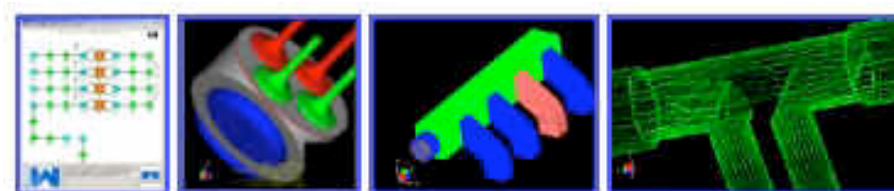


WAVE v7

Engine Simulation



WAVE v7

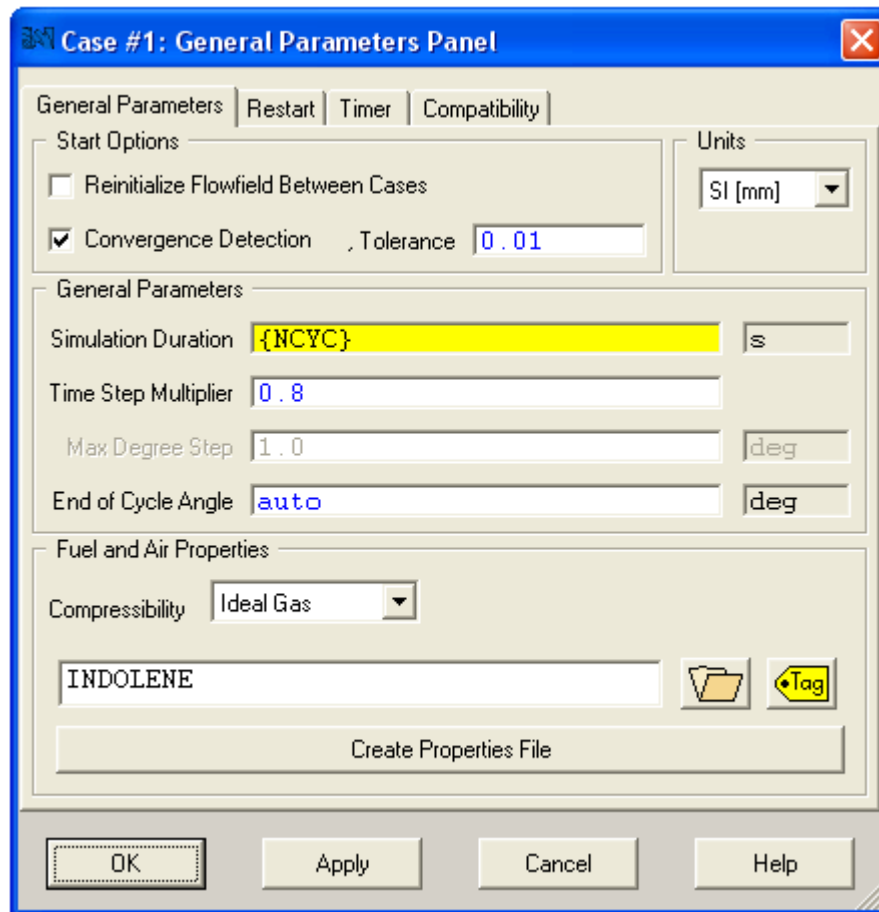
Simulation Solutions



Single Cylinder Model Notes

General Parameters

Before starting the construction of the WAVE model, the *General Parameters Panel* should first be completed.



Click the Simulation menu, then General Parameters to open this window. Type {NCYC} for Simulation Duration. Select the fuel type INDOLENE using the yellow Tag button. Then APPLY

You will be told, 'Simulation Duration is Zero, Do you want to continue' (Click YES).

Then your told, '*The following constants are not defined. NCYC Do you want to add them to the constants table?*' (Click YES).

A new window will open, Now type **20** in the box under **Case 1** for NCYC.

Single Cylinder Model

Construct the simple engine model shown using the *Elements* menu on the left

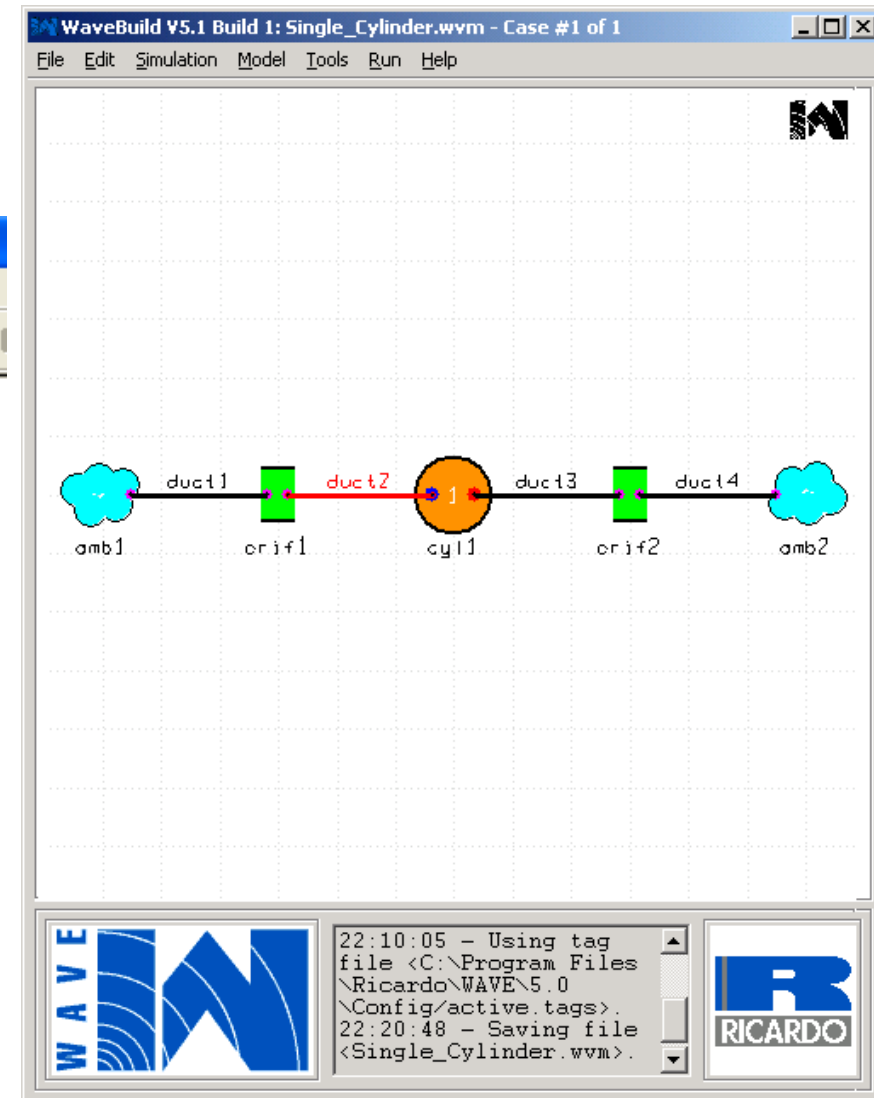
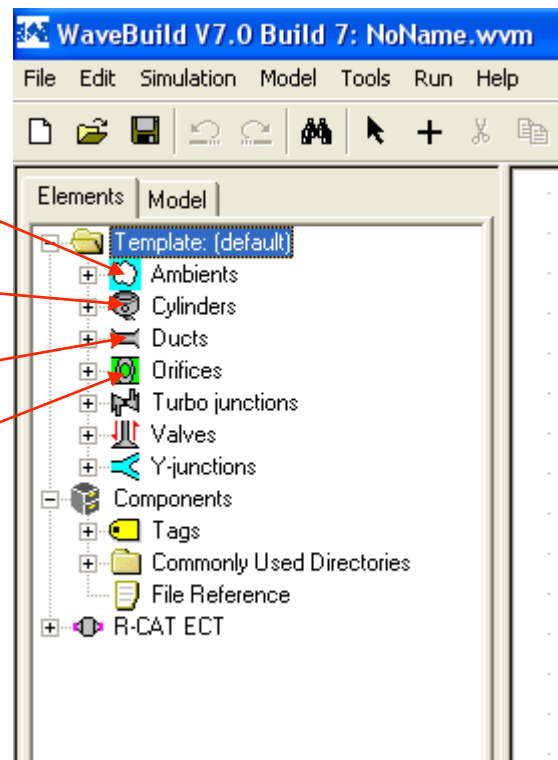
Ambient

Engine
Cylinder

Ducts

Junctions

Note: The ducts can be added by joining the pink dots



Geometry Definition

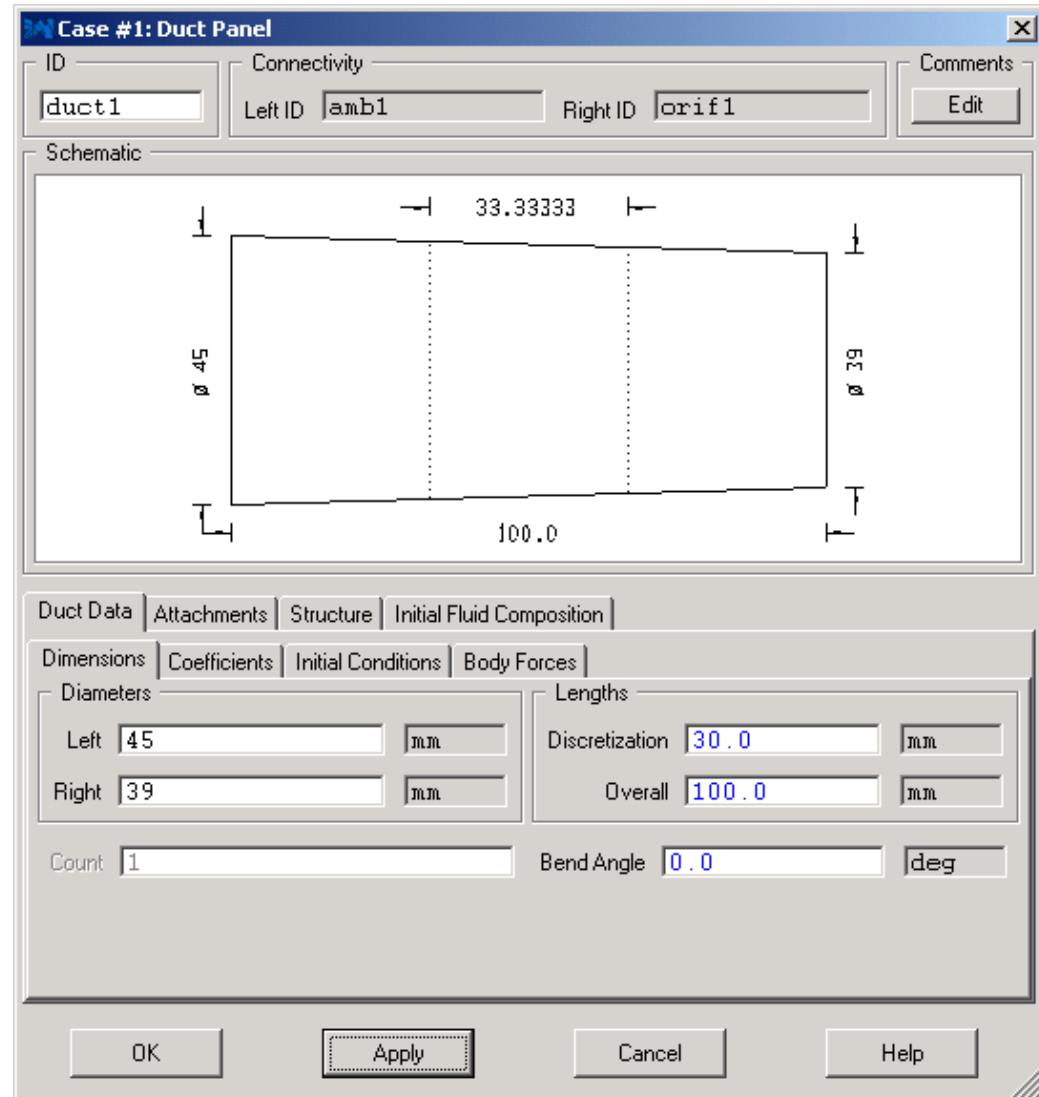
Double Click on the ducts
and define:-

Dimensions

Coefficients

Initial Conditions of the Gas

NOTE: These values are
for duct 1 only. Get the
other dimensions from the
next page.



