

# Intake and exhaust pipe optimization for an internal combustion engine

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**Abstract.** Nowadays the stringent exhaust emission limitations of the internal combustion engines force the researchers toward an optimization process of new/prototype engines; but for limiting the overall emissions of an entire fleet of vehicles, an optimization of existing engines is also a right research direction. Solutions for this optimization process may come from using biofuels made from different plants that produce oxygen via photosynthesis during their vegetative state and therefore compensate the CO<sub>2</sub> in the internal combustion engine exhaust. Other solutions include better exhaust treatment materials and devices. The current paper proposes a study on optimizing the intake pipe and exhaust pipe of a given internal combustion engine (Opel Astra F, code C18NZ, the production year 2000) using Lotus Engine Simulation software. First the model of the engine was implemented and validated with the full load power and torque variation. For the intake and exhaust the geometrical dimensions were then varied and an optimum was obtained.

## 1. Introduction

The four-stroke engine cycle begins with the intake stroke. The engine power is highly influenced by this stroke because in this process the air, which is used to burn the fuel, is entering the cylinder. So, the more air enters the cylinder, the more fuel can be burned, in order to produce power.

The parameter which measures how much air enters the cylinder compared with the maximum quantity of air that can be entering in the cylinder is the volumetric efficiency [1]. This parameter is reduced by every element that composes the intake system. In order to increase the quantity of air which enters the cylinder, we must build the intake elements with the optimum dimensions.

Regarding the exhaust phase, this is done in three ways: natural exhaust, forced exhaust and mixed exhaust. The main parameter that can influence the efficiency of the exhaust process is the residual gases coefficient, which represents the number of burnt gases that remains in the cylinder after the exhaust valve closes [2]. This coefficient is highly influenced by the interference of the exhaust gases with the exhaust manifold, which can make those gases turn back into the exhaust ports.

In this paper the intake and exhaust processes were analyzed, the geometry and construction of the intake and exhaust manifold were simulated to underline the importance of the construction parameters of the manifolds influence on the intake and exhaust processes. In the end the optimum construction of the manifolds regarding the best performances of the engine was chosen. These analyses were done using the Lotus Engine Simulation software.

## 2. Simulation of the engine

For the simulations, a Vauxhall engine was used which equipped the Astra MK3 model from the same constructor. This engine is naturally aspirated, equipped with a single point fuel system. In table 1, the main characteristics of the engine are shown.

**Table 1.** Engine technical data [3]

Engine code	C18NZ
Engine construction type	OHC (4 cylinders)
Displacement [cm <sup>3</sup> ]	1796
Max.Power [kW]/max. power RPM [rot/min]	66/5400
Max Torque [Nm]/max. torque RPM [rot/min]/	145/3000
Bore x Stroke [mm]	84.8 x 79.5
Compression ratio	9.2
Fuel/CO	Gasoline/95

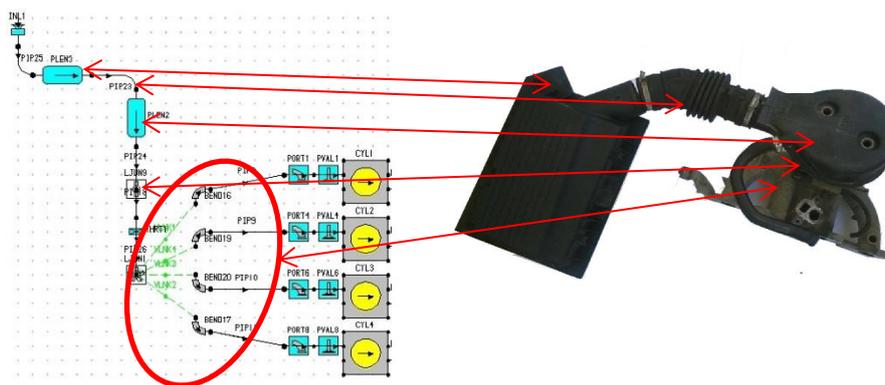
### 2.1. Modeling the engine

The main components of the engine that need to be modeled are: the engine block (bore, stroke, con-rod length, pin-offset, compression ratio), the cylinder head (number of valves, valve open angle, valve close angle, maximum lift of the valves, the diameter of the valves), the intake system (air filter, ducts, intake manifold and the injection module with all the geometry and dimensions) and the exhaust system (the exhaust manifold, catalytic converter and noise silencers with all the geometry and dimensions).

