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Modeling and control of wastegate equipped turbocharged engines

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BY

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Bachelor of Science in Mechanical Engineering
The University of New Mexico, 2007

THESIS

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ABSTRACT OF THESIS

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A method of modeling, simulating (transient), and designing controllers for turbocharged engine systems is presented. The method is specific to spark ignition (SI) engines equipped with pneumatic, spring diaphragm, wastegate actuators, with solenoid valve active boost control. The method revolves around the joint simulation of the engine with Ricardo WAVE software and the control algorithm with Simulink®. A component by component modeling approach is outlined using WAVE, including an experimental approach for modeling the solenoid valve. Controls are designed in MATLAB® using the Zeigler-Nichols's PID tuning method, and a new approach that uses system identification and state-space techniques. Simulink® is then used to produce a transient simulation of the turbocharged engine system.

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1 INTRODUCTION

The concept of using a piston driven, four-stroke, internal combustion, engine to power a motor vehicle has been in practice since the turn of the 20th century and in this most basic description is still the paradigm for engine layout in modern automobiles. Though the basic components (one or more pistons, an engine cylinder block, a crank shaft, a valve train, an ignition system, and an induction system) have remained the same; continuous refinements have made modern engines more powerful per unit of displacement, more economical, and more reliable. These refinements include improved materials, improved tolerances, valve train sophistication, fuel injection, forced induction and electronic control. Innovations like these have allowed modern engines to become much smaller, but maintain power requirements by achieving higher specific outputs. Reduction in displacement results in a smaller and lighter engine, helping to provide better fuel economy.

The amount of power that an engine can develop is directly related to the rate of air that the engine can induct into the cylinders. For a given engine, more air can be inducted into the cylinders by incorporating forced induction. Forced induction is achieved by installing a compressor that forces air into the engine's intake manifold. This pressurized air is known as boost. Boost pressure is measured as gauge pressure (relative to atmosphere); zero boost is equal to atmospheric pressure, and positive boost is higher than atmospheric. The

general term for this kind of device is a supercharger. The device can be driven by any power source, but typically from the engine's crank shaft, an electric motor, or a turbine that is driven by the engine's exhausts gasses. When driven by a turbine the device is known as a turbocharger.

1.1 The Turbocharger

A turbocharger is a device in which a turbine and a compressor are fixed to a common shaft of rotation as shown below in Figure 1-1.

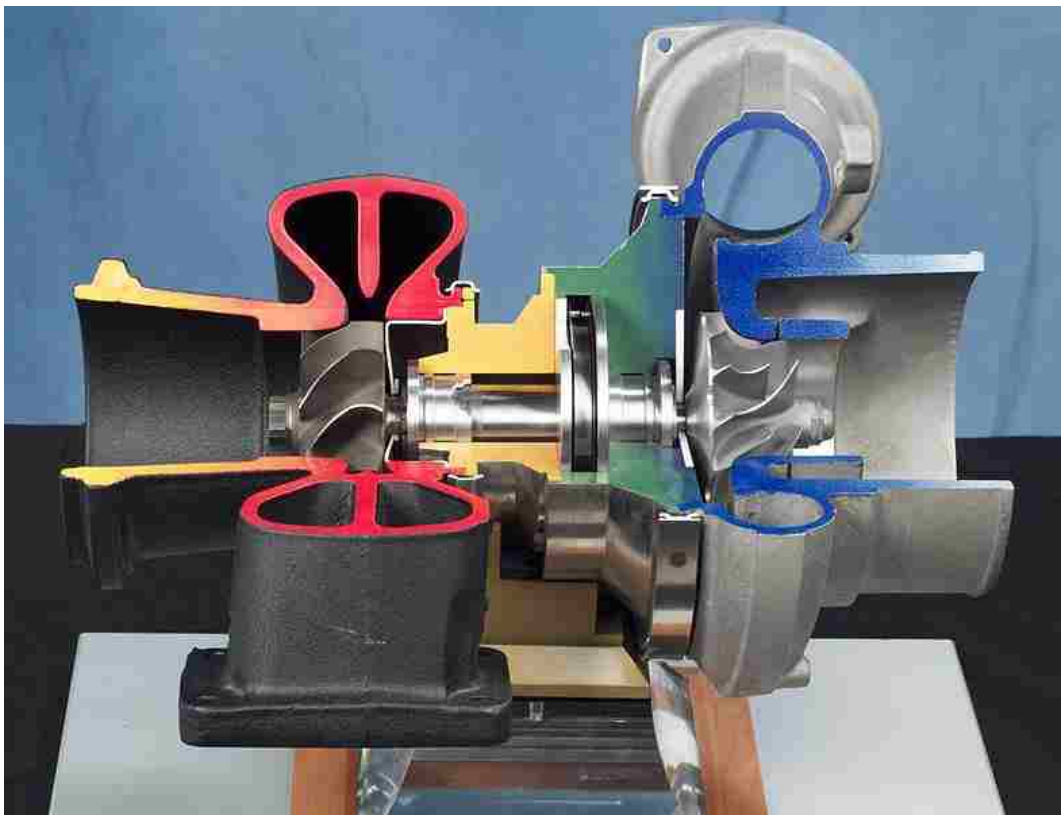


Figure 1-1 Cutaway View of a Turbocharger[1]

[1] source: http://commons.wikimedia.org/wiki/Main_Page

In Figure 1-1, the red section is the turbine housing and the blue section is the compressor housing. The compressor and turbine wheels are located in their respective housings. A bearing is located in the center housing. Because of the coupling of the compressor and the turbine, the outlet pressure of the compressor is dependent on the gas flow through the turbine.

1.2 The Turbocharged Engine

The general installation of a turbocharger into an engine system involves routing the flow of gas in the following sequence: ambient air, air filter, turbine inlet port, compressor wheel, turbine outlet port, intercooler (if equipped), intake manifold, engine intake port, engine cylinder, compression, combustion, engine exhaust port, exhaust manifold, turbine inlet port, turbine wheel, turbine outlet port, and exhaust system to ambient. This sequence is illustrated below in Figure 1-2.

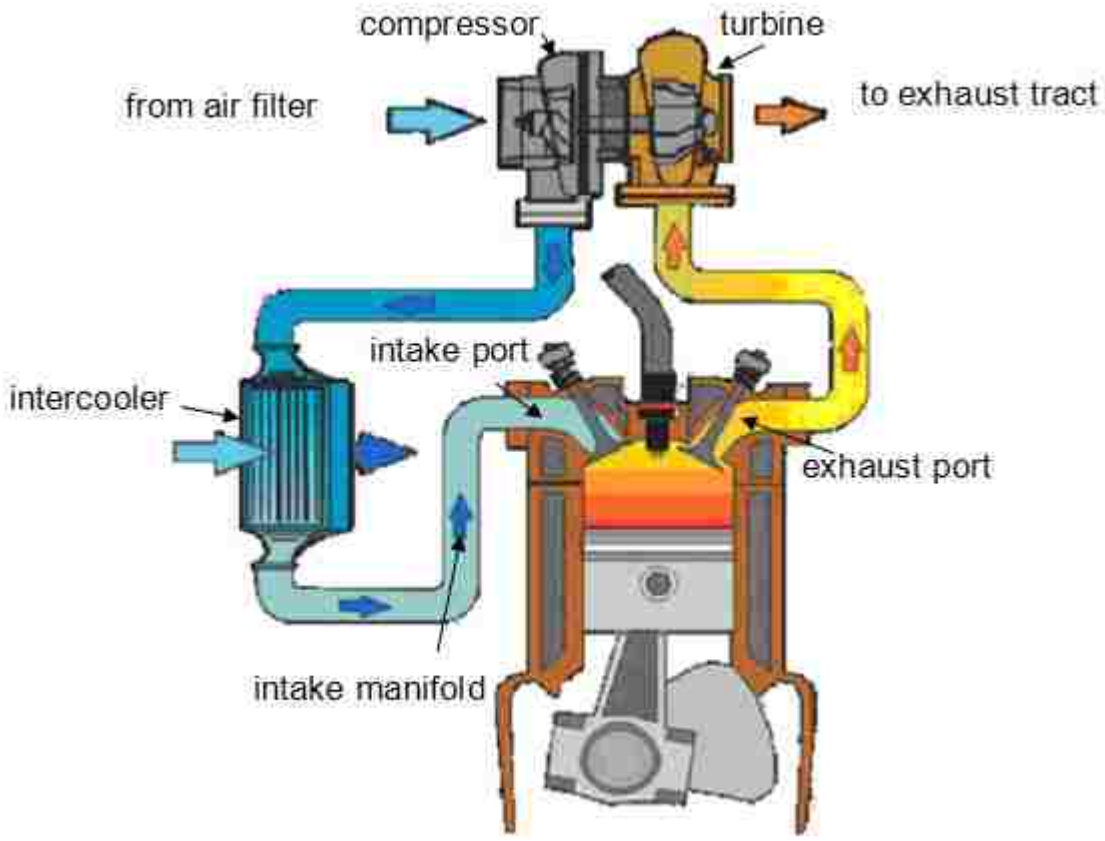


Figure 1-2 General Flow of Gas through a Turbocharged Engine System

If all the exhaust gas passes through the turbine, the turbine will continue to accelerate as the engine draws and passes more gas; as a result the compressor will continue to force more pressurized air into the intake manifold. The compressor will eventually feed more air to the intake than the engine can induct causing intake pressure to increase. For a given engine and fuel, there will be a threshold in cylinder pressure and temperature where the combustion process will transition from a smooth burn to a violent explosion. This process is

know as knock, and can damage an engine.[1] To prevent knock from occurring, boost must be controlled, and kept below an acceptable threshold.

1.3 Boost Control

There are a number of ways to limit boost pressure, but the use of a wastegate has been the most accepted. Bell discuses other boost control methods and explains why they are not advantageous.[2] A wastegate is a valve that when opened allows exhaust gasses to bypass the turbine and feedback into the exhaust system downstream of the turbine, as shown below in Figure 1-3.

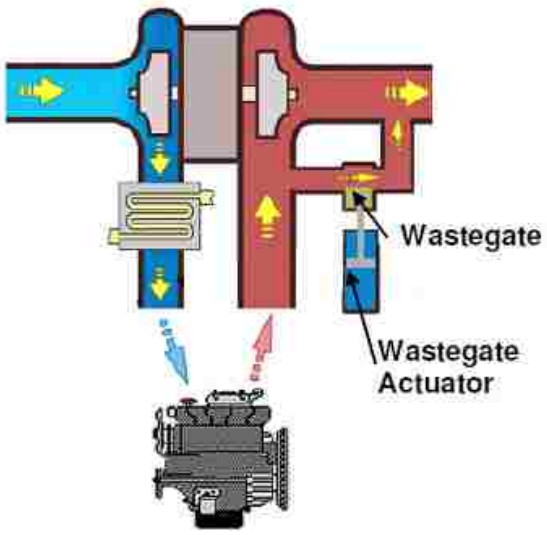


Figure 1-3 Wastegate Equipped Turbocharged Engine System

With less exhaust gas flowing through the turbine, it will cease to accelerate, and because of the direct coupling so will the compressor, thereby keeping the boost

pressure in check. A desired boost pressure can be realized by properly modulating the wastegate.

1.4 Wastegate Actuation

Opening and closing of the wastegate requires an actuator and actuation source. As a turbo engine system is throttled, the system produces increasing boost pressure, so it is a natural choice to use the boost pressure as an actuation source. Boost pressure feedback can be achieved by routing the boost pressure from the compressor outlet through high pressure tubing to a pneumatic, spring-diaphragm type actuator, as shown below in Figure 1-6.

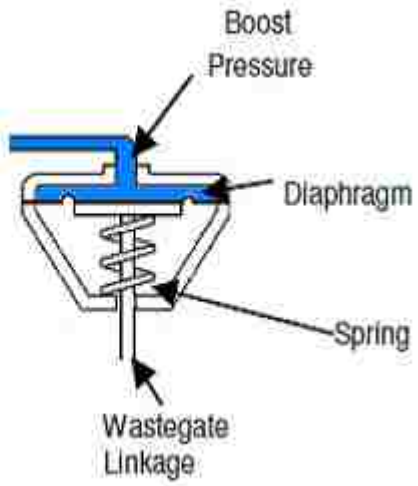


Figure 1-4 Pneumatic, Spring-Diaphragm, Wastegate Actuator

The actuator is connected mechanically to the wastegate linkage. As boost pressure supplied to the actuator rises, the wastegate opens. The advantage of

this method is that, given a spring that will allow the wastegate to open fully at a desired boost level, there will be an inherent stability, because the spring will operate in its linear range and immediately began to open at the onset of any positive boost pressure. The disadvantage is that the transient response to achieve a desired boost will be slow for the same reason. Slow transient boost response results in less power at an engine's low RPM range, when compared to faster transient boost response. For a given pneumatic spring-diaphragm actuator, steady-state boost may be set by adjusting the preload in the spring (most variations of these devices allow for such adjustments). Alternatively the entire pneumatic spring-diaphragm actuator may be replaced with a unit with a different spring constant. A stiffer spring will increase the steady-state boost, for constant diaphragm area. For this passive type of control there is no further means to tune the transient response, and improve low end power.

1.5 Manipulation of the Pressure Signal

Passive feedback control, as described in 1.4, can be improved by installing active hardware within the feedback loop. Wakeman and Wright proposed adding a solenoid control valve between the boost pressure source and the pneumatic spring-diaphragm actuator. [4] This arrangement is illustrated below in Figure 1-5.

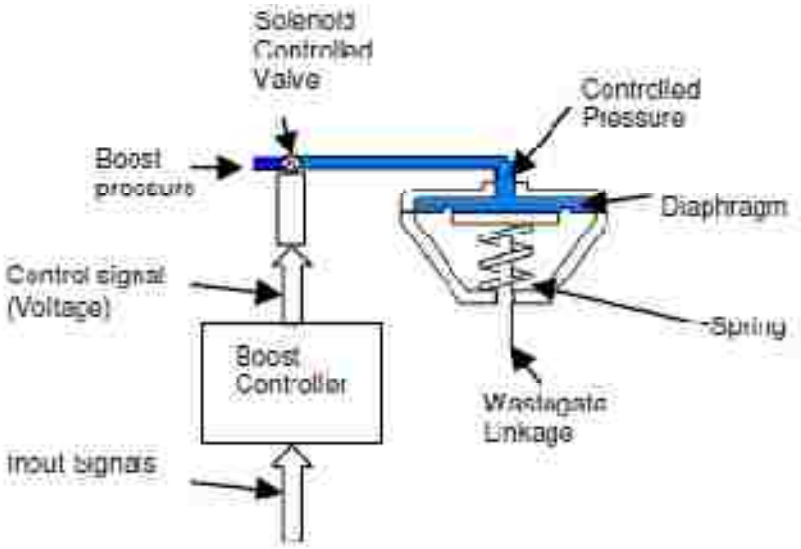


Figure 1-5 Active Boost Control Scheme

This solenoid valve is typically a three port valve as shown below in Figure 1-6.

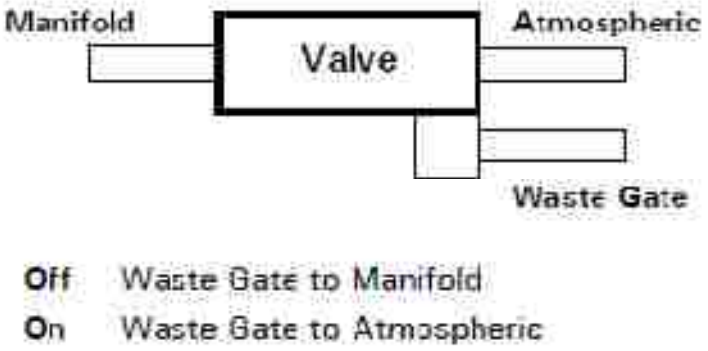


Figure 1-6 Boost Control, Solenoid Valve

As illustrated in Figure 1-6, the solenoid valve can supply the boost pressure or atmospheric pressure to the wastegate actuator. This valve directs all boost

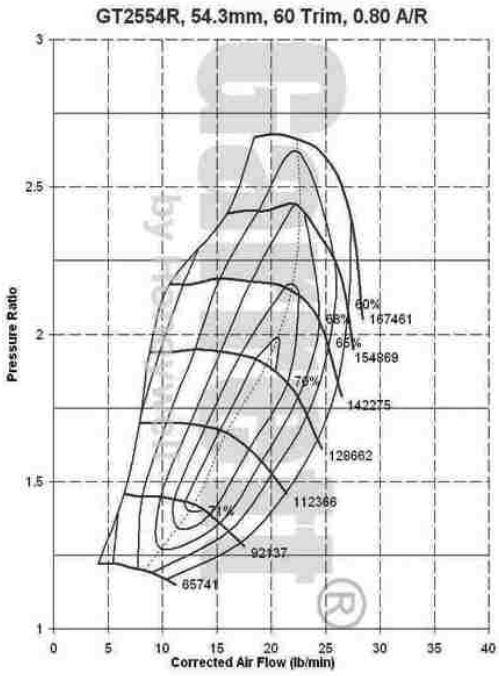
pressure to the pneumatic, spring-diagram actuator when not powered, so that in the event that the valve was not powered, all pressure would be passed to the pneumatic, spring-diaphragm, actuator, and the wastegate opens. The system would then revert to the passive system described in 1.4. When powered, the valve supplies atmospheric pressure to the wastegate actuator; this would not allow the wastage to even slightly open, even under high boost. It is apparent that inserting this hardware into the loop can allow better transient response, if controlled properly. It is also apparent that since the wastage can be kept closed under high boost pressure that inherent stability that was intrinsic to the passive system can be lost, so great caution should be taken. Lastly, because the solenoid valve requires a power supply, there is a need to develop a control algorithm that regulates the power to the valve to achieve the performance requirements.

2 REVIEW, PROBLEM, AND APPROACH

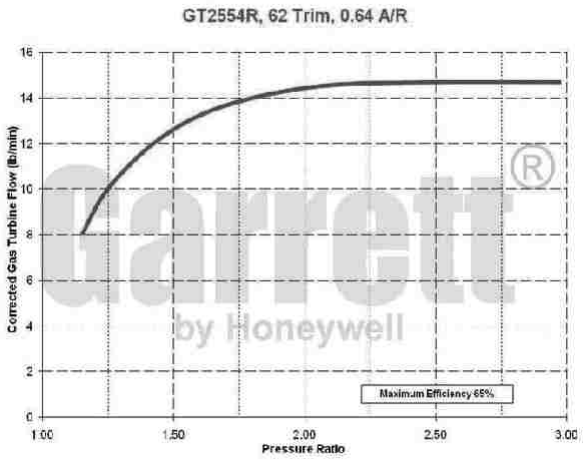
2.1 Previous Work

2.1.1 Turbo Engine Modeling and Simulation

Neil Watson's 1984 SAE Paper [6] demonstrates a thorough methodology for conducting transient simulation of an entire turbocharged engine system. Watson used thermodynamic variable control volumes for each cylinder with a Wiebe combustion model. The intake and exhaust manifolds are modeled as a network of 1-dimensional fixed control volumes, and valves and throttles are modeled as variable area orifices. The turbocharger is modeled with its performance maps; these maps are typically produced by the turbocharger manufacturer, one for the turbine and one for the compressor. The performance maps contain a 4 dimensional data set: rotational speed, pressure ratio, mass flow rate of gas, and efficiency. An example of turbocharger performance maps is illustrated below in Figure 2-1



(A)



(B)

Figure 2-1 Examples of (A) Compressor and (B) Turbine Performance Maps[2]

[2] source: Honeywell

The turbo is coupled to the manifold network as boundary conditions. Watson used passive feedback boost control utilizing a pneumatic, spring-diaphragm actuator as described in 1.4. This actuator is modeled as a 2nd order spring-mass-damper mechanical system, where the boost pressure is supplied as an input, establishing a feedback path. The position of the wastegate varies the effective area of an orifice in the in the exhaust manifold/pipe network, completing the coupling between the mechanical wastegate system and the control volume network as well as completing the feedback loop. Watson validated his simulation with test data form a real engine.

In their 2005 paper Lefebvre and Gulain use a commercial software package, GT Power, to model the transient response of turbocharged SI engine. GT Power is an industry standard, 1-Dimensional gas dynamics engine simulation code. GT Power is fundamentally similar to Watson's approach, but in an out of the box, ready to use, commercial package. The turbo was modeled again from performance MAP data. While the existence of the wastegate was mentioned in this paper, there was no detailed discussion on the boost control system. The primarily focus of this work was improving the GT Power model's transient response to better match test results by using calibrating the Wiebe combustion model and the heat transfer models. Ricardo WAVE is another commercial 1-Dimensional gas dynamics engine simulation code and direct competitor to GT Power. Both codes have proven to be very good at engine

modeling and are used throughout the automotive industry. Ricardo WAVE was the commercial engine simulation package used in this thesis.

2.1.2 Turbocharged Engine Boost Control

The first use of turbocharged engine boost control via a solenoid operated valve published in automotive engineering literature, occurs in 1981 in a paper by Rydqvist, et al. [8] The valve is controlled by a microprocessor, using a simple binary algorithm which "if the pressure is too low, the valve is opened, dumping the pressure in the line to the wastegate actuator….and if the pressure it too high, the solenoid valve is closed and the pressure from the charging pipe operates on the [pneumatic spring-diaphragm] actuator…"

The next leap in boost control algorithms for solenoid operated valves was presented in 1986, by Wakeman and Wright.[4] This paper made several advances, including supplying the solenoid operated valve intermediate amounts of power through pulse width modulation (PWM). PWM supplies full voltage to the solenoid for part of its duty cycle and no voltage the other part and oscillates at a set frequency; the duty cycle is expressed as a percentage of power on. The advantage of PWM over binary manipulation of the solenoid valve, is that intermediate pressures, between atmospheric and the boost pressure can be supplied to the pneumatic spring-diaphragm actuator, for more refined articulation of the wastegate. Another innovation that was published in this paper was the use of a, 3 mode, proportional-derivative-integral (PID) controller. The

set point or reference (desired) boost is described as a 3-dimensional surface that is a function of throttle position and engine speed. The PID will only tack the reference for large throttle openings. There is no indication on the turning methods to select the three PID gains. Interestingly, PID and PI boost controllers are currently found on almost all aftermarket boost control modules, and OEM applications.

In 1989, Rohde and Philipp [9] introduced knock control to the system proposed by Wakeman and Wright [4]. A knock sensor is added and instead of having static reference (desired) boost (also described as a 3-dimensional surface is a function of throttle position and engine speed), the reference can be altered in real-time by an algorithm that uses the knock sensor as an input. The knock control algorithm can not only manipulate the boost control reference input but can also manipulate the spark advance. The control system for the wastage is unchanged from Wakeman and Wright's aside from the closed loop reference input, to include the use of a PID controlled PWM signal to a solenoid valve that manipulates the boost pressure supplied to a pneumatic spring-diaphragm actuator that is connected to the wastegate.

In 2005 Collin et al. presented an approach using a real time predictive control algorithm based on a neutral network. [10] This method was effective in smoothing the transient boost response and helped tracking performance.

2.1.3 System Identification

System identification is the process of creating a model of a dynamic system from inputs and outputs. It is used as tool in this thesis in the form of MATLAB®'s System Identification Toolbox, a software package with ready to use system indentation tools. The software is largely based on the work of Ljung [14, 13], who was the principal developer of the software package.

2.2 Problem Statement

In 1.5 it was explained that adding a solenoid valve to a turbo engine system with a pneumatic, spring-diaphragm, actuated wastegate boost control scheme, that a need arose for the development of an algorithm to manipulate the power to the solenoid valve. A model of the turbo engine system is required, or else an expensive prototype would have to be built. While the data obtained from a prototype engine system will be of the same fidelity of the actual application, prototyping will add considerable time and budget to a project. Much of the prototyping can be circumvented by using high fidelity modeling to down select on early design options. For example, a systems engineer could use such a model to evaluate different turbo and control system on an engine, and gain a reasonable understanding of the effects on systems level performance of component options or control algorithms, without having to build a test-bed.

Modeling the system with modern Computer Aided Engineering (CAE) applications offers the advantage of shorter schedule and reduced budget in the systems engineering and control design aspects of the early stages of turbo

engine development. The focus of this thesis is the development of a method of modeling the systems described in the previous chapter and the design and co-simulation of control algorithms with the engine model to achieve specified performance objectives.

2.3 Approach

The approach to solution of the problem was to outline the method using an example of a hypothetical turbo engine system. The steps involved were to model each subsystem, connect the subsystems, demonstrate a transient simulation, explore boost control design using the model, and present results.

Though this thesis focuses on a specific engine system to demonstrate the methodology, the method is sufficiently general enough that many other turbocharged engines can be modeled using it.

3 SYSTEM MODELING

Engine system modeling is best done in a graded approach, ranging from hand calculations to high fidelity CAE models. The complexity of the engine system model should be commensurate with the goal of the application. In the case of this thesis the objective was to build a model that could capture the transient response of a proposed engine design and serve as a design tool for system engineering and boost control design; this meant that a high fidelity engine model was needed.

The core of the engine modeling was done using Ricardo WAVE software. Ricardo describes WAVE as "… the market-leading ISO approved, 1D engine & gas dynamics simulation software package.... It is used worldwide in industry sectors including passenger car, motorcycle, truck, locomotive, motor sport, marine and power generation. WAVE enables performance simulations to be carried out based on virtually any intake, combustion and exhaust system configuration, and includes a drivetrain model to allow complete vehicle simulation."

WAVE Build is the preprocessing program used for building a WAVE model; it was designed as a GUI interface, with a block diagram style approach. WAVE Build constructs the .wvm input file that is processed by WAVE (see Appendix 1). Elements that represent different components can be interconnected by ducts. Elements that represent the engine block, orifices,

injectors, junctions, valves, turbine, and compressor are available. Additionally, there are control elements that can route signals from one place in the model to other places within the model or between external interfaces. An example of the WAVE Build modeling canvas is shown below in Figure 3-1.

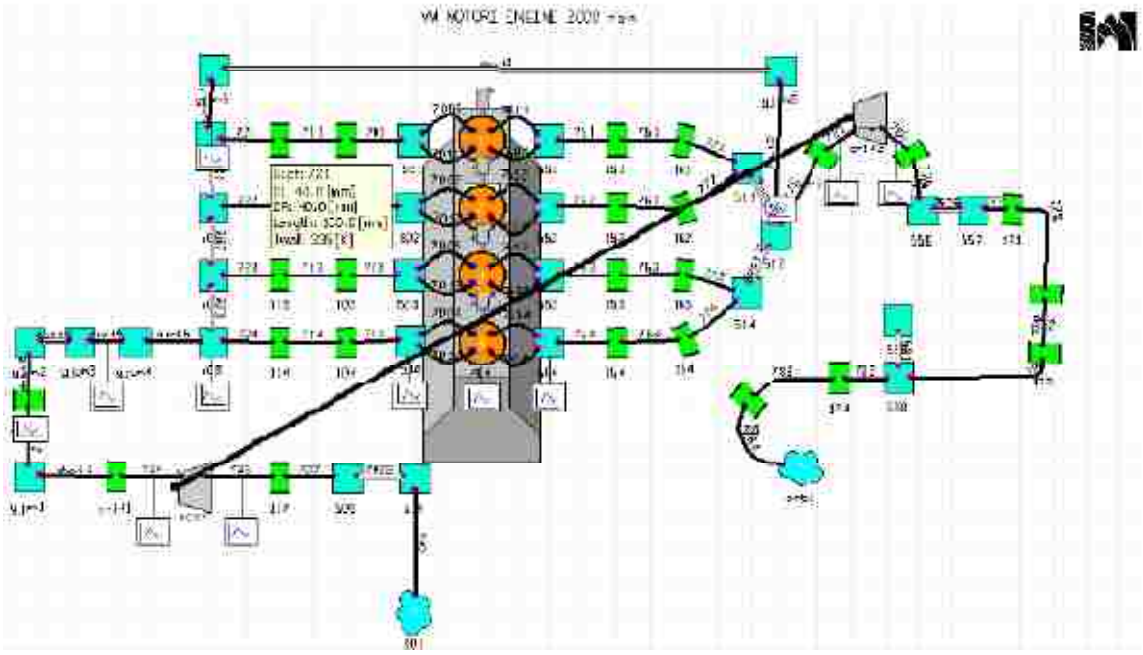


Figure 3-1 Example of WAVE Build Engine Model Canvas

3.1 Engine Block

Because often the rationale for using a turbocharger in an engine application is to get more power out of a smaller engine, it was decided to model a relatively small engine as the example. A 4 cylinder, 4 stroke, spark ignition (SI), engine was chosen. The main engine block parameters are shown below in Table 3-1.

# of Cylinders	4
Stokes per Cycle	4
Engine Type	Spark Ignition
Bore	81 mm
Stoke	86.4 mm
Compression Ratio	9.5:1

Table 3-1 Engine Block Parameters

WAVE default values were used for heat transfer and friction models; however these can be adjusted to suit any application, and should be if a database for a particular engine design is available. Lefebvre and Guilain [7] presented a calibration method for this heat transfer and friction parameters, again these are only applicable if legacy data or a prototype is available; the WAVE Build defaults provide the best alternative in the absence of a database or prototype.

The Wiebe combustion model is an empirical model that gives burn rate and mass fraction burned as a function to crank angle for a particular cylinder, as shown below in Figure 3-2. The Wiebe combustion model is the most common SI combustion model and has proven successful for both Watson [1] and Lefebvre and Guilain [7] in transient turbocharged engine simulations.

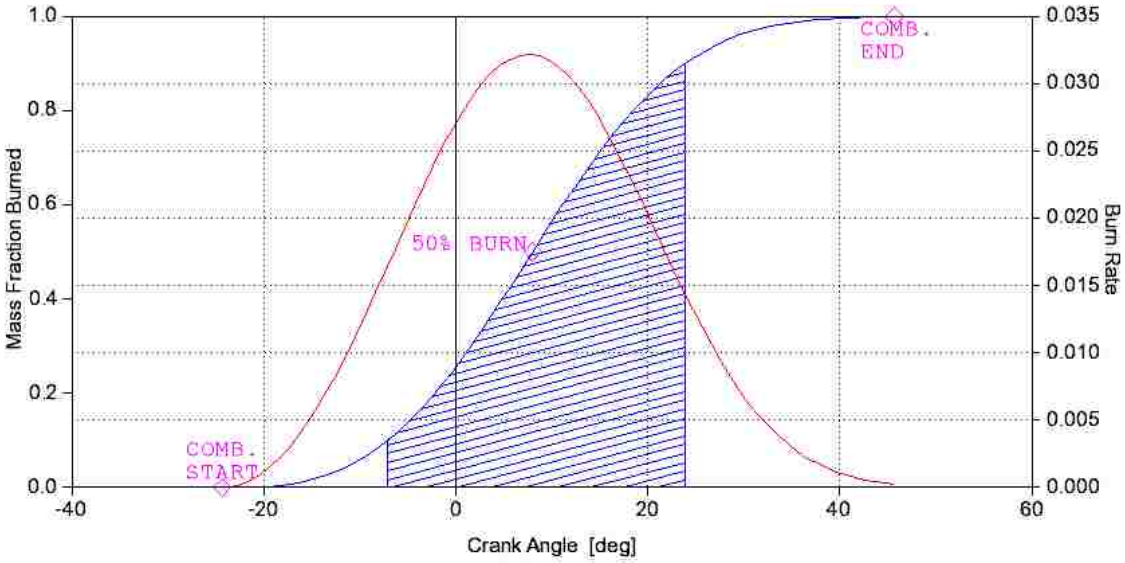


Figure 3-2 Wiebe Combustion Model

The engine example in this study used the WAVE Build default parameters for the Wiebe combustion model, seen in Figure 1-1 ; however, Lefebvre and Guilain [7] have successfully developed a technique for calibrating the model with test data, if the data is available for a particular engine it is highly recommend to calibrate those parameters, again WAVE Build defaults provide the best alternative in the absence of data.

3.2 Valve-train

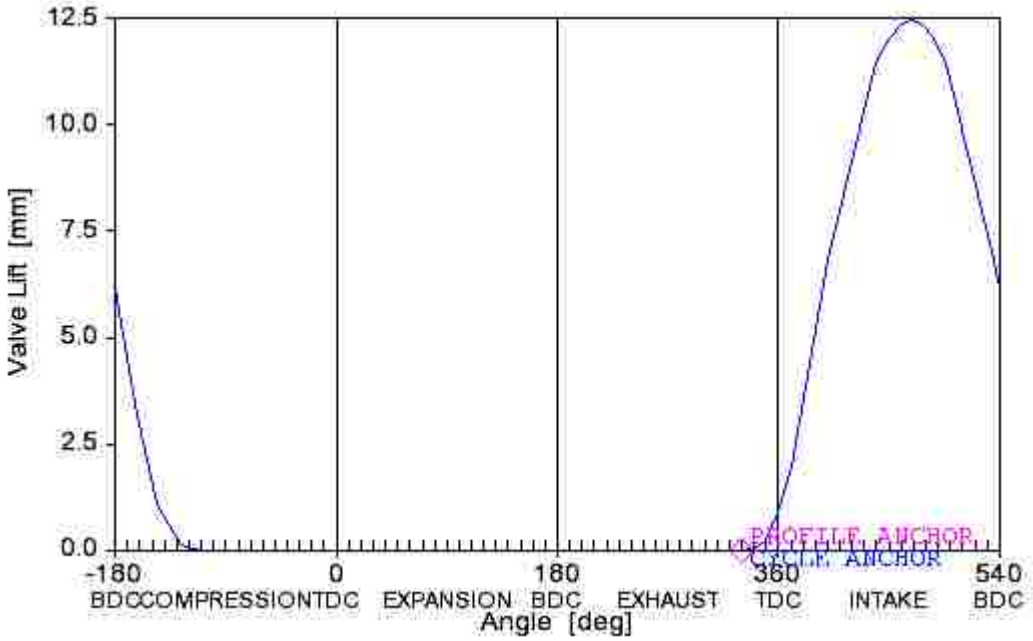
The valve train was modeled by setting up the appropriate number of valves per cylinder and entering details about valve size, lift, and flow. Valve data for each cylinder must be entered referencing a valve model. The Lift Valve model was used in this example, so that the valve would follow a set profile. Ricardo VALDYN is a separate modeling program that models the valves in higher fidelity

taking into account advanced valve train dynamics such as lash and float. If a program such as VALDYN or actual valve lift data is available, it is preferable over data based solely on a camshaft profile. For the example in this study the basic **parameters**, below, in Table 3-2 were used.

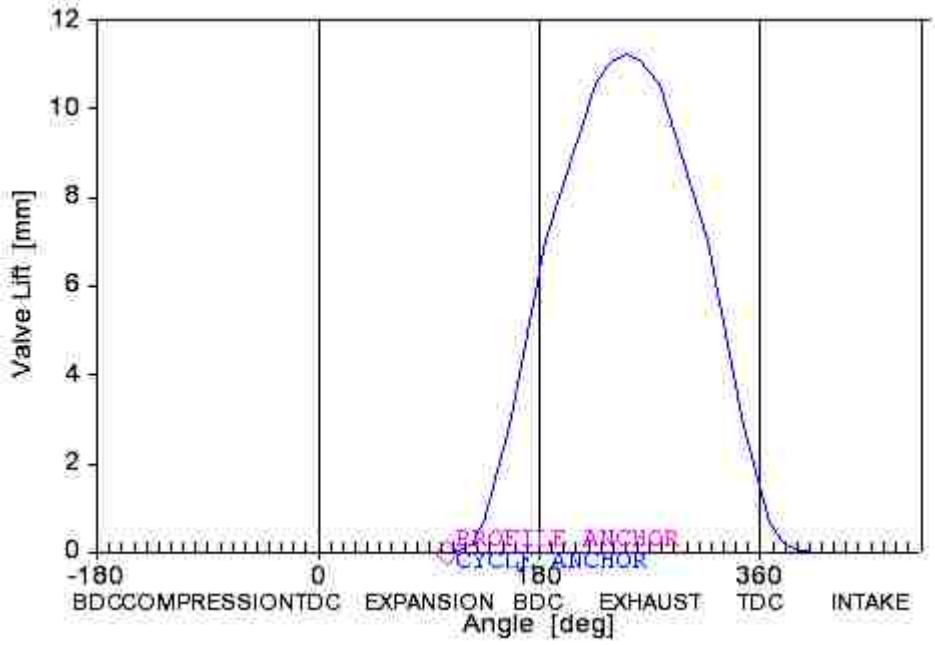
# of Intake Valves per Cylinder	3
# of Exhaust Valves per Cylinder	2
Intake Valve Diameter	30 mm
Exhaust Valve Diameter	28 mm

Table 3-2 Basic Valve Parameters

As stated earlier the Lift model was used. A simple profile was entered for intake and exhaust valves as shown below in Figure 3-3.



(A)



(B)

Figure 3-3 (A) Intake and (B)Exhaust Valve Lift Profiles

Though the Lift Valve model cannot capture some of the advanced valve dynamics as VALDYN can, the Lift Valve model is capable of simplified variable valve timing with use of control elements. This example used fixed valve timing though. Valve flow is calculated with the use of a discharge coefficient which is a function of the lift to diameter ratio, and thus changes with lift. WAVE Build has nominal profiles set as default as shown in Figure 3-4, which were used, or alternatively, if test data is available for a specific engine, it can and should be used.