Case #1: Duct Panel

ID: duct1

Connectivity: Left ID: amb1 Right ID: orif1

Comments: Edit

Schematic

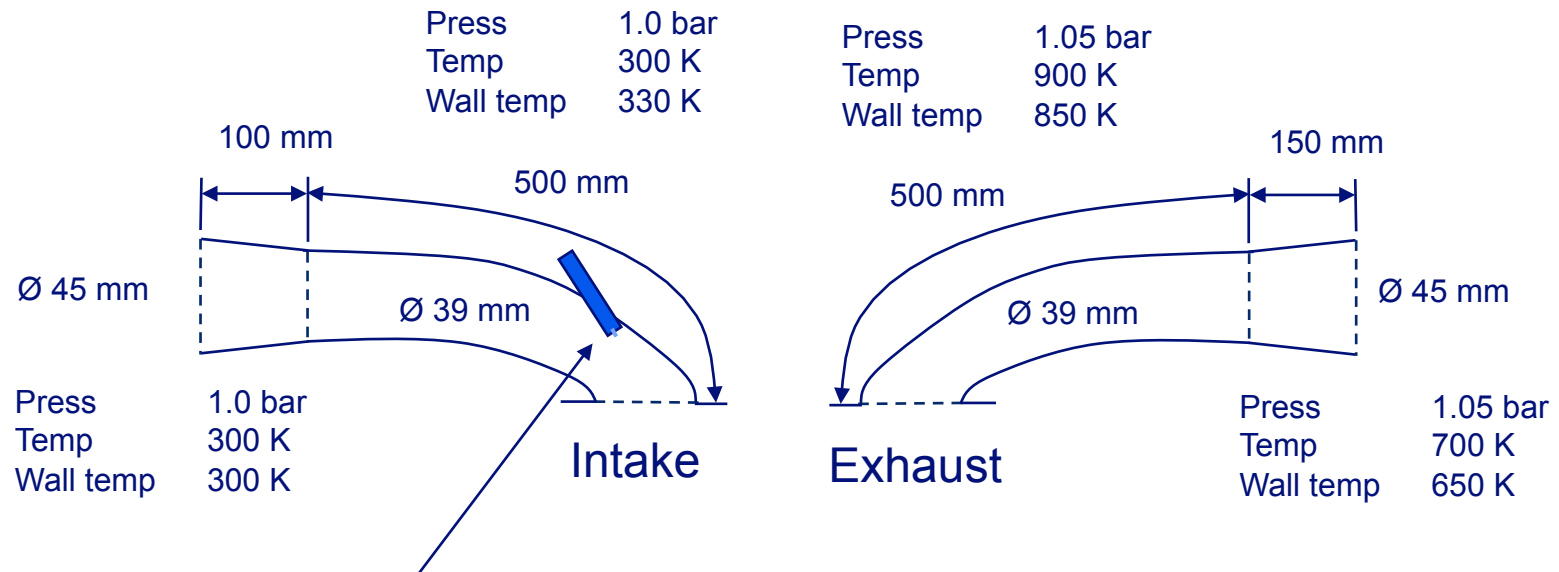
Dimensions: Left: 45 mm Right: 39 mm

Lengths: Discretization: 30.0 mm Overall: 100.0 mm

Count: 1 Bend Angle: 0.0 deg

OK Apply Cancel Help

Geometry Definition



The injector should be placed 150mm away from the end of the second duct

Adding Injectors

Port injectors are by right clicking on the required duct and selecting edit injectors

This example uses port injection

Select 'Edit Duct Injection Types' to define injection type, start of injection, injection profile, and fuel composition:

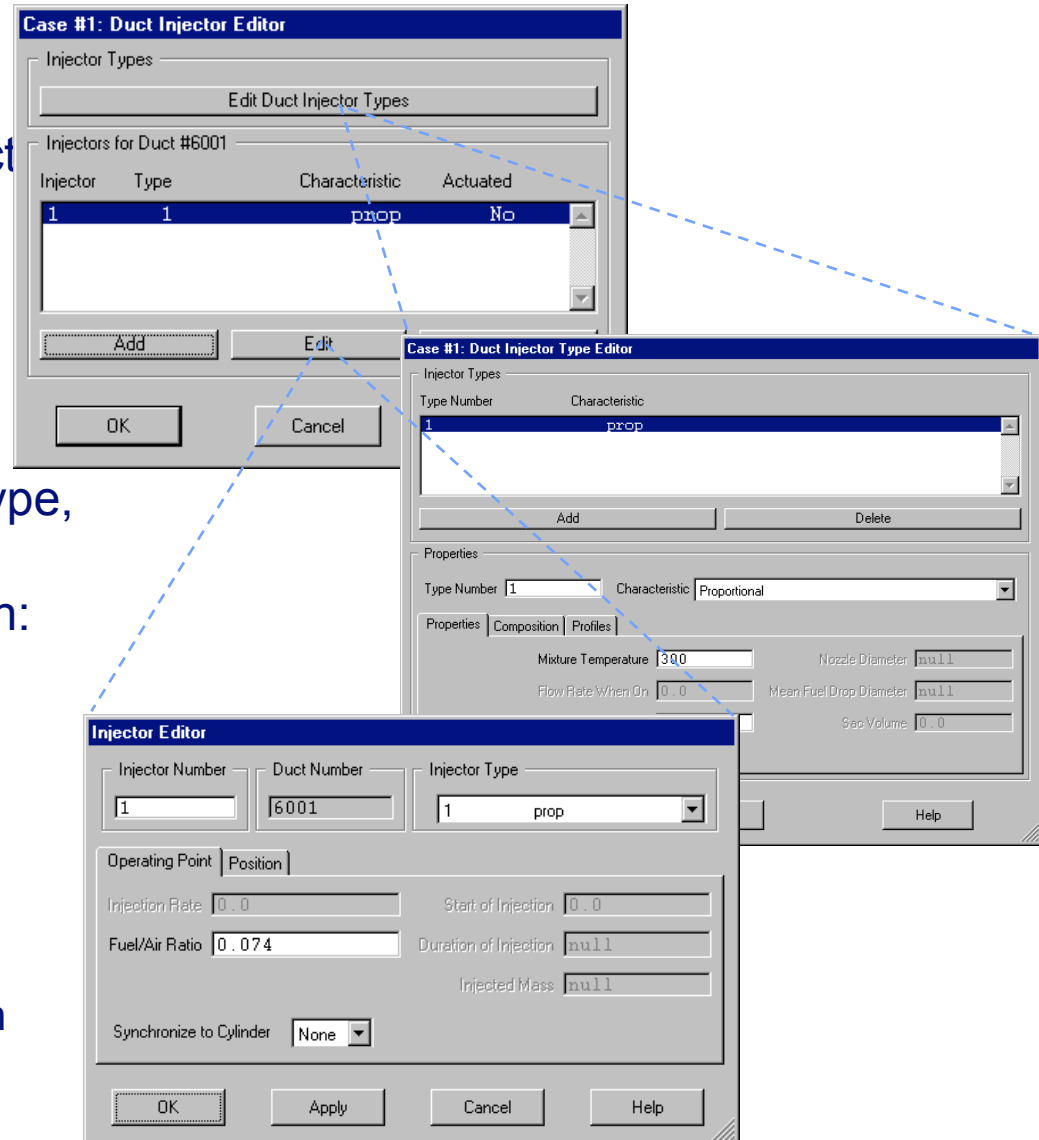
Vaporized Fuel 0.2

Liquid Fuel 0.8

Vaporized Liquid Fraction 0.2

Fuel Temperature 300K

Pressing 'Edit' allows setting of Fuelling ratios or rates for each injector



Case #1: Duct Injector Editor

Injector Types

Edit Duct Injector Types

Injectors for Duct #6001

Injector	Type	Characteristic	Actuated
1	1	prop	No

Add Edit

OK Cancel

Case #1: Duct Injector Type Editor

Injector Types

Type Number	Characteristic
1	prop

Add Delete

Properties

Type Number 1 Characteristic Proportional

Properties Composition Profiles

Mixture Temperature 300 Nozzle Diameter null

Flow Rate When On 0.0 Mean Fuel Drop Diameter null

Sec Volume 0.0

Help

Injector Editor

Injector Number 1 Duct Number 6001 Injector Type 1 prop

Operating Point Position

Injection Rate 0.0 Start of Injection 0.0

Fuel/Air Ratio 0.074 Duration of Injection null

Injected Mass null

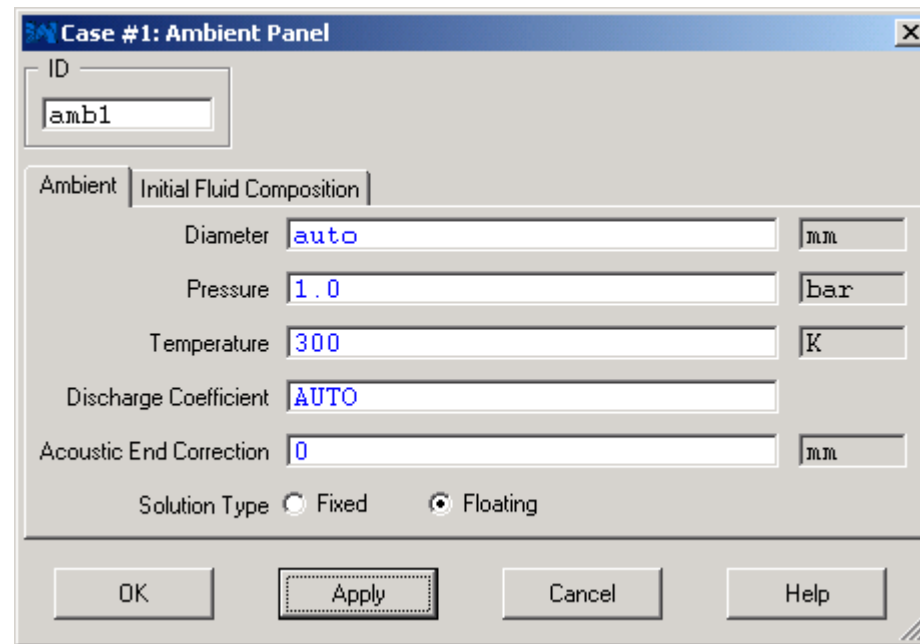
Synchronize to Cylinder None

OK Apply Cancel Help

Ambient Conditions

Double click on the ambient junctions to define the orifice size and gas temperatures and pressures (the same ambients exist for intake and exhaust)

The fluid composition should be made entirely of air (set to 1.0).



