no]
Wall Heat Source All	2009.1	power [W]
Wall Heat Source Zone1	2009.1	power [W]
Wall Heat Source Zone2	2009.1	power [W]
Wall Heat Source Zone3	2009.1	power [W]
Wall Heat Source Zone4	2009.1	power [W]
Wall Heat Source Zone5	2009.1	power [W]
Ambient Wall Temperature	2010	temperature [K]

8.2.2.8. Element "DPF"

Label	since Version	Unit
Actuator Channels		
Core Friction Coefficient	4.1	dimensionless [no]
Core Heat Transfer Factor	4.1	dimensionless [no]
Laminar Friction Coefficient	5.0	dimensionless [no]
Wall Heat Source All	2009.1	power [W]
Wall Heat Source Zone1	2009.1	power [W]
Wall Heat Source Zone2	2009.1	power [W]

Wall Heat Source Zone3	2009.1	power [W]
Wall Heat Source Zone4	2009.1	power [W]
Wall Heat Source Zone5	2009.1	power [W]

8.2.2.9. Element "Pipe"

Label	since Version	Unit
Actuator Channels		
Friction Coefficient	5.0	dimensionless [no]
Heat Transfer Factor	5.0	dimensionless [no]
Wall Temperature	5.0	temperature [K]
Laminar Friction Coefficient	5.0	dimensionless [no]

8.2.2.10. Element "Turbocharger"

Label	since Version	Unit
Actuator Channels		
VTG Position	4.0	dimensionless [no]
Turbine to total Massflow	5.0	dimensionless [no]
Compressor Pressure Ratio	5.0	dimensionless [no]
Turbine Size Multiplier	5.0	dimensionless [no]
Turbine Wall Temp	5.1	temperature [K]
Turbine WHT factor	5.1	dimensionless [no]
TurbMassFlowScalFactor	2010	dimensionless [no]

8.2.2.11. Element "Turbine"

Label	since Version	Unit
Actuator Channels		
VTG Position	4.1	dimensionless [no]
Turbine to total Massflow	4.1	dimensionless [no]
Turbine Size Multiplier	5.0	dimensionless [no]
Turbine Wall Temp	5.1	temperature [K]
Turbine WHT factor	5.1	dimensionless [no]
TurbMassFlowScalFactor	2010	dimensionless [no]

8.2.2.12. Element "PWSC"

Label	since Version	Unit
Actuator Channels		
Rotor Speed	5.0.2	ang_vel [rpm]
Casing Offset	5.0.2	angle [deg]

Channel Friction Coeff	5.0.2	dimensionless [no]
Channel Lam Fric Coeff	5.0.2	dimensionless [no]
Channel Heat Trans Factor	5.0.2	dimensionless [no]

8.2.2.13. Element "Electrical Device"

Label	since Version	Unit
Actuator Channels		
Electric Power	4.1	power [W]
Mechanical Torque	4.1	moment [Nm]

8.2.2.14. Element "Plenum"

Label	since Version	Unit
Actuator Channels		
Fuel Injection A2F Ratio	5.1	dimensionless [no]
Flow Coefficient	2009	dimensionless [no]
Volume	2009	volume [m3]
Volume Derivative	2009	volflow [m3_s]

8.2.2.15. Element "Turbocompressor"

Label	since Version	Unit
Actuator Channels		
Compressor Pressure Ratio	5.0	dimensionless [no]

8.2.2.16. Element "Injector"

Label	since Version	Unit
Actuator Channels		
Injection Angle	5.1	angle [deg]
Delivery Rate	5.1	massflow [kg_s]
Injection Duration	5.1	time [s]
Evaporation Multiplier	5.1	dimensionless [no]
Fuel Film Thickness	5.1	length [m]
Fraction of Fuel in Wallfilm	5.1	dimensionless [no]
A/F Ratio	4.0	dimensionless [no]
Fuel Mass/Cycle	5.1	massflow_cycle [kg_cycle]
Fuel Mass/Time	5.1	massflow [kg_s]
Flow Coefficient	4.0	dimensionless [no]

8.2.2.17. Element "Restriction"

Label	since Version	Unit
Actuator Channels		
Flow Coefficient	4.0	dimensionless [no]

8.2.2.18. Element "System Boundary"

Label	since Version	Unit
Actuator Channels		
Pressure	4.0	pressure [Pa]
Temperature	4.0	temperature [K]
Flow Coefficient	4.0	dimensionless [no]
Residual Gas Concentration	4.0	dimensionless [no]
A/F-Ratio	4.0	dimensionless [no]
Fuel Concentration	4.0	dimensionless [no]
Mass Flow	5.0	massflow [kg_s]

8.2.2.19. Element "Internal Boundary"

Label	since Version	Unit
Actuator Channels		
Pressure	4.0	pressure [Pa]
Temperature	4.0	temperature [K]
Residual Gas Concentration	4.0	dimensionless [no]
A/F-Ratio	4.0	dimensionless [no]
Fuel Concentration	4.0	dimensionless [no]
Mass Flow	5.0	massflow [kg_s]

8.2.2.20. Element "Mechanical Link"

Label	since Version	Unit
Actuator Channels		
Clutch Release Position	5.0	dimensionless [no]
Gear Ratio	5.0	dimensionless [no]
Gear Efficiency	5.0	dimensionless [no]

8.2.2.21. Element "ATB"

Label	since Version	Unit
Actuator Channels		
Pressure	5.0	pressure [Pa]

Temperature	5.0	temperature [K]
Massflow	5.0	massflow [kg_s]
Gas Species Fraction	5.0	dimensionless [no]
Solid Species Fraction	5.0	dimensionless [no]

8.2.2.22. Element "PID Controller"

Label	**since Version**	**Unit**
Actuator Channels		
Proportional Gain	5.0	dimensionless [no]
Integral Gain	5.0	dimensionless [no]
Differential Gain	5.0	dimensionless [no]
Offset	5.0	dimensionless [no]

8.2.2.23. Element "Throttle"

Label	**since Version**	**Unit**
Actuator Channels		
Throttle Angle	5.0.2	angle [deg]

8.2.2.24. Element "ECU"

Label	**since Version**	**Unit**
Actuator Channels		
Load_Signal	4.0	dimensionless [no]

8.2.2.25. Element "Check Valve"

Label	**since Version**	**Unit**
Actuator Channels		
Valve Lift	2009	length [m]

8.2.2.26. Element "ATM Injector"

Label	**since Version**	**Unit**
Actuator Channels		
Inj. Massflow	2009	massflow [kg_s]