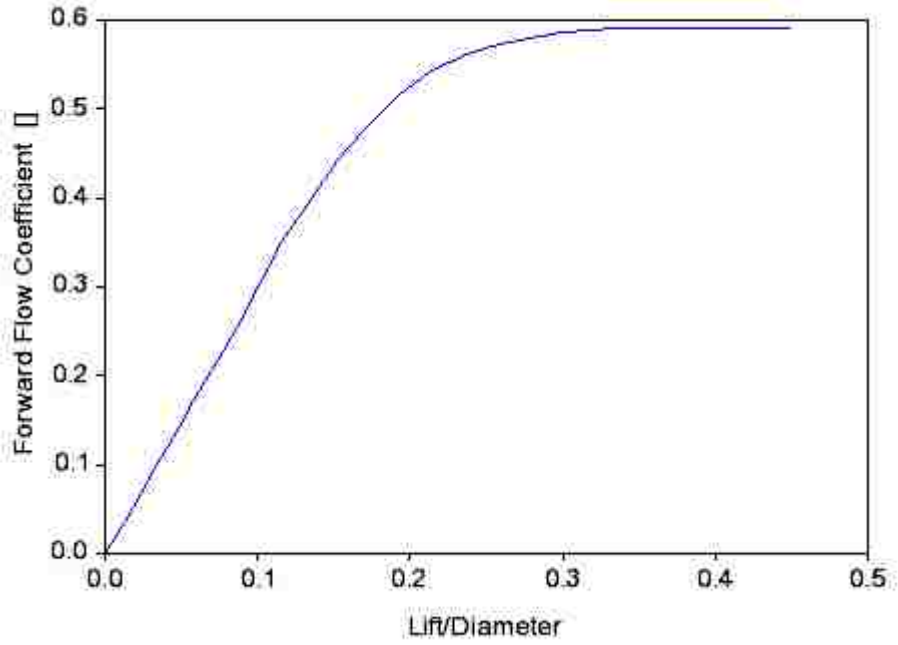


Figure 3-4 Valve Flow Coefficient as a function of Valve Lift/Diameter

3.3 Intake and Exhaust Manifolds

The intake and exhaust valves were modeled using ducts and junctions, where geometry such as length, orientation, and cross sections are specified. Heat transfer and friction data can also be entered. For higher fidelity simulation on complex geometry a coupled 3-dimensional computational fluid dynamics (CFD) /1-dimensinoal simulation can be conducted, WAVE can be ran jointly with several commercially available CFD codes. This example used simple log-style intake manifold, and made use of only 1 dimensional modeling.

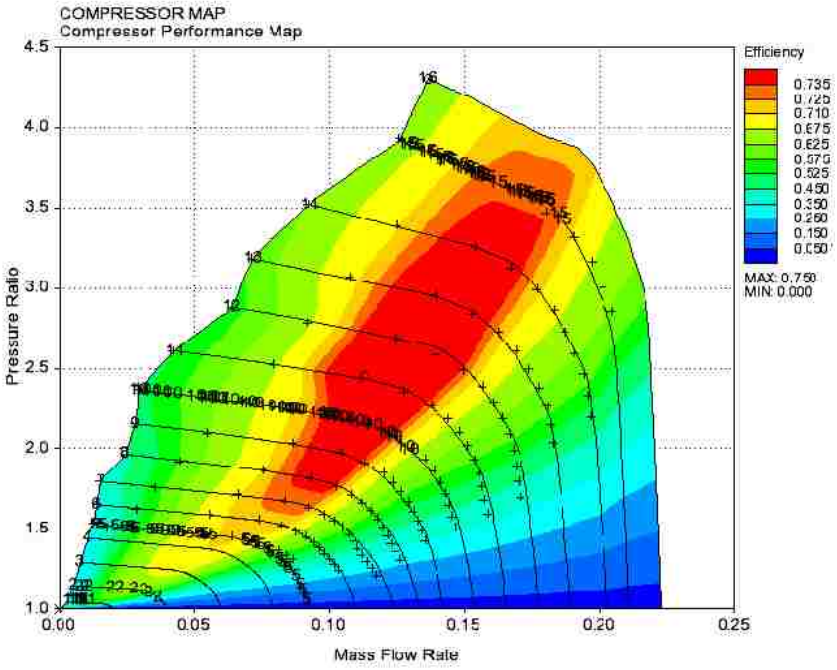
3.4 Fuel System

The system was modeled with port fuel injection. Injector elements were added at each intake runner. While atomization data can be customized, this example used default data. The capability exists to model fuel maps with injector pulse rates as a function of engine variables, as in real fuel injection systems. WAVE modeling provides an excellent way to obtain a baseline fuel map. However since the focus of this study was transient boost response, and not fuel map tuning, a constant air to fuel ratio was assumed. This value was 13.5:1, a slightly rich mixture, often used in turbo application.

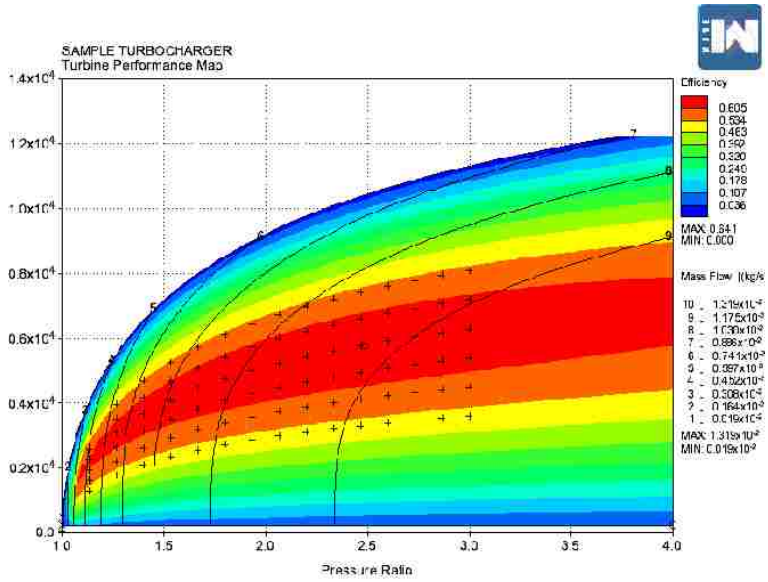
3.5 Turbocharger

The turbine and compressor were modeled with performance maps, as described in 2.1.1. Manufacture performance maps such as those shown in Figure 2-1,

often have incomplete data, especially at slow speeds; however WAVE Build has a routine that has a proven extrapolation algorithm that will convert a performance map into a TCMAP object that WAVE can use to accurately model both compressors and turbines. A TCMAP object is a propriety performance map format that WAVE uses for modeling turbines and compressors. The example used the TCMAPs in Figure 3-5, below.



(A)



(B)

Figure 3-5 WAVE TCMAPs for (A) Compressor and (B) Turbine

3.6 Solenoid Valve

The literature provided no method for modeling a solenoid control valve in a turbo control application. Additionally Ricardo technical support claimed “even our most advanced clients do not model this complexity.” (See correspondence in Appendix 2) Ricardo’s customers include BMW, Ford, Isuzu, Yamaha, Porsche and many others. Because of the lack of an existing model it was decided to characterize the solenoid valve by conducting an experiment. First, the inputs and outputs of the valve were identified. The inputs were: the supplied boost pressure (P1), ambient pressure (AP) which was considered as a constant, and the voltage supplied to the valve. Because there is a desire to modulate the output pressure between the ambient and the supplied boost pressure, PWM was used to supply voltage to the valve. There was only one output, the pressure to the pneumatic, spring-diaphragm, wastegate actuator, P2.

A test-bed was built so each of the outputs and the input could be measured. A block diagram of this illustrated below in Figure 3-6.

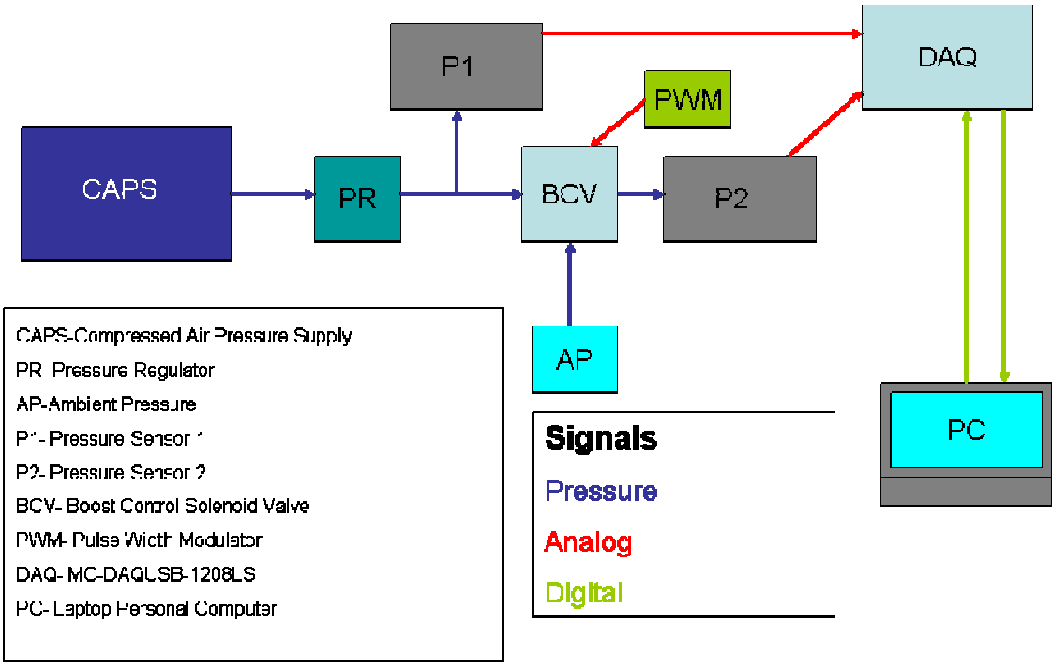


Figure 3-6 Block Diagram of Test Apparatus for Boost Control Solenoid Valve Characterization Experiment

Compressed air was supplied to the valve via a pressure regulator. The regulator was able to adjust the supplied pressure with a control knob. Voltage to the unit was 12V PWM at 120 Hz. The PWM unit was an off-the-shelf unit, designed for electric motor speed control. The duty cycle was adjustable from 0% to 100% via a potentiometer knob. The PWM module required a 12V DC input. The input and output pressures, P1 and P2, were instrumented using two Delphi 3 Bar manifold air pressure (MAP) sensors; these are some of the most common sensors to be installed in a automotive turbo engine application, and are OEM on many vehicles. The MAP sensors are active and required a 12V DC

input. The output voltage of the MAP sensors could be converted to a pressure, in kPa (absolute) via the transfer function:

$$\text{Pressure (kPa)} = (\text{Voltage(V)}/5 + 0.00353) * 314.5 \qquad \textbf{Equation 3-1}$$

The voltage signals were acquired via a MC-DAQUSB-1208LS, which is a USB operated data acquisition (DAQ) system. The sampling rate of the DAQ was 300 Hz. Below, Figure 3-7 is a photograph of the test apparatus.

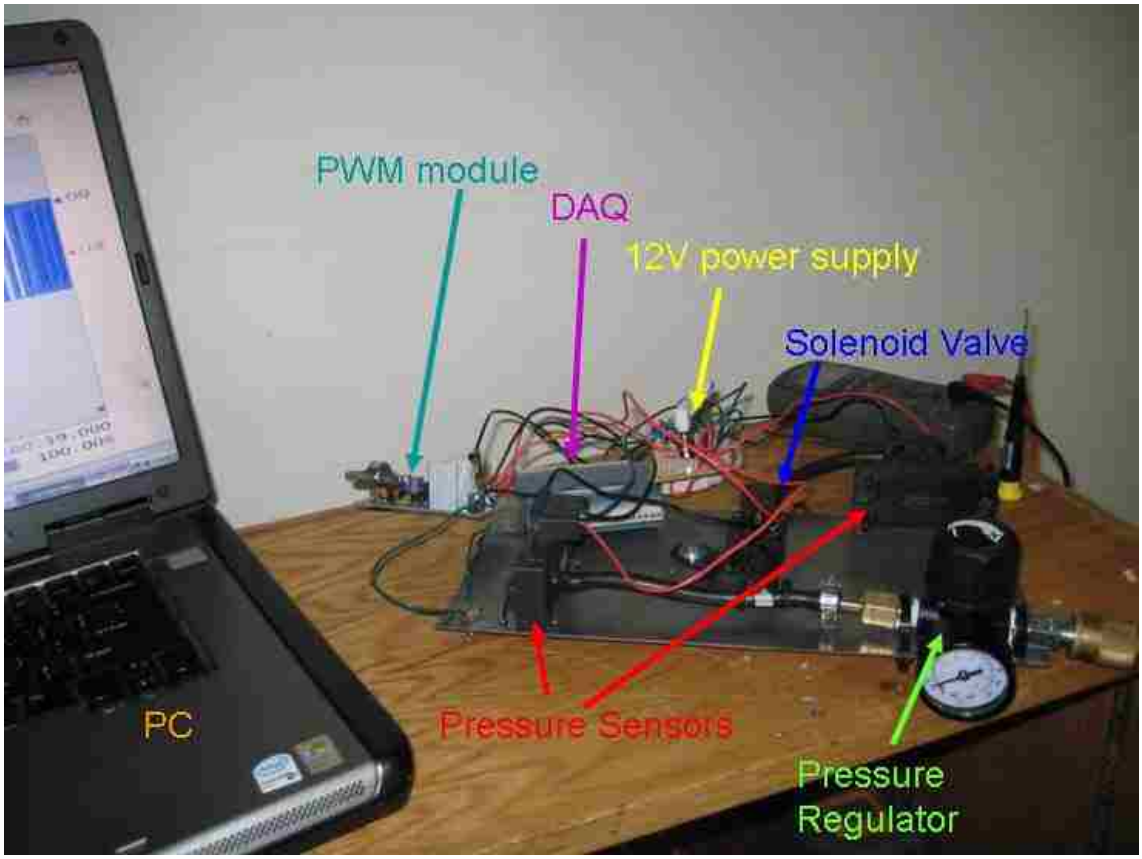


Figure 3-7 Photograph of Test Apparatus

When devising an experiment to model the valve, the first question to be asked was, “do transient effects matter?” Intuitively the answer was no. There is little inertia in the pneumatic control system relative to the rest of the engine system. This was confirmed by performing an experiment where the pressure supply was turned up to a relatively high pressure with the valve unpowered, and then the voltage was stepped from 0 to 12V; PWM was not used in this experiment. Results are plotted below in Figure 3-8.

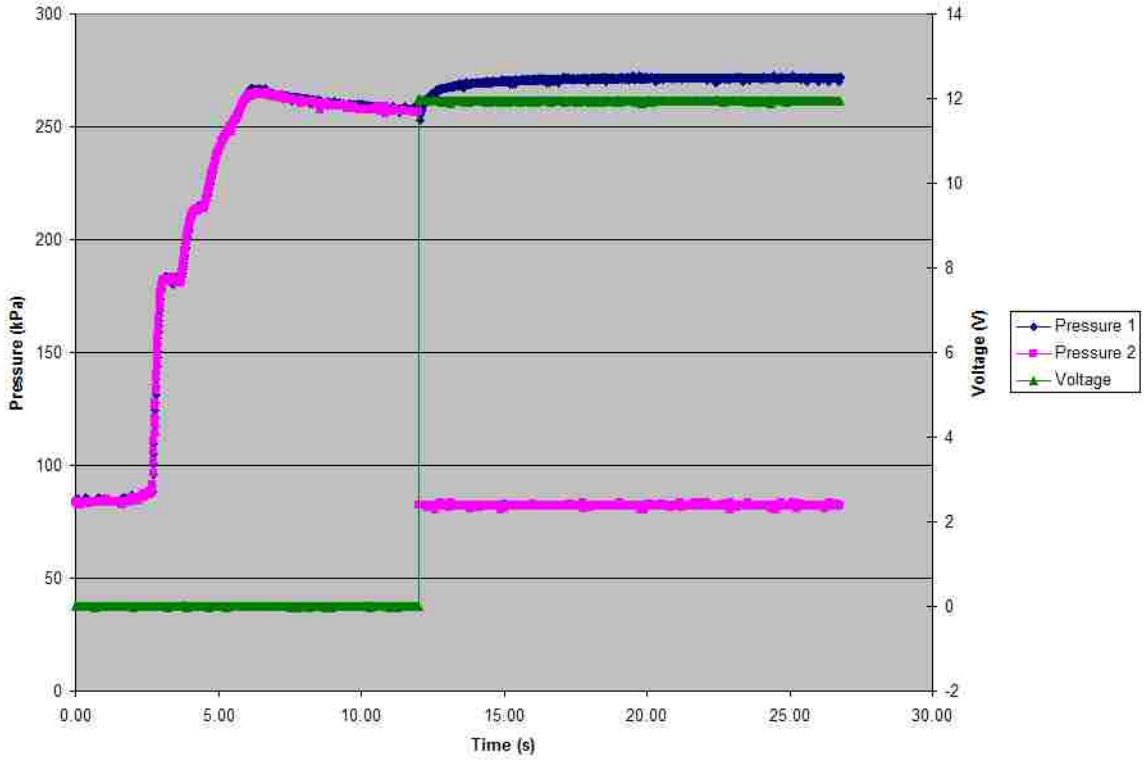


Figure 3-8 Step Response of Solenoid Valve

The response of the valve was so fast that at 300 Hz the P2 dropped from over 255 kPa (absolute) to atmospheric faster than one time-step. This does not

mean that the response was instant, just that it was faster than the sampling rate of 300Hz. Ricardo WAVE operates at a time-step much slower 300 Hz, so even in the transient effects of the valve were modeled, they would not be resolved in the WAVE simulation. Based on the speed that valve operates relative to rest of the system it was appropriate to model the valve as a quasi-steady state process.

The valve has one output and three inputs (including atmospheric pressure), but since atmospheric pressure is a constant, it simplifies the problem to consider the pressure difference between P1 and atmospheric pressure. The input voltage was regulated between 0 and 12V at a constant frequency of 120 Hz, the duty cycle percentage was the input associated with PWM power supply to the solenoid valve. The model needed to express P2 as a function of PWM % duty cycle and pressure difference, ΔP.

A series of data was collected where the pressure was increased to a higher than atmospheric pressure at P1 with the pressure regulator knob, and then the PWM was turned on and manipulated between 0 and 100%. An example of this is plotted below in Figure 3-9.

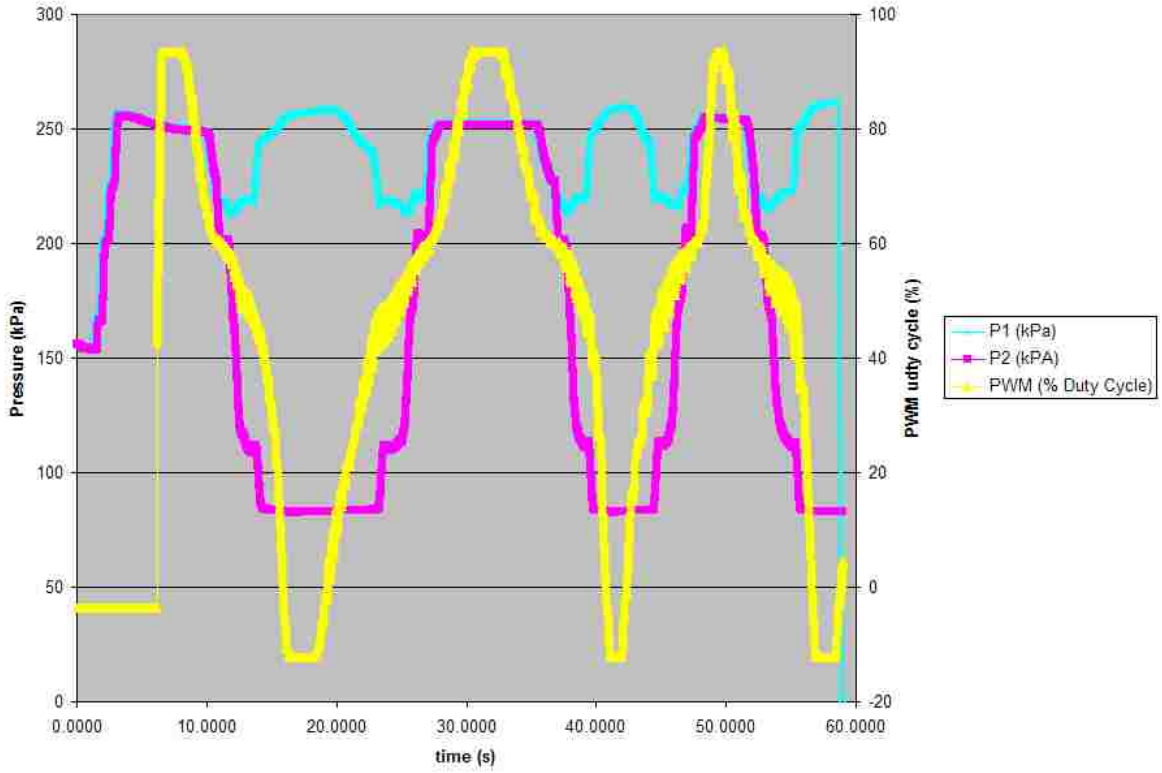


Figure 3-9 Manipulation of PWM

Eight experiments similar to that plotted in Figure 3-9, were conducted for different ΔPs between 0 and 226.5 kPa; the results were then expressed as ΔP as a function of PWM duty cycle percentage plotted below in Figure 3-10.

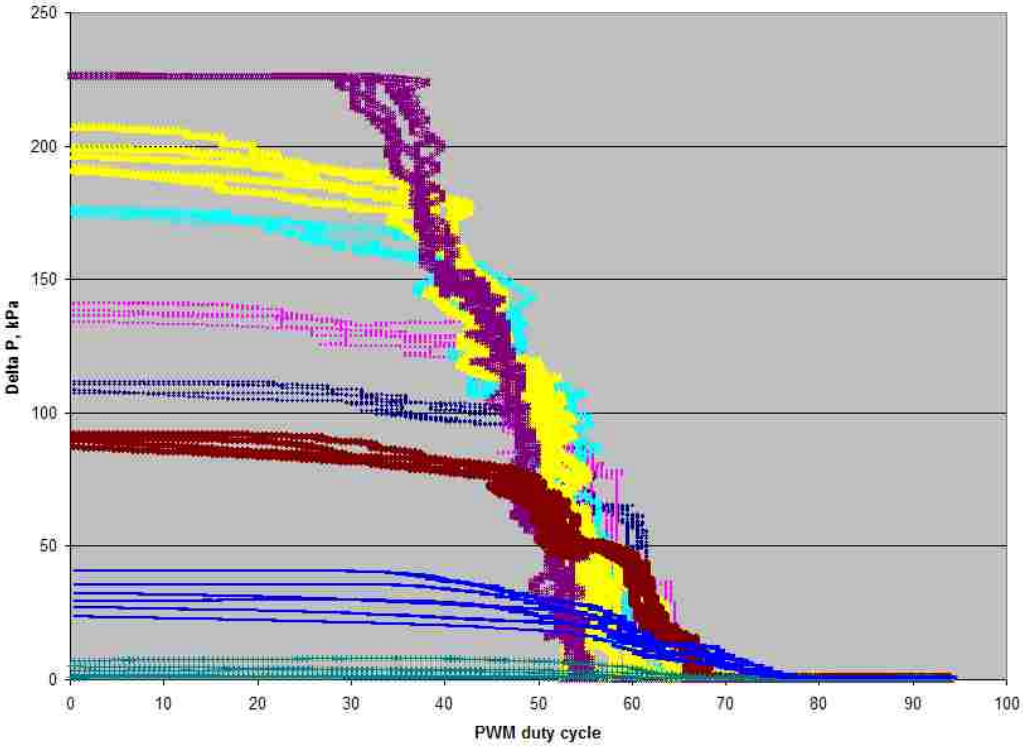


Figure 3-10 Solenoid Valve Performance

Notice that in Figure 3-10, even though the PWM can be adjusted from 0 to 100% duty cycle that the output saturates for duty cycles approximately below 30% and above 75%. This is important because an actuator only has the ability to affect the output to the saturation limits, beyond these a higher or lower control signal will not result in less or more control effort to the output.

The data displayed in Figure 3-10 was insightful but was not a useable model of the valve, to attain the model the data was imported into MATLAB® and converted to a 3-dimensional array where ΔP is a function of PWM and the supplied boost pressure, P1. The data was then used to fit a polynomial. Order was increased until a reasonable fit was achieved. A 5^{th} order polynomial

resulted in an r^2 value of .96. This was found to be acceptable for a model. The surface is plotted below in Figure 3-11.

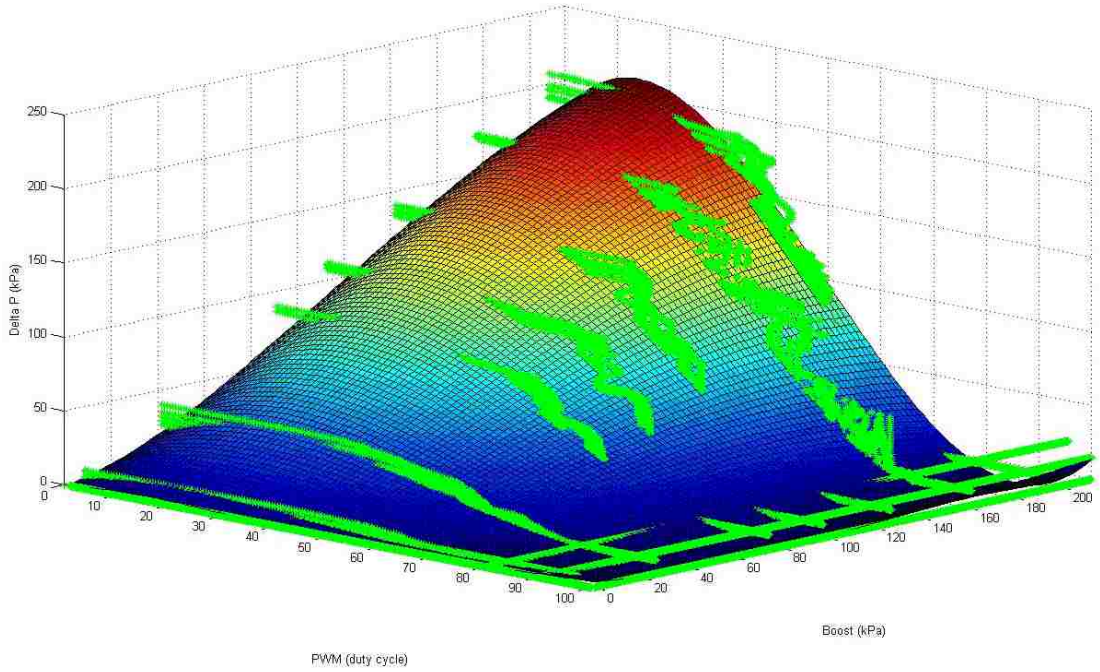


Figure 3-11 Polynomial Surface Fit for Solenoid Valve Function, r^2=.96

Even though the polynomial was a very good fit for the data, it becomes ill behaved in extrapolation. However because of the saturation, the polynomial was stitched to a piece-wise function beyond the data limits to express the saturation effects, thus avoiding the ill behavior.

3.7 Pneumatic, Spring-Diaphragm Wastegate Actuator and Wastegate

An element called a piston driven valve is available in WAVE Build, and is used to model both the wastegate and the wastegate actuator. A driving force is

provided by the instantaneous pressures in the four attached ducts: one pair of ducts to define a diaphragm actuator and one pair to define the valve flow passage, illustrated below in

Figure 3-12.

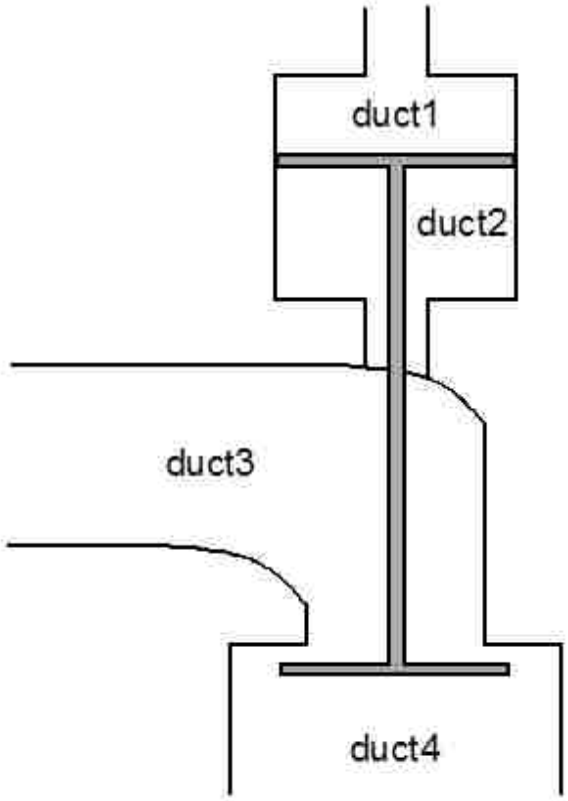


Figure 3-12 Representation of Piston Driven Valve in WAVE

Duct 1 is from the pressure source out of the solenoid valve, duct 2 is atmospheric pressure, duct 3 is connected to the exhaust manifold, and duct 4 is connected to the exhaust tract post turbine. When the valve is open gas can flow

from duct 3 to duct 4, bypassing the turbine. Spring, mass, damping constants can and were added to the piston driven valve, in accordance with Watson's method. [3]

3.8 Load Model

Engine simulations require a load, and WAVE has a simple load that can be used where a specified torque, inertia, and damping are applied to the engine. Alternatively an advanced load model is available where inertias, stiffness, and damping for every driveline component from the flywheel to the tires, along with the mass of the vehicle and aerodynamic and rolling resistance. Additionally a grade can be specified, to simulate driving up or down a hill. The advanced driveline model option was used in the simulation; this is illustrated in Figure 3-13, below.

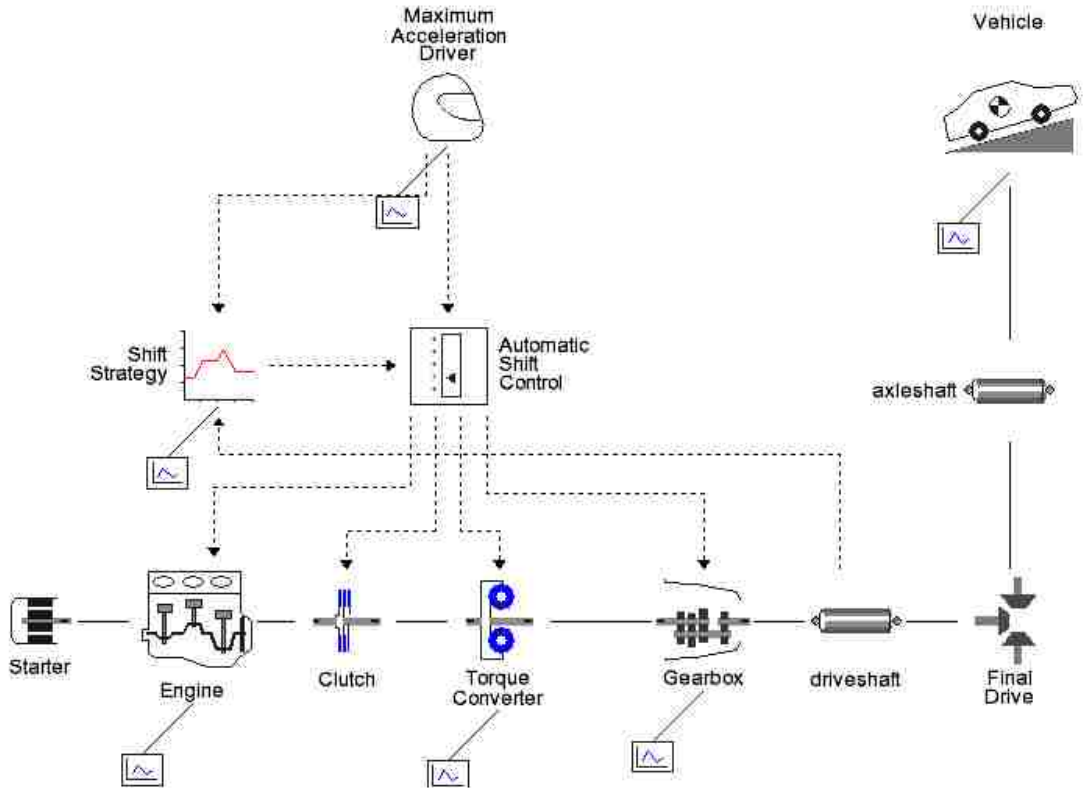


Figure 3-13 WAVE Driveline Model

3.9 Control System

WAVE has some control system capability; however, it is rather limited compared to dedicated control and simulation software packages such, but WAVE does have the ability to interface with Simulink®. Control systems were modeled in Simulink®; this required using a wiring connector element in WAVE Build to connect the inputs and outputs between Simulink and WAVE. Additionally a masked subsystem block containing a C-MEX s-function had to be imported into Simulink, from the WAVE installation directory. Simulink was setup to initiate the

simulations and run WAVE as a slaved application, as shown in Figure 3-14, below.

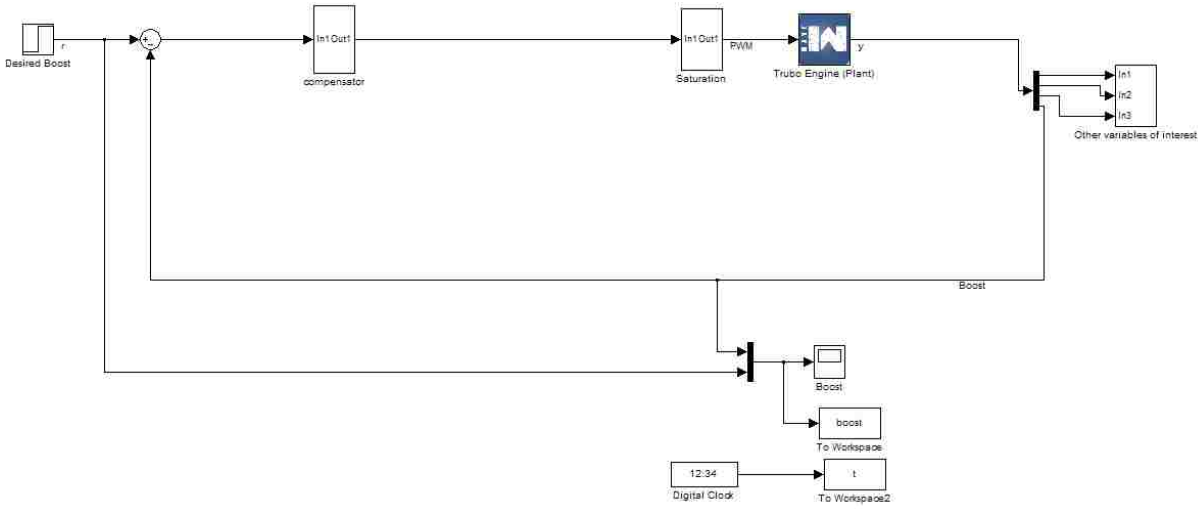


Figure 3-14 Simulink Control System, Coupled with WAVE Model

The corresponding WAVE model is shown below in Figure 3-15.

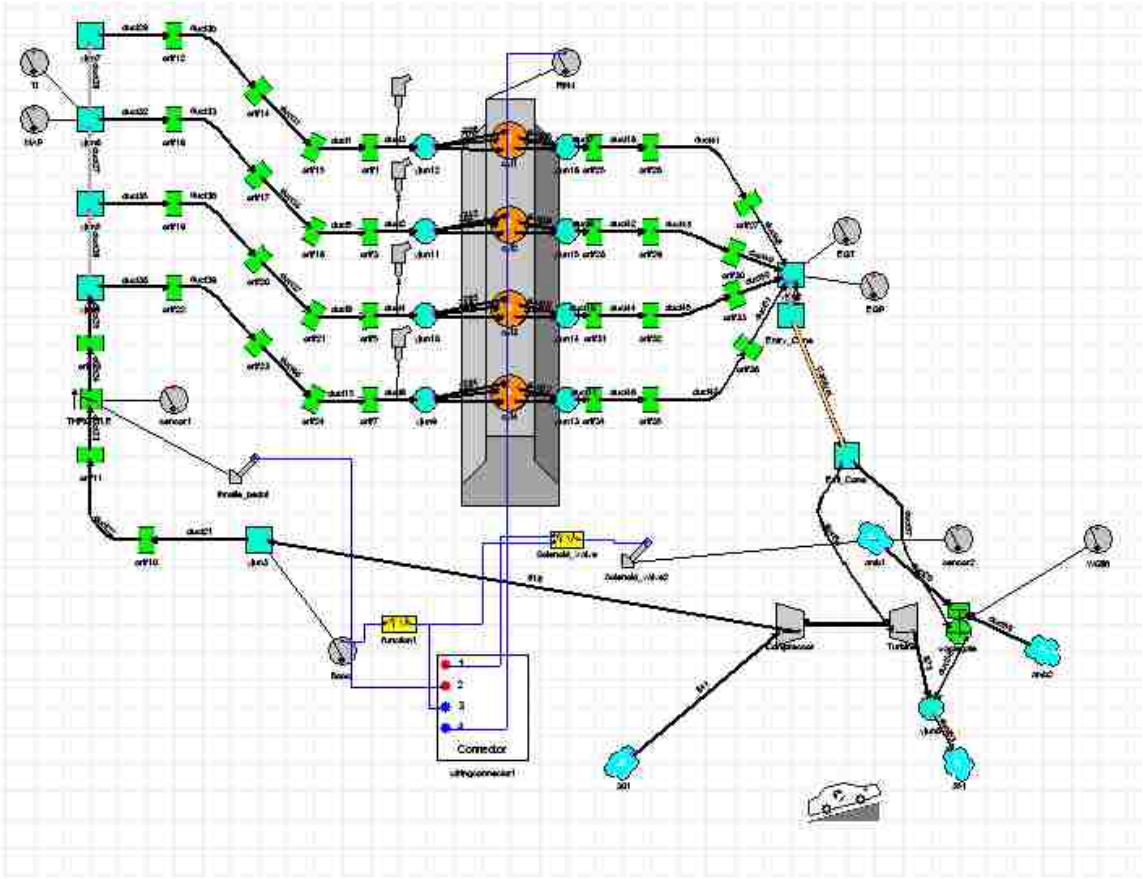


Figure 3-15 Ricardo WAVE Model Coupled with WAVE

4 CONTROL SYSTEM DESIGN

At this point the entire engine system has been modeled, including a block for a control algorithm in the Simulink. Simulink provides a block diagram environment that supports the advanced vector and matrix manipulations found in MATLAB®, a perfect environment to setup control systems. Two approaches of boost control design were explored using the model developed in the previous chapters. The first is a classic model, the PID, and required no process model to tune. The later is a Linear Quadratic compensator, a state space controller, which requires a process model. PID control of turbocharged engines is very common, so it was decided to be simulated to serve as a baseline comparison for the Linear Quadratic compensator.