The image shows a software dialog box titled "Case #1: Ambient Panel". It contains the following fields and controls:

- ID:** A text box containing "amb1".
- Initial Fluid Composition:** A tabbed section with the following fields:
 - Diameter:** A text box with "auto" and a unit dropdown set to "mm".
 - Pressure:** A text box with "1.0" and a unit dropdown set to "bar".
 - Temperature:** A text box with "300" and a unit dropdown set to "K".
 - Discharge Coefficient:** A text box with "AUTO".
 - Acoustic End Correction:** A text box with "0" and a unit dropdown set to "mm".
- Solution Type:** Two radio buttons, "Fixed" and "Floating", with "Floating" selected.
- Buttons:** "OK", "Apply", "Cancel", and "Help" at the bottom.

Engine Data



Select *model* from the tool bar, then *engine*. This displays the input blocks that define the operation of the engine

In this example we will only have to enter data into:-

Geometry, Operating Parameters, Heat Transfer, and Combustion.

In the operating parameters type {SPEED} and enter a value in *simulation - constants - table*

The screenshot shows the 'Case #1: Engine General Panel' window with the following settings:

- Geometry:** No. of Cylinders: 1, Strokes per Cycle: 4, Engine Type: Spark Ignition, Bore: 90.0 mm, Stroke: 85 mm, Connecting Rod Length: 150 mm, Wrist Pin Offset: 0.0 mm, Compression Ratio: 9.5.
- Operating Parameters:** Engine Speed: {SPEED} rpm, Reference Pressure: 1.0 bar, Reference Temperature: 300 K.
- Heat Transfer:** ACF: 0.5 bar, BCF: 0.006, CCF: 630 Pa*min/m, QCF: 0.0 Pa*min^2/m^2.
- Combustion:** Firing Order and Relative TDC table:

Cylinder	TDC
1	0.0
- Printout Flag:** In-Cylinder State: 0, Port Conditions: 0.

Buttons at the bottom: OK, Apply, Cancel, Help.

Engine Data



Geometry Tab

Number of cylinders	1
Number of strokes	4
Engine Type	Spark Ignition
Bore	90mm
Stroke	85mm
Con Rod Length	150mm
Piston pin offset	0.0
Compression ratio	9.5
Friction ACF	0.5
BCF	0.006
CCF	630.0
QCF	0.0

Combustion Tab

Combustion	SI Wiebe
thb50	5.0
bdur	21.2
wexp	2.0
burnfrac	1.0

Heat Transfer Tab

Heat transfer IVO	1.0
Heat transfer IVC	1.0
Piston top SA	1.0
Cyl head SA	1.6

Temperatures:

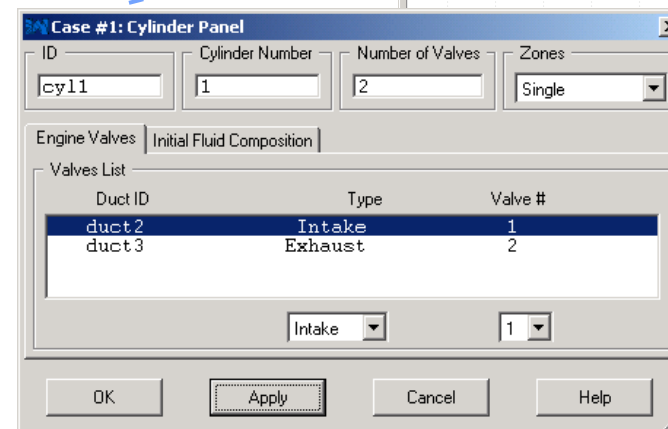
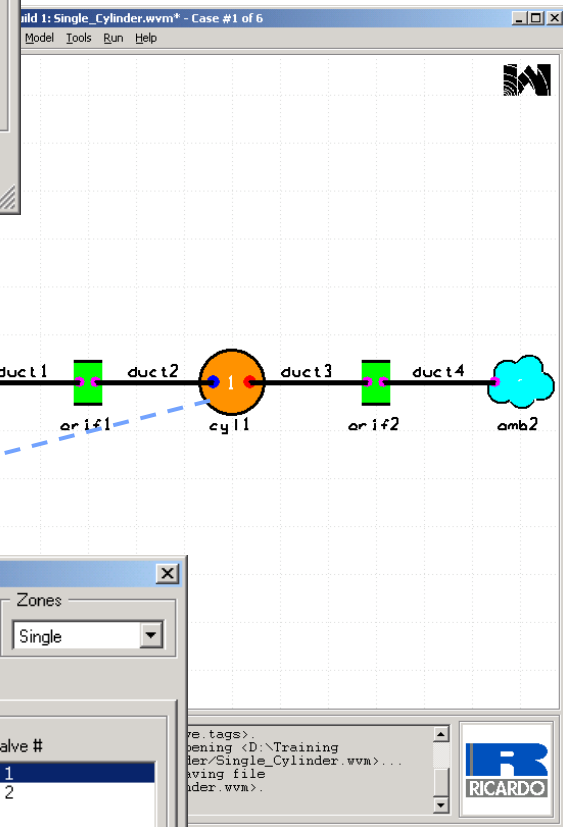
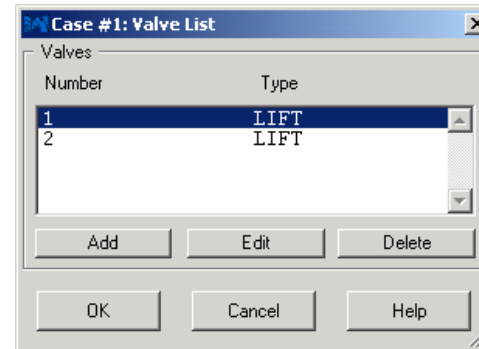
Piston top	520 K
Cyl head	520 K
Cyl liner	400 K
clearance height	2.0

Valve Data

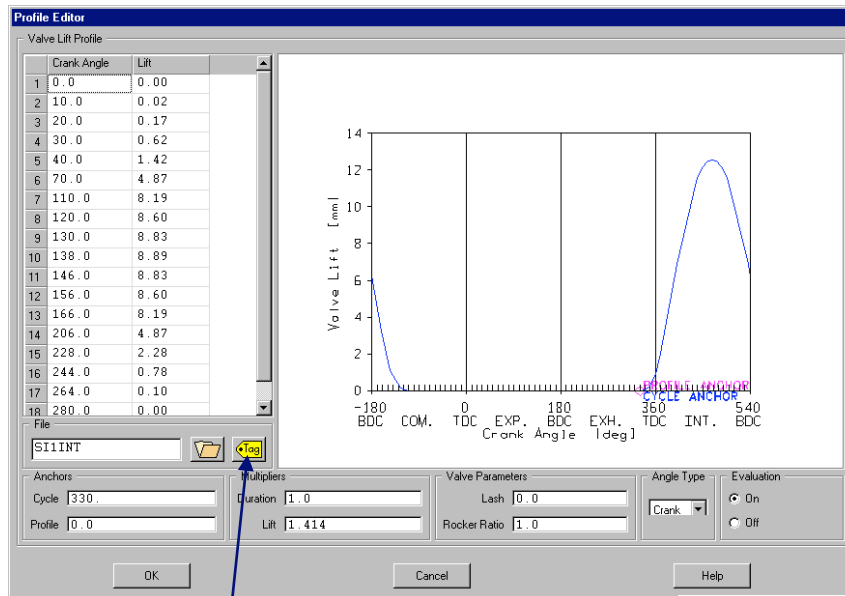
To add valve details to the engine select *model* then *valves* from the tool bar

Select add valve, and define its type. To define the lift and flow coefficients select edit, see following slide

The duct attachments for each valve are defined by double clicking on the cylinder



Valve Data

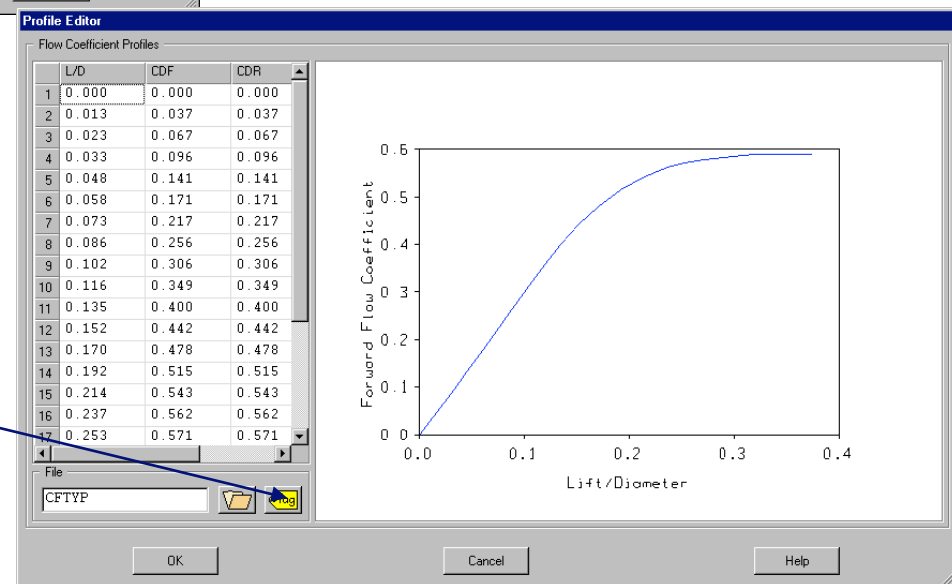


For this exercise reference data from the yellow tag files:-

Intake: SI1INT (lift)
CFTYP (coeff)

Exh: SI1EXH (lift)
CFTYP (coeff)