For the engine block only the parameters need to be introduced, without any kind of geometry. These were taken out from the engine specifications. The most important objective in the modeling of the engine was to measure all the intake and exhaust elements, determine the exact shape of these components and then create the model using the measured data.

### 2.2. Modeling the intake system

The intake system is an assembly made of the injection module (throttle body, injector, idle air controller), the intake manifold, the EGR, the hose for the brake assistance and the fixing screws.



**Figure 2.** The intake system model

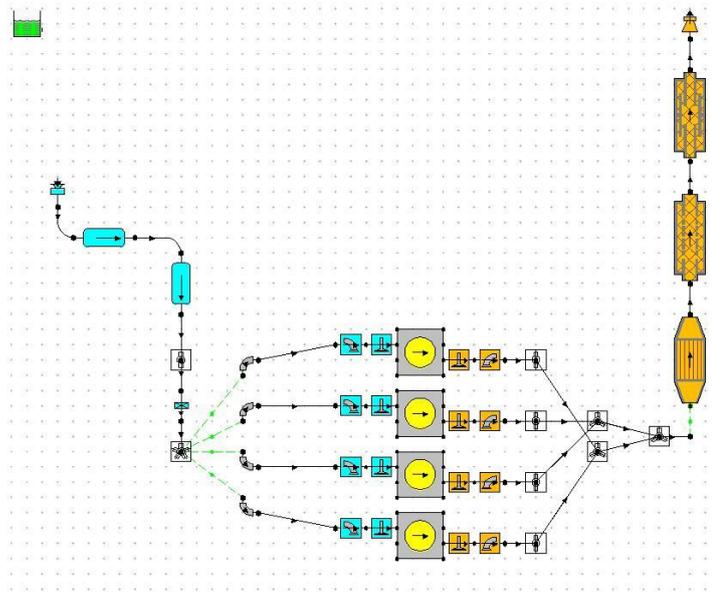
### 2.3. Modeling the exhaust system

The exhaust system is composed of the exhaust manifold, the connection piping, the catalytic converter and the noise silencers. In order to create this model, the following parameters need to be

introduced: geometry and dimension of the exhaust manifold, dimensions of the piping, the type and dimensions of the catalytic converter and the type and dimensions of both noise silencers.

The exhaust manifold of the C18NZ engine combines the first and the fourth cylinder pipes in one outlet and the second and third cylinder pipes in the second outlet. This kind of construction decreases the migration of the burnt gases from the exhaust phase cylinder to the intake phase cylinder, when the valve openings are overlapped. This parameter will then be the input for the correct mixture of fuel and air, in order to obtain the full oxidation of the fuel mixture, thus the exhaust gases will be less pollutant. The construction of the exhaust manifold can be seen in the next figure:

The final model of the engine can be seen in the following figure



**Figure 3.** Final model of the C18NZ engine

The model is composed of the air inlet, air filter, throttle body, injection module, intake manifold, intake valve ports, intake valves, 4 cylinders, exhaust valves, exhaust valve ports, the exhaust manifold, the connection pipes between the exhaust manifold and the catalytic converter and two noise silencers.

### 3. Simulations

For the simulations the manifolds were optimized separately. There are two phases of the simulation: the first simulation was on the intake manifold and the second one was on the exhaust manifold.

The base parameters for both simulations were: minimum engine speed of 800 RPM, maximum engine speed 6400 RPM, the ambient air pressure of 1 bar and the ambient air temperature of 20 Celsius degrees.

#### 3.1. Simulation of the intake manifold

On the intake manifold simulation, two parameters were used: the length of the manifold pipes and the diameter of the pipes.

The first simulation was used to check the model, so with the factory manifold the results should be the same as in the technical documentation of the engine. For this simulation the length of the pipes is 240mm and the diameter is 30mm.

After the simulation the following results were obtained: power – 65kW at 5000 RPM and torque – 140 Nm at 3800 RPM.

In the next step the parametric simulation tool was run. First the length of the intake pipes was used as a parameter and it varied from 50mm to 500mm with the step of 50mm. It can be seen that as the length increases, the volume efficiency increases too, but it drops after 4000 RPM abruptly.