Designing a boost controller for a turbo engine system poses challenges because the system is inherently nonlinear, governed by partial differential equations (PDEs), and complex geometry. Most design tools of classical and modern control theory require a process model composed of linear ordinary differential equations (ODEs). This leaves the control design engineer with two choices: 1) to use a control design method that requires no process model, which most do. [2,4,6,8] or 2) devise a simplified model of the process that is suitable for control design using well established control theory. Both approaches were investigated using the turbo engine model that was developed.

4.1 PID Control System

A PID controller is a 3 term controller, were an error signal is operated on by 3 terms and summed to attain a control signal. The first term is a simple gain, and is proportional to the error. The second term integrates the error then multiplies it by a gain. The third term differentiates the error and multiplies it by a gain. The three gains K_p, K_i, and K_d, respectively, are the tunable parameters for this type of controller. The block diagram depiction of a PID controller is shown below in Figure 4-1.

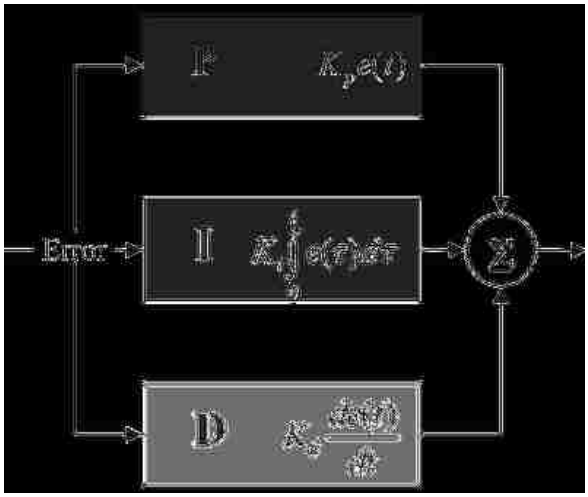


Figure 4-1 Block Diagram of a PID Controller

In this study and in most modern applications the controller is modeled as discrete time system, so that it may be implemented on a microcomputer. Instead of being integrated and differentiated K_i and K_d terms will be delayed and differenced, the discrete time counterpart operations. The discrete time PID block diagram is shown below in Figure 4-2.

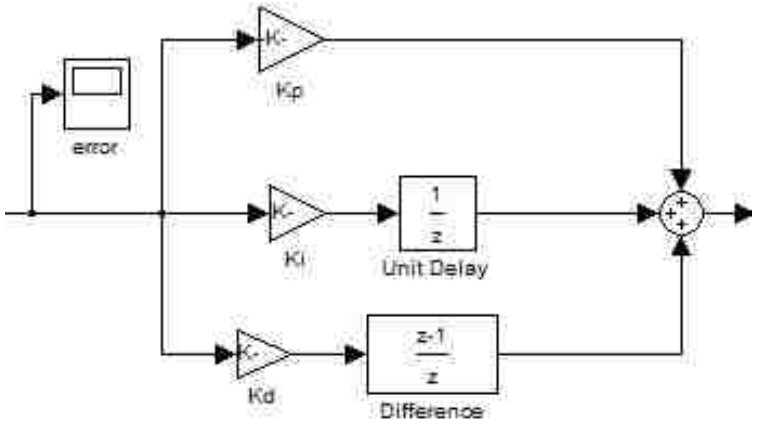


Figure 4-2 Discrete Time Block Diagram of a PID Controller

A PID control can be tuned in a many ways without a process model. One of the most accepted techniques is the Ziegler-Nichols method after the developers who pioneered this technique in the 1940's.[11] For step function response, the K_i and K_d gains are initially set to zero. K_p is incrementally increased until it reaches K_u, the gain at which the output of the loop starts to oscillate. K_u and the period T_u are used to set the gains as shown Table 4-1. [12]

	K_p	K_i	K_d
PID control	$K_u/1.7$	$T_u/2$	$T_u/8$

Table 4-1 Ziegler-Nichols PID Tuning

Applying the method to the model yielded K_u=2 and T_u=1.2, the PID gains were then calculated according to Table 3-1.

4.2 Modern Control System

"Modern Control" systems refer to the state-space approach of modeling dynamic systems with systems of first order ODEs, in the time domain, or, in the case of discrete time, difference equations, as opposed to "Classical Control" where Laplace transforms are used to model in the frequency domain. Because state-space techniques are based on vector and matrix operations, they are an intuitive choice when working with MATLAB and Simulink. MATLAB has many functions that perform the tedious matrix algebra calculations associated with state-space design.

4.2.1 System Identification

The turbo engine model developed in this study is not well suited for a process model for control design; Matlab requires linear time invariant systems, for most of it design tools. An alternate approach would be to use the model to generate a simpler model. The WAVE model can be used to generate data.

System Identification is the process of taking measured data and using it to construct a mathematical model of the system, as opposed to modeling from first principles. There are two main subsets of system identification: grey-box and black-box modeling. In grey box modeling, the structure of the model is known, but parameters are not. The identification algorithm will adjust the algorithm to obtain a good fit between the input and output. Grey-box modeling works excellent for systems that are easily modeled with ODEs, such as

mechanical systems. With black-box modeling, there is no presumed model structure, only input and output data. Even though a great deal is known about the turbo engine system, black box modeling is chosen, because the system is far to complex to use grey-box techniques.

The goal was to attain a discrete state space model in the form:

$$x_{k+1} = Ax_k + Bu_k \qquad \text{Equation 4-1}$$

$$y_k = Cx_k \qquad \text{Equation 4-2}$$

Equation 4-3 is the state difference equation and Equation 4-2 is the output equation. The index, *k* (subscript), represents the time-step. Together the two equations can be used to map inputs to outputs for time invariant, discrete time, systems, with no direct feed-forward. In equation 4-1, the state vector, x, can be found at the next time step by the matrix product of the x and the matrix A summed with the matrix product of input vector, u, and matrix B. The output can be attained form the state vector through Equation 4-2.

In a black-box system identification approach, the state vector and identified structure of matrices A, B, and C, do not generally offer any insight to the physical structure of a system, as they will in a system developed from first principles. The system will however provided insight on how the input is mapped to the output.

The example system was formulated as a single-input single-output (SISO) system, where the input was the PWM duty cycle and the output was the

boost pressure. State-space formulation accommodates multiple-input multiple-output (MIMO) applications, for example a multiple turbo engine, with multiple wastegates and throttle-by-wire; however, this is beyond the scope of this thesis.

Two sets of input-output data were generated, by running the model with the feedback loop of the solenoid valve open. One data set was produced to identify the model, while the other was generated to be used as an independent set to verify the model. In both cases the PWM duty cycle was adjusted in the non-saturated region, while the throttle was wide open. The vehicle model was started from a standstill and was allowed to shift through the gears, in the fashion of a drag race.

Upon simulation, the two distinct data sets were imported into Matlab to be preprocessed. Matlab's System Identification Toolbox requires data with a uniform time step [14], but Wave runs at non-uniform time steps, so the data was reformatted so that it had a uniform time step, with an interpolation approach (see Appendix 3); in this example the time step was .016s. The data and time step was then formatted into an iddata object; this object is used directly by the identification routines in the System Identification Toolbox.

On the first attempt of identifying a model, a linear state-space model was identified using the n4sid() function, which takes the iddata object and a model order (dimension of state vector) as inputs. This would be ideal because the routine returns a system in the form of Equations 4-4 and 4-2. Unfortunately the n4sid() function failed to identify a stable system for orders 1-50.

It was decided that a direct linear identification was not be feasible. System Identification Toolbox has nonlinear identification algorithms, so the next option was to identify a nonlinear model, and if it was stable and a good fit, linearize it. Nonlinear ARX models have the following form:

$$y_k = f(y_{k-1}, y_{k-2}, y_{k-3}...u_k, u_{k-1}, u_{k-2}...) \qquad \text{Equation 4-5}$$

The block diagram for the nonlinear ARX is shown below in Figure 4-3.

Figure 4-3 Block Diagram for Nonlinear ARX structure

The nlarx() function is used to identify a nonlinear ARX model; the function inputs are the iddata object, number of output terms, the number of input terms, the input delays from each input to output, and the type of nonlinearity. Nonlinear estimator choices are wavelet network, sigmoid network, tree partition, or neural network (this requires neural network toolbox and was not used). Ljung explains

each of these nonlinearities in great detail, as well as the nlarx() identification algorithm. [13, 14]

During the identification process there is a need to evaluate how good a particular model is to determine whether the model is good enough or to search for a different model. Ljung suggests comparing the output of an independent set of data, y, to the output that results from running the input of the independent data through the identified model, $\hat{y}$. [13, 14] Ljung refers to the following metric as fit, where $\bar{y}$ is the mean value of y.

$$fit = \left(1 - \frac{|\hat{y} - y|}{|y - \bar{y}|}\right) * 100 \qquad \text{Equation 4-6}$$

For each type of nonlinearity, the free parameters: the number of output terms, the number of input terms, and the input delays from each input to output were incrementally increased until there was no improvement in fit, and then the next lower number for that parameter was used. The best fitting nonlinear ARX model resulted from using a sigmoid network, with four output terms, one input term, and one input delay form the input to outputs; the fit with the independent data was 78.21%, as shown Figure 4-4.

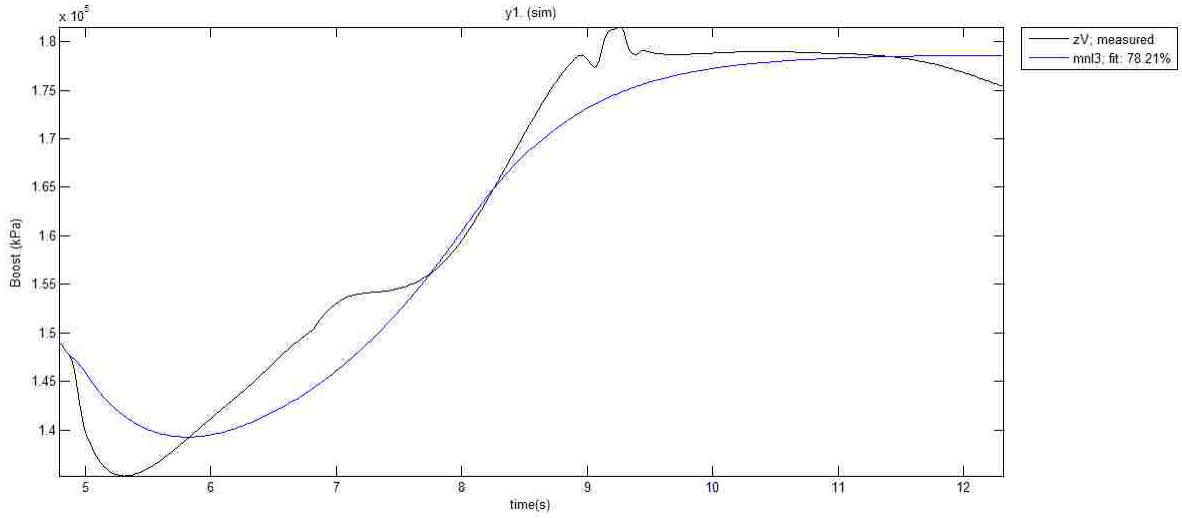


Figure 4-4 Validation of Nonlinear ARX Model with Independent Data

Though a stable model with a moderately good fit was attained, it was nonlinear, it had to be nonlinear as discussed earlier, and not suitable for use with MATLAB®'s control design suite. The nonlinear model was then linearized using the MATLAB® function linapp() and then converted to a state space model with the function ss(), resulting in the following system:

$$x_{k+1} = \begin{bmatrix} 3.4636 & 1.0000 & 0 & 0 \\ -4.6122 & 0 & 1.000 & 0 \\ 2.8075 & 0 & 0 & 1.000 \\ -0.6593 & 0 & 0 & 0 \end{bmatrix} x_k + \begin{bmatrix} 0.9299 \\ 0 \\ 0 \\ 0 \end{bmatrix} u_k \qquad \text{Equation 4-7}$$

$$y_k = \begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix} x_k \qquad \text{Equation 4-8}$$

The discrete time, linear, time invariant, state space system in Equations 4-7 and

4-8 are suitable for control design, though at the cost of going from a 78.21% to a 24.96% fit with independent data, so robustness must be evaluated through simulation, because a plant model that is greatly simplified is used for control design.

4.2.2 Linear Quadratic Control Design

The linearized system in Equations 4-7 and 4-8 was checked for controllability and observability with the corresponding MATLAB functions, and yielded full rank controllability and observability matrices, which said that a full array of control design methods were feasible for this system. [15] A technique known as linear quadratic control was decided on because it offered the ability to optimize the design with regard to balancing control performance within the bounds of the actuators ability to affect the output. This was a major concern, because as the experiment in 3.6 made apparent, the solenoid valve actuator will saturate above and below a rather narrow operational range. If a controller is commanding excessive actuator effort, yet the actuator cannot deliver, then the effort is in vain. Linear Quadratic optimal control ensures this will not happen, as the technique involves penalizing excessive actuator effort.

The linear quadric control problem involves formation of a cost function, and for discrete time system the form is:

$$J = \sum_{k=0}^{\infty} x_k{}^T Q x_k + u_k{}^T R u_k \qquad \text{Equation 4-9}$$

The matrices Q and R are symmetric weighting matrices, with the same dimensions of x and u, respectively. The optimum linear quadratic problem requires finding a control law:

$$u_k = -Kx_k \qquad \text{Equation 4-10}$$

which minimizes Equation 4-9. The MATLAB function lqr() calculates the optimum gain matrix, K, when given the system matrices, *Q*, and *R*. [15]

However, as discussed earlier, in a black-box model, the state vector has no physical interpretation. For the method to truly optimize the system of concern with respect to a cost function that weighs real and tangible variables, the cost function must be restated as:

$$J = \sum_{k=0}^{\infty} y_k{}^T Q y_k + u_k{}^T R u_k \qquad \text{Equation 4-11}$$

In this form the cost function involves the weighing only. The output and the input are variables, but the state vector is not considered. Because the output and input are tangible variables, a cost function in the form of Equation 4-11 is meaningful for an application with a black box model. The Matlab function lqry() solves for the optimum gain matrix that minimizes Equation 4-11.

In the case of a SISO model, as is the case with the system described by Equation 4-7 and 4-8, the Q and R matrices are scalars. Tuning the optimum control law was done by manipulating Q and R based on simulation iterations; both weighting values were initially incremented until the output tracked the reference signal, and then R was decremented until the actuator (solenoid valve) operated within its saturation limits. Calculating the optimum gain matrix does not complete the compensator design. As Equation 4-10 clearly states the output, u is the product of K and the state, x. To implement the control law in Equation 4-10, a state observer was used to provide an estimate of the state, $\hat{x}$. The observer had the flowing form:

$$\hat{x}_{k+1} = A\hat{x}_k + Bu_k + L(y_k - C\hat{x}_k) \qquad \text{Equation 4-12}$$

The observer gain L, was calculated with pole placement, using the MATLAB function place(). In the case of using actual measurements from an experimental engine, rather than simulation data, it is recommended to use a Kalman filter.[15] With the state estimate the control law then becomes:

$$u_k = -K\hat{x}_k \qquad \text{Equation 4-13}$$

The compensator described by Equations 4-12 and 4-13 , a regulator, drives the state to zero. The goal is to track a reference signal of desired boost, r. The

observer was modified so that its input is the error between the output and the desired output, $(y_k - r_k)$:

$$\hat{x}_{k+1} = (A - BK - LC)\hat{x}_k + L(y_k - r_k) \qquad \text{Equation 4-14}$$

The final compensator structure was in the form of Equations 4-13 and 4-14. The final gain values for the optimum gain and observer gain matrices were

$$K = \begin{bmatrix} 2.6888 & 1.0209 & 0.1360 & -0.0850 \end{bmatrix} \qquad \text{Equation 4-15}$$

$$L = \begin{bmatrix} 2.0189 \\ -3.1708 \\ 2.0467 \\ -0.4905 \end{bmatrix} \qquad \text{Equation 4-16}$$

4.3 Simulation Results

Both the PID and the LQ compensators were programmed into a Simulink model, which was coupled to the WAVE turbo engine model, shown below in Figure 4-5 and Figure 4-6.

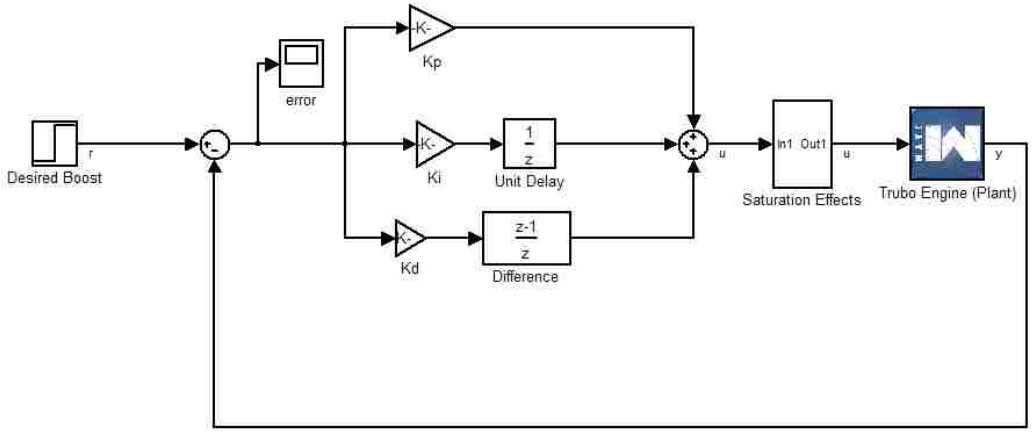


Figure 4-5 Simulink/WAVE PID Compensator Model

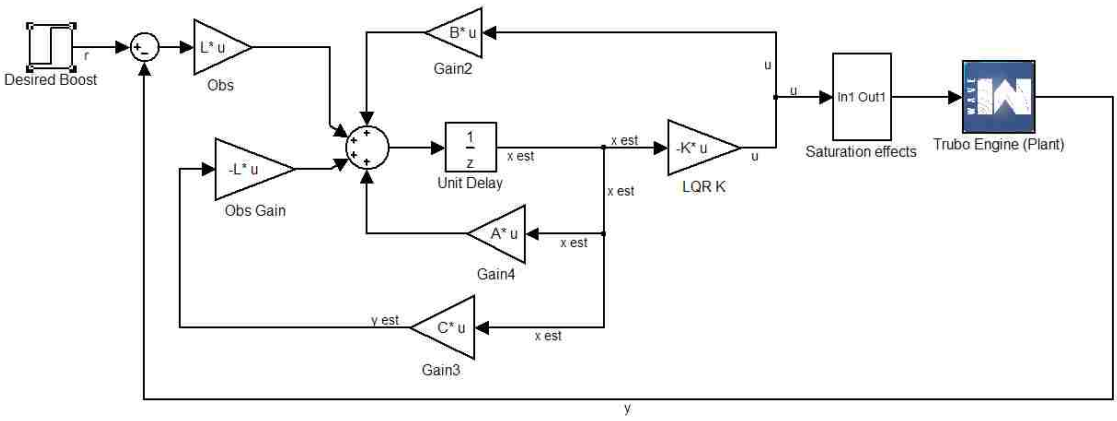


Figure 4-6 Simulink/WAVE LQ Compensator Model

Simulations were conducted with step inputs occurring at 0.5 s for the throttle and the desired boost reference input, 0 to 90º and 0 to 60 kPa respectively. The simulation results are plotted below in Figure 4-7.

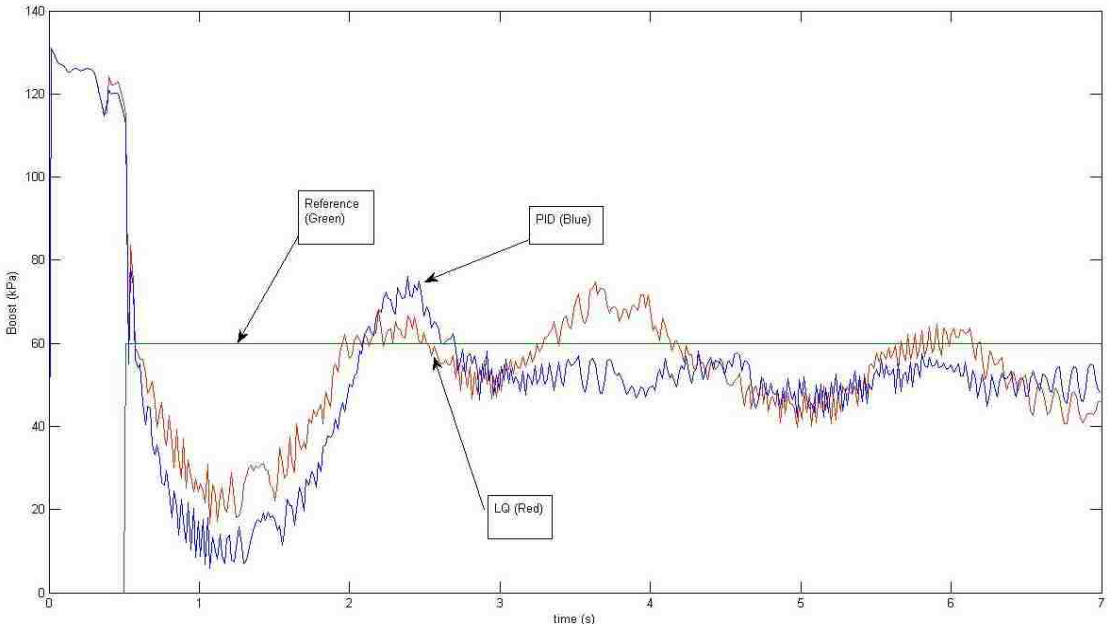


Figure 4-7 Boost Control Results, 60 kPa Step

Figure 4-7 shows the tracking performance of both the PID and LQ control systems. For both controllers, the pressure was very high until both the throttle and reference signal are stepped at 0.5s. In this model the boost was measured between the throttle plate and the turbo, so with the throttle closed, very high pressures are achieved. In practical applications, devices called blow-off valves are placed between the throttle and turbo which allow excessive pressures to be vented to atmosphere when the throttle is rapidly closed. However a blow off valve was not modeled in this application, and thus the high pressures were simulated for times less than 0.5 s. The slight drop off in the signals approximately every few seconds is due to the driveline model changing gears.

In Figure 4-7 the PID controller response is blue, the LQ controller is Red, and the reference (desired boost) signal is green. While the plot gives a

qualitative picture of how well the controllers track the reference input, a more quantitative metric was achieved by calculating the root mean square (RMS) error:

$$RMS \quad error = \sqrt{\frac{\sum_{k=0}^{n} (y_k - r_k)^2}{n}} \qquad \text{Equation 4-17}$$

In Equation 4-17, *y* is the output and r is the reference signal. The indices *k* and *n*, indicate time-steps quantity, the current and last, respectively. For the values of Figure 4-7, $RMS \ \ error$ is computed between the step time, 0.5 s and end time. The $RMS \ \ error$ for each of the controls is displayed below in Table 3-1.

Control Type	RMS error (kPa)
LQ	15.3
PID	20.1

Table 4-2 Root Mean Square Error for Each Controller

The LQ controller provided slightly better results in this case, based on RMS error. Both the LQ and PID controllers allowed some overshoot. This is typical and can be seen in the PID example from the paper by Colin et al. [10] . Rydquist et al. also confirms this phenomena- “it was found that a considerable increased boost level, above the maximum employed during steady states tests, could be allowed for a short duration during transient loading of the engine.” [8]

It was not in the scope of this thesis to determine the how much the steady-state boost requirement could be overshot and for how long. The methods presented here are intended for use by the engine system engineer and control engineer. The results attained using Equation 4-17, should then be taken to a combustion engineer to determine if the overshoot is acceptable, and/or to determine a path forward.

4.4 Robustness

The model used to develop the LQ controller was identified from data that was obtained under nominal conditions (sea level, a flat road, and carrying only the weight of the vehicle and driver). Both LQ and PID controllers were tuned under these nominal conditions.

For the LQ design, the plant used for design has had several iterations of fidelity loss: going from data attained from a simulation under nominal conditions, to a nonlinear model, and then to a linear model. The model that the controller design was based is significantly different than the actual plant it was controlling. This is even more so when the nominal conditions are no longer valid. It was with due diligence that both controllers were simulated under extreme conditions.

A “high load” condition, where 300kg of cargo or passengers are added to the driveline model, along with a 10º grade, and a reduction of atmospheric pressure to 60% of sea level pressure, was simulated. The high load results are below in Figure 4-8.

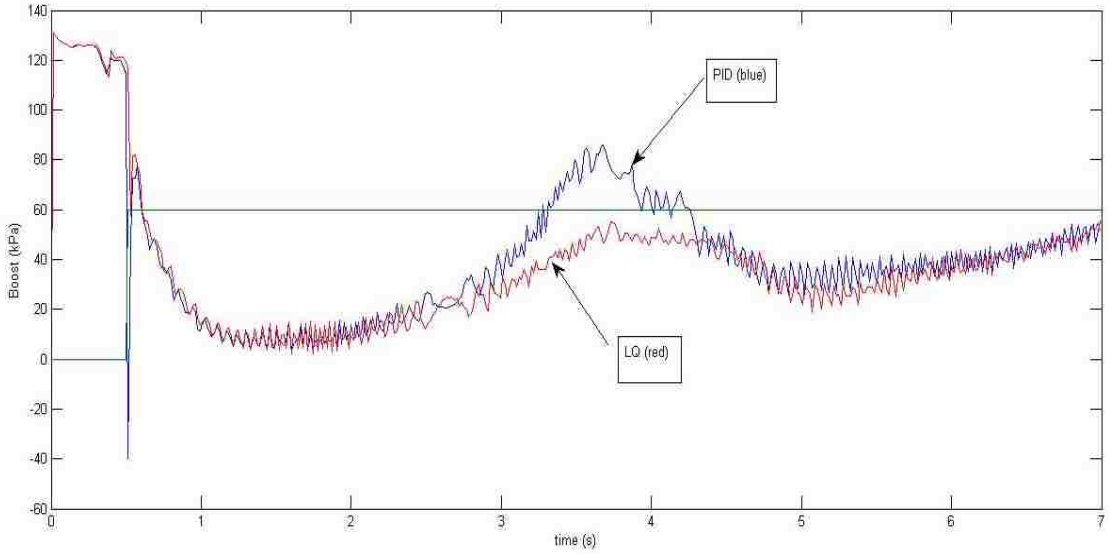


Figure 4-8 Boost Control Results, 60 kPa Step, High Load

A “low load” condition, where the load model was adjusted to simulate the vehicle descending a 15º grade, at sea level pressure, was also simulated, and these results are below in Figure 4-9.

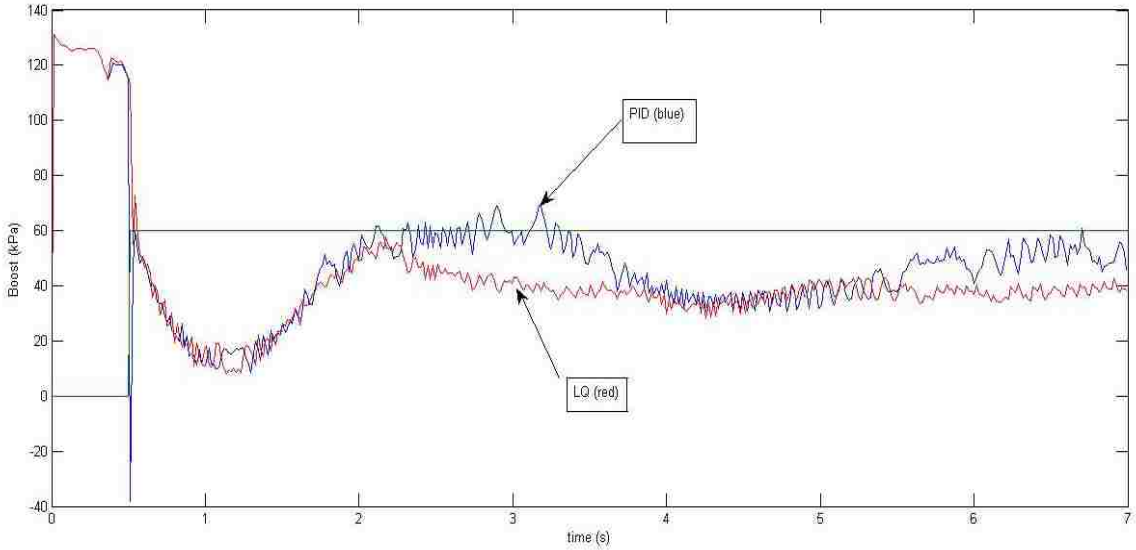


Figure 4-9 Boost Control Results, 60 kPa Step, Low Load

In each of the extreme cases both controllers keep the boost stable. Though tracking performance is important, the fear was of an instability occurring that would allow extreme boost pressures which could destroy the engine. By taking in to account the extreme cases, the operating conditions have been bounded and the controllers remained stable.

5 CONCLUSIONS

This thesis demonstrated a method of using joint WAVE/Simulink modeling to simulate the transient response of a turbocharged engine, to include a detailed representation of the boost control system. The detail of modeling was documented in a sequential manner, for all major components. Two different control algorithms were formulated and then evaluated by simulation.

5.1 Summary of Contributions

Though many of the techniques presented in this thesis have been found in the literature or in textbooks, and some have existed for decades; the major contribution of this thesis is the compilation of the techniques, into a cohesive approach of modeling, simulating, and design of the control system of a turbocharged engine system.

A stand alone contribution includes developing an experiment to characterize and model the solenoid valve, and implementing the result in the WAVE simulation, which according to Ricardo has not been done with their software before.

Another standalone contribution is the approach of using the model to generate data for system identification, development of a state-space model of the engine system. While Linear Quadratic control has been around for decades, this is the first application to a turbo engine system. In the example the LQ design outperformed the PID (tuned with Zeigler-Nichols' method), which is

significant because, PID is still a very prevalent control approach in turbo engines.

5.2 Recommend Future Work

An obvious area of expansion of this thesis is to validate and calibrate the model with an experimental engine. Calibration could be done with the methods of Lefebvre and Guilain.[7]

There is much work that can be done in the area of system identification. It is apparent that the nonlinear nature of a turbocharged engine cannot be ignored. Perhaps a more sophisticated identification approach can be attempted with neural networks. Additionally it would be beneficial to avoid losing a level of fidelity of the model in the linearization process. A technique known as feedback linearization, avoids this loss of fidelity by intentionally designing nonlinearity into the feedback loop that effectively cancels nonlinearities in the plant, resulting in a linear system that would accommodate, linear design approaches such as LQ.

The ultimate intention of this work was to present a method that could be used in the development of turbo engine systems. Using this method to down select design options and to predict the influence of control algorithms on turbocharged engine systems in development or modification, was the motivation of this work, and is an area that can be further pursued.