Enter in manually,
or reference an
external/tag file



Valve Data

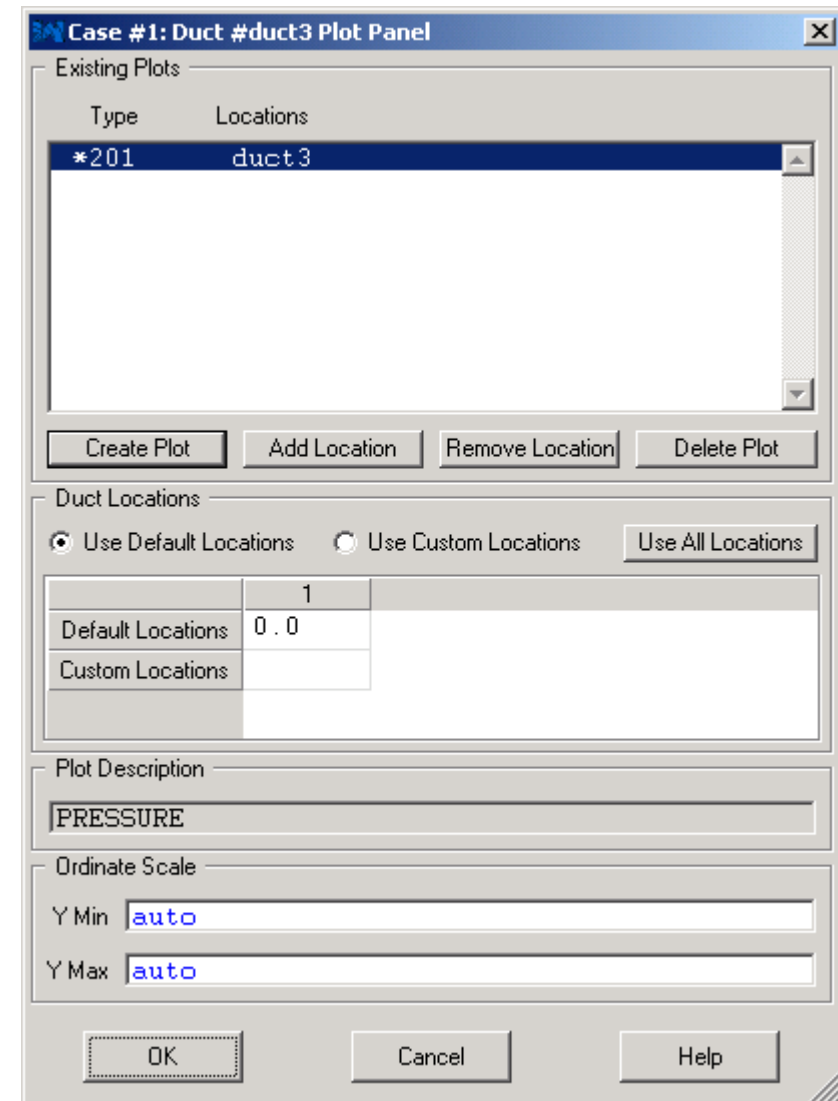


	Intake	Exhaust	
Anchors			
Cycle	330°	105°	
Profile	0.0	0.0	
<i>Multipliers</i>			
Duration		1.0	1.0
Lift	1.414	1.0	
<i>Valve Parameters</i>			
Lash	0.0	0.0	
Rocker ratio	1.0	1.0	
Angle type	Crank	Crank	
Valve Diameters	49.5	30	
Evaluation	On	On	

Requesting Plots

Requesting plots is done by selecting with the right mouse button the duct or volume that you want to plot data from, and then selecting edit plots

Use the options shown opposite to add or modify plot types



The dialog box 'Case #1: Duct #duct3 Plot Panel' contains the following sections:

- Existing Plots:** A table with columns 'Type' and 'Locations'. It contains one entry: '*201' under 'Type' and 'duct3' under 'Locations'.
- Buttons:** 'Create Plot', 'Add Location', 'Remove Location', and 'Delete Plot'.
- Duct Locations:** Radio buttons for 'Use Default Locations' (selected), 'Use Custom Locations', and 'Use All Locations'.
- Table:** A table with 2 columns. The first column has labels 'Default Locations' and 'Custom Locations'. The second column has values '1' and '0.0' respectively.
- Plot Description:** A text field containing 'PRESSURE'.
- Ordinate Scale:** Text fields for 'Y Min' and 'Y Max', both containing 'auto'.
- Buttons:** 'OK', 'Cancel', and 'Help'.

Single Cylinder Model

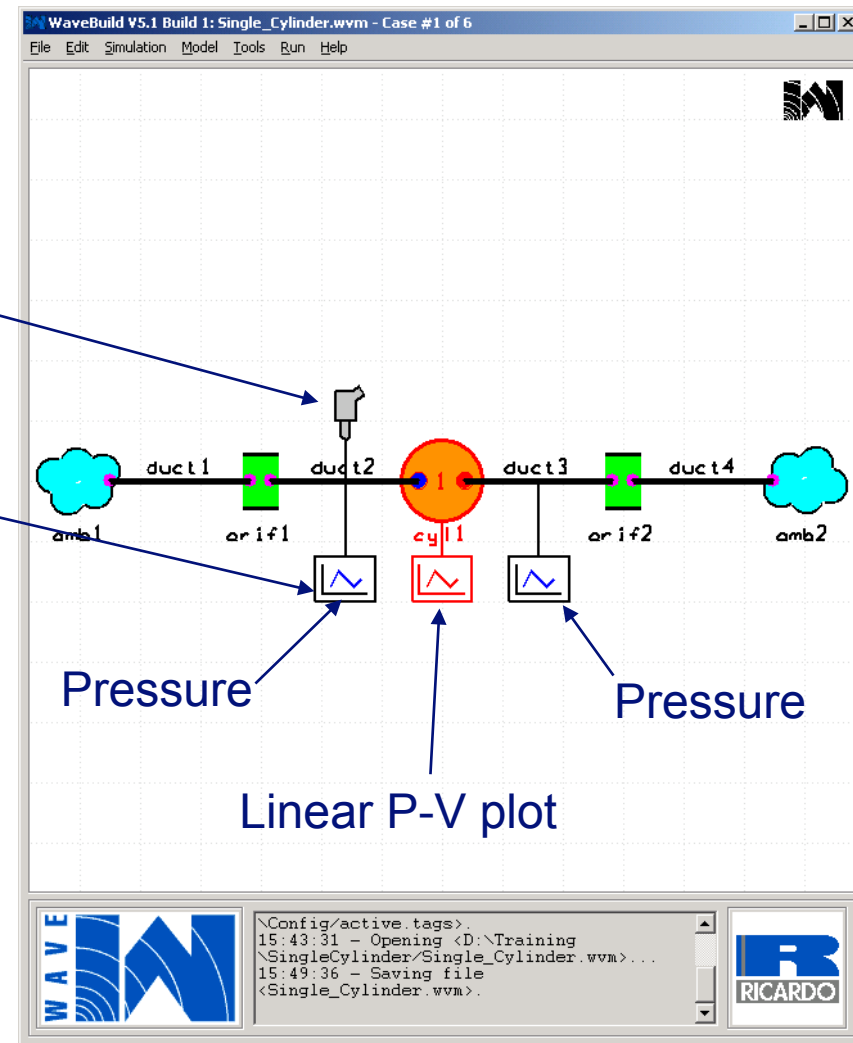
Injector Identifier

Plot Identifier

Pressure

Pressure

Linear P-V plot



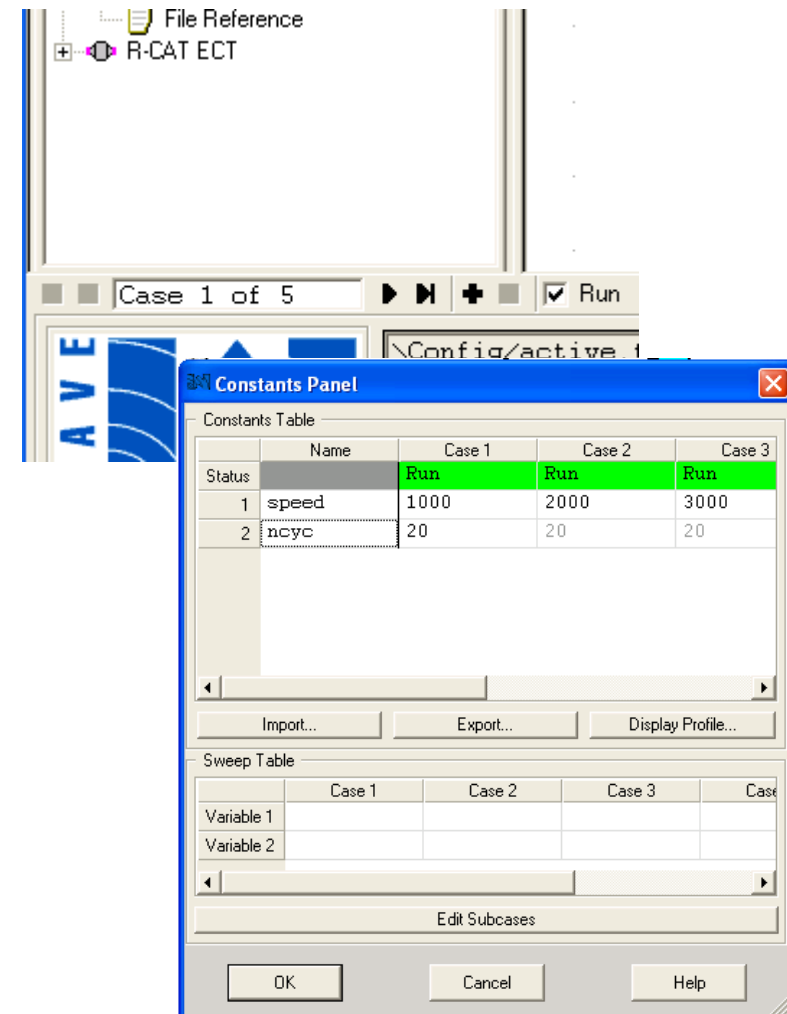
Adding Cases

At this stage the number of extra cases has not been defined, this is set in the bottom left of the screen.

To add a case simply click +

To modify the constants for each case select *simulation – constants – table*. An entry for each constant name should be added (i.e. speed, ncyc).

Add 5 cases – using the + button at the bottom left of the screen. Then set the speeds to 1000 – 5000 rpm for cases 1 – 5 respectively.



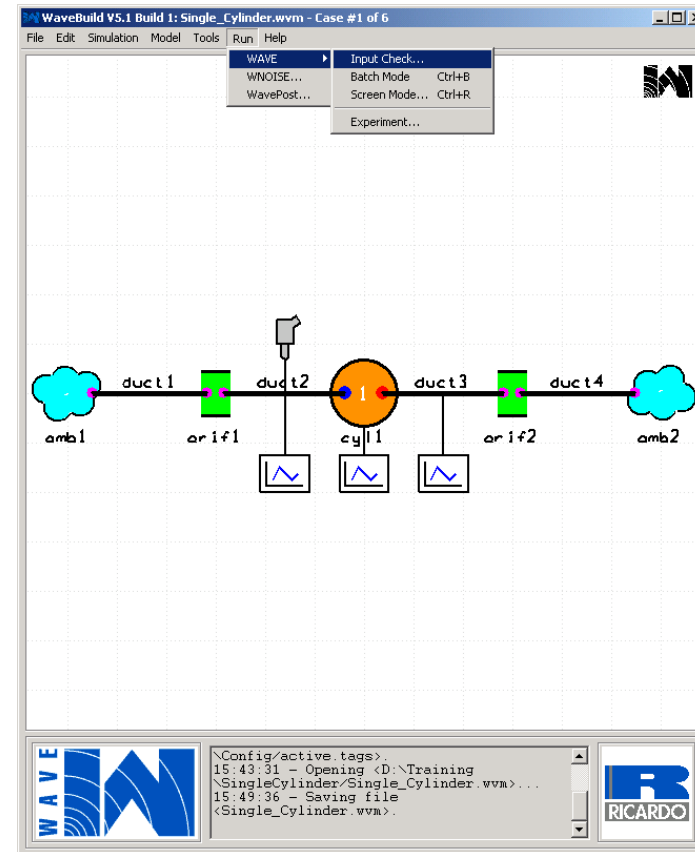
Running WAVE



Before WAVE can be started an input check should be completed - select *Run - WAVE - Input Check*

To actually run the WAVE model select *Run - WAVE - Screen Mode*

When either of the above are selected a DOS/UNIX screen will appear displaying the calculation status