The best choice is the 300mm length because it has a higher value and it decreases with the rpm typically, almost identical to the factory dimensions.

Regarding the power, for each variation of pipe length, the 300mm intake piping was chosen because the highest power is reached at lower rpm.

The last simulation was for the pipes length of 240mm and the variation of the diameter of the pipe from 10mm to 50mm with a step of 10mm.

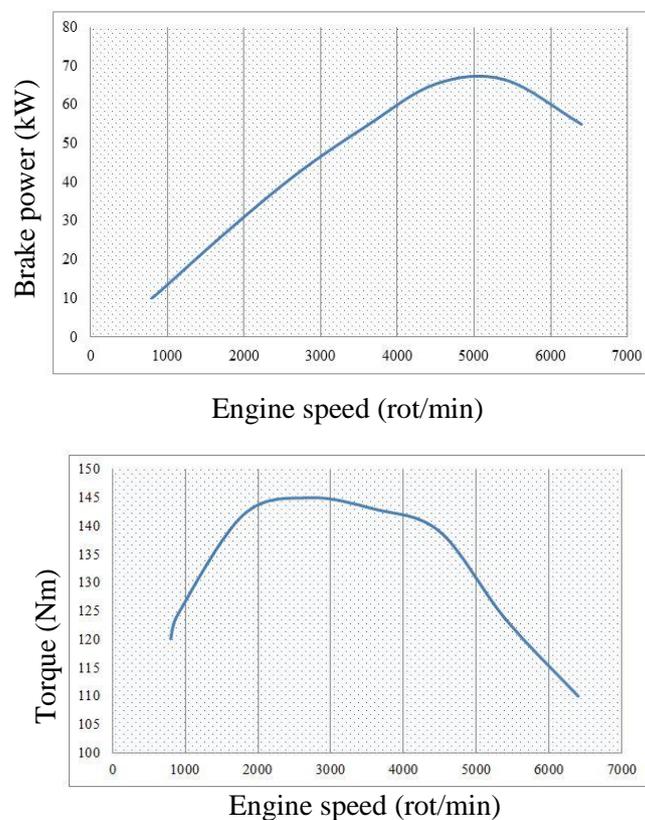
In this case, the highest value of the volume efficiency is reached for the 20mm diameter, but at high rpm, it drops under 75% abruptly, so the best choice is the 30mm diameter of the intake pipes, as the factory diameters.

For the variation of power and rpm considering the variation of the intake pipes diameter we have the following results: if the 20mm pipe diameter is considered as the best choice for getting the highest volume efficiency, in this case, the 20mm diameter is not the best choice because it generates less power than the 30mm pipe diameter.

### 3.2 Simulation of the exhaust manifold

For the exhaust manifold simulation, three constructive variants of the manifold were taken into consideration: the manifold constructed over the interference principle (factory manifold), the manifold with short ramifications and the manifold with individual ramification.

In the first simulation, the base factory dimensions of the manifold were introduced: the pipe length for the first and fourth cylinders is 270mm, the length of the pipes for the second and third cylinders is 250mm, and the diameter of the pipes is 35mm. The results for the simulation are shown in figure 4:

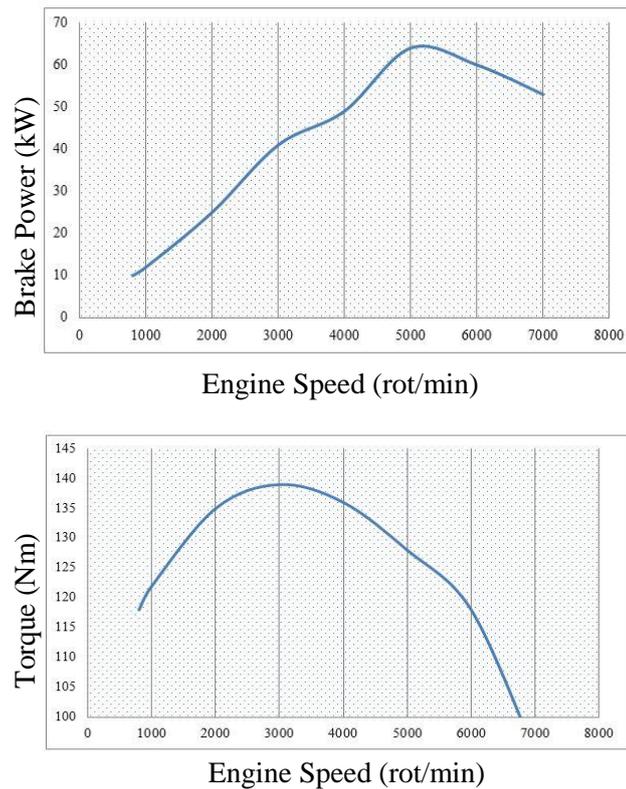


**Figure 4.** Simulation results of the exhaust manifold with the factory dimensions

One of the requirements of the exhaust manifold is to favor a proper evacuation of the exhaust gases out from the cylinder. This can be highlighted by the residual gas coefficient, which needs to have the lowest value. In the simulations this coefficient varies in the range of 3 – 13.2%. Because of the real functioning conditions, the results in the engine speed range of 2000 -3000 RPM (cruise conditions) must be analyzed.

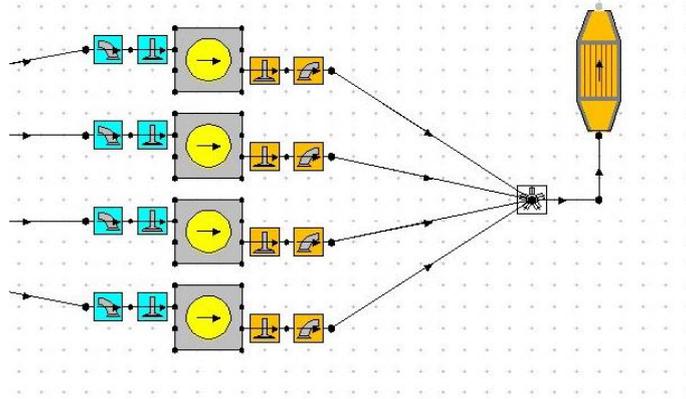
For the second simulation the model was updated, thus the exhaust manifold was updated to a short ramification piping.

The results of this simulation can be seen in figure 5.



**Figure 6.** Results of the short ramification exhaust manifold

In this simulation, the power peak (63.2kW) dropped by 4.8% in comparison to the standard factory exhaust manifold and the peak torque (139.9 Nm) dropped as well by 4.01%. The residual gas coefficient has the worst behaviour, because it is higher than all engine speed ranges by over 4.5%. This behavior could be explained by the fact that there is a more significant flow resistance for the exhaust gases to exit the cylinders. For the next simulation the individual ramification manifold was used. The length of the ramification is the same and varies from 800mm to 1500mm. The model is shown in figure 7.



**Figure 7.** Individual ramification exhaust manifold

For power the peak is 72.2 kW at an engine speed of 5300 RPM. The increase is about 8.7% higher than the standard manifold. These results are for the 1300mm pipe length. The torque increased as well to a peak of 155.2Nm, at an engine speed of 2200 RPM, for the same 1300mm pipe length. The increase is 7.3% higher than the standard manifold.

#### 4. Conclusions

The simulations proved that the intake and exhaust manifold has a significant influence over the performances of the engine.

In the intake manifold case, as seen in the simulation results, the best choice for this type of engine is the length of 30mm and the diameter of 30mm of the intake pipes. However, if the two parameters are combined, maybe there is a possibility to discover better combinations between the length and the diameter of the intake piping.

For the exhaust manifold, the best results were reached with the individual ramification manifold and the length of 1300mm. In this case, the counter-pressure was decreased and a noticeable increase in power and torque was underlined. The problem with this kind of manifold is the cost of production, because in series production casting the entire manifold is cheaper. Usually the individual ramification manifolds are used in high-performance engines.

#### References

- [1] Abăitancei, D., Bobescu, Gh., „Automotive engines” („Motoare pentru automobile”), Editura Didactică și Pedagogică, București, 1975
- [2] Grunwald, B., “The theory, calculus and automotive engine construction” (“Teoria, calculul și construcția motoarelor pentru autovehicule”), Editura Didactică și Pedagogică, București, 1980
- [3] \*\*\* <https://www.auto-data.net/ro/opel-astra-f-1.8i-90hp-2507>
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