6 REFERENCES

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I. APPENDIX 1 - RICARDO WAVE INPUT FILE

```
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  <datfile units="SIMM">
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    A_F = 13.5
    BDUR = 31
    CA50 = 8
    CAT_TEMP = 1075
    EVDIA = 30
    FARAT = 0.083333
    HEAD_TEMP = 635
    IVDIA = 28
    LINER_TEMP = 615
    load = 1.5
    LR = 5
    NCYC = 300
    PISTON_TEMP = 595
    PWM = 80
    SPEED = 900
    THROTTLE_ANGLE = 5
    ZD = 6
    BAS:GENERAL PARAMETERS ============================================================
    100 0.8 1.0 SIMM auto
    N N Y 0.01 1
    INDOLENE
    BAS:OUTPUT &amp;amp; PLOTTING ======================================================
     0 0 0 0 0 0 0 0 0 0
    N 0 0 auto
    POSTSCRIPT DRAFT
    all NULL case
    N N N N N
    case 25
    BAS:TIME PLOTS ====================================================================
    ttitles &amp;quot;V8.0.1&amp;quot;
    L:  0.0
    P: 737   auto   auto
    S: Boost
    P: 737   auto   auto
    S: WGlift
    P: 737   auto   auto
    S: MAP
    P: 736   auto   auto
    A: throttle_pedal
    BAS:TITLE =========================================================================
    VW 1.8t
    CHK:VALVES ========================================================================
    &amp;quot;KEXV LEXL LEXR COUNTV(FLOWDIR #NVD L:LINK#), LEXPL, LEXPR, PRESSDIR, S: SYNCCYL&amp;quot;
    wastegate duct57 duct58 1 (lr #4) duct20 duct59 (lr)
    CTL:ACTUATOR ======================================================================
     throttle_pedal ANGLE_DEG inst THROTTLE
     Solenoid_valve2 PRESSURE inst amb1
    CTL:SENSOR ========================================================================
    sensor1 FLOW inst inst THROTTLE 0.0
    Boost PRESSURE inst inst yjun3 0.0
    WGlift POSITION inst inst wastegate 0.0
    MAP PRESSURE inst inst yjun6 0.0
    EGT TEMPERATURE inst inst yjun2 0.0
    EGP PRESSURE inst inst yjun2 0.0
    Ti TEMPERATURE inst inst yjun6 0.0
    RPM SPEED_RPM inst inst 0 0.0
    sensor2 PRESSURE inst inst amb1 0.0
    sensor3 POWER inst inst 0 0.0
```

```
DUC:BENDS ==========================================================================
duct22 90
duct30 45
duct33 45
duct36 45
duct39 45
duct41 60
duct43 30
duct45 30
duct47 60
duct54 90
duct57 90
DUC:DUCT DATA ======================================================================
1.0 1.0
&amp;quot; LEX   KJL   KJR   DL    DR   SDUCT  DX  TWALD  PDI  TDI   CFR CHT CP  CDL CDR  RHD&amp;quot;
 701 yjun12 cyl1   28   28   50  100 370.  1.0  320  0.0  1.0  0.0  1.0  1.0 0
 702 yjun11 cyl2   28   28   50  100 370.  1.0  320  0.0  1.0  0.0  1.0  1.0 0
 703 yjun10 cyl3   28   28   50  100 370.  1.0  320  0.0  1.0  0.0  1.0  1.0 0
 704 yjun9 cyl4   28   28   50  100 370.  1.0  320  0.0  1.0  0.0  1.0  1.0 0
 705 yjun11 cyl2   28   28   50  100 370.  1.0  320  0.0  1.0  0.0  1.0  1.0 0
 706 yjun12 cyl1   28   28   50  100 370.  1.0  320  0.0  1.0  0.0  1.0  1.0 0
 707 yjun9 cyl4   28   28   50  100 370.  1.0  320  0.0  1.0  0.0  1.0  1.0 0
 708 yjun10 cyl3   28   28   50  100 370.  1.0  320  0.0  1.0  0.0  1.0  1.0 0
 711 yjun12 cyl1   28   28   50  100 370.  1.0  320  0.0  1.0  0.0  1.0  1.0 0
 712 yjun11 cyl2   28   28   50  100 370.  1.0  320  0.0  1.0  0.0  1.0  1.0 0
 713 yjun10 cyl3   28   28   50  100 370.  1.0  320  0.0  1.0  0.0  1.0  1.0 0
 714 yjun9 cyl4   28   28   50  100 370.  1.0  320  0.0  1.0  0.0  1.0  1.0 0
 818 Compressor yjun3   60   60   50   30  300  1.0  305  1.0  1.0  0.0  AUT  AUT 0
 841  301 Compressor   60   60  250   30  300  1.0  305  1.0  1.0  0.0  AUT  AUT 0
 973 Turbine yjun8   50   50  500   30  830   .9  980  1.0  1.0  0.0  AUT  AUT 0
Catalyst Entry_Cone Exit_Cone 1.05543 1.05543   80   40 {CAT_TEMP} 1.05 1100  1.0    5  0.0 auto auto 0
duct1 orif15 orif1   40   35 100.0   35 300.0  1.0 300.0    0  1.5  0.0 auto auto 0
duct10 yjun14 orif31   40   40   30   10 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct11 yjun13 orif34   40   40   30   10 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct12 cyl4 yjun13   30   30   50   10 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct13 orif24 orif7   40   35 100.0   35 300.0  1.0 300.0    0  1.5  0.0 auto auto 0
duct14 cyl4 yjun13   30   30   50   10 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct15 cyl3 yjun14   30   30   50   10 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct16 cyl3 yjun14   30   30   50   10 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct17 cyl2 yjun15   30   30   50   10 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct18 orif25 orif26   40   40   40   40  750 1.05 1100  1.0  1.0  0.0 auto auto 0
duct19 cyl2 yjun15   30   30   50   10 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct2 orif3 yjun11   35   35 100.0 30.0 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct20 amb1 wastegate   25   25    5   10 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct21 yjun3 orif10   60   60  250   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct22 orif10 orif11   60   60  150   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct23 orif11 THROTTLE   60   60   50   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct24 THROTTLE orif13   60   60   50   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct25 orif13 yjun4   60   60  150   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct26 yjun4 yjun5  110  110    0   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct27 yjun5 yjun6  110  110    0   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct28 yjun6 yjun7  110  110    0   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct29 yjun7 orif12   40   40  100   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct3 orif1 yjun12   35   35 100.0 30.0 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct30 orif12 orif14   40   40  100   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct31 orif14 orif15   40   40  150   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct32 yjun6 orif16   40   40  100   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct33 orif16 orif17   40   40  100   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct34 orif17 orif18   40   40  150   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct35 yjun5 orif19   40   40  100   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct36 orif19 orif20   40   40  100   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct37 orif20 orif21   40   40  150   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct38 yjun4 orif22   40   40  100   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct39 orif22 orif23   40   40  100   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct4 orif5 yjun10   35   35 100.0 30.0 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct40 orif23 orif24   40   40  150   35 300.0  1.0 300.0  1.0  1.0  0.0 auto auto 0
duct41 orif26 orif27   40   40   80   40  750 1.05 1100  1.0  1.0  0.0 auto auto 0
```

```
duct42 orif28 orif29   40   40   40   40  750 1.05 1100  1.0  1.0  0.0 auto auto 0
duct43 orif29 orif30   40   40   80   40  750 1.05 1100  1.0  1.0  0.0 auto auto 0
duct44 orif31 orif32   40   40   40   40  750 1.05 1100  1.0  1.0  0.0 auto auto 0
duct45 orif32 orif33   40   40   80   40  750 1.05 1100  1.0  1.0  0.0 auto auto 0
duct46 orif34 orif35   40   40   40   40  750 1.05 1100  1.0  1.0  0.0 auto auto 0
duct47 orif35 orif36   40   40   80   40  750 1.05 1100  1.0  1.0  0.0 auto auto 0
duct48 orif27 yjun2   40   40  120   40  750 1.05 1100  1.0  1.0  0.0 auto auto 0
duct49 orif30 yjun2   40   40  120   40  750 1.05 1100  1.0  1.0  0.0 auto auto 0
duct5 orif18 orif3   40   35 100.0   35 300.0  1.0 300.0    0  1.5  0.0 auto auto 0
duct50 orif33 yjun2   40   40  120   40  750 1.05 1100  1.0  1.0  0.0 auto auto 0
duct51 orif36 yjun2   40   40  120   40  750 1.05 1100  1.0  1.0  0.0 auto auto 0
duct52 yjun2 Entry_Cone   76   76    0   40  750 1.05 1100  1.0  1.0  0.0 auto auto 0
duct53 yjun8  351   50   50   50   10 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct54 Exit_Cone Turbine   50   50 100.0   40  800  1.2 1000  1.0  1.0  0.0 auto auto 0
duct55 cyl1 yjun16   30   30   50   10 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct56 cyl1 yjun16   30   30   50   10 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct57 Exit_Cone wastegate   50   50 100.0   40  800 1.05 1000  1.0  1.0  0.0 auto auto 0
duct58 wastegate yjun8   50   50   50   10 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct59 amb2 wastegate   25   25 100.0 30.0 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct6 orif7 yjun9   35   35 100.0 30.0 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct7 yjun16 orif25   40   40   30   10 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct8 yjun15 orif28   40   40   30   10 300.0  1.0 300.0  1.0  1.0  0.0 AUTO AUTO 0
duct9 orif21 orif5   40   35 100.0   35 300.0  1.0 300.0    0  1.5  0.0 auto auto 0
DUC:SHAPE ==========================================================================
701 CIRCULAR {ivdia} {ivdia}
702 CIRCULAR {ivdia} {ivdia}
703 CIRCULAR {ivdia} {ivdia}
704 CIRCULAR {ivdia} {ivdia}
705 CIRCULAR {ivdia} {ivdia}
706 CIRCULAR {ivdia} {ivdia}
707 CIRCULAR {ivdia} {ivdia}
708 CIRCULAR {ivdia} {ivdia}
711 CIRCULAR {ivdia} {ivdia}
712 CIRCULAR {ivdia} {ivdia}
713 CIRCULAR {ivdia} {ivdia}
714 CIRCULAR {ivdia} {ivdia}
818 CIRCULAR {(ZD)*10} 60
841 CIRCULAR 60 60
973 CIRCULAR 50 50
Catalyst CATALYST 7852.98 600 0.1016 314.159
duct1 CIRCULAR 40 35
duct10 CIRCULAR 40 40
duct11 CIRCULAR 40 40
duct12 CIRCULAR {evdia} {evdia}
duct13 CIRCULAR 40 35
duct14 CIRCULAR {evdia} {evdia}
duct15 CIRCULAR {evdia} {evdia}
duct16 CIRCULAR {evdia} {evdia}
duct17 CIRCULAR {evdia} {evdia}
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duct19 CIRCULAR {evdia} {evdia}
duct2 CIRCULAR 35 35
duct20 CIRCULAR 25 25
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duct22 CIRCULAR 60 60
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duct31 CIRCULAR 40 40
duct32 CIRCULAR 40 40
duct33 CIRCULAR 40 40
duct34 CIRCULAR 40 40
duct35 CIRCULAR 40 40
duct36 CIRCULAR 40 40
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duct37 CIRCULAR 40 40
duct38 CIRCULAR 40 40
duct39 CIRCULAR 40 40
duct4 CIRCULAR 35 35
duct40 CIRCULAR 40 40
duct41 CIRCULAR 40 40
duct42 CIRCULAR 40 40
duct43 CIRCULAR 40 40
duct44 CIRCULAR 40 40
duct45 CIRCULAR 40 40
duct46 CIRCULAR 40 40
duct47 CIRCULAR 40 40
duct48 CIRCULAR 40 40
duct49 CIRCULAR 40 40
duct5 CIRCULAR 40 35
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duct51 CIRCULAR 40 40
duct53 CIRCULAR 50 50
duct54 CIRCULAR 50 50
duct55 CIRCULAR {evdia} {evdia}
duct56 CIRCULAR {evdia} {evdia}
duct57 CIRCULAR 50 50
duct58 CIRCULAR 50 50
duct59 CIRCULAR 25 25
duct6 CIRCULAR 35 35
duct7 CIRCULAR 40 40
duct8 CIRCULAR 40 40
duct9 CIRCULAR 40 35
ENG:GEOMETRY ======================================================================
4 4 SI
81 86.4 120.0 0.0
9.5
 1 3 4 2
 0 180 180 180
0.35  0.005  400  0.2
0  0  0
0.0  0.0  0.0  0.0
ENG:HEAT TRANSFER ==================================================================
original
1.0 1.0 0.0 N
{PISTON_TEMP} {HEAD_TEMP} {LINER_TEMP} {HEAD_TEMP} {HEAD_TEMP}
1.0 1.6 2
ENG:OPERATING PARAMETERS ===========================================================
{SPEED} 1.0 298.0
ENG:SI_WIEBE_COMB ==================================================================
{CA50} {BDUR} 2.0 1.0 profile_limit
ENG:VALVES =========================================================================
&amp;quot;NC, KEXC, (LEXD, IED, #NVD, L:LINK#--Repeated for each valve/duct)&amp;quot;
1 cyl1 701 i #1 711 i #1 duct56 e #2 duct55 e #2 706 i #1
2 cyl2 702 i #1 705 i #1 duct17 e #2 duct19 e #2 712 i #1
3 cyl3 713 i #1 708 i #1 duct16 e #2 duct15 e #2 703 i #1
4 cyl4 714 i #1 707 i #1 duct14 e #2 duct12 e #2 704 i #1
EXT:PINOUT =========================================================================
1 NULL SOURCE 75
2 NULL SOURCE 5
3 NULL SINK 0
4 NULL SINK 900
5 NULL SINK 0
6 NULL SINK 0
INJ:TYPE ===========================================================================
1
prop
300 0.2 auto 0.0 0.3 40 auto
0.0 0.9 0.0 0.0 0.1
------------------------------------------------------ !(separator)
2
prop
```

```
300 0.2 auto 0.0 0.3 40 auto
0.0 0.9 0.0 0.0 0.1
---------------------------------------------------- !(separator)
3
prop
300 0.2 auto 0.0 0.3 40 auto
0.0 0.9 0.0 0.0 0.1
---------------------------------------------------- !(separator)
4
prop
300 0.2 auto 0.0 0.3 40 auto
0.0 0.9 0.0 0.0 0.1
INJ:VOLUME ========================================================================
1 1 duct3 0 {(LR)*10}
NULL {FARAT} NULL
---------------------------------------------------- !(separator)
2 2 duct2 0 {(LR)*10}
NULL {FARAT} NULL
---------------------------------------------------- !(separator)
3 3 duct4 0 {(LR)*10}
NULL {FARAT} NULL
---------------------------------------------------- !(separator)
4 4 duct6 0 {(LR)*10}
NULL {FARAT} NULL
JUN:JUNCTION DATA ================================================================
&amp;quot; KEX    KT1/KT2   AUX1    AUX2    AUX3    AUX4    AUX5&amp;quot;
 301     3     1 AUT 1.000 300.0 AUT 0 FIXED
 351     3     1 AUT 1.000 300.0 AUT 0 FIXED
 amb1     3     1 AUTO 1 273.15 AUTO 0.0 FLOATING
 amb2     3     1 AUTO 1 300.0 AUTO 0.0 FLOATING
 Compressor     1     2
 cyl1     4     1 SINGLEZONE
 cyl2     4     1 SINGLEZONE
 cyl3     4     1 SINGLEZONE
 cyl4     4     1 SINGLEZONE
 Entry_Cone     5     2
 Exit_Cone     5     2
 orif1     1     1 auto
 orif10     1     1 auto
 orif11     1     1 auto
 orif12     1     1 auto
 orif13     1     1 auto
 orif14     1     1 auto
 orif15     1     1 auto
 orif16     1     1 auto
 orif17     1     1 auto
 orif18     1     1 auto
 orif19     1     1 auto
 orif20     1     1 auto
 orif21     1     1 auto
 orif22     1     1 auto
 orif23     1     1 auto
 orif24     1     1 auto
 orif25     1     1 auto
 orif26     1     1 auto
 orif27     1     1 auto
 orif28     1     1 auto
 orif29     1     1 auto
 orif3     1     1 auto
 orif30     1     1 auto
 orif31     1     1 auto
 orif32     1     1 auto
 orif33     1     1 auto
 orif34     1     1 auto
 orif35     1     1 auto
 orif36     1     1 auto
 orif5     1     1 auto
```

```
 orif7     1     1 auto
 THROTTLE     1     12
 Turbine     1     3
 wastegate     1     6 25
 yjun10     5     1
 yjun11     5     1
 yjun12     5     1
 yjun13     5     1
 yjun14     5     1
 yjun15     5     1
 yjun16     5     1
 yjun2     5     2
 yjun3     5     2
 yjun4     5     2
 yjun5     5     2
 yjun6     5     2
 yjun7     5     2
 yjun8     5     1
 yjun9     5     1
JUN:THROTTLE_VALVE ============================================================
 THROTTLE duct23 duct24 lr #3
 {THROTTLE_ANGLE}
JUN:YJUNCTION DATA ============================================================
Entry_Cone 90.2 900 1.05 1100 319000 14400 1.0 1.0
&amp;quot; LEX   VDIR1  VDIR2  VDIR3  DIA   CDK  DELX  DIAB  THICK  COUNT&amp;quot;
duct52 -90 0 90 AUTO AUTO 50 90.2 0 1
Catalyst 90 180 90 AUTO AUTO 50 1.17 0 7303.29
-----------------------------------------     !separator
Exit_Cone 76.4 900 1.0 1100 229000 13200 1.0 1.0
&amp;quot; LEX   VDIR1  VDIR2  VDIR3  DIA   CDK  DELX  DIAB  THICK  COUNT&amp;quot;
duct54 90 180 90 AUTO AUTO 50 76.4 0 1
Catalyst -90 0 90 AUTO AUTO 50 1.17 0 7303.29
duct57 0 90 90 AUTO AUTO 76.4 AUTO 0 1
-----------------------------------------     !separator
yjun10 35 300.0 1.0 300.0 1.0 1.0
&amp;quot; LEX   VDIR1  VDIR2  VDIR3  DIA   CDK  DELX  DIAB  THICK  COUNT&amp;quot;
703 0.0 90.0 90.0 AUTO AUTO
708 0.0 90.0 90.0 AUTO AUTO
713 0.0 90.0 90.0 AUTO AUTO
duct4 0.0 90.0 90.0 AUTO AUTO
-----------------------------------------     !separator
yjun11 35 300.0 1.0 300.0 1.0 1.0
&amp;quot; LEX   VDIR1  VDIR2  VDIR3  DIA   CDK  DELX  DIAB  THICK  COUNT&amp;quot;
705 0.0 90.0 90.0 AUTO AUTO
702 0.0 90.0 90.0 AUTO AUTO
712 0.0 90.0 90.0 AUTO AUTO
duct2 0.0 90.0 90.0 AUTO AUTO
-----------------------------------------     !separator
yjun12 35 300.0 1.0 300.0 1.0 1.0
&amp;quot; LEX   VDIR1  VDIR2  VDIR3  DIA   CDK  DELX  DIAB  THICK  COUNT&amp;quot;
706 0.0 90.0 90.0 AUTO AUTO
701 0.0 90.0 90.0 AUTO AUTO
711 0.0 90.0 90.0 AUTO AUTO
duct3 0.0 90.0 90.0 AUTO AUTO
-----------------------------------------     !separator
yjun13 40 300.0 1.0 300.0 1.0 1.0
&amp;quot; LEX   VDIR1  VDIR2  VDIR3  DIA   CDK  DELX  DIAB  THICK  COUNT&amp;quot;
duct14 0.0 90.0 90.0 AUTO AUTO
duct11 0.0 90.0 90.0 AUTO AUTO
duct12 0.0 90.0 90.0 AUTO AUTO
-----------------------------------------     !separator
yjun14 40 300.0 1.0 300.0 1.0 1.0
&amp;quot; LEX   VDIR1  VDIR2  VDIR3  DIA   CDK  DELX  DIAB  THICK  COUNT&amp;quot;
duct10 0.0 90.0 90.0 AUTO AUTO
duct15 0.0 90.0 90.0 AUTO AUTO
duct16 0.0 90.0 90.0 AUTO AUTO
-----------------------------------------     !separator
```