WAVE v5

Simulation Solutions

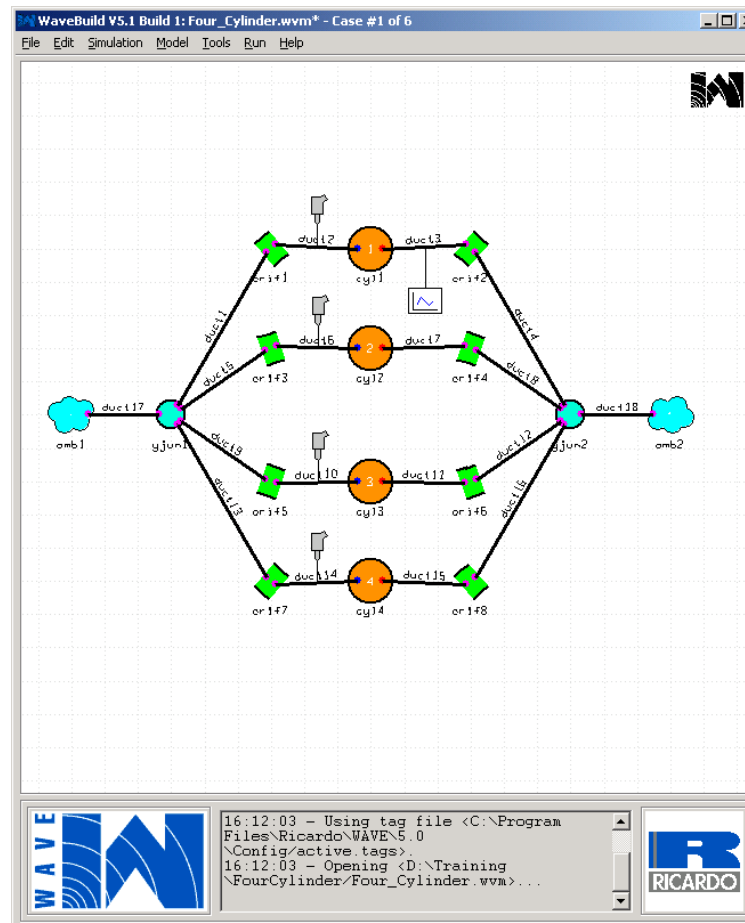


Four Cylinder Model Notes

Four Cylinder Model

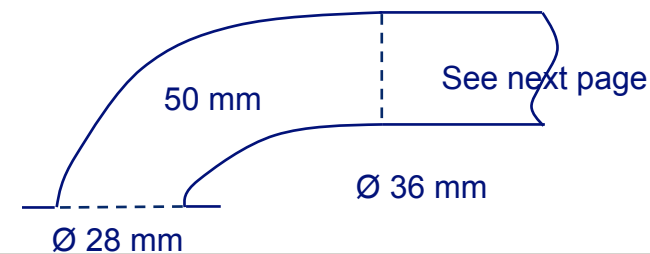
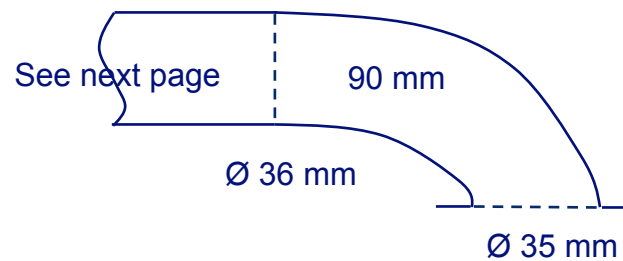


The purpose of this exercise is to transform the single cylinder model into an 8 valve four cylinder engine, similar to the one shown below



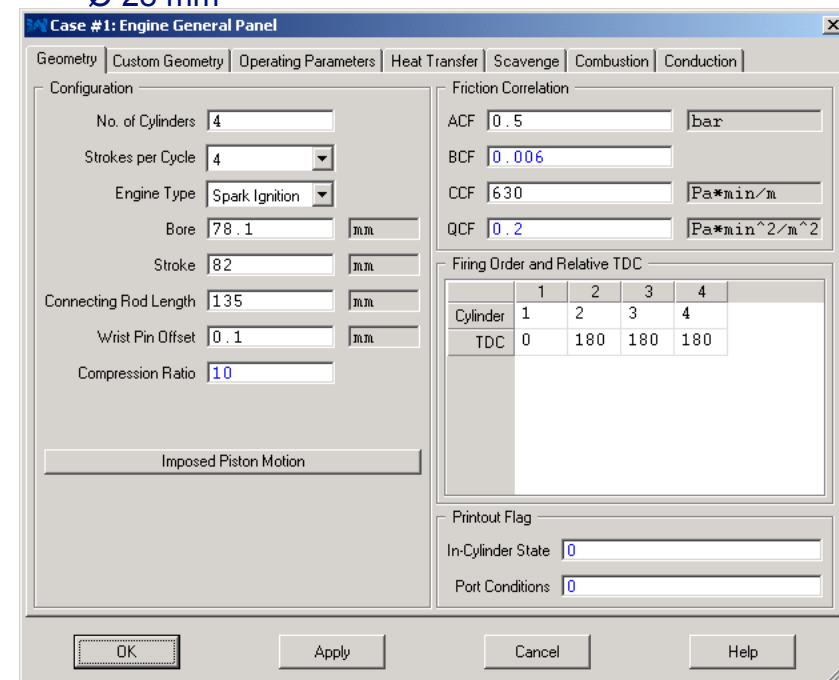
Geometry Modifications

Transform the single cylinder ducting into a single port and runner



Valve Diameters should also be changed to reflect the new ports

Modify the model - engine - geometry block (remember data is already in mm)



Case #1: Engine General Panel

Geometry | Custom Geometry | Operating Parameters | Heat Transfer | Scavenge | Combustion | Conduction

Configuration

No. of Cylinders: 4
 Strokes per Cycle: 4
 Engine Type: Spark Ignition
 Bore: 78.1 mm
 Stroke: 82 mm
 Connecting Rod Length: 135 mm
 Wrist Pin Offset: 0.1 mm
 Compression Ratio: 10

Friction Correlation

ACF: 0.5 bar
 BCF: 0.006
 CCF: 630 Pa*min/m
 QCF: 0.2 Pa*min²/m²

Firing Order and Relative TDC

	1	2	3	4
Cylinder	1	2	3	4
TDC	0	180	180	180

Printout Flag

In-Cylinder State: 0
 Port Conditions: 0

Buttons: OK, Apply, Cancel, Help

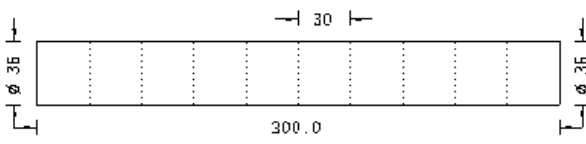
Intake and Exhaust Runners

Intake runner

Case #1: Duct Panel

ID: duct1 Connectivity: Left ID: yjun1 Right ID: orif1 Comments: Edit

Schematic



Duct Data Attachments Structure Initial Fluid Composition

Dimensions Coefficients Initial Conditions Body Forces

Diameters

Left: 36 mm Right: 36 mm

Lengths

Discretization: 30.0 mm Overall: 300.0 mm

Count: 1 Bend Angle: 0.0 deg

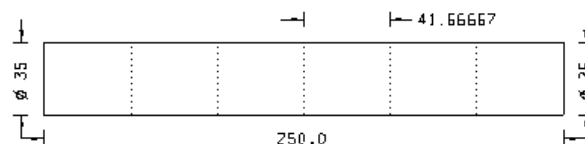
OK Apply Cancel Help

Exhaust runner

Case #1: Duct Panel

ID: duct4 Connectivity: Left ID: orif2 Right ID: yjun2 Comments: Edit

Schematic



Duct Data Attachments Structure Initial Fluid Composition

Dimensions Coefficients Initial Conditions Body Forces

Diameters

Left: 35 mm Right: 35 mm

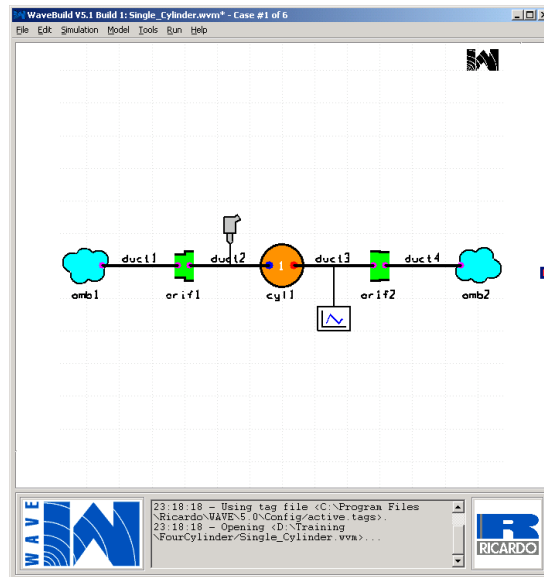
Lengths

Discretization: 40.0 mm Overall: 250.0 mm

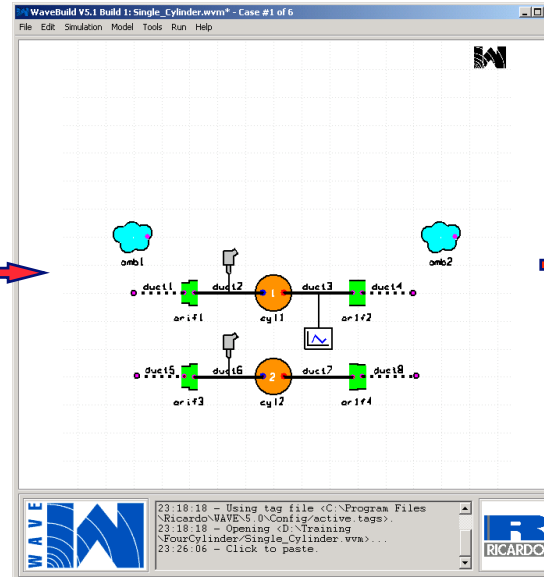
Count: 1 Bend Angle: 0.0 deg

OK Apply Cancel Help

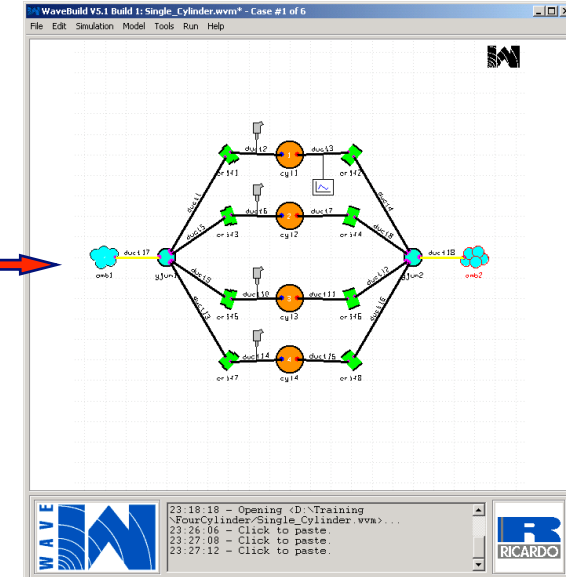
Creating Four Cylinders



Separate the ambients
(Use Middle Mouse
Button to do this)



Highlight the model, copy
and paste the geometry to
create four cylinders



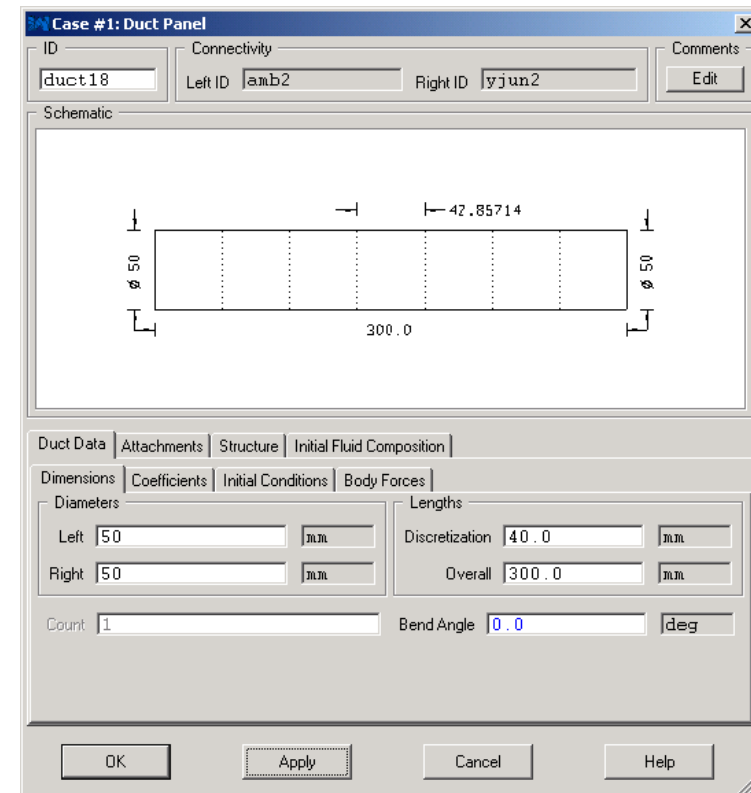
Add two Y junctions
Connect the ducts to
them

Finally connect the
ambients to the Y
junctions using a single
duct

Inlet and Exhaust Pipes



The ducts connecting both the inlet and exhaust manifolds to the ambient junction should be made from the geometry shown



Intake Y-Junction

Case #1: Simple Y-junction Panel

ID:

Simple Y-junction | Initial Fluid Composition | Structure | Absorptive

Diameter: mm

Wall Friction Multiplier:

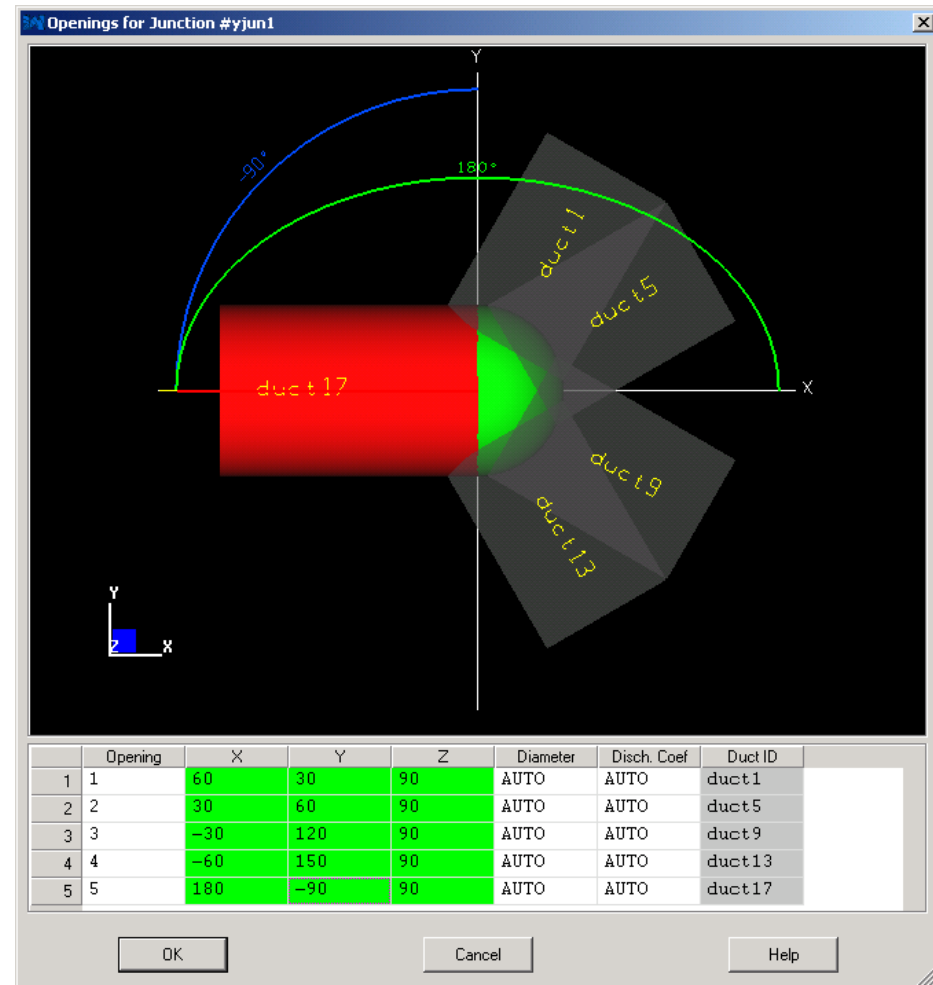
Heat Transfer Multiplier:

Initial Pressure: bar

Initial Fluid Temperature: K

Wall Temperature: K

To rotate the image use **shift**
and **middle mouse button**



Exhaust Y-Junction

Case #1: Simple Y-junction Panel

ID:

Simple Y-junction | Initial Fluid Composition | Structure | Absorptive

Diameter: mm

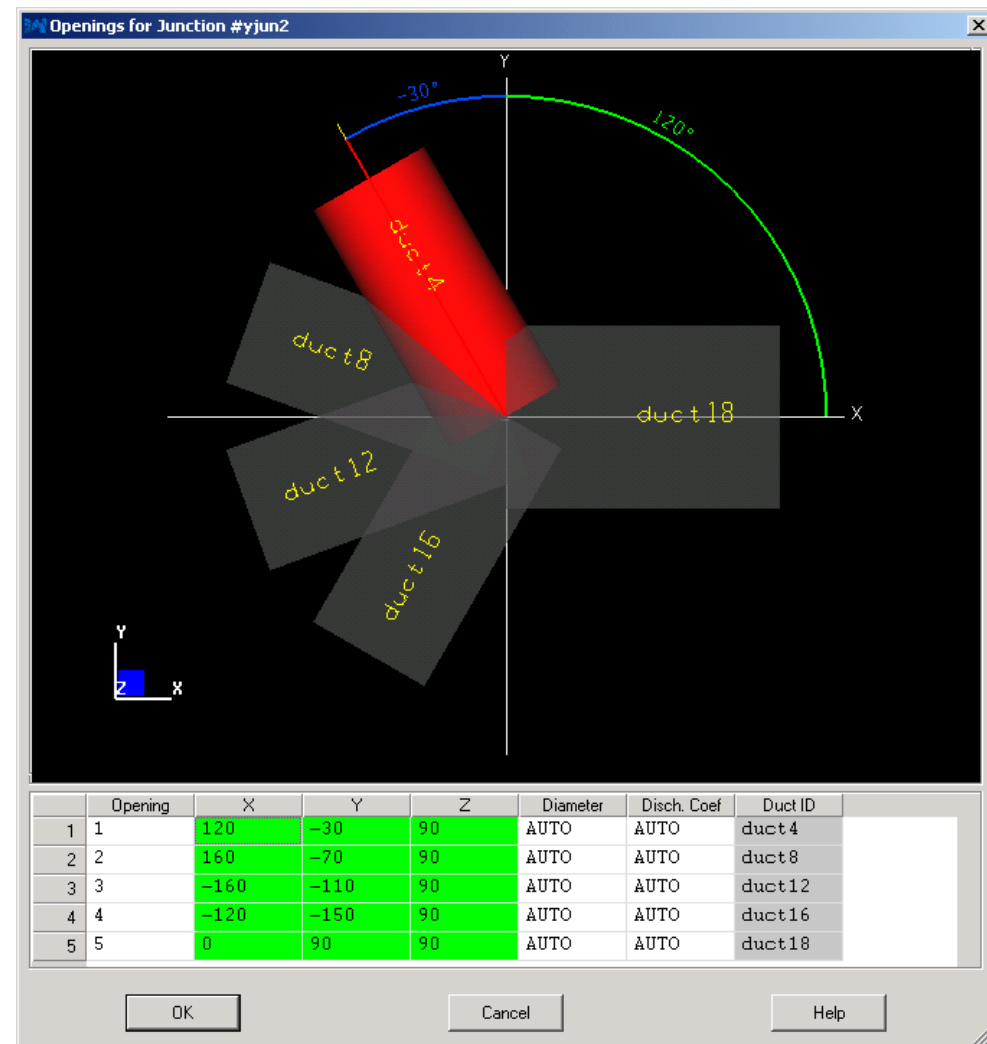
Wall Friction Multiplier:

Heat Transfer Multiplier:

Initial Pressure: bar

Initial Fluid Temperature: K

Wall Temperature: K



Adding Case Data



Constants Panel													
Constants Table													
	Name	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11	Case 12
1	NCYC	12	10	10	8	8	8	8	10	10	10	10	10
2	SPEED	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500
3	pamb	1.013	1.013	1.013	1.013	1.013	1.013	1.013	1.013	1.013	1.013	1.013	1.013
4	tamb	298	298	298	298	298	298	298	298	298	298	298	298
5	thb50	9	9	9	9	9	9	8.5	8.5	8.5	8	8	8
6	bdur	28	28	29	29.5	31	31	31	32	32	32	31	31
7	tpis	500	520	530	540	550	570	580	585	585	590	595	595
8	thead	550	570	580	585	595	610	620	625	625	630	635	635
9	tcyl	540	560	570	575	580	590	595	600	600	610	615	615
10	thrt	48	48	48	48	48	48	48	48	48	48	48	48
11	fard	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Display Profile													

This model will be run at more than one engine speed. Because several of the input parameters will change with engine speed constant names must be used and referenced in the *constants panel*