yjun15 40 300.0 1.0 300.0 1.0 1.0
" LEX VDIR1 VDIR2 VDIR3 DIA CDK DELX DIAB THICK COUNT"
duct8 0.0 90.0 90.0 AUTO AUTO
duct17 0.0 90.0 90.0 AUTO AUTO
duct19 0.0 90.0 90.0 AUTO AUTO
---------- !separator
yjun16 40 300.0 1.0 300.0 1.0 1.0
" LEX VDIR1 VDIR2 VDIR3 DIA CDK DELX DIAB THICK COUNT"
duct7 0.0 90.0 90.0 AUTO AUTO
duct55 0.0 90.0 90.0 AUTO AUTO
duct56 0.0 90.0 90.0 AUTO AUTO
---------- !separator
yjun2 80 900 1.05 1100 268083 20106.2 1.0 1.0
" LEX VDIR1 VDIR2 VDIR3 DIA CDK DELX DIAB THICK COUNT"
duct52 90 90 180 AUTO AUTO 80 80 0 1
duct48 -120 -30 90 AUTO AUTO 80 80 0 1
duct49 -150 -60 90 AUTO AUTO 80 80 0 1
duct50 150 -120 90 AUTO AUTO 80 80 0 1
duct51 120 -150 90 AUTO AUTO 80 80 0 1
---------- !separator
yjun3 200 300.0 1.0 300.0 2e6 71628 1.0 1.0
" LEX VDIR1 VDIR2 VDIR3 DIA CDK DELX DIAB THICK COUNT"
duct21 180 90 90 AUTO AUTO 64 200 0 1
818 0.0 90.0 90.0 AUTO AUTO 200 AUTO 0.0 1
---------- !separator
yjun4 110 300.0 1.0 300.0 0.75e6 27300 1.0 1.0
" LEX VDIR1 VDIR2 VDIR3 DIA CDK DELX DIAB THICK COUNT"
duct25 90 180 90 AUTO AUTO 79 110 0 1
duct26 -90 0 90 AUTO AUTO 79 110 0 1
duct38 0 90 90 AUTO 0.99 110 105 0 1
---------- !separator
yjun5 110 300.0 1.0 300.0 0.75e6 27300 1.0 1.0
" LEX VDIR1 VDIR2 VDIR3 DIA CDK DELX DIAB THICK COUNT"
duct26 90 180 90 AUTO AUTO 79 110 0 1
duct27 -90 0 90 AUTO AUTO 79 110 0 1
duct35 0 90 90 AUTO 0.99 110 105 0 1
---------- !separator
yjun6 110 300.0 1.0 300.0 0.75e6 27300 1.0 1.0
" LEX VDIR1 VDIR2 VDIR3 DIA CDK DELX DIAB THICK COUNT"
duct28 90 180 90 AUTO AUTO 79 110 0 1
duct27 -90 0 90 AUTO AUTO 79 110 0 1
duct32 0 90 90 AUTO 0.99 110 105 0 1
---------- !separator
yjun7 110 300.0 1.0 300.0 0.75e6 27300 1.0 1.0
" LEX VDIR1 VDIR2 VDIR3 DIA CDK DELX DIAB THICK COUNT"
duct28 90 180 90 AUTO AUTO 79 110 0 1
duct29 0 90 90 AUTO 0.99 110 105 0 1
---------- !separator
yjun8 50 300.0 .9 300.0 1.0 1.0
" LEX VDIR1 VDIR2 VDIR3 DIA CDK DELX DIAB THICK COUNT"
duct53 0.0 90.0 90.0 AUTO AUTO
973 0.0 90.0 90.0 AUTO AUTO
duct58 0.0 90.0 90.0 AUTO AUTO
---------- !separator
yjun9 35 300.0 1.0 300.0 1.0 1.0
" LEX VDIR1 VDIR2 VDIR3 DIA CDK DELX DIAB THICK COUNT"
704 0.0 90.0 90.0 AUTO AUTO
714 0.0 90.0 90.0 AUTO AUTO
707 0.0 90.0 90.0 AUTO AUTO
duct6 0.0 90.0 90.0 AUTO AUTO
LOAD:DRIVELINE ==========
auto_maximum_acceleration
T/C:COMPRESSOR ==========
TURBO.TCC
Compressor IN: 841 OUT: 818 Turbine
BAL 80000 1.0 -1 1.0 off 50 off OFF 85.0
tot stat

```
1.0 1.0 1.0 n 0.0
T/C:TURBINE ============================================================================
gt20_35_
Turbine IN:  duct54 OUT: 973  Compressor
OFF 0
BAL 0.0 1.0 1.0 1.0
tot stat
1.0 1.0 1.0 N 0.0
VAL:BOUNCE ============================================================================
&amp;quot;#NVB     RATEUP     DAMPUP     RATEDOWN     DAMPDOWN&amp;quot;
#4 .008 6000 .008 6000
VAL:VALVES ============================================================================
#1 lift {ivdia} 330 0
crank 0 1.0 1.4 1.0
FILE: SI1INT
FILE: CFTYP
---------------------------------------------------- !(separator)
#2 lift {evdia} 105 0
crank 0 1.0 1.3 1.0
FILE: SI1EXH
FILE: CFTYP
---------------------------------------------------- !(separator)
#3 butterfly
60 5 5
VLI2:
 5 85.22 #
CDF2:
 0.5 1.0 #
CDR2:
 0.5 1.0 #
---------------------------------------------------- !(separator)
#4 pressure 25 0.0 0.0
0 22
VLI3:
 0 23 #
XMRD:
 100 100 #
CSRD:
 8000 8000 #
DPRD:
 6000 6000 #
ARDF:
 0 1 #
ARDR:
 0 1 #
VLI2:
 0 0.026 0.046 0.066 0.096 0.116 0.146 0.172 0.204 0.232 0.27 0.304 0.34 0.384 0.428
 0.474 0.506 0.544 0.598 0.638 0.668 0.712 0.75 0.9 #
CDF2:
 0 0.06105 0.11055 0.1584 0.23265 0.28215 0.35805 0.4224 0.5049 0.57585 0.66 0.7293
 0.7887 0.84975 0.89595 0.9273 0.94215 0.9537 0.9669 0.97185 0.9735 0.9735 0.9735
 0.9735 #
CDR2:
 0 0.06105 0.11055 0.1584 0.23265 0.28215 0.35805 0.4224 0.5049 0.57585 0.66 0.7293
 0.7887 0.84975 0.89595 0.9273 0.94215 0.9537 0.9669 0.97185 0.9735 0.9735 0.9735
 0.9735 #
 END:RUN ============================================================================
</datfile>
<model>
 <case number="1">
  <block name="BAS:CONSTANTS">
   <constant name="A_F" value="13.5"/>
   <constant name="BDUR" value="31" units="deg"/>
   <constant name="CA50" value="8" units="deg"/>
   <constant name="CAT_TEMP" value="1075" units="K"/>
   <constant name="EVDIA" value="30" units="mm"/>
   <constant name="FARAT" value="0.083333"/>
```

```
  <constant name="HEAD_TEMP" value="635" units="K"/>
  <constant name="IVDIA" value="28" units="mm"/>
  <constant name="LINER_TEMP" value="615" units="K"/>
  <constant name="load" value="1.5" units="kg*m^2"/>
  <constant name="LR" value="5" units="cm"/>
  <constant name="NCYC" value="300" units="cycles"/>
  <constant name="PISTON_TEMP" value="595" units="K"/>
  <constant name="PWM" value="80"/>
  <constant name="SPEED" value="900" units="rpm"/>
  <constant name="THROTTLE_ANGLE" value="5" units="deg"/>
  <constant name="ZD" value="6" units="cm"/>
</block>
<block name="BAS:GENERAL PARAMETERS">
  <var type="text" name="autoconverge" val="0.01"/>
  <var type="text" name="ccc" val="1"/>
  <var type="text" name="compressibility" val=""/>
  <var type="text" name="dumpckp" val="N"/>
  <var type="text" name="duration" val="100" units="cycles"/>
  <var type="text" name="end_of_cycle_angle" val="auto" units="deg"/>
  <var type="fileref" name="fuelfile" ref_type="tag" val="INDOLENE"/>
  <var type="text" name="max_timestep_size" val="1.0" units="deg"/>
  <var type="text" name="restart" val="N"/>
  <var type="text" name="skipinit" val="Y"/>
  <var type="text" name="time_step_multipier" val="0.8"/>
  <var type="text" name="units" val="SIMM"/>
</block>
<block name="BAS:OUTPUT &amp;amp; PLOTTING">
  <var type="toggle" name="animate" val="N"/>
  <var type="toggle" name="diesel3d" val="N"/>
  <var type="toggle" name="fixstep" val="NULL"/>
  <var type="text" name="font" val="DRAFT"/>
  <var type="array" name="iout" size="10">
    <val>0</val>
    <val>0</val>
    <val>0</val>
    <val>0</val>
    <val>0</val>
    <val>0</val>
    <val>0</val>
    <val>0</val>
    <val>0</val>
    <val>0</val>
  </var>
  <var type="text" name="max_warnings" val="25"/>
  <var type="text" name="plot_format" val="POSTSCRIPT"/>
  <var type="toggle" name="soundtrace" val="N"/>
  <var type="toggle" name="steadytrace" val="N"/>
  <var type="text" name="storage_interval" val="auto"/>
  <var type="text" name="sumfreq" val="case"/>
  <var type="text" name="summary" val="all"/>
  <var type="text" name="tzoom0" val="0" units="deg"/>
  <var type="text" name="tzoom1" val="0" units="deg"/>
  <var type="text" name="warnfreq" val="case"/>
  <var type="toggle" name="writemon" val="N"/>
  <var type="text" name="zoom" val="FULL"/>
</block>
<block name="CTL:ACTUATOR">
  <actuator name="throttle_pedal" is_valve="false">
    <var type="text" name="bandwidth" val="inst" units="Hz"/>
    <var type="toggle" name="create_plot" val="on"/>
    <var type="array" name="locs" size="1">
      <val>THROTTLE</val>
    </var>
    <var type="text" name="pin_number" val=""/>
    <var type="toggle" name="pulse_control1" val="off"/>
    <var type="toggle" name="pulse_control2" val="off"/>
    <var type="toggle" name="pulse_control3" val="off"/>
```

```
    <var type="toggle" name="pulse_control4" val="off"/>
    <var type="toggle" name="pulse_control5" val="off"/>
    <var type="toggle" name="pulse_control6" val="off"/>
    <var type="toggle" name="pulse_control7" val="off"/>
    <var type="toggle" name="pulse_control8" val="off"/>
    <var type="text" name="type" val="ANGLE_DEG"/>
    <var type="text" name="y_max" val="auto"/>
    <var type="text" name="y_min" val="auto"/>
    <appearance x="-280" y="-360" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Actuator"/>
   </actuator>
   <actuator name="Solenoid_valve2" is_valve="false">
    <var type="text" name="bandwidth" val="inst" units="Hz"/>
    <var type="toggle" name="create_plot" val="off"/>
    <var type="array" name="locs" size="1">
     <val>amb1</val>
    </var>
    <var type="text" name="pin_number" val=""/>
    <var type="toggle" name="pulse_control1" val="off"/>
    <var type="toggle" name="pulse_control2" val="off"/>
    <var type="toggle" name="pulse_control3" val="off"/>
    <var type="toggle" name="pulse_control4" val="off"/>
    <var type="toggle" name="pulse_control5" val="off"/>
    <var type="toggle" name="pulse_control6" val="off"/>
    <var type="toggle" name="pulse_control7" val="off"/>
    <var type="toggle" name="pulse_control8" val="off"/>
    <var type="text" name="type" val="PRESSURE"/>
    <var type="text" name="y_max" val="auto"/>
    <var type="text" name="y_min" val="auto"/>
    <appearance x="680" y="40" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Actuator"/>
   </actuator>
  </block>
  <block name="CTL:SENSOR">
   <sensor name="sensor1">
    <var type="text" name="bandwidth" val="inst" units="Hz"/>
    <var type="text" name="bandwidth_freq" val="0.0" units="Hz"/>
    <var type="toggle" name="create_plot" val="off"/>
    <var type="text" name="ductlocation" val="0.0" units="mm"/>
    <var type="text" name="filter" val="0.0" units="Hz"/>
    <var type="text" name="filter_freq" val="inst" units="Hz"/>
    <var type="text" name="location" val="THROTTLE"/>
    <var type="toggle" name="massflow_create_plot" val="off"/>
    <var type="text" name="massflow_y_max" val="auto"/>
    <var type="text" name="massflow_y_min" val="auto"/>
    <var type="toggle" name="molefraction_create_plot" val="off"/>
    <var type="text" name="molefraction_y_max" val="auto"/>
    <var type="text" name="molefraction_y_min" val="auto"/>
    <var type="toggle" name="passive_create_plot" val="off"/>
    <var type="text" name="passive_y_max" val="auto"/>
    <var type="text" name="passive_y_min" val="auto"/>
    <var type="text" name="pin_number" val=""/>
    <var type="text" name="position" val="0.0" units="mm"/>
    <var type="text" name="type" val="FLOW"/>
    <var type="text" name="y_max" val="auto"/>
    <var type="text" name="y_min" val="auto"/>
    <appearance x="40" y="280" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Sensor"/>
   </sensor>
   <sensor name="Boost">
    <var type="text" name="bandwidth" val="inst" units="Hz"/>
    <var type="text" name="bandwidth_freq" val="0.0" units="Hz"/>
    <var type="toggle" name="create_plot" val="on"/>
    <var type="text" name="ductlocation" val="0.0" units="mm"/>
    <var type="text" name="filter" val="0.0" units="Hz"/>
    <var type="text" name="filter_freq" val="inst" units="Hz"/>
    <var type="text" name="location" val="yjun3"/>
```

```
  <var type="toggle" name="massflow_create_plot" val="off"/>
  <var type="text" name="massflow_y_max" val="auto"/>
  <var type="text" name="massflow_y_min" val="auto"/>
  <var type="toggle" name="molefraction_create_plot" val="off"/>
  <var type="text" name="molefraction_y_max" val="auto"/>
  <var type="text" name="molefraction_y_min" val="auto"/>
  <var type="toggle" name="passive_create_plot" val="off"/>
  <var type="text" name="passive_y_max" val="auto"/>
  <var type="text" name="passive_y_min" val="auto"/>
  <var type="text" name="pin_number" val=""/>
  <var type="text" name="position" val="0.0" units="mm"/>
  <var type="text" name="type" val="PRESSURE"/>
  <var type="text" name="y_max" val="auto"/>
  <var type="text" name="y_min" val="auto"/>
  <edge output="out" to="function1" input="in1" user="false">
    <x _size="4">0 71.5625 71.5625 143.125 </x>
    <y _size="4">-66 -66 -160 -160 </y>
  </edge>
  <appearance x="0" y="-80" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Sensor"/>
 </sensor>
 <sensor name="WGlift">
  <var type="text" name="bandwidth" val="inst" units="Hz"/>
  <var type="text" name="bandwidth_freq" val="0.0" units="Hz"/>
  <var type="toggle" name="create_plot" val="on"/>
  <var type="text" name="ductlocation" val="0.0" units="mm"/>
  <var type="text" name="filter" val="0.0" units="Hz"/>
  <var type="text" name="filter_freq" val="inst" units="Hz"/>
  <var type="text" name="location" val="wastegate"/>
  <var type="toggle" name="massflow_create_plot" val="off"/>
  <var type="text" name="massflow_y_max" val="auto"/>
  <var type="text" name="massflow_y_min" val="auto"/>
  <var type="toggle" name="molefraction_create_plot" val="off"/>
  <var type="text" name="molefraction_y_max" val="auto"/>
  <var type="text" name="molefraction_y_min" val="auto"/>
  <var type="toggle" name="passive_create_plot" val="off"/>
  <var type="text" name="passive_y_max" val="auto"/>
  <var type="text" name="passive_y_min" val="auto"/>
  <var type="text" name="pin_number" val=""/>
  <var type="text" name="position" val="0.0" units="mm"/>
  <var type="text" name="type" val="POSITION"/>
  <var type="text" name="y_max" val="auto"/>
  <var type="text" name="y_min" val="auto"/>
  <appearance x="1360" y="80" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Sensor"/>
 </sensor>
 <sensor name="MAP">
  <var type="text" name="bandwidth" val="inst" units="Hz"/>
  <var type="text" name="bandwidth_freq" val="0.0" units="Hz"/>
  <var type="toggle" name="create_plot" val="on"/>
  <var type="text" name="ductlocation" val="0.0" units="mm"/>
  <var type="text" name="filter" val="0.0" units="Hz"/>
  <var type="text" name="filter_freq" val="inst" units="Hz"/>
  <var type="text" name="location" val="yjun6"/>
  <var type="toggle" name="massflow_create_plot" val="off"/>
  <var type="text" name="massflow_y_max" val="auto"/>
  <var type="text" name="massflow_y_min" val="auto"/>
  <var type="toggle" name="molefraction_create_plot" val="off"/>
  <var type="text" name="molefraction_y_max" val="auto"/>
  <var type="text" name="molefraction_y_min" val="auto"/>
  <var type="toggle" name="passive_create_plot" val="off"/>
  <var type="text" name="passive_y_max" val="auto"/>
  <var type="text" name="passive_y_min" val="auto"/>
  <var type="text" name="pin_number" val=""/>
  <var type="text" name="position" val="0.0" units="mm"/>
  <var type="text" name="type" val="PRESSURE"/>
  <var type="text" name="y_max" val="auto"/>
```

```
  <var type="text" name="y_min" val="auto"/>
  <edge output="out" to="function2" input="in1" user="false">
    <x _size="4">-160 -128.438 -128.438 -96.875 </x>
    <y _size="4">694 694 -280 -280 </y>
  </edge>
  <appearance x="-160" y="680" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Sensor"/>
 </sensor>
 <sensor name="EGT">
  <var type="text" name="bandwidth" val="inst" units="Hz"/>
  <var type="text" name="bandwidth_freq" val="0.0" units="Hz"/>
  <var type="toggle" name="create_plot" val="off"/>
  <var type="text" name="ductlocation" val="0.0" units="mm"/>
  <var type="text" name="filter" val="0.0" units="Hz"/>
  <var type="text" name="filter_freq" val="inst" units="Hz"/>
  <var type="text" name="location" val="yjun2"/>
  <var type="toggle" name="massflow_create_plot" val="off"/>
  <var type="text" name="massflow_y_max" val="auto"/>
  <var type="text" name="massflow_y_min" val="auto"/>
  <var type="toggle" name="molefraction_create_plot" val="off"/>
  <var type="text" name="molefraction_y_max" val="auto"/>
  <var type="text" name="molefraction_y_min" val="auto"/>
  <var type="toggle" name="passive_create_plot" val="off"/>
  <var type="text" name="passive_y_max" val="auto"/>
  <var type="text" name="passive_y_min" val="auto"/>
  <var type="text" name="pin_number" val=""/>
  <var type="text" name="position" val="0.0" units="mm"/>
  <var type="text" name="type" val="TEMPERATURE"/>
  <var type="text" name="y_max" val="auto"/>
  <var type="text" name="y_min" val="auto"/>
  <appearance x="1000" y="520" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Sensor"/>
 </sensor>
 <sensor name="EGP">
  <var type="text" name="bandwidth" val="inst" units="Hz"/>
  <var type="text" name="bandwidth_freq" val="0.0" units="Hz"/>
  <var type="toggle" name="create_plot" val="off"/>
  <var type="text" name="ductlocation" val="0.0" units="mm"/>
  <var type="text" name="filter" val="0.0" units="Hz"/>
  <var type="text" name="filter_freq" val="inst" units="Hz"/>
  <var type="text" name="location" val="yjun2"/>
  <var type="toggle" name="massflow_create_plot" val="off"/>
  <var type="text" name="massflow_y_max" val="auto"/>
  <var type="text" name="massflow_y_min" val="auto"/>
  <var type="toggle" name="molefraction_create_plot" val="off"/>
  <var type="text" name="molefraction_y_max" val="auto"/>
  <var type="text" name="molefraction_y_min" val="auto"/>
  <var type="toggle" name="passive_create_plot" val="off"/>
  <var type="text" name="passive_y_max" val="auto"/>
  <var type="text" name="passive_y_min" val="auto"/>
  <var type="text" name="pin_number" val=""/>
  <var type="text" name="position" val="0.0" units="mm"/>
  <var type="text" name="type" val="PRESSURE"/>
  <var type="text" name="y_max" val="auto"/>
  <var type="text" name="y_min" val="auto"/>
  <appearance x="1040" y="440" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Sensor"/>
 </sensor>
 <sensor name="Ti">
  <var type="text" name="bandwidth" val="inst" units="Hz"/>
  <var type="text" name="bandwidth_freq" val="0.0" units="Hz"/>
  <var type="toggle" name="create_plot" val="off"/>
  <var type="text" name="ductlocation" val="0.0" units="mm"/>
  <var type="text" name="filter" val="0.0" units="Hz"/>
  <var type="text" name="filter_freq" val="inst" units="Hz"/>
  <var type="text" name="location" val="yjun6"/>
  <var type="toggle" name="massflow_create_plot" val="off"/>
```

```
  <var type="text" name="massflow_y_max" val="auto"/>
  <var type="text" name="massflow_y_min" val="auto"/>
  <var type="toggle" name="molefraction_create_plot" val="off"/>
  <var type="text" name="molefraction_y_max" val="auto"/>
  <var type="text" name="molefraction_y_min" val="auto"/>
  <var type="toggle" name="passive_create_plot" val="off"/>
  <var type="text" name="passive_y_max" val="auto"/>
  <var type="text" name="passive_y_min" val="auto"/>
  <var type="text" name="pin_number" val=""/>
  <var type="text" name="position" val="0.0" units="mm"/>
  <var type="text" name="type" val="TEMPERATURE"/>
  <var type="text" name="y_max" val="auto"/>
  <var type="text" name="y_min" val="auto"/>
  <appearance x="-160" y="760" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Sensor"/>
 </sensor>
 <sensor name="RPM">
  <var type="text" name="bandwidth" val="inst" units="Hz"/>
  <var type="text" name="bandwidth_freq" val="0.0" units="Hz"/>
  <var type="toggle" name="create_plot" val="off"/>
  <var type="text" name="ductlocation" val="0.0" units="mm"/>
  <var type="text" name="filter" val="0.0" units="Hz"/>
  <var type="text" name="filter_freq" val="inst" units="Hz"/>
  <var type="text" name="location" val="0"/>
  <var type="toggle" name="massflow_create_plot" val="off"/>
  <var type="text" name="massflow_y_max" val="auto"/>
  <var type="text" name="massflow_y_min" val="auto"/>
  <var type="toggle" name="molefraction_create_plot" val="off"/>
  <var type="text" name="molefraction_y_max" val="auto"/>
  <var type="text" name="molefraction_y_min" val="auto"/>
  <var type="toggle" name="passive_create_plot" val="off"/>
  <var type="text" name="passive_y_max" val="auto"/>
  <var type="text" name="passive_y_min" val="auto"/>
  <var type="text" name="pin_number" val=""/>
  <var type="text" name="position" val="0.0" units="mm"/>
  <var type="text" name="type" val="SPEED_RPM"/>
  <var type="text" name="y_max" val="auto"/>
  <var type="text" name="y_min" val="auto"/>
  <edge output="out" to="wiringconnector1" input="in4" user="false">
   <x _size="4">160 224.599 224.599 289.197 </x>
   <y _size="4">934 934 -280 -280 </y>
  </edge>
  <appearance x="160" y="920" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Sensor"/>
 </sensor>
 <sensor name="sensor2">
  <var type="text" name="bandwidth" val="inst" units="Hz"/>
  <var type="text" name="bandwidth_freq" val="0.0" units="Hz"/>
  <var type="toggle" name="create_plot" val="off"/>
  <var type="text" name="ductlocation" val="0.0" units="mm"/>
  <var type="text" name="filter" val="0.0" units="Hz"/>
  <var type="text" name="filter_freq" val="inst" units="Hz"/>
  <var type="text" name="location" val="amb1"/>
  <var type="toggle" name="massflow_create_plot" val="off"/>
  <var type="text" name="massflow_y_max" val="auto"/>
  <var type="text" name="massflow_y_min" val="auto"/>
  <var type="toggle" name="molefraction_create_plot" val="off"/>
  <var type="text" name="molefraction_y_max" val="auto"/>
  <var type="text" name="molefraction_y_min" val="auto"/>
  <var type="toggle" name="passive_create_plot" val="off"/>
  <var type="text" name="passive_y_max" val="auto"/>
  <var type="text" name="passive_y_min" val="auto"/>
  <var type="text" name="pin_number" val=""/>
  <var type="text" name="position" val="0.0" units="mm"/>
  <var type="text" name="type" val="PRESSURE"/>
  <var type="text" name="y_max" val="auto"/>
  <var type="text" name="y_min" val="auto"/>
```

```
    <appearance x="1160" y="80" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Sensor"/>
   </sensor>
   <sensor name="sensor3">
    <var type="text" name="bandwidth" val="inst" units="Hz"/>
    <var type="text" name="bandwidth_freq" val="0.0" units="Hz"/>
    <var type="toggle" name="create_plot" val="off"/>
    <var type="text" name="ductlocation" val="0.0" units="mm"/>
    <var type="text" name="filter" val="0.0" units="Hz"/>
    <var type="text" name="filter_freq" val="inst" units="Hz"/>
    <var type="text" name="location" val="0"/>
    <var type="toggle" name="massflow_create_plot" val="off"/>
    <var type="text" name="massflow_y_max" val="auto"/>
    <var type="text" name="massflow_y_min" val="auto"/>
    <var type="toggle" name="molefraction_create_plot" val="off"/>
    <var type="text" name="molefraction_y_max" val="auto"/>
    <var type="text" name="molefraction_y_min" val="auto"/>
    <var type="toggle" name="passive_create_plot" val="off"/>
    <var type="text" name="passive_y_max" val="auto"/>
    <var type="text" name="passive_y_min" val="auto"/>
    <var type="text" name="pin_number" val=""/>
    <var type="text" name="position" val="0.0" units="mm"/>
    <var type="text" name="type" val="POWER"/>
    <var type="text" name="y_max" val="auto"/>
    <var type="text" name="y_min" val="auto"/>
    <edge output="out" to="wiringconnector1" input="in5" user="false">
     <x _size="4">680 484.599 484.599 289.197 </x>
     <y _size="4">174 174 -295 -295 </y>
    </edge>
    <appearance x="680" y="160" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Sensor"/>
   </sensor>
  </block>
  <block name="DUC:DUCT DATA">
   <global_friction_multiplier value="1.0"/>
   <global_ht_multiplier value="1.0"/>
   <duct name="701">
    <var type="text" name="count" val="1.0"/>
    <var type="text" name="discretization" val="10" units="cm"/>
    <var type="text" name="friction" val="0.0"/>
    <var type="text" name="heat_transfer" val="1.0"/>
    <var type="text" name="left_discharge_coefficient" val="1.0"/>
    <var type="text" name="overall" val="50" units="mm"/>
    <var type="text" name="pressure" val="1.0" units="bar"/>
    <var type="text" name="pressure_loss" val="0.0"/>
    <var type="text" name="right_discharge_coefficient" val="1.0"/>
    <var type="text" name="roughness_height" val="0" units="um"/>
    <var type="text" name="temperature" val="320" units="K"/>
    <var type="text" name="wall_temperature" val="370." units="K"/>
    <connectivity left="yjun12" right="cyl1"/>
    <appearance network="show">
     <x _size="2">413.537 504.231 </x>
     <y _size="2">641.64 652.625 </y>
    </appearance>
    <comment>
     ! Intake ports
     ! Intake ports
    </comment>
   </duct>
   <duct name="702">
    <var type="text" name="count" val="1.0"/>
    <var type="text" name="discretization" val="10" units="cm"/>
    <var type="text" name="friction" val="0.0"/>
    <var type="text" name="heat_transfer" val="1.0"/>
    <var type="text" name="left_discharge_coefficient" val="1.0"/>
    <var type="text" name="overall" val="50" units="mm"/>
    <var type="text" name="pressure" val="1.0" units="bar"/>
```

```
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="1.0"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="320" units="K"/>
  <var type="text" name="wall_temperature" val="370." units="K"/>
  <connectivity left="yjun11" right="cyl2"/>
  <appearance network="show">
    <x _size="2">413.537 504.231 </x>
    <y _size="2">521.64 532.625 </y>
  </appearance>
 </duct>
 <duct name="703">
  <var type="text" name="count" val="1.0"/>
  <var type="text" name="discretization" val="10" units="cm"/>
  <var type="text" name="friction" val="0.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="1.0"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="1.0"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="320" units="K"/>
  <var type="text" name="wall_temperature" val="370." units="K"/>
  <connectivity left="yjun10" right="cyl3"/>
  <appearance network="show">
    <x _size="2">413.363 517.755 </x>
    <y _size="2">402.717 423.942 </y>
  </appearance>
 </duct>
 <duct name="704">
  <var type="text" name="count" val="1.0"/>
  <var type="text" name="discretization" val="10" units="cm"/>
  <var type="text" name="friction" val="0.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="1.0"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="1.0"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="320" units="K"/>
  <var type="text" name="wall_temperature" val="370." units="K"/>
  <connectivity left="yjun9" right="cyl4"/>
  <appearance network="show">
    <x _size="2">413.363 517.755 </x>
    <y _size="2">282.717 303.942 </y>
  </appearance>
 </duct>
 <duct name="705">
  <var type="text" name="count" val="1.0"/>
  <var type="text" name="discretization" val="10" units="cm"/>
  <var type="text" name="friction" val="0.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="1.0"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="1.0"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="320" units="K"/>
  <var type="text" name="wall_temperature" val="370." units="K"/>
  <connectivity left="yjun11" right="cyl2"/>
  <appearance network="show">
    <x _size="2">413.629 510.815 </x>
    <y _size="2">519.541 516.267 </y>
  </appearance>
```

```
  <comment>
   ! Intake ports
   ! Intake ports
  </comment>
 </duct>
 <duct name="706">
  <var type="text" name="count" val="1.0"/>
  <var type="text" name="discretization" val="10" units="cm"/>
  <var type="text" name="friction" val="0.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="1.0"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="1.0"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="320" units="K"/>
  <var type="text" name="wall_temperature" val="370." units="K"/>
  <connectivity left="yjun12" right="cyl1"/>
  <appearance network="show">
   <x _size="2">413.363 517.755 </x>
   <y _size="2">642.717 663.942 </y>
  </appearance>
  <comment>
   ! Intake ports
   ! Intake ports
  </comment>
 </duct>
 <duct name="707">
  <var type="text" name="count" val="1.0"/>
  <var type="text" name="discretization" val="10" units="cm"/>
  <var type="text" name="friction" val="0.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="1.0"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="1.0"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="320" units="K"/>
  <var type="text" name="wall_temperature" val="370." units="K"/>
  <connectivity left="yjun9" right="cyl4"/>
  <appearance network="show">
   <x _size="2">413.629 510.815 </x>
   <y _size="2">279.541 276.267 </y>
  </appearance>
  <comment>
   ! Intake ports
   ! Intake ports
  </comment>
 </duct>
 <duct name="708">
  <var type="text" name="count" val="1.0"/>
  <var type="text" name="discretization" val="10" units="cm"/>
  <var type="text" name="friction" val="0.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="1.0"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="1.0"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="320" units="K"/>
  <var type="text" name="wall_temperature" val="370." units="K"/>
  <connectivity left="yjun10" right="cyl3"/>
  <appearance network="show">
   <x _size="2">413.629 510.815 </x>
```

```
    <y _size="2">399.541 396.267 </y>
   </appearance>
   <comment>
    ! Intake ports
    ! Intake ports
   </comment>
  </duct>
  <duct name="711">
   <var type="text" name="count" val="1.0"/>
   <var type="text" name="discretization" val="10" units="cm"/>
   <var type="text" name="friction" val="0.0"/>
   <var type="text" name="heat_transfer" val="1.0"/>
   <var type="text" name="left_discharge_coefficient" val="1.0"/>
   <var type="text" name="overall" val="50" units="mm"/>
   <var type="text" name="pressure" val="1.0" units="bar"/>
   <var type="text" name="pressure_loss" val="0.0"/>
   <var type="text" name="right_discharge_coefficient" val="1.0"/>
   <var type="text" name="roughness_height" val="0" units="um"/>
   <var type="text" name="temperature" val="320" units="K"/>
   <var type="text" name="wall_temperature" val="370." units="K"/>
   <connectivity left="yjun12" right="cyl1"/>
   <appearance network="show">
    <x _size="2">413.629 510.815 </x>
    <y _size="2">639.541 636.267 </y>
   </appearance>
  </duct>
  <duct name="712">
   <var type="text" name="count" val="1.0"/>
   <var type="text" name="discretization" val="10" units="cm"/>
   <var type="text" name="friction" val="0.0"/>
   <var type="text" name="heat_transfer" val="1.0"/>
   <var type="text" name="left_discharge_coefficient" val="1.0"/>
   <var type="text" name="overall" val="50" units="mm"/>
   <var type="text" name="pressure" val="1.0" units="bar"/>
   <var type="text" name="pressure_loss" val="0.0"/>
   <var type="text" name="right_discharge_coefficient" val="1.0"/>
   <var type="text" name="roughness_height" val="0" units="um"/>
   <var type="text" name="temperature" val="320" units="K"/>
   <var type="text" name="wall_temperature" val="370." units="K"/>
   <connectivity left="yjun11" right="cyl2"/>
   <appearance network="show">
    <x _size="2">413.363 517.755 </x>
    <y _size="2">522.717 543.942 </y>
   </appearance>
  </duct>
  <duct name="713">
   <var type="text" name="count" val="1.0"/>
   <var type="text" name="discretization" val="10" units="cm"/>
   <var type="text" name="friction" val="0.0"/>
   <var type="text" name="heat_transfer" val="1.0"/>
   <var type="text" name="left_discharge_coefficient" val="1.0"/>
   <var type="text" name="overall" val="50" units="mm"/>
   <var type="text" name="pressure" val="1.0" units="bar"/>
   <var type="text" name="pressure_loss" val="0.0"/>
   <var type="text" name="right_discharge_coefficient" val="1.0"/>
   <var type="text" name="roughness_height" val="0" units="um"/>
   <var type="text" name="temperature" val="320" units="K"/>
   <var type="text" name="wall_temperature" val="370." units="K"/>
   <connectivity left="yjun10" right="cyl3"/>
   <appearance network="show">
    <x _size="2">413.537 504.231 </x>
    <y _size="2">401.64 412.625 </y>
   </appearance>
  </duct>
  <duct name="714">
   <var type="text" name="count" val="1.0"/>
   <var type="text" name="discretization" val="10" units="cm"/>
```

```
  <var type="text" name="friction" val="0.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="1.0"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="1.0"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="320" units="K"/>
  <var type="text" name="wall_temperature" val="370." units="K"/>
  <connectivity left="yjun9" right="cyl4"/>
  <appearance network="show">
    <x _size="2">413.537 504.231 </x>
    <y _size="2">281.64 292.625 </y>
  </appearance>
 </duct>
 <duct name="818">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="3." units="cm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUT"/>
  <var type="text" name="overall" val="5.0" units="cm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUT"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="305" units="K"/>
  <var type="text" name="wall_temperature" val="300" units="K"/>
  <connectivity left="Compressor" right="yjun3"/>
  <appearance network="show">
    <x _size="2">933.5 173.442 </x>
    <y _size="2">-52 77.7061 </y>
  </appearance>
  <comment>
    ! Throttle body
    ! Throttle body
  </comment>
 </duct>
 <duct name="841">
  <var type="text" name="count" val="1.0"/>
  <var type="text" name="discretization" val="3." units="cm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUT"/>
  <var type="text" name="overall" val="25.0" units="cm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUT"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="305" units="K"/>
  <var type="text" name="wall_temperature" val="300" units="K"/>
  <connectivity left="301" right="Compressor"/>
  <appearance network="show">
    <x _size="2">695.305 903.5 </x>
    <y _size="2">-227.126 -52 </y>
  </appearance>
  <comment>
    ! Intake
    ! Intake
  </comment>
 </duct>
 <duct name="973">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="3." units="cm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
```

```
  <var type="text" name="left_discharge_coefficient" val="AUT"/>
  <var type="text" name="overall" val="50.0" units="cm"/>
  <var type="text" name="pressure" val=".9" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUT"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="980" units="K"/>
  <var type="text" name="wall_temperature" val="830" units="K"/>
  <connectivity left="Turbine" right="yjun8"/>
  <appearance network="show">
    <x _size="2">1096.5 1117.1 </x>
    <y _size="2">-52 -146.675 </y>
  </appearance>
  <comment>
    ! Downpipe
    ! Downpipe
  </comment>
 </duct>
 <duct name="Catalyst" type="catalyst">
  <var type="text" name="count" val="7303.29"/>
  <var type="text" name="discretization" val="40" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="5"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="80" units="mm"/>
  <var type="text" name="pressure" val="1.05" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="1100" units="K"/>
  <var type="text" name="wall_temperature" val="{CAT_TEMP}" units="K"/>
  <connectivity left="Entry_Cone" right="Exit_Cone"/>
  <appearance network="show">
    <x _size="2">925.064 994.936 </x>
    <y _size="2">387.339 212.661 </y>
  </appearance>
 </duct>
 <duct name="duct1">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="0"/>
  <var type="text" name="heat_transfer" val="1.5"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="100.0" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="orif15" right="orif1"/>
  <appearance network="show">
    <x _size="2">246.153 313.102 </x>
    <y _size="2">636.878 639.845 </y>
  </appearance>
 </duct>
 <duct name="duct10">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="10" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="30" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
```

```
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="yjun14" right="orif31"/>
  <appearance network="show">
    <x _size="2">613.636 633.1 </x>
    <y _size="2">400 400 </y>
  </appearance>
 </duct>
 <duct name="duct11">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="10" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="30" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="yjun13" right="orif34"/>
  <appearance network="show">
    <x _size="2">613.636 633.1 </x>
    <y _size="2">280 280 </y>
  </appearance>
 </duct>
 <duct name="duct12">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="10" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="cyl4" right="yjun13"/>
  <appearance network="show">
    <x _size="2">532.696 586.673 </x>
    <y _size="2">294.578 282.887 </y>
  </appearance>
 </duct>
 <duct name="duct13">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="0"/>
  <var type="text" name="heat_transfer" val="1.5"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="100.0" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="orif24" right="orif7"/>
  <appearance network="show">
    <x _size="2">246.153 313.102 </x>
    <y _size="2">276.878 279.845 </y>
  </appearance>
 </duct>
 <duct name="duct14">
  <var type="text" name="count" val="1"/>
```

```
  <var type="text" name="discretization" val="10" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="cyl4" right="yjun13"/>
  <appearance network="show">
    <x _size="2">528.408 586.372 </x>
    <y _size="2">277.474 279.519 </y>
  </appearance>
 </duct>
 <duct name="duct15">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="10" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="cyl3" right="yjun14"/>
  <appearance network="show">
    <x _size="2">532.696 586.673 </x>
    <y _size="2">414.578 402.887 </y>
  </appearance>
 </duct>
 <duct name="duct16">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="10" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="cyl3" right="yjun14"/>
  <appearance network="show">
    <x _size="2">528.408 586.372 </x>
    <y _size="2">397.474 399.519 </y>
  </appearance>
 </duct>
 <duct name="duct17">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="10" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
```

```
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="cyl2" right="yjun15"/>
  <appearance network="show">
    <x _size="2">528.408 586.372 </x>
    <y _size="2">517.474 519.519 </y>
  </appearance>
 </duct>
 <duct name="duct18">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="40" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="40" units="mm"/>
  <var type="text" name="pressure" val="1.05" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="1100" units="K"/>
  <var type="text" name="wall_temperature" val="750" units="K"/>
  <connectivity left="orif25" right="orif26"/>
  <appearance network="show">
    <x _size="2">646.9 713.1 </x>
    <y _size="2">640 640 </y>
  </appearance>
 </duct>
 <duct name="duct19">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="10" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="cyl2" right="yjun15"/>
  <appearance network="show">
    <x _size="2">532.696 586.673 </x>
    <y _size="2">534.578 522.887 </y>
  </appearance>
 </duct>
 <duct name="duct2">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="30.0" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="100.0" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="orif3" right="yjun11"/>
  <appearance network="show">
    <x _size="2">326.898 386.364 </x>
    <y _size="2">520.155 520.029 </y>
  </appearance>
 </duct>
 <duct name="duct20">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="10" units="mm"/>
```

```
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="5" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="amb1" right="wastegate"/>
  <appearance network="show">
    <x _size="2">1055.13 1149.29 </x>
    <y _size="2">66.9183 -14.5 </y>
  </appearance>
 </duct>
 <duct name="duct21">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="250" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="yjun3" right="orif10"/>
  <appearance network="show">
    <x _size="2">146.364 6.9 </x>
    <y _size="2">80 80 </y>
  </appearance>
 </duct>
 <duct name="duct22">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="150" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="orif10" right="orif11"/>
  <appearance network="show">
    <x _size="4">-6.9 -40 -80 -80 </x>
    <y _size="4">80 80 120 193.1 </y>
  </appearance>
 </duct>
 <duct name="duct23">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
```

```
  <connectivity left="orif11" right="THROTTLE"/>
  <appearance network="show">
    <x _size="2">-80 -80 </x>
    <y _size="2">206.9 270.1 </y>
  </appearance>
 </duct>
 <duct name="duct24">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="THROTTLE" right="orif13"/>
  <appearance network="show">
    <x _size="2">-80 -80 </x>
    <y _size="2">289.9 353.1 </y>
  </appearance>
 </duct>
 <duct name="duct25">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="150" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="orif13" right="yjun4"/>
  <appearance network="show">
    <x _size="2">-80 -80 </x>
    <y _size="2">366.9 426.364 </y>
  </appearance>
 </duct>
 <duct name="duct26">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="0" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="yjun4" right="yjun5"/>
  <appearance network="show">
    <x _size="2">-80 -80 </x>
    <y _size="2">453.636 546.364 </y>
  </appearance>
 </duct>
 <duct name="duct27">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
```

```
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="0" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="yjun5" right="yjun6"/>
  <appearance network="show">
    <x _size="2">-80 -80 </x>
    <y _size="2">573.636 666.364 </y>
  </appearance>
 </duct>
 <duct name="duct28">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="0" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="yjun6" right="yjun7"/>
  <appearance network="show">
    <x _size="2">-80 -80 </x>
    <y _size="2">693.636 786.364 </y>
  </appearance>
 </duct>
 <duct name="duct29">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="100" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="yjun7" right="orif12"/>
  <appearance network="show">
    <x _size="2">-66.3636 33.1 </x>
    <y _size="2">800 800 </y>
  </appearance>
 </duct>
 <duct name="duct3">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="30.0" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="100.0" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="orif1" right="yjun12"/>
```

```
  <appearance network="show">
    <x _size="2">326.898 386.364 </x>
    <y _size="2">640.155 640.029 </y>
  </appearance>
 </duct>
 <duct name="duct30">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="100" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="orif12" right="orif14"/>
  <appearance network="show">
    <x _size="3">46.9 80 155.169 </x>
    <y _size="3">800 800 724.926 </y>
  </appearance>
 </duct>
 <duct name="duct31">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="150" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="orif14" right="orif15"/>
  <appearance network="show">
    <x _size="2">164.831 233.847 </x>
    <y _size="2">715.074 643.122 </y>
  </appearance>
 </duct>
 <duct name="duct32">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="100" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="yjun6" right="orif16"/>
  <appearance network="show">
    <x _size="2">-66.3636 33.1 </x>
    <y _size="2">680 680 </y>
  </appearance>
 </duct>
 <duct name="duct33">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
```

```
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="100" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="orif16" right="orif17"/>
  <appearance network="show">
    <x _size="3">46.9 80 155.169 </x>
    <y _size="3">680 680 604.926 </y>
  </appearance>
 </duct>
 <duct name="duct34">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="150" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="orif17" right="orif18"/>
  <appearance network="show">
    <x _size="2">164.831 233.847 </x>
    <y _size="2">595.074 523.122 </y>
  </appearance>
 </duct>
 <duct name="duct35">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="100" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="yjun5" right="orif19"/>
  <appearance network="show">
    <x _size="2">-66.3636 33.1 </x>
    <y _size="2">560 560 </y>
  </appearance>
 </duct>
 <duct name="duct36">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="100" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="orif19" right="orif20"/>
  <appearance network="show">
```

```
    <x _size="3">46.9 80 155.169 </x>
    <y _size="3">560 560 484.926 </y>
   </appearance>
  </duct>
  <duct name="duct37">
   <var type="text" name="count" val="1"/>
   <var type="text" name="discretization" val="35" units="mm"/>
   <var type="text" name="friction" val="1.0"/>
   <var type="text" name="heat_transfer" val="1.0"/>
   <var type="text" name="left_discharge_coefficient" val="auto"/>
   <var type="text" name="overall" val="150" units="mm"/>
   <var type="text" name="pressure" val="1.0" units="bar"/>
   <var type="text" name="pressure_loss" val="0.0"/>
   <var type="text" name="right_discharge_coefficient" val="auto"/>
   <var type="text" name="roughness_height" val="0" units="um"/>
   <var type="text" name="temperature" val="300.0" units="K"/>
   <var type="text" name="wall_temperature" val="300.0" units="K"/>
   <connectivity left="orif20" right="orif21"/>
   <appearance network="show">
    <x _size="2">164.831 233.847 </x>
    <y _size="2">475.074 403.122 </y>
   </appearance>
  </duct>
  <duct name="duct38">
   <var type="text" name="count" val="1"/>
   <var type="text" name="discretization" val="35" units="mm"/>
   <var type="text" name="friction" val="1.0"/>
   <var type="text" name="heat_transfer" val="1.0"/>
   <var type="text" name="left_discharge_coefficient" val="auto"/>
   <var type="text" name="overall" val="100" units="mm"/>
   <var type="text" name="pressure" val="1.0" units="bar"/>
   <var type="text" name="pressure_loss" val="0.0"/>
   <var type="text" name="right_discharge_coefficient" val="auto"/>
   <var type="text" name="roughness_height" val="0" units="um"/>
   <var type="text" name="temperature" val="300.0" units="K"/>
   <var type="text" name="wall_temperature" val="300.0" units="K"/>
   <connectivity left="yjun4" right="orif22"/>
   <appearance network="show">
    <x _size="2">-66.3636 33.1 </x>
    <y _size="2">440 440 </y>
   </appearance>
  </duct>
  <duct name="duct39">
   <var type="text" name="count" val="1"/>
   <var type="text" name="discretization" val="35" units="mm"/>
   <var type="text" name="friction" val="1.0"/>
   <var type="text" name="heat_transfer" val="1.0"/>
   <var type="text" name="left_discharge_coefficient" val="auto"/>
   <var type="text" name="overall" val="100" units="mm"/>
   <var type="text" name="pressure" val="1.0" units="bar"/>
   <var type="text" name="pressure_loss" val="0.0"/>
   <var type="text" name="right_discharge_coefficient" val="auto"/>
   <var type="text" name="roughness_height" val="0" units="um"/>
   <var type="text" name="temperature" val="300.0" units="K"/>
   <var type="text" name="wall_temperature" val="300.0" units="K"/>
   <connectivity left="orif22" right="orif23"/>
   <appearance network="show">
    <x _size="3">46.9 80 155.169 </x>
    <y _size="3">440 440 364.926 </y>
   </appearance>
  </duct>
  <duct name="duct4">
   <var type="text" name="count" val="1"/>
   <var type="text" name="discretization" val="30.0" units="mm"/>
   <var type="text" name="friction" val="1.0"/>
   <var type="text" name="heat_transfer" val="1.0"/>
   <var type="text" name="left_discharge_coefficient" val="AUTO"/>
```

```
  <var type="text" name="overall" val="100.0" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="orif5" right="yjun10"/>
  <appearance network="show">
    <x _size="2">326.898 386.364 </x>
    <y _size="2">400.155 400.029 </y>
  </appearance>
 </duct>
 <duct name="duct40">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="150" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="orif23" right="orif24"/>
  <appearance network="show">
    <x _size="2">164.831 233.847 </x>
    <y _size="2">355.074 283.122 </y>
  </appearance>
 </duct>
 <duct name="duct41">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="40" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="80" units="mm"/>
  <var type="text" name="pressure" val="1.05" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="1100" units="K"/>
  <var type="text" name="wall_temperature" val="750" units="K"/>
  <connectivity left="orif26" right="orif27"/>
  <appearance network="show">
    <x _size="3">726.9 800 855.554 </x>
    <y _size="3">640 640 566.146 </y>
  </appearance>
 </duct>
 <duct name="duct42">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="40" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="40" units="mm"/>
  <var type="text" name="pressure" val="1.05" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="1100" units="K"/>
  <var type="text" name="wall_temperature" val="750" units="K"/>
  <connectivity left="orif28" right="orif29"/>
  <appearance network="show">
    <x _size="2">646.9 713.1 </x>
```

```
    <y _size="2">520 520 </y>
   </appearance>
  </duct>
  <duct name="duct43">
   <var type="text" name="count" val="1"/>
   <var type="text" name="discretization" val="40" units="mm"/>
   <var type="text" name="friction" val="1.0"/>
   <var type="text" name="heat_transfer" val="1.0"/>
   <var type="text" name="left_discharge_coefficient" val="auto"/>
   <var type="text" name="overall" val="80" units="mm"/>
   <var type="text" name="pressure" val="1.05" units="bar"/>
   <var type="text" name="pressure_loss" val="0.0"/>
   <var type="text" name="right_discharge_coefficient" val="auto"/>
   <var type="text" name="roughness_height" val="0" units="um"/>
   <var type="text" name="temperature" val="1100" units="K"/>
   <var type="text" name="wall_temperature" val="750" units="K"/>
   <connectivity left="orif29" right="orif30"/>
   <appearance network="show">
    <x _size="3">726.9 760 831.945 </x>
    <y _size="3">520 520 492.165 </y>
   </appearance>
  </duct>
  <duct name="duct44">
   <var type="text" name="count" val="1"/>
   <var type="text" name="discretization" val="40" units="mm"/>
   <var type="text" name="friction" val="1.0"/>
   <var type="text" name="heat_transfer" val="1.0"/>
   <var type="text" name="left_discharge_coefficient" val="auto"/>
   <var type="text" name="overall" val="40" units="mm"/>
   <var type="text" name="pressure" val="1.05" units="bar"/>
   <var type="text" name="pressure_loss" val="0.0"/>
   <var type="text" name="right_discharge_coefficient" val="auto"/>
   <var type="text" name="roughness_height" val="0" units="um"/>
   <var type="text" name="temperature" val="1100" units="K"/>
   <var type="text" name="wall_temperature" val="750" units="K"/>
   <connectivity left="orif31" right="orif32"/>
   <appearance network="show">
    <x _size="2">646.9 713.1 </x>
    <y _size="2">400 400 </y>
   </appearance>
  </duct>
  <duct name="duct45">
   <var type="text" name="count" val="1"/>
   <var type="text" name="discretization" val="40" units="mm"/>
   <var type="text" name="friction" val="1.0"/>
   <var type="text" name="heat_transfer" val="1.0"/>
   <var type="text" name="left_discharge_coefficient" val="auto"/>
   <var type="text" name="overall" val="80" units="mm"/>
   <var type="text" name="pressure" val="1.05" units="bar"/>
   <var type="text" name="pressure_loss" val="0.0"/>
   <var type="text" name="right_discharge_coefficient" val="auto"/>
   <var type="text" name="roughness_height" val="0" units="um"/>
   <var type="text" name="temperature" val="1100" units="K"/>
   <var type="text" name="wall_temperature" val="750" units="K"/>
   <connectivity left="orif32" right="orif33"/>
   <appearance network="show">
    <x _size="3">726.9 760 833.523 </x>
    <y _size="3">400 400 427.932 </y>
   </appearance>
  </duct>
  <duct name="duct46">
   <var type="text" name="count" val="1"/>
   <var type="text" name="discretization" val="40" units="mm"/>
   <var type="text" name="friction" val="1.0"/>
   <var type="text" name="heat_transfer" val="1.0"/>
   <var type="text" name="left_discharge_coefficient" val="auto"/>
   <var type="text" name="overall" val="40" units="mm"/>
```

```
  <var type="text" name="pressure" val="1.05" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="1100" units="K"/>
  <var type="text" name="wall_temperature" val="750" units="K"/>
  <connectivity left="orif34" right="orif35"/>
  <appearance network="show">
    <x _size="2">646.9 713.1 </x>
    <y _size="2">280 280 </y>
  </appearance>
 </duct>
 <duct name="duct47">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="40" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="80" units="mm"/>
  <var type="text" name="pressure" val="1.05" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="1100" units="K"/>
  <var type="text" name="wall_temperature" val="750" units="K"/>
  <connectivity left="orif35" right="orif36"/>
  <appearance network="show">
    <x _size="3">726.9 800 854.731 </x>
    <y _size="3">280 280 348.669 </y>
  </appearance>
 </duct>
 <duct name="duct48">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="40" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="120" units="mm"/>
  <var type="text" name="pressure" val="1.05" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="1100" units="K"/>
  <var type="text" name="wall_temperature" val="750" units="K"/>
  <connectivity left="orif27" right="yjun2"/>
  <appearance network="show">
    <x _size="2">863.202 913.004 </x>
    <y _size="2">554.66 470.282 </y>
  </appearance>
 </duct>
 <duct name="duct49">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="40" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="120" units="mm"/>
  <var type="text" name="pressure" val="1.05" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="1100" units="K"/>
  <var type="text" name="wall_temperature" val="750" units="K"/>
  <connectivity left="orif30" right="yjun2"/>
  <appearance network="show">
    <x _size="2">844.825 907.195 </x>
    <y _size="2">487.213 463.402 </y>
```

```
  </appearance>
 </duct>
 <duct name="duct5">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="35" units="mm"/>
  <var type="text" name="friction" val="0"/>
  <var type="text" name="heat_transfer" val="1.5"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="100.0" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="orif18" right="orif3"/>
  <appearance network="show">
    <x _size="2">246.153 313.102 </x>
    <y _size="2">516.878 519.845 </y>
  </appearance>
 </duct>
 <duct name="duct50">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="40" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="120" units="mm"/>
  <var type="text" name="pressure" val="1.05" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="1100" units="K"/>
  <var type="text" name="wall_temperature" val="750" units="K"/>
  <connectivity left="orif33" right="yjun2"/>
  <appearance network="show">
    <x _size="2">846.477 907.072 </x>
    <y _size="2">432.69 454.013 </y>
  </appearance>
 </duct>
 <duct name="duct51">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="40" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="120" units="mm"/>
  <var type="text" name="pressure" val="1.05" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="1100" units="K"/>
  <var type="text" name="wall_temperature" val="750" units="K"/>
  <connectivity left="orif36" right="yjun2"/>
  <appearance network="show">
    <x _size="2">862.475 913.061 </x>
    <y _size="2">360.091 446.762 </y>
  </appearance>
 </duct>
 <duct name="duct52">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="40" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="0" units="mm"/>
  <var type="text" name="pressure" val="1.05" units="bar"/>
```

```
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="1100" units="K"/>
  <var type="text" name="wall_temperature" val="750" units="K"/>
  <connectivity left="yjun2" right="Entry_Cone"/>
  <appearance network="show">
    <x _size="2">919.95 919.985 </x>
    <y _size="2">444.903 413.636 </y>
  </appearance>
 </duct>
 <duct name="duct53">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="10" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="yjun8" right="351"/>
  <appearance network="show">
    <x _size="2">1126.1 1151.06 </x>
    <y _size="2">-172.197 -222.111 </y>
  </appearance>
 </duct>
 <duct name="duct54">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="40" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="100.0" units="mm"/>
  <var type="text" name="pressure" val="1.2" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="1000" units="K"/>
  <var type="text" name="wall_temperature" val="800" units="K"/>
  <connectivity left="Exit_Cone" right="Turbine"/>
  <appearance network="show">
    <x _size="4">993.902 960 1000 1066.5 </x>
    <y _size="4">187.803 120 40 -52 </y>
  </appearance>
 </duct>
 <duct name="duct55">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="10" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="cyl1" right="yjun16"/>
  <appearance network="show">
    <x _size="2">532.696 586.673 </x>
    <y _size="2">654.578 642.887 </y>
  </appearance>
```

```
</duct>
<duct name="duct56">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="10" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="cyl1" right="yjun16"/>
  <appearance network="show">
    <x _size="2">528.408 586.372 </x>
    <y _size="2">637.474 639.519 </y>
  </appearance>
</duct>
<duct name="duct57">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="40" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="auto"/>
  <var type="text" name="overall" val="100.0" units="mm"/>
  <var type="text" name="pressure" val="1.05" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="auto"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="1000" units="K"/>
  <var type="text" name="wall_temperature" val="800" units="K"/>
  <connectivity left="Exit_Cone" right="wastegate"/>
  <appearance network="show">
    <x _size="4">1009.64 1080 1080 1148 </x>
    <y _size="4">190.358 120 80 -47 </y>
  </appearance>
</duct>
<duct name="duct58">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="10" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="50" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="wastegate" right="yjun8"/>
  <appearance network="show">
    <x _size="2">1172 1126.15 </x>
    <y _size="2">-57 -147.827 </y>
  </appearance>
</duct>
<duct name="duct59">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="30.0" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="100.0" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
```

```
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="amb2" right="wastegate"/>
  <appearance network="show">
    <x _size="2">1262.04 1170.71 </x>
    <y _size="2">-71.2063 -26.5 </y>
  </appearance>
 </duct>
 <duct name="duct6">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="30.0" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="100.0" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="orif7" right="yjun9"/>
  <appearance network="show">
    <x _size="2">326.898 386.364 </x>
    <y _size="2">280.155 280.029 </y>
  </appearance>
 </duct>
 <duct name="duct7">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="10" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="30" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="yjun16" right="orif25"/>
  <appearance network="show">
    <x _size="2">613.636 633.1 </x>
    <y _size="2">640 640 </y>
  </appearance>
 </duct>
 <duct name="duct8">
  <var type="text" name="count" val="1"/>
  <var type="text" name="discretization" val="10" units="mm"/>
  <var type="text" name="friction" val="1.0"/>
  <var type="text" name="heat_transfer" val="1.0"/>
  <var type="text" name="left_discharge_coefficient" val="AUTO"/>
  <var type="text" name="overall" val="30" units="mm"/>
  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <connectivity left="yjun15" right="orif28"/>
  <appearance network="show">
    <x _size="2">613.636 633.1 </x>
    <y _size="2">520 520 </y>
  </appearance>
 </duct>
```

```
  <duct name="duct9">
    <var type="text" name="count" val="1"/>
    <var type="text" name="discretization" val="35" units="mm"/>
    <var type="text" name="friction" val="0"/>
    <var type="text" name="heat_transfer" val="1.5"/>
    <var type="text" name="left_discharge_coefficient" val="auto"/>
    <var type="text" name="overall" val="100.0" units="mm"/>
    <var type="text" name="pressure" val="1.0" units="bar"/>
    <var type="text" name="pressure_loss" val="0.0"/>
    <var type="text" name="right_discharge_coefficient" val="auto"/>
    <var type="text" name="roughness_height" val="0" units="um"/>
    <var type="text" name="temperature" val="300.0" units="K"/>
    <var type="text" name="wall_temperature" val="300.0" units="K"/>
    <connectivity left="orif21" right="orif5"/>
    <appearance network="show">
      <x _size="2">246.153 313.102 </x>
      <y _size="2">396.878 399.845 </y>
    </appearance>
  </duct>
</block>
<block name="ENG:HEAT TRANSFER">
  <var type="text" name="aht_head" val="1.6"/>
  <var type="text" name="aht_piston_top" val="1.0"/>
  <var type="text" name="clearance" val="2" units="mm"/>
  <var type="text" name="exhaust_valve_temperature" val="{HEAD_TEMP}" units="K"/>
  <var type="text" name="head_temperature" val="{HEAD_TEMP}" units="K"/>
  <var type="text" name="intake_valve_temperature" val="{HEAD_TEMP}" units="K"/>
  <var type="text" name="liner_temperature" val="{LINER_TEMP}" units="K"/>
  <var type="text" name="model" val="original"/>
  <var type="text" name="piston_top_temperature" val="{PISTON_TEMP}" units="K"/>
  <var type="text" name="predict_swirl" val="N"/>
  <var type="text" name="swirl_ratio" val="0.0"/>
  <var type="text" name="valve_closed_multiplier" val="1.0"/>
  <var type="text" name="valve_open_multiplier" val="1.0"/>
</block>
<block name="ENG:VALVES">
  <eng_valves>
    <var type="text" name="cylinder_number" val="1"/>
    <var type="array" name="ied" size="5">
      <val>i</val>
      <val>i</val>
      <val>e</val>
      <val>e</val>
      <val>i</val>
    </var>
    <var type="text" name="junction" val="cyl1"/>
    <var type="array" name="lexd" size="5">
      <val>701</val>
      <val>711</val>
      <val>duct56</val>
      <val>duct55</val>
      <val>706</val>
    </var>
    <var type="array" name="link" size="5">
      <val></val>
      <val></val>
      <val></val>
      <val></val>
      <val></val>
    </var>
    <var type="array" name="nvd" size="5">
      <val>1</val>
      <val>1</val>
      <val>2</val>
      <val>2</val>
      <val>1</val>
    </var>
```

```
</eng_valves>
<eng_valves>
  <var type="text" name="cylinder_number" val="2"/>
  <var type="array" name="ied" size="5">
    <val>i</val>
    <val>i</val>
    <val>e</val>
    <val>e</val>
    <val>i</val>
  </var>
  <var type="text" name="junction" val="cyl2"/>
  <var type="array" name="lexd" size="5">
    <val>702</val>
    <val>705</val>
    <val>duct17</val>
    <val>duct19</val>
    <val>712</val>
  </var>
  <var type="array" name="link" size="5">
    <val></val>
    <val></val>
    <val></val>
    <val></val>
    <val></val>
  </var>
  <var type="array" name="nvd" size="5">
    <val>1</val>
    <val>1</val>
    <val>2</val>
    <val>2</val>
    <val>1</val>
  </var>
</eng_valves>
<eng_valves>
  <var type="text" name="cylinder_number" val="3"/>
  <var type="array" name="ied" size="5">
    <val>i</val>
    <val>i</val>
    <val>e</val>
    <val>e</val>
    <val>i</val>
  </var>
  <var type="text" name="junction" val="cyl3"/>
  <var type="array" name="lexd" size="5">
    <val>713</val>
    <val>708</val>
    <val>duct16</val>
    <val>duct15</val>
    <val>703</val>
  </var>
  <var type="array" name="link" size="5">
    <val></val>
    <val></val>
    <val></val>
    <val></val>
    <val></val>
  </var>
  <var type="array" name="nvd" size="5">
    <val>1</val>
    <val>1</val>
    <val>2</val>
    <val>2</val>
    <val>1</val>
  </var>
</eng_valves>
<eng_valves>
  <var type="text" name="cylinder_number" val="4"/>
```

```
    <var type="array" name="ied" size="5">
      <val>i</val>
      <val>i</val>
      <val>e</val>
      <val>e</val>
      <val>i</val>
    </var>
    <var type="text" name="junction" val="cyl4"/>
    <var type="array" name="lexd" size="5">
      <val>714</val>
      <val>707</val>
      <val>duct14</val>
      <val>duct12</val>
      <val>704</val>
    </var>
    <var type="array" name="link" size="5">
      <val></val>
      <val></val>
      <val></val>
      <val></val>
      <val></val>
    </var>
    <var type="array" name="nvd" size="5">
      <val>1</val>
      <val>1</val>
      <val>2</val>
      <val>2</val>
      <val>1</val>
    </var>
  </eng_valves>
</block>
<block name="EXT:PINOUT">
  <wiringconnector name="wiringconnector1">
    <edge output="in1" to="Solenoid_Valve" input="P" user="false">
      <x _size="4">289.197 436.161 436.161 583.125 </x>
      <y _size="4">-235 -235 84 84 </y>
    </edge>
    <edge output="in2" to="throttle_pedal" input="in" user="false">
      <x _size="4">289.197 22.5987 22.5987 -244 </x>
      <y _size="4">-250 -250 -324 -324 </y>
    </edge>
    <appearance x="320" y="-280" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Wiring Connector"/>
    <pin name="wiringconnector1_pin1" number="1" type="SOURCE" init="75"/>
    <pin name="wiringconnector1_pin2" number="2" type="SOURCE" init="5"/>
    <pin name="wiringconnector1_pin3" number="3" type="SINK" init="0"/>
    <pin name="wiringconnector1_pin4" number="4" type="SINK" init="900"/>
    <pin name="wiringconnector1_pin5" number="5" type="SINK" init="0"/>
    <pin name="wiringconnector1_pin6" number="6" type="SINK" init="0"/>
  </wiringconnector>
</block>
<block name="JUN:JUNCTION DATA">
  <junction name="301" type="3" subtype="1">
    <var type="text" name="acoustic_end_correction" val="0.0" units="cm"/>
    <var type="text" name="diameter" val="AUT" units="cm"/>
    <var type="text" name="discharge_coefficient" val="AUT"/>
    <var type="text" name="pressure" val="1.000" units="bar"/>
    <var type="text" name="solution_type" val="FIXED"/>
    <var type="text" name="temperature" val="300.0" units="K"/>
    <appearance x="680" y="-240" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Ambient"/>
  </junction>
  <junction name="351" type="3" subtype="1">
    <var type="text" name="acoustic_end_correction" val="0.0" units="cm"/>
    <var type="text" name="diameter" val="AUT" units="cm"/>
    <var type="text" name="discharge_coefficient" val="AUT"/>
    <var type="text" name="pressure" val="1.000" units="bar"/>
```