Constants will need to be added to the following blocks:-

Operating parameters

Heat transfer

Combustion

Duct injection panel

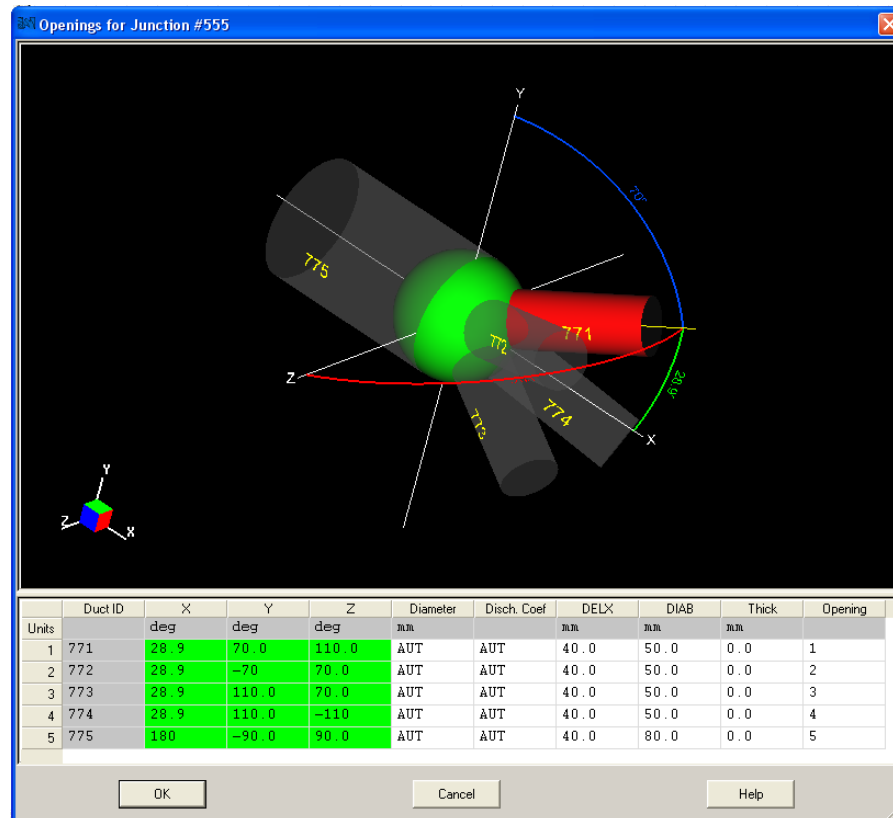
WAVE v5

Simulation Solutions



Intake and Exhaust Geometry Modifications

Complex Y-Junctions



For greater accuracy, all **Simple Y-Junctions** should now be replaced with the **Complex Y-Junctions**

This allows you more control over what happens within the junction, using the values **DELX** and **DIAB**

DELX is the distance to the opposite side of the junction (usually the junction diameter)

DIAB is the effective diameter of the volume that the gas can expand into.

More Information on DIAB



For a junction like an exhaust collector or a port in a cylinder head, the value of **DIAB** would normally equal the junction diameter.

For a junction connected to something like an air filter, this would not be the case. The gas flowing through each hole would not be free to expand into the whole volume, because it would interfere with the gas flowing from the hole next to it.

In a case such as this, the value of **DIAB** will be much less.

It will be equal to the diameter of the small hole in the filter **plus** the distance to the next hole along. This is due to the fact that the gas can expand half way to the next hole in both directions before it interferes with the gas flowing from another hole.

Intake Manifold System

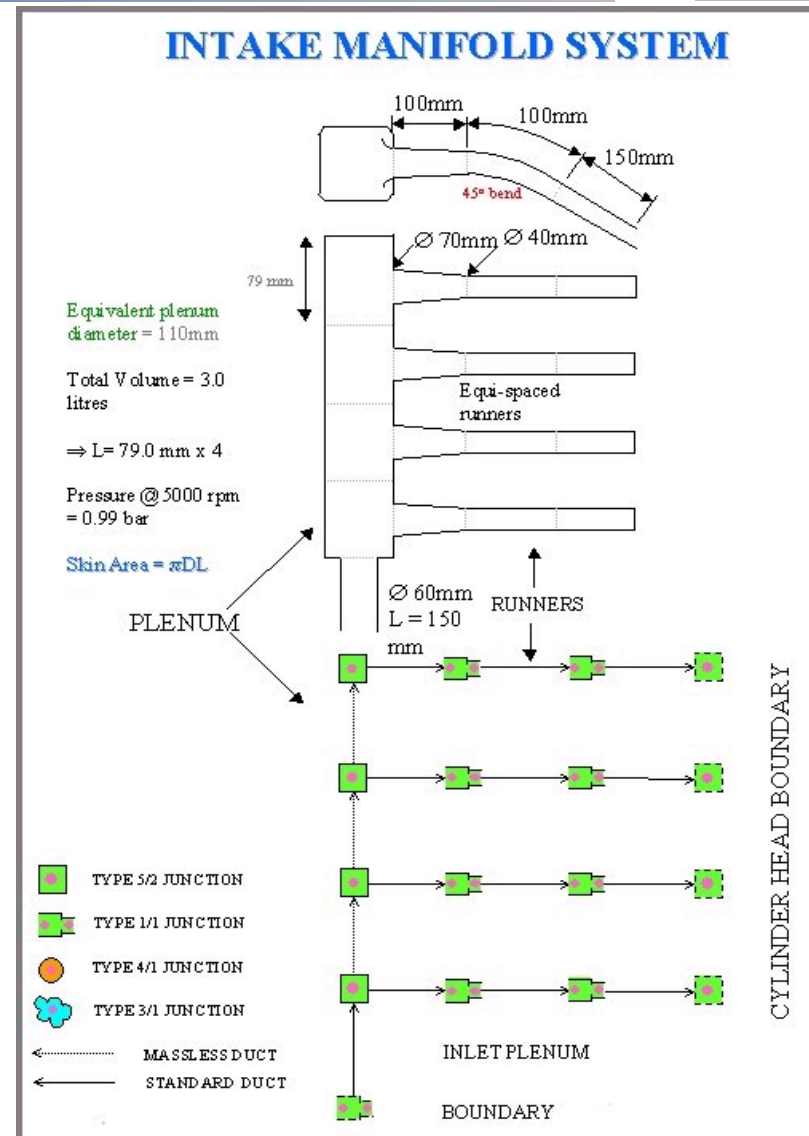
The plenum volume is divided into 4 volumes (complex y-junctions).

Its effective diameter is 110mm

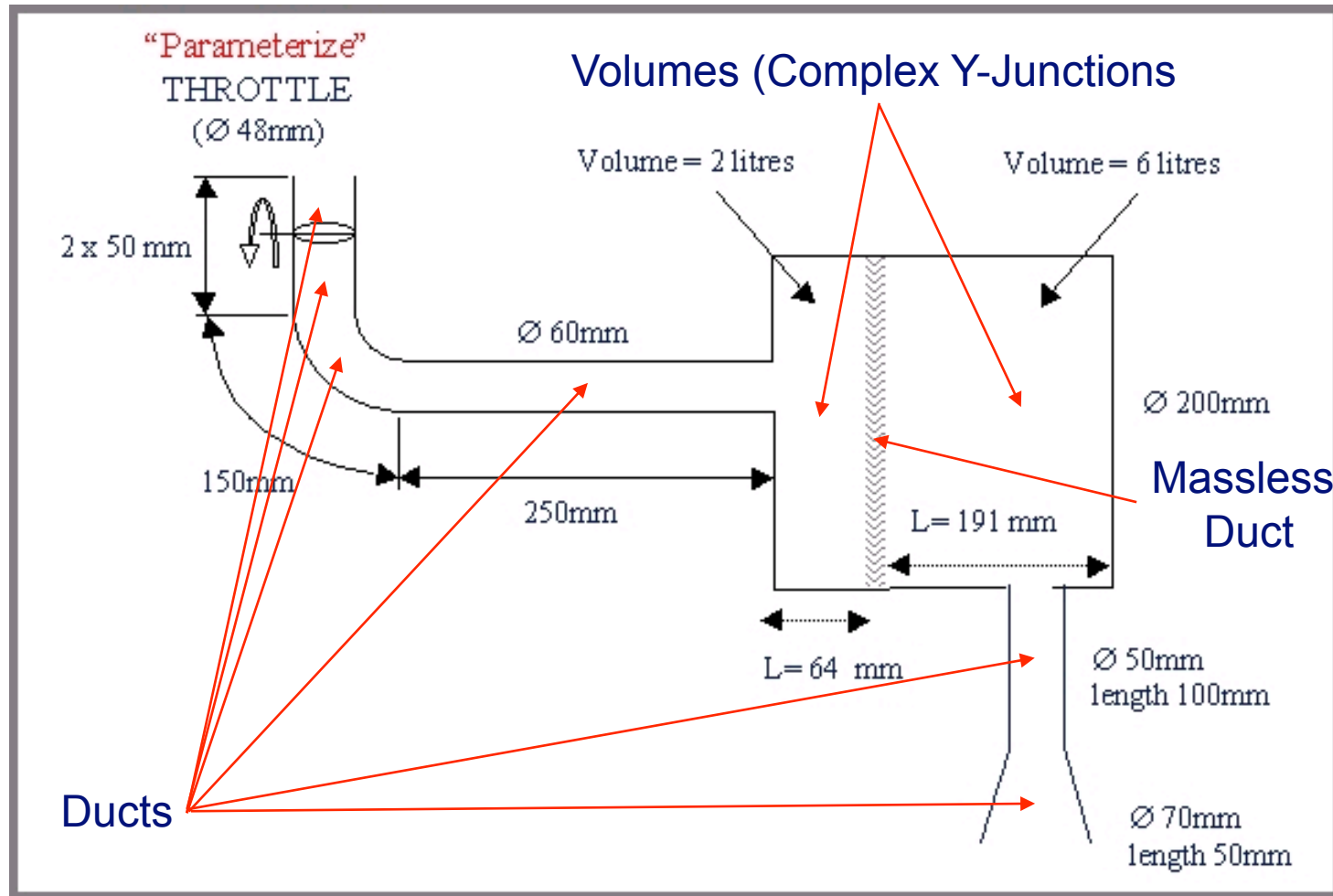
Total Volume = 3 litres

Length of each volume is equal to 79mm (this will be the value of **DELX** in the edit openings panel of the volume (complex y-junction)).

The volumes are connected by *Zero Length* Ducts (usually called **Massless** Ducts)



Air Filter and Throttle



Air Filter Duct



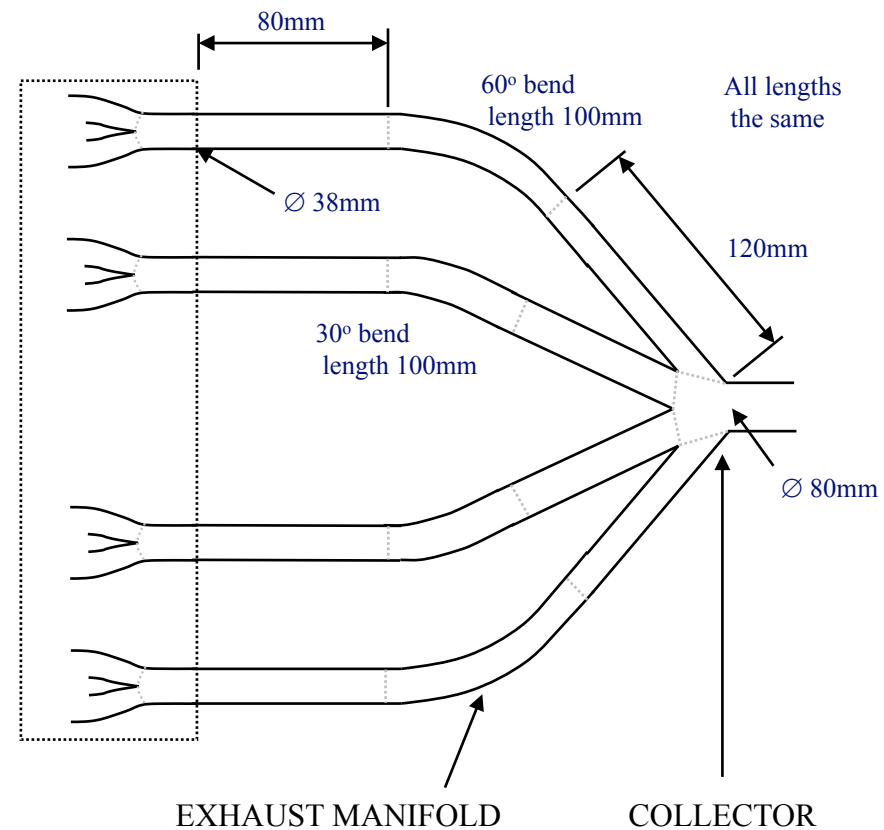
The Air filter can be thought of as a thin plate which has a large number of very small holes in it. This can be represented by a **Massless Duct** (A duct with Zero Length), which is connecting the two volumes together.
The two volumes represent the top and bottom of the airbox.

The diameter of the holes in the filter are very small ~ 1.5mm and there are a lot of them ~ 7500.

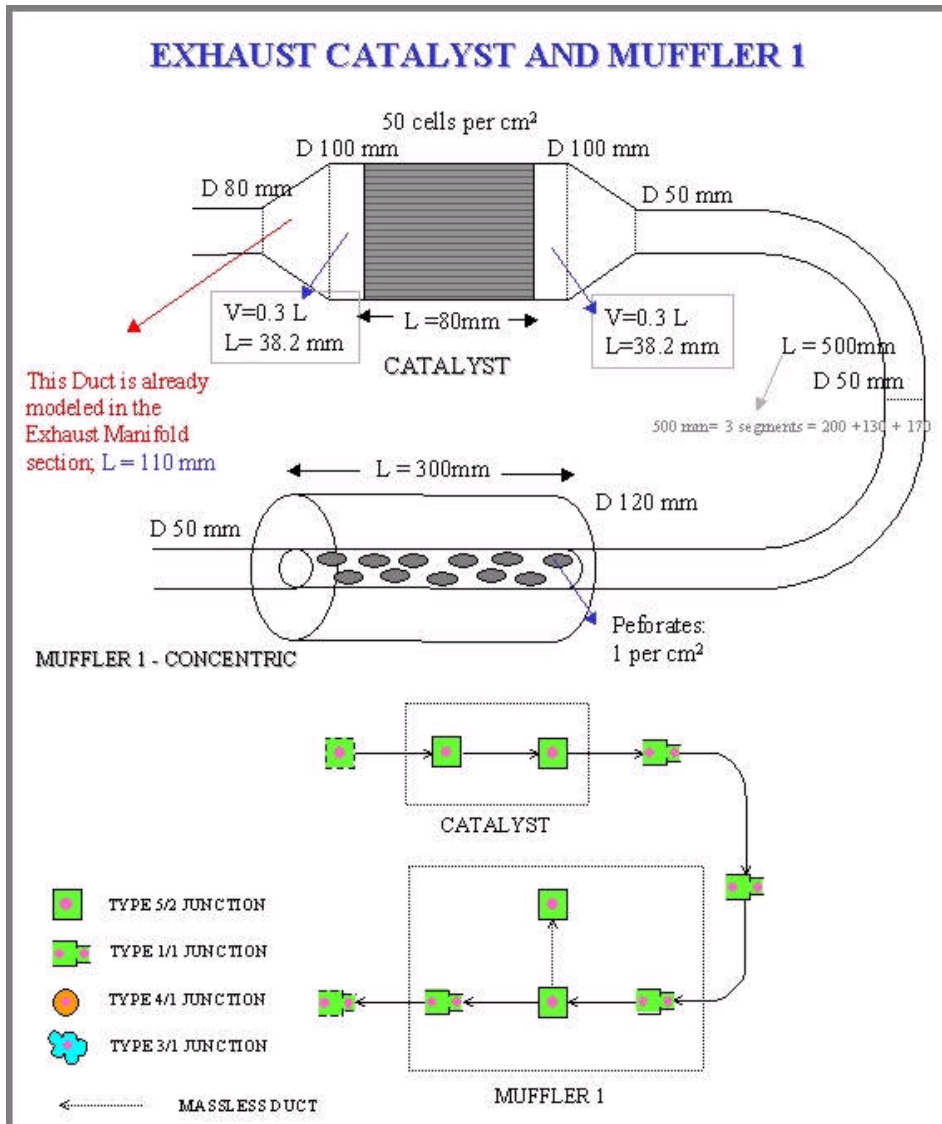
So the diameter of the duct should be 1.5mm on both sides and the **Count** should be 7500

The duct should appear grey on the model schematic

Exhaust Manifold System



Catalyst and Silencer



The Exhaust Catalyst, in a similar way to the air filter, can be modelled as two volumes connected by a duct with a high **Count**. This time however it is not *Massless*.

The silencer can be modelled as 2 volumes connected by a *Massless* duct with multiple **Count**, representing the perforations in the exhaust tube.

Ideally you should split the exhaust into a number of sections, like you did for the plenum. This will allow for more accuracy in the model.

WAVE v5

Simulation Solutions



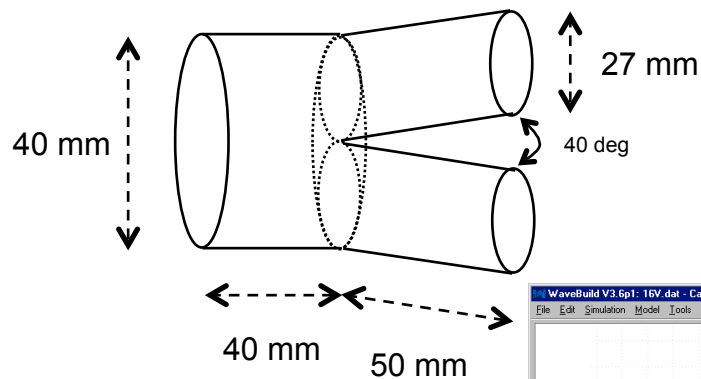
16 Valve Four Cylinder Model

Intake and Exhaust Ports

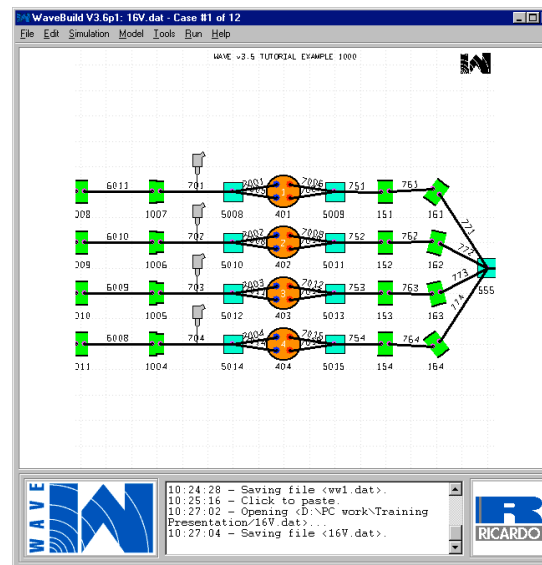
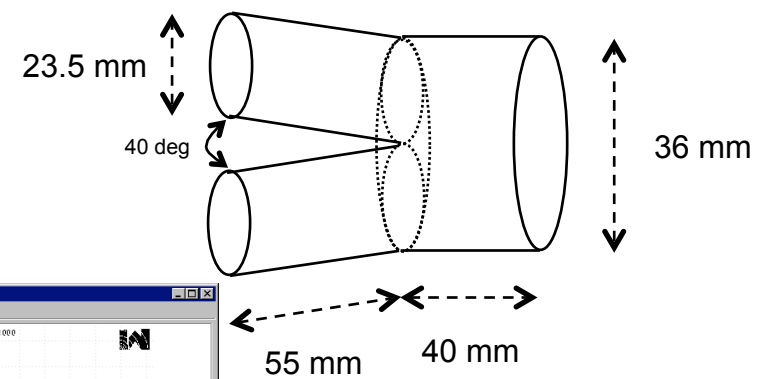


Valve Diameters

28mm
Intake Port



23.5mm
Exhaust Port



Intake Complex Y-Junction

Case #1: Complex YJunction Panel

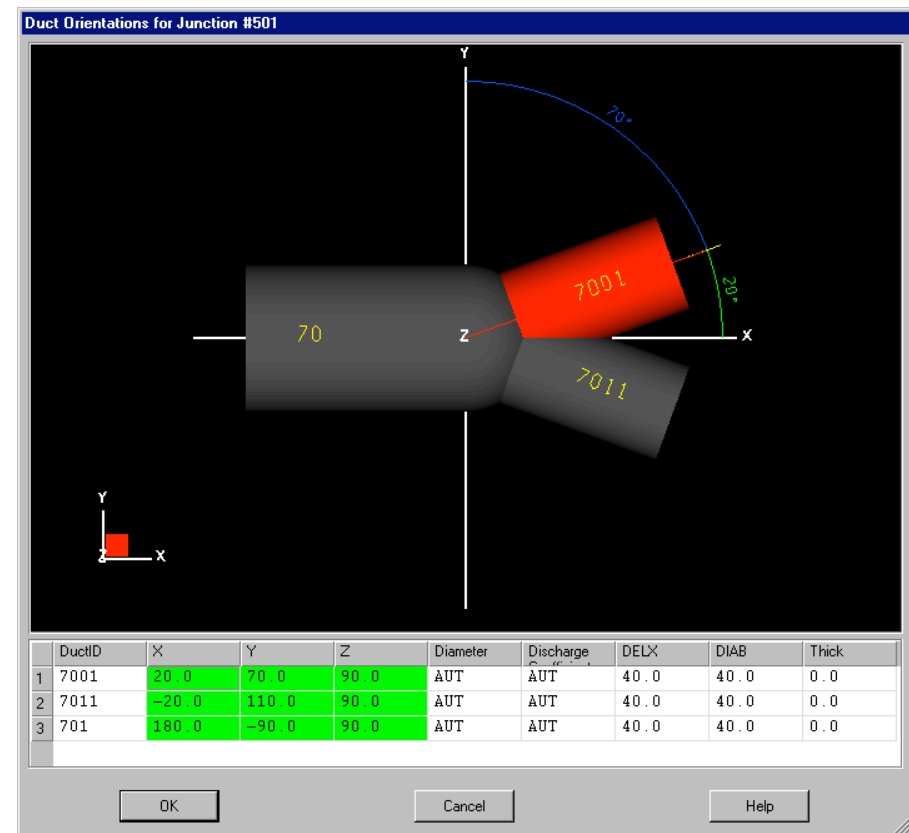
ID Number
501

Complex YJunction | Initial Fluid Composition | Structure | Absorptive

Diameter 40.0 Initial Pressure 1.0
Volume 50617.0 Initial Fluid Temperature 320.0
Wall Friction Multiplier 1.0 Wall Temperature 370.0
Heat Transfer Multiplier 1.0 Edit Duct Orientation
Heat Transfer/Skin Friction Area 5055.0

OK Apply Cancel Help

Ensure that you get the orientation of the ducts correct for all the intake and exhaust junctions in your model.



Example Exercises



When the model is completed, input check, and run the model in screen mode (It should be run with the same cases used for the 8 valve engine)

When the model has finished running try altering the following:-

Intake runner length

Valve timing and lift

Compression ratio

Spark timing (thb50)

Back Pressure (adjust friction levels in catalyst)