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  <var type="text" name="solution_type" val="FIXED"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <appearance x="1160" y="-240" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Ambient"/>
</junction>
<junction name="amb1" type="3" subtype="1">
  <var type="text" name="acoustic_end_correction" val="0.0" units="mm"/>
  <var type="text" name="diameter" val="AUTO" units="mm"/>
  <var type="text" name="discharge_coefficient" val="AUTO"/>
  <var type="text" name="pressure" val="100" units="kPa"/>
  <var type="text" name="solution_type" val="FLOATING"/>
  <var type="text" name="temperature" val="32" units="degF"/>
  <appearance x="1040" y="80" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Ambient"/>
</junction>
<junction name="amb2" type="3" subtype="1">
  <var type="text" name="acoustic_end_correction" val="0.0" units="mm"/>
  <var type="text" name="diameter" val="AUTO" units="mm"/>
  <var type="text" name="discharge_coefficient" val="AUTO"/>
  <var type="text" name="pressure" val="100" units="kPa"/>
  <var type="text" name="solution_type" val="FLOATING"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <appearance x="1280" y="-80" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Ambient"/>
</junction>
<junction name="Compressor" type="1" subtype="2">
  <appearance x="920" y="-40" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Fixed Compressor"/>
</junction>
<junction name="cyl1" type="4" subtype="1">
  <var type="text" name="zones" val="SINGLEZONE"/>
  <appearance x="518.781" y="648.977" scale="30" angle="345.924" autoangle="1"
    network="show"/>
  <template name="Default Engine Cylinder"/>
</junction>
<junction name="cyl2" type="4" subtype="1">
  <var type="text" name="zones" val="SINGLEZONE"/>
  <appearance x="518.781" y="528.977" scale="30" angle="345.924" autoangle="1"
    network="show"/>
  <template name="Default Engine Cylinder"/>
</junction>
<junction name="cyl3" type="4" subtype="1">
  <var type="text" name="zones" val="SINGLEZONE"/>
  <appearance x="518.781" y="408.977" scale="30" angle="345.924" autoangle="1"
    network="show"/>
  <template name="Default Engine Cylinder"/>
</junction>
<junction name="cyl4" type="4" subtype="1">
  <var type="text" name="zones" val="SINGLEZONE"/>
  <appearance x="518.781" y="288.977" scale="30" angle="345.924" autoangle="1"
    network="show"/>
  <template name="Default Engine Cylinder"/>
</junction>
<junction name="Entry_Cone" type="5" subtype="2">
  <appearance x="920" y="400" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Complex Y-junction"/>
</junction>
<junction name="Exit_Cone" type="5" subtype="2">
  <appearance x="1000" y="200" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Complex Y-junction"/>
</junction>
<junction name="orif1" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="320" y="640" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif10" type="1" subtype="1">
```

```
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="0" y="80" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif11" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="-80" y="200" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif12" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="40" y="800" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif13" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="-80" y="360" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif14" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="160" y="720" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif15" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="240" y="640" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif16" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="40" y="680" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif17" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="160" y="600" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif18" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="240" y="520" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif19" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="40" y="560" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif20" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="160" y="480" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif21" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="240" y="400" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif22" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="40" y="440" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif23" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="160" y="360" scale="30" angle="0" autoangle="1" network="show"/>
```

```
  <template name="Default Orifice"/>
</junction>
<junction name="orif24" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="240" y="280" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif25" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="640" y="640" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif26" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="720" y="640" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif27" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="859.378" y="560.403" scale="30" angle="0" autoangle="1"
    network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif28" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="640" y="520" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif29" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="720" y="520" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif3" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="320" y="520" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif30" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="838.385" y="489.689" scale="30" angle="0" autoangle="1"
    network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif31" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="640" y="400" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif32" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="720" y="400" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif33" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="840" y="430.311" scale="30" angle="0" autoangle="1"
    network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif34" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="640" y="280" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif35" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
```

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  <appearance x="720" y="280" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif36" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="858.603" y="354.38" scale="30" angle="0" autoangle="1"
     network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif5" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="320" y="400" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="orif7" type="1" subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
  <appearance x="320" y="280" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Orifice"/>
</junction>
<junction name="THROTTLE" type="1" subtype="12">
  <appearance x="-80" y="280" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Throttle Valve"/>
</junction>
<junction name="Turbine" type="1" subtype="3">
  <appearance x="1080" y="-40" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Fixed Turbine"/>
</junction>
<junction name="wastegate" type="1" subtype="6">
  <var type="text" name="count" val="1"/>
  <var type="text" name="diameter" val="25" units="mm"/>
  <var type="text" name="duct_id_above_piston" val="duct60"/>
  <var type="text" name="duct_id_below_piston" val="duct59"/>
  <var type="text" name="flow_direction" val="Left to Right"/>
  <var type="text" name="opening_direction" val="Down"/>
  <var type="text" name="valve#" val="4"/>
  <appearance x="1160" y="-40" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Piston Driven Valve"/>
</junction>
<junction name="yjun10" type="5" subtype="1">
  <appearance x="400" y="400" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Simple Y-junction"/>
</junction>
<junction name="yjun11" type="5" subtype="1">
  <appearance x="400" y="520" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Simple Y-junction"/>
</junction>
<junction name="yjun12" type="5" subtype="1">
  <appearance x="400" y="640" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Simple Y-junction"/>
</junction>
<junction name="yjun13" type="5" subtype="1">
  <appearance x="600" y="280" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Simple Y-junction"/>
</junction>
<junction name="yjun14" type="5" subtype="1">
  <appearance x="600" y="400" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Simple Y-junction"/>
</junction>
<junction name="yjun15" type="5" subtype="1">
  <appearance x="600" y="520" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Simple Y-junction"/>
</junction>
<junction name="yjun16" type="5" subtype="1">
  <appearance x="600" y="640" scale="30" angle="0" autoangle="1" network="show"/>
  <template name="Default Simple Y-junction"/>
</junction>
<junction name="yjun2" type="5" subtype="2">
```

```
    <appearance x="919.935" y="458.539" scale="30" angle="0" autoangle="1"
      network="show"/>
    <template name="Default Complex Y-junction"/>
   </junction>
   <junction name="yjun3" type="5" subtype="2">
    <appearance x="160" y="80" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Complex Y-junction"/>
   </junction>
   <junction name="yjun4" type="5" subtype="2">
    <appearance x="-80" y="440" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Complex Y-junction"/>
   </junction>
   <junction name="yjun5" type="5" subtype="2">
    <appearance x="-80" y="560" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Complex Y-junction"/>
   </junction>
   <junction name="yjun6" type="5" subtype="2">
    <appearance x="-80" y="680" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Complex Y-junction"/>
   </junction>
   <junction name="yjun7" type="5" subtype="2">
    <appearance x="-80" y="800" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Complex Y-junction"/>
   </junction>
   <junction name="yjun8" type="5" subtype="1">
    <appearance x="1120" y="-160" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Simple Y-junction"/>
   </junction>
   <junction name="yjun9" type="5" subtype="1">
    <appearance x="400" y="280" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Simple Y-junction"/>
   </junction>
  </block>
  <block name="VAL:VALVES">
   <valve name="1">
    <var type="text" name="bore_diameter" val="0.0" units="mm"/>
    <var type="text" name="camcr" val="crank"/>
    <var type="text" name="closing_duration" val="0.0" units="deg"/>
    <var type="text" name="crank_timing" val="330" units="deg"/>
    <var type="text" name="diameter" val="{ivdia}" units="mm"/>
    <var type="array" name="flow_coefficients_2d" size="0"/>
    <var type="array" name="flow_ordinates" size="0"/>
    <var type="fileref" name="flowcoeff_file" ref_type="tag" val="CFTYP"/>
    <var type="fileref" name="force_file"/>
    <var type="text" name="force_scaling" val="0.0"/>
    <var type="array" name="forward_flow_coefficients" size="0"/>
    <var type="text" name="fwd_flow_coeff" val="0.0"/>
    <var type="text" name="head_diameter" val="0.0" units="mm"/>
    <var type="text" name="heat_transfer_diameter" val="0.0" units="mm"/>
    <var type="text" name="horizontal_scaling" val="1.0"/>
    <var type="text" name="inner_seat_diameter" val="0.0" units="mm"/>
    <var type="text" name="lash" val="0" units="mm"/>
    <var type="array" name="lift_2d" size="0"/>
    <var type="text" name="lift_curve_type" val="scurv"/>
    <var type="fileref" name="lift_file" ref_type="tag" val="SI1INT"/>
    <var type="text" name="lift_file_type" val="FILE"/>
    <var type="text" name="lift_profile_type" val="THV"/>
    <var type="text" name="max_lift" val="0.0" units="mm"/>
    <var type="text" name="max_lift_to_stop" val="0.0" units="mm"/>
    <var type="text" name="minimum_angle" val="0.0" units="deg"/>
    <var type="text" name="open_duration" val="0.0" units="deg"/>
    <var type="text" name="opening_duration" val="0.0" units="deg"/>
    <var type="text" name="polynomial_type" val="user"/>
    <var type="text" name="preload_distance" val="0.0" units="mm"/>
    <var type="array" name="pressure_2d" size="0"/>
    <var type="array" name="profile_coefficients" size="7">
     <val>0.0</val>
```

```
    <val>0.0</val>
    <val>0.0</val>
    <val>0.0</val>
    <val>0.0</val>
    <val>0.0</val>
    <val>0.0</val>
   </var>
   <var type="text" name="rev_flow_coeff" val="0.0"/>
   <var type="array" name="reverse_flow_coefficients" size="0"/>
   <var type="text" name="rocker_ratio" val="1.0"/>
   <var type="text" name="shaft_diameter" val="0.0" units="mm"/>
   <var type="text" name="solenoid_position" val="Open"/>
   <var type="text" name="stem_diameter" val="0.0" units="mm"/>
   <var type="text" name="stem_pressure" val="0.0" units="bar"/>
   <var type="text" name="swirl_coefficient" val="0.0"/>
   <var type="fileref" name="swirl_file"/>
   <var type="text" name="type" val="lift"/>
   <var type="toggle" name="use_dvalve_r" val="off"/>
   <var type="text" name="valve_timing" val="0" units="deg"/>
   <var type="text" name="vertical_scaling" val="1.4"/>
   <flow_coeff_type value="forward_reverse"/>
   <swirl_coeff_type value="swirl_lift"/>
  </valve>
  <valve name="2">
   <var type="text" name="bore_diameter" val="0.0" units="mm"/>
   <var type="text" name="camcr" val="crank"/>
   <var type="text" name="closing_duration" val="0.0" units="deg"/>
   <var type="text" name="crank_timing" val="105" units="deg"/>
   <var type="text" name="diameter" val="{evdia}" units="mm"/>
   <var type="array" name="flow_coefficients_2d" size="0"/>
   <var type="array" name="flow_ordinates" size="0"/>
   <var type="fileref" name="flowcoeff_file" ref_type="tag" val="CFTYP"/>
   <var type="fileref" name="force_file"/>
   <var type="text" name="force_scaling" val="0.0"/>
   <var type="array" name="forward_flow_coefficients" size="0"/>
   <var type="text" name="fwd_flow_coeff" val="0.0"/>
   <var type="text" name="head_diameter" val="0.0" units="mm"/>
   <var type="text" name="heat_transfer_diameter" val="0.0" units="mm"/>
   <var type="text" name="horizontal_scaling" val="1.0"/>
   <var type="text" name="inner_seat_diameter" val="0.0" units="mm"/>
   <var type="text" name="lash" val="0" units="mm"/>
   <var type="array" name="lift_2d" size="0"/>
   <var type="text" name="lift_curve_type" val="scurv"/>
   <var type="fileref" name="lift_file" ref_type="tag" val="SI1EXH"/>
   <var type="text" name="lift_file_type" val="FILE"/>
   <var type="text" name="lift_profile_type" val="THV"/>
   <var type="text" name="max_lift" val="0.0" units="mm"/>
   <var type="text" name="max_lift_to_stop" val="0.0" units="mm"/>
   <var type="text" name="minimum_angle" val="0.0" units="deg"/>
   <var type="text" name="open_duration" val="0.0" units="deg"/>
   <var type="text" name="opening_duration" val="0.0" units="deg"/>
   <var type="text" name="polynomial_type" val="user"/>
   <var type="text" name="preload_distance" val="0.0" units="mm"/>
   <var type="array" name="pressure_2d" size="0"/>
   <var type="array" name="profile_coefficients" size="7">
    <val>0.0</val>
    <val>0.0</val>
    <val>0.0</val>
    <val>0.0</val>
    <val>0.0</val>
    <val>0.0</val>
    <val>0.0</val>
   </var>
   <var type="text" name="rev_flow_coeff" val="0.0"/>
   <var type="array" name="reverse_flow_coefficients" size="0"/>
   <var type="text" name="rocker_ratio" val="1.0"/>
   <var type="text" name="shaft_diameter" val="0.0" units="mm"/>
```

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  <var type="text" name="solenoid_position" val="Open"/>
  <var type="text" name="stem_diameter" val="0.0" units="mm"/>
  <var type="text" name="stem_pressure" val="0.0" units="bar"/>
  <var type="text" name="swirl_coefficient" val="0.0"/>
  <var type="fileref" name="swirl_file"/>
  <var type="text" name="type" val="lift"/>
  <var type="toggle" name="use_dvalve_r" val="off"/>
  <var type="text" name="valve_timing" val="0" units="deg"/>
  <var type="text" name="vertical_scaling" val="1.3"/>
  <flow_coeff_type value="forward_reverse"/>
  <swirl_coeff_type value="swirl_lift"/>
 </valve>
 <valve name="3">
  <var type="text" name="bore_diameter" val="60" units="mm"/>
  <var type="text" name="camcr" val="crank"/>
  <var type="text" name="closing_duration" val="0.0" units="deg"/>
  <var type="text" name="crank_timing" val="0.0" units="deg"/>
  <var type="text" name="diameter" val="0.0" units="mm"/>
  <var type="array" name="flow_coefficients_2d" size="0"/>
  <var type="array" name="flow_ordinates" size="2">
   <val>5</val>
   <val>85.22</val>
  </var>
  <var type="fileref" name="flowcoeff_file"/>
  <var type="fileref" name="force_file"/>
  <var type="text" name="force_scaling" val="0.0"/>
  <var type="array" name="forward_flow_coefficients" size="2">
   <val>0.5</val>
   <val>1.0</val>
  </var>
  <var type="text" name="fwd_flow_coeff" val="0.0"/>
  <var type="text" name="head_diameter" val="0.0" units="mm"/>
  <var type="text" name="heat_transfer_diameter" val="0.0" units="mm"/>
  <var type="text" name="horizontal_scaling" val="1.0"/>
  <var type="text" name="inner_seat_diameter" val="0.0" units="mm"/>
  <var type="text" name="lash" val="0.0" units="mm"/>
  <var type="array" name="lift_2d" size="0"/>
  <var type="text" name="lift_curve_type" val="scurv"/>
  <var type="fileref" name="lift_file"/>
  <var type="text" name="lift_file_type" val="FILE"/>
  <var type="text" name="lift_profile_type" val="THV"/>
  <var type="text" name="max_lift" val="0.0" units="mm"/>
  <var type="text" name="max_lift_to_stop" val="0.0" units="mm"/>
  <var type="text" name="minimum_angle" val="5" units="deg"/>
  <var type="text" name="open_duration" val="0.0" units="deg"/>
  <var type="text" name="opening_duration" val="0.0" units="deg"/>
  <var type="text" name="polynomial_type" val="user"/>
  <var type="text" name="preload_distance" val="0.0" units="mm"/>
  <var type="array" name="pressure_2d" size="0"/>
  <var type="array" name="profile_coefficients" size="7">
   <val>0.0</val>
   <val>0.0</val>
   <val>0.0</val>
   <val>0.0</val>
   <val>0.0</val>
   <val>0.0</val>
   <val>0.0</val>
  </var>
  <var type="text" name="rev_flow_coeff" val="0.0"/>
  <var type="array" name="reverse_flow_coefficients" size="2">
   <val>0.5</val>
   <val>1.0</val>
  </var>
  <var type="text" name="rocker_ratio" val="1.0"/>
  <var type="text" name="shaft_diameter" val="5" units="mm"/>
  <var type="text" name="solenoid_position" val="Open"/>
  <var type="text" name="stem_diameter" val="0.0" units="mm"/>
```

```
  <var type="text" name="stem_pressure" val="0.0" units="bar"/>
  <var type="text" name="swirl_coefficient" val="0.0"/>
  <var type="fileref" name="swirl_file"/>
  <var type="text" name="type" val="butterfly"/>
  <var type="toggle" name="use_dvalve_r" val="off"/>
  <var type="text" name="valve_timing" val="0.0" units="deg"/>
  <var type="text" name="vertical_scaling" val="1.0"/>
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  <swirl_coeff_type value="swirl_lift"/>
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  <var type="text" name="closing_duration" val="0.0" units="deg"/>
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  <var type="text" name="diameter" val="25" units="mm"/>
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    </column>
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    </column>
    <column name="spring_constant" units="N/m">
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    </column>
    <column name="damping" units="N*s/m">
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    <column name="fwd_area_multiplier">
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  <var type="text" name="force_scaling" val="0.0"/>
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   <val>0.1584</val>
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  <var type="text" name="lift_curve_type" val="scurv"/>
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  <var type="text" name="minimum_angle" val="0.0" units="deg"/>
  <var type="text" name="open_duration" val="0.0" units="deg"/>
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   <val>0.1584</val>
   <val>0.23265</val>
   <val>0.28215</val>
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  <var type="array" name="defaultlocs" size="1">
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  <text>VW 1.8t</text>
  <font face="Draft" size="10"/>
</block>
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  <chk_valves name="wastegate">
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    <var type="text" name="pressdir" val="lr"/>
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  <duc_bends name="duct22">
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</duc_shape>
<duc_shape name="duct54" shape="circular">
  <var type="text" name="left_diameter" val="50" units="mm"/>
  <var type="text" name="right_diameter" val="50" units="mm"/>
</duc_shape>
<duc_shape name="duct55" shape="circular">
  <var type="text" name="left_diameter" val="{evdia}" units="mm"/>
  <var type="text" name="right_diameter" val="{evdia}" units="mm"/>
</duc_shape>
<duc_shape name="duct56" shape="circular">
  <var type="text" name="left_diameter" val="{evdia}" units="mm"/>
  <var type="text" name="right_diameter" val="{evdia}" units="mm"/>
</duc_shape>
<duc_shape name="duct57" shape="circular">
  <var type="text" name="left_diameter" val="50" units="mm"/>
  <var type="text" name="right_diameter" val="50" units="mm"/>
</duc_shape>
<duc_shape name="duct58" shape="circular">
  <var type="text" name="left_diameter" val="50" units="mm"/>
  <var type="text" name="right_diameter" val="50" units="mm"/>
</duc_shape>
<duc_shape name="duct59" shape="circular">
  <var type="text" name="left_diameter" val="25" units="mm"/>
  <var type="text" name="right_diameter" val="25" units="mm"/>
</duc_shape>
<duc_shape name="duct6" shape="circular">
  <var type="text" name="left_diameter" val="35" units="mm"/>
  <var type="text" name="right_diameter" val="35" units="mm"/>
</duc_shape>
<duc_shape name="duct7" shape="circular">
  <var type="text" name="left_diameter" val="40" units="mm"/>
  <var type="text" name="right_diameter" val="40" units="mm"/>
</duc_shape>
<duc_shape name="duct8" shape="circular">
  <var type="text" name="left_diameter" val="40" units="mm"/>
  <var type="text" name="right_diameter" val="40" units="mm"/>
</duc_shape>
<duc_shape name="duct9" shape="circular">
  <var type="text" name="left_diameter" val="40" units="mm"/>
  <var type="text" name="right_diameter" val="35" units="mm"/>
</duc_shape>
```

```
</block>
<block name="ENG:GEOMETRY">
  <var type="text" name="acf" val="0.35" units="bar"/>
  <var type="text" name="bcf" val="0.005"/>
  <var type="text" name="bore" val="81" units="mm"/>
  <var type="text" name="ccf" val="400" units="Pa.min/m"/>
  <var type="text" name="compression_ratio" val="9.5"/>
  <var type="text" name="conrod_length" val="120.0" units="mm"/>
  <var type="text" name="engine_type" val="SI"/>
  <var type="array" name="firing_order" size="4">
    <val>1</val>
    <val>3</val>
    <val>4</val>
    <val>2</val>
  </var>
  <var type="text" name="iout1" val="0"/>
  <var type="text" name="iout2" val="0"/>
  <var type="text" name="iout3" val="0"/>
  <var type="text" name="ncyl" val="4"/>
  <var type="text" name="num_strokes" val="4"/>
  <var type="text" name="piston_bowl_volume" val="0.0" units="mm^3"/>
  <var type="text" name="piston_cup_depth" val="0.0" units="mm"/>
  <var type="text" name="piston_cup_dia" val="0.0" units="mm"/>
  <var type="text" name="piston_cuprim_dia" val="0.0" units="mm"/>
  <var type="text" name="qcf" val="0.2" units="Pa.min^2/m^2"/>
  <var type="text" name="stroke" val="86.4" units="mm"/>
  <var type="array" name="tdc" size="4">
    <val>0</val>
    <val>180</val>
    <val>180</val>
    <val>180</val>
  </var>
  <var type="text" name="wristpin_offset" val="0.0" units="mm"/>
</block>
<block name="ENG:OPERATING PARAMETERS">
  <var type="text" name="reference_pressure" val="1.0" units="bar"/>
  <var type="text" name="reference_temperature" val="298.0" units="K"/>
  <var type="text" name="speed" val="{SPEED}" units="rpm"/>
</block>
<block name="ENG:SI_WIEBE_COMB">
  <var type="text" name="burn_duration" val="{BDUR}" units="deg"/>
  <var type="text" name="burn_fraction" val="1.0"/>
  <var type="text" name="scale_or_limit" val="profile_limit"/>
  <var type="text" name="thb50" val="{CA50}" units="deg"/>
  <var type="text" name="wiebe_exponent" val="2.0"/>
</block>
<block name="INJ:TYPE">
  <injector_type name="1">
    <var type="text" name="air" val="0.0"/>
    <var type="text" name="burned_air" val="0.0"/>
    <var type="text" name="burned_fuel" val="0.0"/>
    <var type="text" name="drop_diameter" val="auto" units="um"/>
    <var type="text" name="evap_fraction" val="0.3"/>
    <var type="text" name="flow_rate" val="0.0" units="kg/hr"/>
    <var type="text" name="fuel_vapor" val="0.9"/>
    <var type="text" name="initial_velocity" val="auto"/>
    <var type="text" name="liquid_fuel" val="0.1"/>
    <var type="profile" name="mass_profile" numcol="2" size="2">
      <column name="time" units="ms">
        <val>0.0</val>
        <val>0.0</val>
      </column>
      <column name="mass" units="mg">
        <val>0.0</val>
        <val>0.0</val>
      </column>
    </var>
```

```
  <var type="text" name="mixture_temp" val="300" units="K"/>
  <var type="profile" name="multipulse_mass_profile" numcol="8" size="2">
    <column name="injpress" units="bar">
      <val>bar</val>
      <val>0.0</val>
    </column>
    <column name="starttime" units="deg">
      <val>deg</val>
      <val>0.0</val>
    </column>
    <column name="riseint" units="ms">
      <val>deg</val>
      <val>0.0</val>
    </column>
    <column name="platint" units="ms">
      <val>deg</val>
      <val>0.0</val>
    </column>
    <column name="fallint" units="ms">
      <val>deg</val>
      <val>0.0</val>
    </column>
    <column name="rise1" units=" ">
      <val></val>
      <val>0.0</val>
    </column>
    <column name="rise2" units=" ">
      <val></val>
      <val>0.0</val>
    </column>
    <column name="injmass" units="kg/hr">
      <val>kg/hr</val>
      <val>0.0</val>
    </column>
  </var>
  <var type="text" name="nozzle_diameter" val="0.2" units="mm"/>
  <var type="profile" name="pressure_profile" numcol="2" size="2">
    <column name="crank_angle" units="deg">
      <val>0.0</val>
      <val>0.0</val>
    </column>
    <column name="pressure" units="bar">
      <val>0.0</val>
      <val>0.0</val>
    </column>
  </var>
  <var type="fileref" name="profile_file"/>
  <var type="profile" name="rate_profile" numcol="2" size="2">
    <column name="crank_angle" units="deg">
      <val>0.0</val>
      <val>0.0</val>
    </column>
    <column name="rate">
      <val>0.0</val>
      <val>0.0</val>
    </column>
  </var>
  <var type="text" name="sac_volume" val="0.0" units="mm^3"/>
  <var type="text" name="spray_angle" val="40" units="deg"/>
  <var type="text" name="type" val="prop"/>
  <var type="text" name="velocity" val="200.0" units="m/s"/>
</injector_type>
<injector_type name="2">
  <var type="text" name="air" val="0.0"/>
  <var type="text" name="burned_air" val="0.0"/>
  <var type="text" name="burned_fuel" val="0.0"/>
  <var type="text" name="drop_diameter" val="auto" units="um"/>
```

```
<var type="text" name="evap_fraction" val="0.3"/>
<var type="text" name="flow_rate" val="0.0" units="kg/hr"/>
<var type="text" name="fuel_vapor" val="0.9"/>
<var type="text" name="initial_velocity" val="auto"/>
<var type="text" name="liquid_fuel" val="0.1"/>
<var type="profile" name="mass_profile" numcol="2" size="2">
  <column name="time" units="ms">
    <val>0.0</val>
    <val>0.0</val>
  </column>
  <column name="mass" units="mg">
    <val>0.0</val>
    <val>0.0</val>
  </column>
</var>
<var type="text" name="mixture_temp" val="300" units="K"/>
<var type="profile" name="multipulse_mass_profile" numcol="8" size="2">
  <column name="injpress" units="bar">
    <val>bar</val>
    <val>0.0</val>
  </column>
  <column name="starttime" units="deg">
    <val>deg</val>
    <val>0.0</val>
  </column>
  <column name="riseint" units="ms">
    <val>deg</val>
    <val>0.0</val>
  </column>
  <column name="platint" units="ms">
    <val>deg</val>
    <val>0.0</val>
  </column>
  <column name="fallint" units="ms">
    <val>deg</val>
    <val>0.0</val>
  </column>
  <column name="rise1" units=" ">
    <val></val>
    <val>0.0</val>
  </column>
  <column name="rise2" units=" ">
    <val></val>
    <val>0.0</val>
  </column>
  <column name="injmass" units="kg/hr">
    <val>kg/hr</val>
    <val>0.0</val>
  </column>
</var>
<var type="text" name="nozzle_diameter" val="0.2" units="mm"/>
<var type="profile" name="pressure_profile" numcol="2" size="2">
  <column name="crank_angle" units="deg">
    <val>0.0</val>
    <val>0.0</val>
  </column>
  <column name="pressure" units="bar">
    <val>0.0</val>
    <val>0.0</val>
  </column>
</var>
<var type="fileref" name="profile_file"/>
<var type="profile" name="rate_profile" numcol="2" size="2">
  <column name="crank_angle" units="deg">
    <val>0.0</val>
    <val>0.0</val>
  </column>
```

```
    <column name="rate">
      <val>0.0</val>
      <val>0.0</val>
    </column>
  </var>
  <var type="text" name="sac_volume" val="0.0" units="mm^3"/>
  <var type="text" name="spray_angle" val="40" units="deg"/>
  <var type="text" name="type" val="prop"/>
  <var type="text" name="velocity" val="200.0" units="m/s"/>
</injector_type>
<injector_type name="3">
  <var type="text" name="air" val="0.0"/>
  <var type="text" name="burned_air" val="0.0"/>
  <var type="text" name="burned_fuel" val="0.0"/>
  <var type="text" name="drop_diameter" val="auto" units="um"/>
  <var type="text" name="evap_fraction" val="0.3"/>
  <var type="text" name="flow_rate" val="0.0" units="kg/hr"/>
  <var type="text" name="fuel_vapor" val="0.9"/>
  <var type="text" name="initial_velocity" val="auto"/>
  <var type="text" name="liquid_fuel" val="0.1"/>
  <var type="profile" name="mass_profile" numcol="2" size="2">
    <column name="time" units="ms">
      <val>0.0</val>
      <val>0.0</val>
    </column>
    <column name="mass" units="mg">
      <val>0.0</val>
      <val>0.0</val>
    </column>
  </var>
  <var type="text" name="mixture_temp" val="300" units="K"/>
  <var type="profile" name="multipulse_mass_profile" numcol="8" size="2">
    <column name="injpress" units="bar">
      <val>bar</val>
      <val>0.0</val>
    </column>
    <column name="starttime" units="deg">
      <val>deg</val>
      <val>0.0</val>
    </column>
    <column name="riseint" units="ms">
      <val>deg</val>
      <val>0.0</val>
    </column>
    <column name="platint" units="ms">
      <val>deg</val>
      <val>0.0</val>
    </column>
    <column name="fallint" units="ms">
      <val>deg</val>
      <val>0.0</val>
    </column>
    <column name="rise1" units=" ">
      <val></val>
      <val>0.0</val>
    </column>
    <column name="rise2" units=" ">
      <val></val>
      <val>0.0</val>
    </column>
    <column name="injmass" units="kg/hr">
      <val>kg/hr</val>
      <val>0.0</val>
    </column>
  </var>
  <var type="text" name="nozzle_diameter" val="0.2" units="mm"/>
  <var type="profile" name="pressure_profile" numcol="2" size="2">
```

```
    <column name="crank_angle" units="deg">
      <val>0.0</val>
      <val>0.0</val>
    </column>
    <column name="pressure" units="bar">
      <val>0.0</val>
      <val>0.0</val>
    </column>
  </var>
  <var type="fileref" name="profile_file"/>
  <var type="profile" name="rate_profile" numcol="2" size="2">
    <column name="crank_angle" units="deg">
      <val>0.0</val>
      <val>0.0</val>
    </column>
    <column name="rate">
      <val>0.0</val>
      <val>0.0</val>
    </column>
  </var>
  <var type="text" name="sac_volume" val="0.0" units="mm^3"/>
  <var type="text" name="spray_angle" val="40" units="deg"/>
  <var type="text" name="type" val="prop"/>
  <var type="text" name="velocity" val="200.0" units="m/s"/>
 </injector_type>
 <injector_type name="4">
  <var type="text" name="air" val="0.0"/>
  <var type="text" name="burned_air" val="0.0"/>
  <var type="text" name="burned_fuel" val="0.0"/>
  <var type="text" name="drop_diameter" val="auto" units="um"/>
  <var type="text" name="evap_fraction" val="0.3"/>
  <var type="text" name="flow_rate" val="0.0" units="kg/hr"/>
  <var type="text" name="fuel_vapor" val="0.9"/>
  <var type="text" name="initial_velocity" val="auto"/>
  <var type="text" name="liquid_fuel" val="0.1"/>
  <var type="profile" name="mass_profile" numcol="2" size="2">
    <column name="time" units="ms">
      <val>0.0</val>
      <val>0.0</val>
    </column>
    <column name="mass" units="mg">
      <val>0.0</val>
      <val>0.0</val>
    </column>
  </var>
  <var type="text" name="mixture_temp" val="300" units="K"/>
  <var type="profile" name="multipulse_mass_profile" numcol="8" size="2">
    <column name="injpress" units="bar">
      <val>bar</val>
      <val>0.0</val>
    </column>
    <column name="starttime" units="deg">
      <val>deg</val>
      <val>0.0</val>
    </column>
    <column name="riseint" units="ms">
      <val>deg</val>
      <val>0.0</val>
    </column>
    <column name="platint" units="ms">
      <val>deg</val>
      <val>0.0</val>
    </column>
    <column name="fallint" units="ms">
      <val>deg</val>
      <val>0.0</val>
    </column>
```

```
      <column name="rise1" units=" ">
        <val></val>
        <val>0.0</val>
      </column>
      <column name="rise2" units=" ">
        <val></val>
        <val>0.0</val>
      </column>
      <column name="injmass" units="kg/hr">
        <val>kg/hr</val>
        <val>0.0</val>
      </column>
    </var>
    <var type="text" name="nozzle_diameter" val="0.2" units="mm"/>
    <var type="profile" name="pressure_profile" numcol="2" size="2">
      <column name="crank_angle" units="deg">
        <val>0.0</val>
        <val>0.0</val>
      </column>
      <column name="pressure" units="bar">
        <val>0.0</val>
        <val>0.0</val>
      </column>
    </var>
    <var type="fileref" name="profile_file"/>
    <var type="profile" name="rate_profile" numcol="2" size="2">
      <column name="crank_angle" units="deg">
        <val>0.0</val>
        <val>0.0</val>
      </column>
      <column name="rate">
        <val>0.0</val>
        <val>0.0</val>
      </column>
    </var>
    <var type="text" name="sac_volume" val="0.0" units="mm^3"/>
    <var type="text" name="spray_angle" val="40" units="deg"/>
    <var type="text" name="type" val="prop"/>
    <var type="text" name="velocity" val="200.0" units="m/s"/>
  </injector_type>
</block>
<block name="INJ:VOLUME">
  <injector name="1" injector_type_name="1">
    <var type="text" name="duration" val="0.0" units="ms"/>
    <var type="text" name="fa_ratio" val="{FARAT}"/>
    <var type="text" name="location" val="duct3"/>
    <var type="text" name="mass" val="0.0" units="mg"/>
    <var type="text" name="position" val="{LR}" units="cm"/>
    <var type="text" name="rate" val="NULL" units="kg/hr"/>
    <var type="text" name="start" val="NULL" units="deg"/>
    <var type="text" name="sync_cyl" val="0"/>
    <var type="text" name="type" val="1"/>
    <appearance x="360" y="720" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Injector"/>
  </injector>
  <injector name="2" injector_type_name="2">
    <var type="text" name="duration" val="0.0" units="ms"/>
    <var type="text" name="fa_ratio" val="{FARAT}"/>
    <var type="text" name="location" val="duct2"/>
    <var type="text" name="mass" val="0.0" units="mg"/>
    <var type="text" name="position" val="{LR}" units="cm"/>
    <var type="text" name="rate" val="NULL" units="kg/hr"/>
    <var type="text" name="start" val="NULL" units="deg"/>
    <var type="text" name="sync_cyl" val="0"/>
    <var type="text" name="type" val="2"/>
    <appearance x="360" y="600" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Injector"/>
```

```
  </injector>
  <injector name="3" injector_type_name="3">
    <var type="text" name="duration" val="0.0" units="ms"/>
    <var type="text" name="fa_ratio" val="{FARAT}"/>
    <var type="text" name="location" val="duct4"/>
    <var type="text" name="mass" val="0.0" units="mg"/>
    <var type="text" name="position" val="{LR}" units="cm"/>
    <var type="text" name="rate" val="NULL" units="kg/hr"/>
    <var type="text" name="start" val="NULL" units="deg"/>
    <var type="text" name="sync_cyl" val="0"/>
    <var type="text" name="type" val="3"/>
    <appearance x="360" y="480" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Injector"/>
  </injector>
  <injector name="4" injector_type_name="4">
    <var type="text" name="duration" val="0.0" units="ms"/>
    <var type="text" name="fa_ratio" val="{FARAT}"/>
    <var type="text" name="location" val="duct6"/>
    <var type="text" name="mass" val="0.0" units="mg"/>
    <var type="text" name="position" val="{LR}" units="cm"/>
    <var type="text" name="rate" val="NULL" units="kg/hr"/>
    <var type="text" name="start" val="NULL" units="deg"/>
    <var type="text" name="sync_cyl" val="0"/>
    <var type="text" name="type" val="4"/>
    <appearance x="360" y="360" scale="30" angle="0" autoangle="1" network="show"/>
    <template name="Default Injector"/>
  </injector>
</block>
<block name="JUN:THROTTLE_VALVE">
  <jun_throttlevalve name="THROTTLE">
    <var type="text" name="default_angle" val="{THROTTLE_ANGLE}" units="deg"/>
    <var type="text" name="flow_direction" val="lr"/>
    <var type="text" name="left_duct" val="duct23"/>
    <var type="text" name="right_duct" val="duct24"/>
    <var type="text" name="valve_number" val="3"/>
  </jun_throttlevalve>
</block>
<block name="JUN:YJUNCTION DATA">
  <y_junction name="Entry_Cone">
    <var type="text" name="diameter" val="90.2" units="mm"/>
    <var type="text" name="heat_transfer_multiplier" val="1.0"/>
    <var type="text" name="heat_transfer_skin_friction_area" val="14400"
      units="mm^2"/>
    <var type="text" name="initial_fluid_temperature" val="1100" units="K"/>
    <var type="text" name="initial_pressure" val="1.05" units="bar"/>
    <var type="text" name="volume" val="319000" units="mm^3"/>
    <var type="text" name="wall_friction_multiplier" val="1.0"/>
    <var type="text" name="wall_temperature" val="900" units="K"/>
    <opening name="1">
      <var type="text" name="cdk" val="AUTO"/>
      <var type="text" name="delx" val="50" units="mm"/>
      <var type="text" name="dia" val="AUTO" units="mm"/>
      <var type="text" name="diab" val="90.2" units="mm"/>
      <var type="text" name="duct_name" val="duct52"/>
      <var type="text" name="thick" val="0" units="mm"/>
      <var type="text" name="x_angle" val="-90" units="deg"/>
      <var type="text" name="y_angle" val="0" units="deg"/>
      <var type="text" name="z_angle" val="90" units="deg"/>
    </opening>
    <opening name="2">
      <var type="text" name="cdk" val="AUTO"/>
      <var type="text" name="delx" val="50" units="mm"/>
      <var type="text" name="dia" val="AUTO" units="mm"/>
      <var type="text" name="diab" val="1.17" units="mm"/>
      <var type="text" name="duct_name" val="Catalyst"/>
      <var type="text" name="thick" val="0" units="mm"/>
      <var type="text" name="x_angle" val="90" units="deg"/>
```

```
    <var type="text" name="y_angle" val="180" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
   </opening>
  </y_junction>
  <y_junction name="Exit_Cone">
   <var type="text" name="diameter" val="76.4" units="mm"/>
   <var type="text" name="heat_transfer_multiplier" val="1.0"/>
   <var type="text" name="heat_transfer_skin_friction_area" val="13200"
     units="mm^2"/>
   <var type="text" name="initial_fluid_temperature" val="1100" units="K"/>
   <var type="text" name="initial_pressure" val="1.0" units="bar"/>
   <var type="text" name="volume" val="229000" units="mm^3"/>
   <var type="text" name="wall_friction_multiplier" val="1.0"/>
   <var type="text" name="wall_temperature" val="900" units="K"/>
   <opening name="1">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="50" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="76.4" units="mm"/>
    <var type="text" name="duct_name" val="duct54"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="90" units="deg"/>
    <var type="text" name="y_angle" val="180" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
   </opening>
   <opening name="2">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="50" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="1.17" units="mm"/>
    <var type="text" name="duct_name" val="Catalyst"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="-90" units="deg"/>
    <var type="text" name="y_angle" val="0" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
   </opening>
   <opening name="3">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="76.4" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct57"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="0" units="deg"/>
    <var type="text" name="y_angle" val="90" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
   </opening>
  </y_junction>
  <y_junction name="yjun10">
   <var type="text" name="diameter" val="35" units="mm"/>
   <var type="text" name="heat_transfer_multiplier" val="1.0"/>
   <var type="text" name="heat_transfer_skin_friction_area" val="0.0" units="mm^2"/>
   <var type="text" name="initial_fluid_temperature" val="300.0" units="K"/>
   <var type="text" name="initial_pressure" val="1.0" units="bar"/>
   <var type="text" name="volume" val="0.0" units="mm^3"/>
   <var type="text" name="wall_friction_multiplier" val="1.0"/>
   <var type="text" name="wall_temperature" val="300.0" units="K"/>
   <opening name="2">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="703"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
```

```
  </opening>
  <opening name="3">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="708"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
  </opening>
  <opening name="4">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="713"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
  </opening>
  <opening name="5">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct4"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
  </opening>
 </y_junction>
 <y_junction name="yjun11">
  <var type="text" name="diameter" val="35" units="mm"/>
  <var type="text" name="heat_transfer_multiplier" val="1.0"/>
  <var type="text" name="heat_transfer_skin_friction_area" val="0.0" units="mm^2"/>
  <var type="text" name="initial_fluid_temperature" val="300.0" units="K"/>
  <var type="text" name="initial_pressure" val="1.0" units="bar"/>
  <var type="text" name="volume" val="0.0" units="mm^3"/>
  <var type="text" name="wall_friction_multiplier" val="1.0"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <opening name="1">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="705"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
  </opening>
  <opening name="2">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="702"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
  </opening>
  <opening name="3">
```

```
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="712"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
  </opening>
  <opening name="4">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct2"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
  </opening>
 </y_junction>
 <y_junction name="yjun12">
  <var type="text" name="diameter" val="35" units="mm"/>
  <var type="text" name="heat_transfer_multiplier" val="1.0"/>
  <var type="text" name="heat_transfer_skin_friction_area" val="0.0" units="mm^2"/>
  <var type="text" name="initial_fluid_temperature" val="300.0" units="K"/>
  <var type="text" name="initial_pressure" val="1.0" units="bar"/>
  <var type="text" name="volume" val="0.0" units="mm^3"/>
  <var type="text" name="wall_friction_multiplier" val="1.0"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <opening name="1">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="706"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
  </opening>
  <opening name="2">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="701"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
  </opening>
  <opening name="3">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="711"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
  </opening>
  <opening name="4">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
```

```
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct3"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
  </y_junction>
  <y_junction name="yjun13">
   <var type="text" name="diameter" val="40" units="mm"/>
   <var type="text" name="heat_transfer_multiplier" val="1.0"/>
   <var type="text" name="heat_transfer_skin_friction_area" val="0.0" units="mm^2"/>
   <var type="text" name="initial_fluid_temperature" val="300.0" units="K"/>
   <var type="text" name="initial_pressure" val="1.0" units="bar"/>
   <var type="text" name="volume" val="0.0" units="mm^3"/>
   <var type="text" name="wall_friction_multiplier" val="1.0"/>
   <var type="text" name="wall_temperature" val="300.0" units="K"/>
   <opening name="1">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct14"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
   <opening name="2">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct11"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
   <opening name="3">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct12"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
  </y_junction>
  <y_junction name="yjun14">
   <var type="text" name="diameter" val="40" units="mm"/>
   <var type="text" name="heat_transfer_multiplier" val="1.0"/>
   <var type="text" name="heat_transfer_skin_friction_area" val="0.0" units="mm^2"/>
   <var type="text" name="initial_fluid_temperature" val="300.0" units="K"/>
   <var type="text" name="initial_pressure" val="1.0" units="bar"/>
   <var type="text" name="volume" val="0.0" units="mm^3"/>
   <var type="text" name="wall_friction_multiplier" val="1.0"/>
   <var type="text" name="wall_temperature" val="300.0" units="K"/>
   <opening name="1">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct10"/>
```

```
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
   <opening name="2">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct15"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
   <opening name="3">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct16"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
  </y_junction>
  <y_junction name="yjun15">
   <var type="text" name="diameter" val="40" units="mm"/>
   <var type="text" name="heat_transfer_multiplier" val="1.0"/>
   <var type="text" name="heat_transfer_skin_friction_area" val="0.0" units="mm^2"/>
   <var type="text" name="initial_fluid_temperature" val="300.0" units="K"/>
   <var type="text" name="initial_pressure" val="1.0" units="bar"/>
   <var type="text" name="volume" val="0.0" units="mm^3"/>
   <var type="text" name="wall_friction_multiplier" val="1.0"/>
   <var type="text" name="wall_temperature" val="300.0" units="K"/>
   <opening name="1">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct8"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
   <opening name="2">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct17"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
   <opening name="3">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct19"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
```

```
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
  </y_junction>
  <y_junction name="yjun16">
   <var type="text" name="diameter" val="40" units="mm"/>
   <var type="text" name="heat_transfer_multiplier" val="1.0"/>
   <var type="text" name="heat_transfer_skin_friction_area" val="0.0" units="mm^2"/>
   <var type="text" name="initial_fluid_temperature" val="300.0" units="K"/>
   <var type="text" name="initial_pressure" val="1.0" units="bar"/>
   <var type="text" name="volume" val="0.0" units="mm^3"/>
   <var type="text" name="wall_friction_multiplier" val="1.0"/>
   <var type="text" name="wall_temperature" val="300.0" units="K"/>
   <opening name="1">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct7"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
   <opening name="2">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct55"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
   <opening name="3">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct56"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
  </y_junction>
  <y_junction name="yjun2">
   <var type="text" name="diameter" val="80" units="mm"/>
   <var type="text" name="heat_transfer_multiplier" val="1.0"/>
   <var type="text" name="heat_transfer_skin_friction_area" val="20106.2"
     units="mm^2"/>
   <var type="text" name="initial_fluid_temperature" val="1100" units="K"/>
   <var type="text" name="initial_pressure" val="1.05" units="bar"/>
   <var type="text" name="volume" val="268083" units="mm^3"/>
   <var type="text" name="wall_friction_multiplier" val="1.0"/>
   <var type="text" name="wall_temperature" val="900" units="K"/>
   <opening name="1">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="80" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="80" units="mm"/>
    <var type="text" name="duct_name" val="duct52"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="90" units="deg"/>
    <var type="text" name="y_angle" val="90" units="deg"/>
    <var type="text" name="z_angle" val="180" units="deg"/>
```

```
  </opening>
  <opening name="2">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="80" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="80" units="mm"/>
    <var type="text" name="duct_name" val="duct48"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="-120" units="deg"/>
    <var type="text" name="y_angle" val="-30" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
  </opening>
  <opening name="3">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="80" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="80" units="mm"/>
    <var type="text" name="duct_name" val="duct49"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="-150" units="deg"/>
    <var type="text" name="y_angle" val="-60" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
  </opening>
  <opening name="4">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="80" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="80" units="mm"/>
    <var type="text" name="duct_name" val="duct50"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="150" units="deg"/>
    <var type="text" name="y_angle" val="-120" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
  </opening>
  <opening name="5">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="80" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="80" units="mm"/>
    <var type="text" name="duct_name" val="duct51"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="120" units="deg"/>
    <var type="text" name="y_angle" val="-150" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
  </opening>
</y_junction>
<y_junction name="yjun3">
  <var type="text" name="diameter" val="200" units="mm"/>
  <var type="text" name="heat_transfer_multiplier" val="1.0"/>
  <var type="text" name="heat_transfer_skin_friction_area" val="71628"
    units="mm^2"/>
  <var type="text" name="initial_fluid_temperature" val="300.0" units="K"/>
  <var type="text" name="initial_pressure" val="1.0" units="bar"/>
  <var type="text" name="volume" val="2e6" units="mm^3"/>
  <var type="text" name="wall_friction_multiplier" val="1.0"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <opening name="1">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="64" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="200" units="mm"/>
    <var type="text" name="duct_name" val="duct21"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="180" units="deg"/>
    <var type="text" name="y_angle" val="90" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
  </opening>
```

```
  <opening name="4">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="200" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="818"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
  </opening>
</y_junction>
<y_junction name="yjun4">
  <var type="text" name="diameter" val="110" units="mm"/>
  <var type="text" name="heat_transfer_multiplier" val="1.0"/>
  <var type="text" name="heat_transfer_skin_friction_area" val="27300"
     units="mm^2"/>
  <var type="text" name="initial_fluid_temperature" val="300.0" units="K"/>
  <var type="text" name="initial_pressure" val="1.0" units="bar"/>
  <var type="text" name="volume" val="0.75e6" units="mm^3"/>
  <var type="text" name="wall_friction_multiplier" val="1.0"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <opening name="1">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="79" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="110" units="mm"/>
    <var type="text" name="duct_name" val="duct25"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="90" units="deg"/>
    <var type="text" name="y_angle" val="180" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
  </opening>
  <opening name="2">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="79" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="110" units="mm"/>
    <var type="text" name="duct_name" val="duct26"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="-90" units="deg"/>
    <var type="text" name="y_angle" val="0" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
  </opening>
  <opening name="3">
    <var type="text" name="cdk" val="0.99"/>
    <var type="text" name="delx" val="110" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="105" units="mm"/>
    <var type="text" name="duct_name" val="duct38"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="0" units="deg"/>
    <var type="text" name="y_angle" val="90" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
  </opening>
</y_junction>
<y_junction name="yjun5">
  <var type="text" name="diameter" val="110" units="mm"/>
  <var type="text" name="heat_transfer_multiplier" val="1.0"/>
  <var type="text" name="heat_transfer_skin_friction_area" val="27300"
     units="mm^2"/>
  <var type="text" name="initial_fluid_temperature" val="300.0" units="K"/>
  <var type="text" name="initial_pressure" val="1.0" units="bar"/>
  <var type="text" name="volume" val="0.75e6" units="mm^3"/>
  <var type="text" name="wall_friction_multiplier" val="1.0"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <opening name="1">
```

```
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="79" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="110" units="mm"/>
    <var type="text" name="duct_name" val="duct26"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="90" units="deg"/>
    <var type="text" name="y_angle" val="180" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
  </opening>
  <opening name="2">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="79" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="110" units="mm"/>
    <var type="text" name="duct_name" val="duct27"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="-90" units="deg"/>
    <var type="text" name="y_angle" val="0" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
  </opening>
  <opening name="3">
    <var type="text" name="cdk" val="0.99"/>
    <var type="text" name="delx" val="110" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="105" units="mm"/>
    <var type="text" name="duct_name" val="duct35"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="0" units="deg"/>
    <var type="text" name="y_angle" val="90" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
  </opening>
</y_junction>
<y_junction name="yjun6">
  <var type="text" name="diameter" val="110" units="mm"/>
  <var type="text" name="heat_transfer_multiplier" val="1.0"/>
  <var type="text" name="heat_transfer_skin_friction_area" val="27300"
     units="mm^2"/>
  <var type="text" name="initial_fluid_temperature" val="300.0" units="K"/>
  <var type="text" name="initial_pressure" val="1.0" units="bar"/>
  <var type="text" name="volume" val="0.75e6" units="mm^3"/>
  <var type="text" name="wall_friction_multiplier" val="1.0"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <opening name="1">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="79" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="110" units="mm"/>
    <var type="text" name="duct_name" val="duct28"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="90" units="deg"/>
    <var type="text" name="y_angle" val="180" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
  </opening>
  <opening name="2">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="79" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="110" units="mm"/>
    <var type="text" name="duct_name" val="duct27"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="-90" units="deg"/>
    <var type="text" name="y_angle" val="0" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
  </opening>
  <opening name="3">
    <var type="text" name="cdk" val="0.99"/>
```

```
    <var type="text" name="delx" val="110" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="105" units="mm"/>
    <var type="text" name="duct_name" val="duct32"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="0" units="deg"/>
    <var type="text" name="y_angle" val="90" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
   </opening>
  </y_junction>
  <y_junction name="yjun7">
   <var type="text" name="diameter" val="110" units="mm"/>
   <var type="text" name="heat_transfer_multiplier" val="1.0"/>
   <var type="text" name="heat_transfer_skin_friction_area" val="27300"
     units="mm^2"/>
   <var type="text" name="initial_fluid_temperature" val="300.0" units="K"/>
   <var type="text" name="initial_pressure" val="1.0" units="bar"/>
   <var type="text" name="volume" val="0.75e6" units="mm^3"/>
   <var type="text" name="wall_friction_multiplier" val="1.0"/>
   <var type="text" name="wall_temperature" val="300.0" units="K"/>
   <opening name="1">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="79" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="110" units="mm"/>
    <var type="text" name="duct_name" val="duct28"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="90" units="deg"/>
    <var type="text" name="y_angle" val="180" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
   </opening>
   <opening name="2">
    <var type="text" name="cdk" val="0.99"/>
    <var type="text" name="delx" val="110" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="105" units="mm"/>
    <var type="text" name="duct_name" val="duct29"/>
    <var type="text" name="thick" val="0" units="mm"/>
    <var type="text" name="x_angle" val="0" units="deg"/>
    <var type="text" name="y_angle" val="90" units="deg"/>
    <var type="text" name="z_angle" val="90" units="deg"/>
   </opening>
  </y_junction>
  <y_junction name="yjun8">
   <var type="text" name="diameter" val="50" units="mm"/>
   <var type="text" name="heat_transfer_multiplier" val="1.0"/>
   <var type="text" name="heat_transfer_skin_friction_area" val="0.0" units="mm^2"/>
   <var type="text" name="initial_fluid_temperature" val="300.0" units="K"/>
   <var type="text" name="initial_pressure" val=".9" units="bar"/>
   <var type="text" name="volume" val="0.0" units="mm^3"/>
   <var type="text" name="wall_friction_multiplier" val="1.0"/>
   <var type="text" name="wall_temperature" val="300.0" units="K"/>
   <opening name="1">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct53"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
   <opening name="3">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
```

```
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="973"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
   <opening name="2">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="50" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct58"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
  </y_junction>
  <y_junction name="yjun9">
   <var type="text" name="diameter" val="35" units="mm"/>
   <var type="text" name="heat_transfer_multiplier" val="1.0"/>
   <var type="text" name="heat_transfer_skin_friction_area" val="0.0" units="mm^2"/>
   <var type="text" name="initial_fluid_temperature" val="300.0" units="K"/>
   <var type="text" name="initial_pressure" val="1.0" units="bar"/>
   <var type="text" name="volume" val="0.0" units="mm^3"/>
   <var type="text" name="wall_friction_multiplier" val="1.0"/>
   <var type="text" name="wall_temperature" val="300.0" units="K"/>
   <opening name="1">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="704"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
   <opening name="2">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="714"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
   <opening name="3">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="707"/>
    <var type="text" name="thick" val="0.0" units="mm"/>
    <var type="text" name="x_angle" val="0.0" units="deg"/>
    <var type="text" name="y_angle" val="90.0" units="deg"/>
    <var type="text" name="z_angle" val="90.0" units="deg"/>
   </opening>
   <opening name="4">
    <var type="text" name="cdk" val="AUTO"/>
    <var type="text" name="delx" val="0.0" units="mm"/>
    <var type="text" name="dia" val="AUTO" units="mm"/>
    <var type="text" name="diab" val="AUTO" units="mm"/>
    <var type="text" name="duct_name" val="duct6"/>
```

```
      <var type="text" name="thick" val="0.0" units="mm"/>
      <var type="text" name="x_angle" val="0.0" units="deg"/>
      <var type="text" name="y_angle" val="90.0" units="deg"/>
      <var type="text" name="z_angle" val="90.0" units="deg"/>
    </opening>
  </y_junction>
</block>
<block name="LOAD:DRIVELINE">
  <appearance x="995.434" y="-289.058"/>
  <var type="fileref" name="driveline_model" ref_type="tag"
     val="auto_maximum_acceleration"/>
</block>
<block name="T/C:COMPRESSOR">
  <tc_compressor kex="Compressor">
    <var type="text" name="allow_reverse_flow" val="off"/>
    <var type="text" name="calculate_rotor_lag" val="OFF"/>
    <var type="text" name="compressor_efficiency" val="n"/>
    <var type="text" name="compressor_speed" val="80000" units="rpm"/>
    <var type="text" name="compressor_speed_option" val="BAL"/>
    <var type="text" name="constant_efficiency" val="0.0"/>
    <var type="text" name="diameter" val="1.0"/>
    <var type="text" name="effective_length" val="50" units="mm"/>
    <var type="text" name="efficiency" val="1.0"/>
    <var type="fileref" name="filename" ref_type="tag" val="TURBO.TCC"/>
    <var type="text" name="gear_ratio" val="1.0"/>
    <var type="text" name="inlet_pressure" val="tot"/>
    <var type="text" name="length_area_ratio" val="0.203" units="1/mm"/>
    <var type="text" name="mass_flow" val="1.0"/>
    <var type="text" name="mechanical_efficiency" val="1.0"/>
    <var type="text" name="meridional_length" val="85.0" units="mm"/>
    <var type="text" name="moment_of_inertia" val="-1" units="kg*m^2"/>
    <var type="text" name="momentum_source_physics" val="off"/>
    <var type="text" name="outlet_pressure" val="stat"/>
    <inlet_duct name="841"/>
    <outlet_ducts>
      <duct name="818"/>
    </outlet_ducts>
    <turbine name="Turbine"/>
  </tc_compressor>
</block>
<block name="T/C:TURBINE">
  <tc_turbine kex="Turbine">
    <var type="text" name="constant_efficiency" val="0.0"/>
    <var type="text" name="diameter" val="1.0"/>
    <var type="text" name="efficiency" val="1.0"/>
    <var type="fileref" name="filename" ref_type="tag" val="gt20_35_"/>
    <var type="text" name="gear_ratio" val="1.0"/>
    <var type="text" name="inlet_pressure" val="tot"/>
    <var type="text" name="mass_flow" val="1.0"/>
    <var type="text" name="mechanical_efficiency" val="1.0"/>
    <var type="text" name="outlet_pressure" val="stat"/>
    <var type="text" name="turbine_efficiency" val="N"/>
    <var type="text" name="turbine_speed" val="0.0" units="rpm"/>
    <var type="text" name="turbine_speed_option" val="BAL"/>
    <var type="text" name="wastegate" val="OFF"/>
    <var type="text" name="wastegate_open_area" val="0" units="mm^2"/>
    <outlet_duct name="973"/>
    <inlet_ducts>
      <duct name="duct54" flow_fraction="1.0"/>
    </inlet_ducts>
    <compressor name="Compressor"/>
  </tc_turbine>
</block>
<block name="VAL:BOUNCE">
  <valve_bounce name="4">
    <var type="text" name="bottom_damping" val="6000" units="N*s/m"/>
    <var type="text" name="bottom_stiffness" val=".008" units="MN/m"/>
```

```
      <var type="text" name="top_damping" val="6000" units="N*s/m"/>
      <var type="text" name="top_stiffness" val=".008" units="MN/m"/>
    </valve_bounce>
  </block>
  <function_container>
    <function name="Solenoid_Valve">
      <edge output="out" to="Solenoid_valve2" input="in" user="false">
        <x _size="4">616.875 666.438 666.438 716 </x>
        <y _size="4">80 80 76 76 </y>
      </edge>
      <appearance x="600" y="80" scale="30" angle="0" autoangle="1" network="show"/>
      <template name="Default Function"/>
    </function>
    <function name="function1">
      <edge output="out" to="Solenoid_Valve" input="B" user="false">
        <x _size="4">176.875 380 380 583.125 </x>
        <y _size="4">-160 -160 76 76 </y>
      </edge>
      <edge output="out" to="wiringconnector1" input="in3" user="false">
        <x _size="4">176.875 233.036 233.036 289.197 </x>
        <y _size="4">-160 -160 -265 -265 </y>
      </edge>
      <appearance x="160" y="-160" scale="30" angle="0" autoangle="1" network="show"/>
      <template name="Default Function"/>
    </function>
    <function name="function2">
      <edge output="out" to="wiringconnector1" input="in6" user="false">
        <x _size="4">-63.125 113.036 113.036 289.197 </x>
        <y _size="4">-280 -280 -310 -310 </y>
      </edge>
      <appearance x="-80" y="-280" scale="30" angle="0" autoangle="1" network="show"/>
      <template name="Default Function"/>
    </function>
  </function_container>
</case>
<groups>
  <group name="Airbox">
    <member element="yjun3"/>
  </group>
  <group name="Clean Air Hose">
    <member element="duct21"/>
    <member element="duct22"/>
    <member element="orif10"/>
  </group>
  <group name="Close-Coupled Catalytic Convertor">
    <member element="Catalyst"/>
    <member element="Entry_Cone"/>
    <member element="Exit_Cone"/>
  </group>
  <group name="Down Pipe">
    <member element="duct54"/>
  </group>
  <group name="Engine">
    <member element="cyl1"/>
    <member element="cyl2"/>
    <member element="cyl3"/>
    <member element="cyl4"/>
  </group>
  <group name="Exhaust Manifold">
    <member element="duct18"/>
    <member element="duct41"/>
    <member element="duct42"/>
    <member element="duct43"/>
    <member element="duct44"/>
    <member element="duct45"/>
    <member element="duct46"/>
    <member element="duct47"/>
```

```
    <member element="duct48"/>
    <member element="duct49"/>
    <member element="duct50"/>
    <member element="duct51"/>
    <member element="duct52"/>
    <member element="orif25"/>
    <member element="orif26"/>
    <member element="orif27"/>
    <member element="orif28"/>
    <member element="orif29"/>
    <member element="orif30"/>
    <member element="orif31"/>
    <member element="orif32"/>
    <member element="orif33"/>
    <member element="orif34"/>
    <member element="orif35"/>
    <member element="orif36"/>
    <member element="yjun2"/>
  </group>
  <group name="Exhaust Ports"/>
  <group name="Intake Manifold">
    <member element="duct25"/>
    <member element="duct26"/>
    <member element="duct27"/>
    <member element="duct28"/>
    <member element="duct29"/>
    <member element="duct30"/>
    <member element="duct31"/>
    <member element="duct32"/>
    <member element="duct33"/>
    <member element="duct34"/>
    <member element="duct35"/>
    <member element="duct36"/>
    <member element="duct37"/>
    <member element="duct38"/>
    <member element="duct39"/>
    <member element="duct40"/>
    <member element="orif12"/>
    <member element="orif14"/>
    <member element="orif15"/>
    <member element="orif16"/>
    <member element="orif17"/>
    <member element="orif18"/>
    <member element="orif19"/>
    <member element="orif20"/>
    <member element="orif21"/>
    <member element="orif22"/>
    <member element="orif23"/>
    <member element="orif24"/>
    <member element="yjun4"/>
    <member element="yjun5"/>
    <member element="yjun6"/>
    <member element="yjun7"/>
  </group>
  <group name="Intake Ports">
    <member element="duct1"/>
    <member element="duct13"/>
    <member element="duct5"/>
    <member element="duct9"/>
    <member element="orif1"/>
    <member element="orif3"/>
    <member element="orif5"/>
    <member element="orif7"/>
  </group>
  <group name="Mid Pipe"/>
  <group name="Muffler"/>
  <group name="Silencer"/>
```

```
    <group name="Snorkle"/>
    <group name="Throttle Body">
      <member element="duct23"/>
      <member element="duct24"/>
      <member element="orif11"/>
      <member element="orif13"/>
      <member element="THROTTLE"/>
    </group>
  </groups>
</model>
<controlSystem>
  <elements>
    <actuator name="throttle_pedal">
      <input name="in"/>
    </actuator>
    <actuator name="Solenoid_valve2">
      <input name="in" units="kPa"/>
    </actuator>
    <sensor name="sensor1">
      <output name="out"/>
    </sensor>
    <sensor name="Boost">
      <output name="out" units="bar"/>
    </sensor>
    <sensor name="WGlift">
      <output name="out" units="mm"/>
    </sensor>
    <sensor name="MAP">
      <output name="out" units="bar"/>
    </sensor>
    <sensor name="EGT">
      <output name="out"/>
    </sensor>
    <sensor name="EGP">
      <output name="out"/>
    </sensor>
    <sensor name="Ti">
      <output name="out"/>
    </sensor>
    <sensor name="RPM">
      <output name="out"/>
    </sensor>
    <sensor name="sensor2">
      <output name="out" units="bar"/>
    </sensor>
    <sensor name="sensor3">
      <output name="out" units="hp"/>
    </sensor>
    <pinSource name="wiringconnector1_pin1" pin="1">
      <output name="out"/>
    </pinSource>
    <pinSource name="wiringconnector1_pin2" pin="2">
      <output name="out"/>
    </pinSource>
    <pinSink name="wiringconnector1_pin3" pin="3">
      <input name="in"/>
    </pinSink>
    <pinSink name="wiringconnector1_pin4" pin="4">
      <input name="in"/>
    </pinSink>
    <pinSink name="wiringconnector1_pin5" pin="5">
      <input name="in"/>
    </pinSink>
    <pinSink name="wiringconnector1_pin6" pin="6">
      <input name="in"/>
    </pinSink>
    <pinSource name="engine_demand" pin="-1000">
```

```
      <output name="out"/>
    </pinSource>
    <function name="Solenoid_Valve"
      definition="100+1/10000000*(-14.6741*P^4+52.8657*P^3*B+3473.8515*P^3+8.4102*P^2*B^2-9796.8647*P^2*B-
250532.7183*P^2+1.4829*P*B^3-1295.7842*P*B^2+400757.0361*P*B+5456034.6568*P+0.2314*B^4-
280.5978*B^3+76235.9712*B^2+2692151.4172*B-7234012.3154) ">

      <output name="out"/>
      <input name="P"/>
      <input name="B"/>
    </function>
    <function name="function1" definition="in1*100-100">
      <output name="out"/>
      <input name="in1"/>
    </function>
    <function name="function2" definition="in1*100-100">
      <output name="out"/>
      <input name="in1"/>
    </function>
  </elements>
  <wiring>
    <connection>
      <from element="Boost" output="out"/>
      <to element="function1" input="in1"/>
    </connection>
    <connection>
      <from element="MAP" output="out"/>
      <to element="function2" input="in1"/>
    </connection>
    <connection>
      <from element="RPM" output="out"/>
      <to element="wiringconnector1_pin4" input="in"/>
    </connection>
    <connection>
      <from element="sensor3" output="out"/>
      <to element="wiringconnector1_pin5" input="in"/>
    </connection>
    <connection>
      <from element="wiringconnector1_pin1" output="out"/>
      <to element="Solenoid_Valve" input="P"/>
    </connection>
    <connection>
      <from element="wiringconnector1_pin2" output="out"/>
      <to element="throttle_pedal" input="in"/>
    </connection>
    <connection>
      <from element="Solenoid_Valve" output="out"/>
      <to element="Solenoid_valve2" input="in"/>
    </connection>
    <connection>
      <from element="function1" output="out"/>
      <to element="Solenoid_Valve" input="B"/>
      <to element="wiringconnector1_pin3" input="in"/>
    </connection>
    <connection>
      <from element="function2" output="out"/>
      <to element="wiringconnector1_pin6" input="in"/>
    </connection>
  </wiring>
 </controlSystem>
 <fileProperties>
  <description>VW 1.8t.wvm</description>
  <author>pcn</author>
  <created>October 5, 2003  12:14:35 PM</created>
  <comments>
   1.8t
   open loop PWM for ID data
```

```
 </comments>
 <platform exe="win32"/>
</fileProperties>
<wgm>
 <engine layout="inline" x="518.781" y="418.977" scale="1" spacing="120" hide="0">
  <cylinders _size="4"> cyl1  cyl2  cyl3  cyl4 </cylinders>
 </engine>
 <case number="1">
  <junction id="Entry_Cone" x="920" y="400" scale="30" angle="0" autoangle="1"
    templatename="Default Complex Y-junction">
   <opening name="1"/>
   <opening name="2"/>
  </junction>
  <junction id="Exit_Cone" x="1000" y="200" scale="30" angle="0" autoangle="1"
    templatename="Default Complex Y-junction">
   <opening name="1"/>
   <opening name="2"/>
   <opening name="3"/>
  </junction>
  <junction id="yjun10" x="400" y="400" scale="30" angle="0" autoangle="1"
    templatename="Default Simple Y-junction">
   <opening name="2"/>
   <opening name="3"/>
   <opening name="4"/>
   <opening name="5"/>
  </junction>
  <junction id="yjun11" x="400" y="520" scale="30" angle="0" autoangle="1"
    templatename="Default Simple Y-junction">
   <opening name="1"/>
   <opening name="2"/>
   <opening name="3"/>
   <opening name="4"/>
  </junction>
  <junction id="yjun12" x="400" y="640" scale="30" angle="0" autoangle="1"
    templatename="Default Simple Y-junction">
   <opening name="1"/>
   <opening name="2"/>
   <opening name="3"/>
   <opening name="4"/>
  </junction>
  <junction id="yjun13" x="600" y="280" scale="30" angle="0" autoangle="1"
    templatename="Default Simple Y-junction">
   <opening name="1"/>
   <opening name="2"/>
   <opening name="3"/>
  </junction>
  <junction id="yjun14" x="600" y="400" scale="30" angle="0" autoangle="1"
    templatename="Default Simple Y-junction">
   <opening name="1"/>
   <opening name="2"/>
   <opening name="3"/>
  </junction>
  <junction id="yjun15" x="600" y="520" scale="30" angle="0" autoangle="1"
    templatename="Default Simple Y-junction">
   <opening name="1"/>
   <opening name="2"/>
   <opening name="3"/>
  </junction>
  <junction id="yjun16" x="600" y="640" scale="30" angle="0" autoangle="1"
    templatename="Default Simple Y-junction">
   <opening name="1"/>
   <opening name="2"/>
   <opening name="3"/>
  </junction>
  <junction id="yjun2" x="919.935" y="458.539" scale="30" angle="0" autoangle="1"
    templatename="Default Complex Y-junction">
   <opening name="1"/>
```

```
  <opening name="2"/>
  <opening name="3"/>
  <opening name="4"/>
  <opening name="5"/>
</junction>
<junction id="yjun3" x="160" y="80" scale="30" angle="0" autoangle="1"
   templatename="Default Complex Y-junction">
  <opening name="1"/>
  <opening name="4"/>
</junction>
<junction id="yjun4" x="-80" y="440" scale="30" angle="0" autoangle="1"
   templatename="Default Complex Y-junction">
  <opening name="1"/>
  <opening name="2"/>
  <opening name="3"/>
</junction>
<junction id="yjun5" x="-80" y="560" scale="30" angle="0" autoangle="1"
   templatename="Default Complex Y-junction">
  <opening name="1"/>
  <opening name="2"/>
  <opening name="3"/>
</junction>
<junction id="yjun6" x="-80" y="680" scale="30" angle="0" autoangle="1"
   templatename="Default Complex Y-junction">
  <opening name="1"/>
  <opening name="2"/>
  <opening name="3"/>
</junction>
<junction id="yjun7" x="-80" y="800" scale="30" angle="0" autoangle="1"
   templatename="Default Complex Y-junction">
  <opening name="1"/>
  <opening name="2"/>
</junction>
<junction id="yjun8" x="1120" y="-160" scale="30" angle="0" autoangle="1"
   templatename="Default Simple Y-junction">
  <opening name="1"/>
  <opening name="3"/>
  <opening name="2"/>
</junction>
<junction id="yjun9" x="400" y="280" scale="30" angle="0" autoangle="1"
   templatename="Default Simple Y-junction">
  <opening name="1"/>
  <opening name="2"/>
  <opening name="3"/>
  <opening name="4"/>
</junction>
<junction id="Compressor" x="920" y="-40" scale="30" angle="0" autoangle="1"
   templatename="Default Fixed Compressor"/>
<junction id="orif1" x="320" y="640" scale="30" angle="1.28739" autoangle="1"
   templatename="Default Orifice"/>
<junction id="orif10" x="0" y="80" scale="30" angle="180" autoangle="1"
   templatename="Default Orifice"/>
<junction id="orif11" x="-80" y="200" scale="30" angle="90" autoangle="1"
   templatename="Default Orifice"/>
<junction id="orif12" x="40" y="800" scale="30" angle="0" autoangle="1"
   templatename="Default Orifice"/>
<junction id="orif13" x="-80" y="360" scale="30" angle="90" autoangle="1"
   templatename="Default Orifice"/>
<junction id="orif14" x="160" y="720" scale="30" angle="314.441" autoangle="1"
   templatename="Default Orifice"/>
<junction id="orif15" x="240" y="640" scale="30" angle="153.098" autoangle="1"
   templatename="Default Orifice"/>
<junction id="orif16" x="40" y="680" scale="30" angle="0" autoangle="1"
   templatename="Default Orifice"/>
<junction id="orif17" x="160" y="600" scale="30" angle="314.441" autoangle="1"
   templatename="Default Orifice"/>
<junction id="orif18" x="240" y="520" scale="30" angle="333.098" autoangle="1"
```

```
  templatename="Default Orifice"/>
<junction id="orif19" x="40" y="560" scale="30" angle="0" autoangle="1"
  templatename="Default Orifice"/>
<junction id="orif20" x="160" y="480" scale="30" angle="314.441" autoangle="1"
  templatename="Default Orifice"/>
<junction id="orif21" x="240" y="400" scale="30" angle="333.098" autoangle="1"
  templatename="Default Orifice"/>
<junction id="orif22" x="40" y="440" scale="30" angle="0" autoangle="1"
  templatename="Default Orifice"/>
<junction id="orif23" x="160" y="360" scale="30" angle="314.441" autoangle="1"
  templatename="Default Orifice"/>
<junction id="orif24" x="240" y="280" scale="30" angle="153.098" autoangle="1"
  templatename="Default Orifice"/>
<junction id="orif25" x="640" y="640" scale="30" angle="180" autoangle="1"
  templatename="Default Orifice"/>
<junction id="orif26" x="720" y="640" scale="30" angle="0" autoangle="1"
  templatename="Default Orifice"/>
<junction id="orif27" x="859.378" y="560.403" scale="30" angle="303.657"
  autoangle="1" templatename="Default Orifice"/>
<junction id="orif28" x="640" y="520" scale="30" angle="180" autoangle="1"
  templatename="Default Orifice"/>
<junction id="orif29" x="720" y="520" scale="30" angle="0" autoangle="1"
  templatename="Default Orifice"/>
<junction id="orif3" x="320" y="520" scale="30" angle="181.287" autoangle="1"
  templatename="Default Orifice"/>
<junction id="orif30" x="838.385" y="489.689" scale="30" angle="338.968"
  autoangle="1" templatename="Default Orifice"/>
<junction id="orif31" x="640" y="400" scale="30" angle="0" autoangle="1"
  templatename="Default Orifice"/>
<junction id="orif32" x="720" y="400" scale="30" angle="0" autoangle="1"
  templatename="Default Orifice"/>
<junction id="orif33" x="840" y="430.311" scale="30" angle="20.1659"
  autoangle="1" templatename="Default Orifice"/>
<junction id="orif34" x="640" y="280" scale="30" angle="0" autoangle="1"
  templatename="Default Orifice"/>
<junction id="orif35" x="720" y="280" scale="30" angle="0" autoangle="1"
  templatename="Default Orifice"/>
<junction id="orif36" x="858.603" y="354.38" scale="30" angle="55.8635"
  autoangle="1" templatename="Default Orifice"/>
<junction id="orif5" x="320" y="400" scale="30" angle="181.287" autoangle="1"
  templatename="Default Orifice"/>
<junction id="orif7" x="320" y="280" scale="30" angle="1.28739" autoangle="1"
  templatename="Default Orifice"/>
<junction id="THROTTLE" x="-80" y="280" scale="30" angle="90" autoangle="1"
  templatename="Default Throttle Valve"/>
<junction id="Turbine" x="1080" y="-40" scale="30" angle="0" autoangle="1"
  templatename="Default Fixed Turbine"/>
<junction id="wastegate" x="1160" y="-40" scale="30" angle="0" autoangle="1"
  templatename="Default Piston Driven Valve"/>
<junction id="301" x="680" y="-240" scale="30" angle="40.0693" autoangle="1"
  templatename="Default Ambient"/>
<junction id="351" x="1160" y="-240" scale="30" angle="116.565" autoangle="1"
  templatename="Default Ambient"/>
<junction id="amb1" x="1040" y="80" scale="30" angle="319.15" autoangle="1"
  templatename="Default Ambient"/>
<junction id="amb2" x="1280" y="-80" scale="30" angle="153.916" autoangle="1"
  templatename="Default Ambient"/>
<junction id="cyl1" x="518.781" y="648.977" scale="30" angle="345.924"
  autoangle="1" templatename="Default Engine Cylinder"/>
<junction id="cyl2" x="518.781" y="528.977" scale="30" angle="345.924"
  autoangle="1" templatename="Default Engine Cylinder"/>
<junction id="cyl3" x="518.781" y="408.977" scale="30" angle="345.924"
  autoangle="1" templatename="Default Engine Cylinder"/>
<junction id="cyl4" x="518.781" y="288.977" scale="30" angle="345.924"
  autoangle="1" templatename="Default Engine Cylinder"/>
<duct id="701" templatename="Default Duct">
  <comment>
```

```
    ! Intake ports
    ! Intake ports
  </comment>
  <x _size="2">413.537 504.231 </x>
  <y _size="2">641.64 652.625 </y>
</duct>
<duct id="702" templatename="Default Duct">
  <x _size="2">413.537 504.231 </x>
  <y _size="2">521.64 532.625 </y>
</duct>
<duct id="703" templatename="Default Duct">
  <x _size="2">413.363 517.755 </x>
  <y _size="2">402.717 423.942 </y>
</duct>
<duct id="704" templatename="Default Duct">
  <x _size="2">413.363 517.755 </x>
  <y _size="2">282.717 303.942 </y>
</duct>
<duct id="705" templatename="Default Duct">
  <comment>
    ! Intake ports
    ! Intake ports
  </comment>
  <x _size="2">413.629 510.815 </x>
  <y _size="2">519.541 516.267 </y>
</duct>
<duct id="706" templatename="Default Duct">
  <comment>
    ! Intake ports
    ! Intake ports
  </comment>
  <x _size="2">413.363 517.755 </x>
  <y _size="2">642.717 663.942 </y>
</duct>
<duct id="707" templatename="Default Duct">
  <comment>
    ! Intake ports
    ! Intake ports
  </comment>
  <x _size="2">413.629 510.815 </x>
  <y _size="2">279.541 276.267 </y>
</duct>
<duct id="708" templatename="Default Duct">
  <comment>
    ! Intake ports
    ! Intake ports
  </comment>
  <x _size="2">413.629 510.815 </x>
  <y _size="2">399.541 396.267 </y>
</duct>
<duct id="711" templatename="Default Duct">
  <x _size="2">413.629 510.815 </x>
  <y _size="2">639.541 636.267 </y>
</duct>
<duct id="712" templatename="Default Duct">
  <x _size="2">413.363 517.755 </x>
  <y _size="2">522.717 543.942 </y>
</duct>
<duct id="713" templatename="Default Duct">
  <x _size="2">413.537 504.231 </x>
  <y _size="2">401.64 412.625 </y>
</duct>
<duct id="714" templatename="Default Duct">
  <x _size="2">413.537 504.231 </x>
  <y _size="2">281.64 292.625 </y>
</duct>
<duct id="818" templatename="Default Duct">
```

```
  <comment>
    ! Throttle body
    ! Throttle body
  </comment>
  <x _size="2">933.5 173.442 </x>
  <y _size="2">-52 77.7061 </y>
</duct>
<duct id="841" templatename="Default Duct">
  <comment>
    ! Intake
    ! Intake
  </comment>
  <x _size="2">695.305 903.5 </x>
  <y _size="2">-227.126 -52 </y>
</duct>
<duct id="973" templatename="Default Duct">
  <comment>
    ! Downpipe
    ! Downpipe
  </comment>
  <x _size="2">1096.5 1117.1 </x>
  <y _size="2">-52 -146.675 </y>
</duct>
<duct id="Catalyst" templatename="Default Duct">
  <x _size="2">925.064 994.936 </x>
  <y _size="2">387.339 212.661 </y>
</duct>
<duct id="duct1" templatename="Default Duct">
  <x _size="2">246.153 313.102 </x>
  <y _size="2">636.878 639.845 </y>
</duct>
<duct id="duct10" templatename="Default Duct">
  <x _size="2">613.636 633.1 </x>
  <y _size="2">400 400 </y>
</duct>
<duct id="duct11" templatename="Default Duct">
  <x _size="2">613.636 633.1 </x>
  <y _size="2">280 280 </y>
</duct>
<duct id="duct12" templatename="Default Duct">
  <x _size="2">532.696 586.673 </x>
  <y _size="2">294.578 282.887 </y>
</duct>
<duct id="duct13" templatename="Default Duct">
  <x _size="2">246.153 313.102 </x>
  <y _size="2">276.878 279.845 </y>
</duct>
<duct id="duct14" templatename="Default Duct">
  <x _size="2">528.408 586.372 </x>
  <y _size="2">277.474 279.519 </y>
</duct>
<duct id="duct15" templatename="Default Duct">
  <x _size="2">532.696 586.673 </x>
  <y _size="2">414.578 402.887 </y>
</duct>
<duct id="duct16" templatename="Default Duct">
  <x _size="2">528.408 586.372 </x>
  <y _size="2">397.474 399.519 </y>
</duct>
<duct id="duct17" templatename="Default Duct">
  <x _size="2">528.408 586.372 </x>
  <y _size="2">517.474 519.519 </y>
</duct>
<duct id="duct18" templatename="Default Duct">
  <x _size="2">646.9 713.1 </x>
  <y _size="2">640 640 </y>
</duct>
```

```
<duct id="duct19" templatename="Default Duct">
  <x _size="2">532.696 586.673 </x>
  <y _size="2">534.578 522.887 </y>
</duct>
<duct id="duct2" templatename="Default Duct">
  <x _size="2">326.898 386.364 </x>
  <y _size="2">520.155 520.029 </y>
</duct>
<duct id="duct20" templatename="Default Duct">
  <x _size="2">1055.13 1149.29 </x>
  <y _size="2">66.9183 -14.5 </y>
</duct>
<duct id="duct21" templatename="Default Duct">
  <x _size="2">146.364 6.9 </x>
  <y _size="2">80 80 </y>
</duct>
<duct id="duct22" templatename="Default Duct">
  <x _size="4">-6.9 -40 -80 -80 </x>
  <y _size="4">80 80 120 193.1 </y>
</duct>
<duct id="duct23" templatename="Default Duct">
  <x _size="2">-80 -80 </x>
  <y _size="2">206.9 270.1 </y>
</duct>
<duct id="duct24" templatename="Default Duct">
  <x _size="2">-80 -80 </x>
  <y _size="2">289.9 353.1 </y>
</duct>
<duct id="duct25" templatename="Default Duct">
  <x _size="2">-80 -80 </x>
  <y _size="2">366.9 426.364 </y>
</duct>
<duct id="duct26" templatename="Default Duct">
  <x _size="2">-80 -80 </x>
  <y _size="2">453.636 546.364 </y>
</duct>
<duct id="duct27" templatename="Default Duct">
  <x _size="2">-80 -80 </x>
  <y _size="2">573.636 666.364 </y>
</duct>
<duct id="duct28" templatename="Default Duct">
  <x _size="2">-80 -80 </x>
  <y _size="2">693.636 786.364 </y>
</duct>
<duct id="duct29" templatename="Default Duct">
  <x _size="2">-66.3636 33.1 </x>
  <y _size="2">800 800 </y>
</duct>
<duct id="duct3" templatename="Default Duct">
  <x _size="2">326.898 386.364 </x>
  <y _size="2">640.155 640.029 </y>
</duct>
<duct id="duct30" templatename="Default Duct">
  <x _size="3">46.9 80 155.169 </x>
  <y _size="3">800 800 724.926 </y>
</duct>
<duct id="duct31" templatename="Default Duct">
  <x _size="2">164.831 233.847 </x>
  <y _size="2">715.074 643.122 </y>
</duct>
<duct id="duct32" templatename="Default Duct">
  <x _size="2">-66.3636 33.1 </x>
  <y _size="2">680 680 </y>
</duct>
<duct id="duct33" templatename="Default Duct">
  <x _size="3">46.9 80 155.169 </x>
  <y _size="3">680 680 604.926 </y>
```

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</duct>
<duct id="duct34" templatename="Default Duct">
  <x _size="2">164.831 233.847 </x>
  <y _size="2">595.074 523.122 </y>
</duct>
<duct id="duct35" templatename="Default Duct">
  <x _size="2">-66.3636 33.1 </x>
  <y _size="2">560 560 </y>
</duct>
<duct id="duct36" templatename="Default Duct">
  <x _size="3">46.9 80 155.169 </x>
  <y _size="3">560 560 484.926 </y>
</duct>
<duct id="duct37" templatename="Default Duct">
  <x _size="2">164.831 233.847 </x>
  <y _size="2">475.074 403.122 </y>
</duct>
<duct id="duct38" templatename="Default Duct">
  <x _size="2">-66.3636 33.1 </x>
  <y _size="2">440 440 </y>
</duct>
<duct id="duct39" templatename="Default Duct">
  <x _size="3">46.9 80 155.169 </x>
  <y _size="3">440 440 364.926 </y>
</duct>
<duct id="duct4" templatename="Default Duct">
  <x _size="2">326.898 386.364 </x>
  <y _size="2">400.155 400.029 </y>
</duct>
<duct id="duct40" templatename="Default Duct">
  <x _size="2">164.831 233.847 </x>
  <y _size="2">355.074 283.122 </y>
</duct>
<duct id="duct41" templatename="Default Duct">
  <x _size="3">726.9 800 855.554 </x>
  <y _size="3">640 640 566.146 </y>
</duct>
<duct id="duct42" templatename="Default Duct">
  <x _size="2">646.9 713.1 </x>
  <y _size="2">520 520 </y>
</duct>
<duct id="duct43" templatename="Default Duct">
  <x _size="3">726.9 760 831.945 </x>
  <y _size="3">520 520 492.165 </y>
</duct>
<duct id="duct44" templatename="Default Duct">
  <x _size="2">646.9 713.1 </x>
  <y _size="2">400 400 </y>
</duct>
<duct id="duct45" templatename="Default Duct">
  <x _size="3">726.9 760 833.523 </x>
  <y _size="3">400 400 427.932 </y>
</duct>
<duct id="duct46" templatename="Default Duct">
  <x _size="2">646.9 713.1 </x>
  <y _size="2">280 280 </y>
</duct>
<duct id="duct47" templatename="Default Duct">
  <x _size="3">726.9 800 854.731 </x>
  <y _size="3">280 280 348.669 </y>
</duct>
<duct id="duct48" templatename="Default Duct">
  <x _size="2">863.202 913.004 </x>
  <y _size="2">554.66 470.282 </y>
</duct>
<duct id="duct49" templatename="Default Duct">
  <x _size="2">844.825 907.195 </x>
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    <y _size="2">487.213 463.402 </y>
   </duct>
   <duct id="duct5" templatename="Default Duct">
    <x _size="2">246.153 313.102 </x>
    <y _size="2">516.878 519.845 </y>
   </duct>
   <duct id="duct50" templatename="Default Duct">
    <x _size="2">846.477 907.072 </x>
    <y _size="2">432.69 454.013 </y>
   </duct>
   <duct id="duct51" templatename="Default Duct">
    <x _size="2">862.475 913.061 </x>
    <y _size="2">360.091 446.762 </y>
   </duct>
   <duct id="duct52" templatename="Default Duct">
    <x _size="2">919.95 919.985 </x>
    <y _size="2">444.903 413.636 </y>
   </duct>
   <duct id="duct53" templatename="Default Duct">
    <x _size="2">1126.1 1151.06 </x>
    <y _size="2">-172.197 -222.111 </y>
   </duct>
   <duct id="duct54" templatename="Default Duct">
    <x _size="4">993.902 960 1000 1066.5 </x>
    <y _size="4">187.803 120 40 -52 </y>
   </duct>
   <duct id="duct55" templatename="Default Duct">
    <x _size="2">532.696 586.673 </x>
    <y _size="2">654.578 642.887 </y>
   </duct>
   <duct id="duct56" templatename="Default Duct">
    <x _size="2">528.408 586.372 </x>
    <y _size="2">637.474 639.519 </y>
   </duct>
   <duct id="duct57" templatename="Default Duct">
    <x _size="4">1009.64 1080 1080 1148 </x>
    <y _size="4">190.358 120 80 -47 </y>
   </duct>
   <duct id="duct58" templatename="Default Duct">
    <x _size="2">1172 1126.15 </x>
    <y _size="2">-57 -147.827 </y>
   </duct>
   <duct id="duct59" templatename="Default Duct">
    <x _size="2">1262.04 1170.71 </x>
    <y _size="2">-71.2063 -26.5 </y>
   </duct>
   <duct id="duct6" templatename="Default Duct">
    <x _size="2">326.898 386.364 </x>
    <y _size="2">280.155 280.029 </y>
   </duct>
   <duct id="duct7" templatename="Default Duct">
    <x _size="2">613.636 633.1 </x>
    <y _size="2">640 640 </y>
   </duct>
   <duct id="duct8" templatename="Default Duct">
    <x _size="2">613.636 633.1 </x>
    <y _size="2">520 520 </y>
   </duct>
   <duct id="duct9" templatename="Default Duct">
    <x _size="2">246.153 313.102 </x>
    <y _size="2">396.878 399.845 </y>
   </duct>
  </case>
  <junctionID _size="60">
   0 0 0 0 0 0 0 0 0 0
   0 0 0 0 0 0 0 0 0 0
   0 0 0 0 0 0 0 0 0 0
```

```
    0 0 0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0
    0 0 301 351 0 0 0 0 0 0
   </junctionID>
   <ductID _size="75">
    701 702 703 704 705 706 707 708 711 712
    713 714 818 841 973 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0
    0 0 0 0 0
   </ductID>
   <layout>
    <canvas xOrigin="-634.748" yOrigin="-585.155" xSize="2150.7" ySize="1474.54"/>
    <annotations name="on" arrows="on" title="on" annotations="on" shafts="on"
      plots="on" font="draft"/>
    <grid visibility="lines" snap="on" xSpacing="40" ySpacing="40" gridThickness="7"
      gridBrightness="15"/>
    <network_mode flow="show" control="show"/>
    <boundingBox xmin="-80" xmax="1280" ymin="-240" ymax="1280"/>
   </layout>
   <title>
    <DisplaySettings Font="Draft" Fontsize="10"/>
    <Text>VW 1.8t</Text>
   </title>
  </wgm>
  <template>
   <element_template name="Default Ambient" type="junction" junction_type="3"
     junction_subtype="1">
    <var type="text" name="acoustic_end_correction" val="0.0" units="mm"/>
    <var type="text" name="diameter" val="AUTO" units="mm"/>
    <var type="text" name="discharge_coefficient" val="AUTO"/>
    <var type="text" name="pressure" val="1.0" units="bar"/>
    <var type="text" name="solution_type" val="FLOATING"/>
    <var type="text" name="temperature" val="300.0" units="K"/>
   </element_template>
   <element_template name="Default Engine Cylinder" type="junction"
     junction_type="4" junction_subtype="1">
    <var type="text" name="zones" val="SINGLEZONE"/>
    <eng_valves>
     <var type="array" name="ied" size="2">
      <val>i</val>
      <val>e</val>
     </var>
     <var type="array" name="lexd" size="2">
      <val>000</val>
      <val>000</val>
     </var>
     <var type="array" name="link" size="2">
      <val></val>
      <val></val>
     </var>
     <var type="array" name="nvd" size="2">
      <val>1</val>
      <val>2</val>
     </var>
    </eng_valves>
   </element_template>
   <element_template name="Default Duct" type="duct:regular">
    <var type="text" name="count" val="1"/>
    <var type="text" name="discretization" val="30.0" units="mm"/>
    <var type="text" name="friction" val="1.0"/>
    <var type="text" name="heat_transfer" val="1.0"/>
    <var type="text" name="left_discharge_coefficient" val="AUTO"/>
    <var type="text" name="overall" val="100.0" units="mm"/>
```

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  <var type="text" name="pressure" val="1.0" units="bar"/>
  <var type="text" name="pressure_loss" val="0.0"/>
  <var type="text" name="right_discharge_coefficient" val="AUTO"/>
  <var type="text" name="roughness_height" val="0" units="um"/>
  <var type="text" name="temperature" val="300.0" units="K"/>
  <var type="text" name="wall_temperature" val="300.0" units="K"/>
  <duc_shape>
    <var type="text" name="left_diameter" val="0.0" units="mm"/>
    <var type="text" name="right_diameter" val="0.0" units="mm"/>
  </duc_shape>
</element_template>
<element_template name="Default Injector" type="injector" injector_type="prop">
  <var type="text" name="duration" val="0.0" units="ms"/>
  <var type="text" name="fa_ratio" val="{FARAT}"/>
  <var type="text" name="mass" val="0.0" units="mg"/>
  <var type="text" name="position" val="{LR}" units="cm"/>
  <var type="text" name="rate" val="NULL" units="kg/hr"/>
  <var type="text" name="start" val="NULL" units="deg"/>
  <var type="text" name="type" val="prop"/>
  <var type="text" name="air" val="0.0"/>
  <var type="text" name="burned_air" val="0.0"/>
  <var type="text" name="burned_fuel" val="0.0"/>
  <var type="text" name="drop_diameter" val="auto" units="um"/>
  <var type="text" name="evap_fraction" val="0.3"/>
  <var type="text" name="flow_rate" val="0.0" units="kg/hr"/>
  <var type="text" name="fuel_vapor" val="0.9"/>
  <var type="text" name="initial_velocity" val="auto"/>
  <var type="text" name="liquid_fuel" val="0.1"/>
  <var type="profile" name="mass_profile" numcol="2" size="2">
    <column name="time" units="ms">
      <val>0.0</val>
      <val>0.0</val>
    </column>
    <column name="mass" units="mg">
      <val>0.0</val>
      <val>0.0</val>
    </column>
  </var>
  <var type="text" name="mixture_temp" val="300" units="K"/>
  <var type="profile" name="multipulse_mass_profile" numcol="8" size="2">
    <column name="injpress" units="bar">
      <val>bar</val>
      <val>0.0</val>
    </column>
    <column name="starttime" units="deg">
      <val>deg</val>
      <val>0.0</val>
    </column>
    <column name="riseint" units="ms">
      <val>deg</val>
      <val>0.0</val>
    </column>
    <column name="platint" units="ms">
      <val>deg</val>
      <val>0.0</val>
    </column>
    <column name="fallint" units="ms">
      <val>deg</val>
      <val>0.0</val>
    </column>
    <column name="rise1" units=" ">
      <val></val>
      <val>0.0</val>
    </column>
    <column name="rise2" units=" ">
      <val></val>
      <val>0.0</val>
```

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    </column>
    <column name="injmass" units="kg/hr">
      <val>kg/hr</val>
      <val>0.0</val>
    </column>
  </var>
  <var type="text" name="nozzle_diameter" val="0.2" units="mm"/>
  <var type="profile" name="pressure_profile" numcol="2" size="2">
    <column name="crank_angle" units="deg">
      <val>0.0</val>
      <val>0.0</val>
    </column>
    <column name="pressure" units="bar">
      <val>0.0</val>
      <val>0.0</val>
    </column>
  </var>
  <var type="fileref" name="profile_file"/>
  <var type="profile" name="rate_profile" numcol="2" size="2">
    <column name="crank_angle" units="deg">
      <val>0.0</val>
      <val>0.0</val>
    </column>
    <column name="rate">
      <val>0.0</val>
      <val>0.0</val>
    </column>
  </var>
  <var type="text" name="sac_volume" val="0.0" units="mm^3"/>
  <var type="text" name="spray_angle" val="40" units="deg"/>
  <var type="text" name="type" val="prop"/>
  <var type="text" name="velocity" val="200.0" units="m/s"/>
</element_template>
<element_template name="Default Orifice" type="junction" junction_type="1"
  junction_subtype="1">
  <var type="text" name="diameter" val="auto" units="mm"/>
</element_template>
<element_template id="Compressor" name="Default Fixed Compressor"
  type="junction" junction_type="1" junction_subtype="2">
  <tc_compressor>
    <var type="text" name="allow_reverse_flow" val="off"/>
    <var type="text" name="calculate_rotor_lag" val="OFF"/>
    <var type="text" name="compressor_efficiency" val="n"/>
    <var type="text" name="compressor_speed" val="80000" units="rpm"/>
    <var type="text" name="compressor_speed_option" val="FRPM"/>
    <var type="text" name="constant_efficiency" val="0.0"/>
    <var type="text" name="diameter" val="1.0"/>
    <var type="text" name="effective_length" val="50" units="mm"/>
    <var type="text" name="efficiency" val="1.0"/>
    <var type="fileref" name="filename" ref_type="tag" val="TURBO.TCC"/>
    <var type="text" name="gear_ratio" val="1.0"/>
    <var type="text" name="inlet_pressure" val="tot"/>
    <var type="text" name="length_area_ratio" val="0.203" units="1/mm"/>
    <var type="text" name="mass_flow" val="1.0"/>
    <var type="text" name="mechanical_efficiency" val="1.0"/>
    <var type="text" name="meridional_length" val="85.0" units="mm"/>
    <var type="text" name="moment_of_inertia" val="-1" units="kg*m^2"/>
    <var type="text" name="momentum_source_physics" val="off"/>
    <var type="text" name="outlet_pressure" val="stat"/>
  </tc_compressor>
</element_template>
<element_template id="Turbine" name="Default Fixed Turbine" type="junction"
  junction_type="1" junction_subtype="3">
  <tc_turbine>
    <var type="text" name="constant_efficiency" val="0.0"/>
    <var type="text" name="diameter" val="1.0"/>
    <var type="text" name="efficiency" val="1.0"/>
```

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    <var type="fileref" name="filename" ref_type="tag" val="TURBO.TCT"/>
    <var type="text" name="gear_ratio" val="1.0"/>
    <var type="text" name="inlet_pressure" val="tot"/>
    <var type="text" name="mass_flow" val="1.0"/>
    <var type="text" name="mechanical_efficiency" val="1.0"/>
    <var type="text" name="outlet_pressure" val="stat"/>
    <var type="text" name="turbine_efficiency" val="N"/>
    <var type="text" name="turbine_speed" val="0.0" units="rpm"/>
    <var type="text" name="turbine_speed_option" val="FRPM"/>
    <var type="text" name="wastegate" val="ON"/>
    <var type="text" name="wastegate_open_area" val="0" units="mm^2"/>
  </tc_turbine>
</element_template>
<element_template name="Default Throttle Valve" type="junction"
  junction_type="1" junction_subtype="12"/>
<element_template id="orif37" name="Default Piston Driven Valve" type="junction"
  junction_type="1" junction_subtype="6">
  <var type="text" name="count" val="1"/>
  <var type="text" name="diameter" val="25" units="mm"/>
  <var type="text" name="duct_id_above_piston" val="duct28"/>
  <var type="text" name="duct_id_below_piston" val="duct29"/>
  <var type="text" name="flow_direction" val="Left to Right"/>
  <var type="text" name="opening_direction" val="Down"/>
  <var type="text" name="valve#" val="5"/>
  <chk_valves>
    <var type="array" name="countv" size="1">
      <val>1</val>
    </var>
    <var type="text" name="duct_above_piston" val="000"/>
    <var type="text" name="duct_below_piston" val="000"/>
    <var type="array" name="flowdir" size="1">
      <val>lr</val>
    </var>
    <var type="text" name="kexcontrol" val="cyl1"/>
    <var type="text" name="left_duct" val="000"/>
    <var type="array" name="link" size="0"/>
    <var type="array" name="nvd" size="1">
      <val>5</val>
    </var>
    <var type="text" name="pressdir" val="lr"/>
    <var type="text" name="right_duct" val="000"/>
    <var type="text" name="synccyl" val="End of Cycle"/>
  </chk_valves>
</element_template>
<element_template name="Default Complex Y-junction" type="junction"
  junction_type="5" junction_subtype="2"/>
<element_template id="yjun8" name="Default Simple Y-junction" type="junction"
  junction_type="5" junction_subtype="1">
  <y_junction>
    <var type="text" name="diameter" val="50" units="mm"/>
    <var type="text" name="heat_transfer_multiplier" val="1.0"/>
    <var type="text" name="heat_transfer_skin_friction_area" val="0.0" units="mm^2"/>
    <var type="text" name="initial_fluid_temperature" val="300.0" units="K"/>
    <var type="text" name="initial_pressure" val="1.0" units="bar"/>
    <var type="text" name="volume" val="0.0" units="mm^3"/>
    <var type="text" name="wall_friction_multiplier" val="1.0"/>
    <var type="text" name="wall_temperature" val="300.0" units="K"/>
    <opening id="1">
      <var type="text" name="cdk" val="AUTO"/>
      <var type="text" name="delx" val="0.0" units="mm"/>
      <var type="text" name="dia" val="AUTO" units="mm"/>
      <var type="text" name="diab" val="AUTO" units="mm"/>
      <var type="text" name="duct_name" val="duct27"/>
      <var type="text" name="thick" val="0.0" units="mm"/>
      <var type="text" name="x_angle" val="0.0" units="deg"/>
      <var type="text" name="y_angle" val="90.0" units="deg"/>
      <var type="text" name="z_angle" val="90.0" units="deg"/>
```

```
    </opening>
    <opening id="3">
      <var type="text" name="cdk" val="AUTO"/>
      <var type="text" name="delx" val="0.0" units="mm"/>
      <var type="text" name="dia" val="AUTO" units="mm"/>
      <var type="text" name="diab" val="AUTO" units="mm"/>
      <var type="text" name="duct_name" val="973"/>
      <var type="text" name="thick" val="0.0" units="mm"/>
      <var type="text" name="x_angle" val="0.0" units="deg"/>
      <var type="text" name="y_angle" val="90.0" units="deg"/>
      <var type="text" name="z_angle" val="90.0" units="deg"/>
    </opening>
  </y_junction>
 </element_template>
 <element_template name="Default Actuator" type="control"
   control_type="actuator_control" bandwidth_type="inst">
  <var type="text" name="bandwidth" val="inst" units="Hz"/>
  <var type="toggle" name="create_plot" val="off"/>
  <var type="array" name="locs" size="0"/>
  <var type="text" name="pin_number" val=""/>
  <var type="toggle" name="pulse_control1" val="off"/>
  <var type="toggle" name="pulse_control2" val="off"/>
  <var type="toggle" name="pulse_control3" val="off"/>
  <var type="toggle" name="pulse_control4" val="off"/>
  <var type="toggle" name="pulse_control5" val="off"/>
  <var type="toggle" name="pulse_control6" val="off"/>
  <var type="toggle" name="pulse_control7" val="off"/>
  <var type="toggle" name="pulse_control8" val="off"/>
  <var type="text" name="type" val=""/>
  <var type="text" name="y_max" val="auto"/>
  <var type="text" name="y_min" val="auto"/>
 </element_template>
 <element_template name="Default Function" type="control"
   control_type="function_control" expression="">
  <input name="in1"/>
 </element_template>
 <element_template name="Default Sensor" type="control"
   control_type="sensor_control" bandwidth_type="inst" filter_type="inst">
  <var type="text" name="bandwidth" val="inst" units="Hz"/>
  <var type="text" name="bandwidth_freq" val="0.0" units="Hz"/>
  <var type="toggle" name="create_plot" val="off"/>
  <var type="text" name="ductlocation" val="0.0" units="mm"/>
  <var type="text" name="filter" val="0.0" units="Hz"/>
  <var type="text" name="filter_freq" val="inst" units="Hz"/>
  <var type="text" name="location" val=""/>
  <var type="toggle" name="massflow_create_plot" val="off"/>
  <var type="text" name="massflow_y_max" val="auto"/>
  <var type="text" name="massflow_y_min" val="auto"/>
  <var type="toggle" name="molefraction_create_plot" val="off"/>
  <var type="text" name="molefraction_y_max" val="auto"/>
  <var type="text" name="molefraction_y_min" val="auto"/>
  <var type="toggle" name="passive_create_plot" val="off"/>
  <var type="text" name="passive_y_max" val="auto"/>
  <var type="text" name="passive_y_min" val="auto"/>
  <var type="text" name="pin_number" val=""/>
  <var type="text" name="position" val="0.0" units="mm"/>
  <var type="text" name="type" val=""/>
  <var type="text" name="y_max" val="auto"/>
  <var type="text" name="y_min" val="auto"/>
 </element_template>
 <element_template name="Default Wiring Connector" type="control"
   control_type="wiring_connector_control">
  <wiringconnector_data>
    <var type="array" name="pins" size="0"/>
  </wiringconnector_data>
 </element_template>
</template>
```

</WAVE>

II. APPENDIX 2 - CORRESPONDENCE WITH RICARDO® REGARDING BOOST CONTROL HARDWARE

From: dr.jjrussell@gmail.com [mailto:dr.jjrussell@gmail.com] **On Behalf Of** John Russell
Sent: Tuesday, November 03, 2009 9:37 AM
To: Brito, Isaac
Subject: Fwd: UNMF0911020: Re: Modeling boost control actuators

Isaac,

Here is Ricardo's response? Please address their questions - it will help me.

The statement they make about the modeling is important - as it clearly states how original your work is.

Dr R

Hello John,

I have reviewed the students approach modeling the wastegate, actuator and solenoid. This seems very complex for a simple engine model which may or may not be necessary depending on what he hopes to accomplish. Even our most advanced clients do not model this complexity. However, if he feels this is the investigation is warrented, he is approaching the modeling correctly using the pressure driven valve for the pneumatic actuator.

If he wishes to include a solenoid, this can be done two different ways. If he has the complex input information for the solenoid valve, he would model using an inline valve element between his junction and piston valve as type solenoid. This type cannot be actuated. If he wishes to control the solenoid, he would then use the inline valve element with a valve actuated valve, having an actuator connected to it.

Should you have further questions, do not hesitate to contact us.

Regards,

Denise

The Customer Support Team

Ricardo Software
Software Support UK Tel: +44 1273 79 4444
Software Support UK Fax: +44 1273 79 4553
Software Support US Tel: 734-394-3860
E-mail Support: RS_Support@ricardo.com

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