HIGH ALTITUDE AIR FLOW REGULATION FOR AUTOMOBILES

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ABSTRACT

High altitude performance is a major concern for automobiles. Due to lack of air density and pressure at high altitude the mass flow rate to engine drops considerably with altitude. This in turn will affect the volumetric efficiency of the engine. This is an area of great concern for Indian road conditions. The Indian road condition varies from sea level to around 6000m. Thus the engine performance varies drastically will altitude.

We had considered flow through the inlet manifold for a four cylinder turbocharger diesel engine at low and high rpm. At lower rpm at around 1500 the turbocharger boost pressure will negligible, thus the engine will be in natural aspiration. Now at this normal running condition the mass flow to engine drops considerably with altitude. Now for a speed of around 2500 rpm there is sufficient flow to around 3000m and then drops. The flow pattern for a single cylinder in open condition has analyzed to find the average mass flow for different altitude.

Keywords- Automobile, High Altitude, Turbulence Effect, Engine Performance, Turbocharger

I. INTRODUCTION

Altitude has a big effect on engine performance. The reason as altitude increases, air thins and as air is required for combustion, power produced by the engine decreases .But engine horse power falls off about 3 percent for each 1000 feet above sea level. In India the road conditions ranges from sea level to 6000m. That is power produced by engine falls to 18%. We know that volumetric efficiency is one of major factor that determines the performance of an ICE. One of the major factors that influence on volumetric efficiency is air mass flow rate towards engine. As altitude increases atmospheric pressure decreases so mean effective pressure decreases. Altitude increases air density also decreases. We can note considerable deduction in engine performance. One of the methods of increasing power output is by means of increasing mean effective pressure.

Our aim is to provide sufficient air flow to the engine so as to improve the efficiency of the engine at normal speeds even at high altitudes. In order to obtain that we are modifying intake system of an engine, by providing an additional passage with an electric supercharger at one end and connected to existing intake manifold. The mass flow rate and volumetric efficiency of existing system and proposed system has been studied and compared. Engine performs well at atmospheric condition so our aim is to provide sea level conditions at higher altitude. Supercharger is controlled with help of microcontroller governed by pressure and altitude sensors. When we reach an altitude of 1000m the supercharger is switched on. This system operates with in the turbo lag period

Chao He et al. (2011),conducted a study on emission characteristic of a heavy duty diesel engine at higher altitudes and they inferred that as the altitude increases, the emissions of HC, CO, NOx and smoke of diesel engine increase, as well as diesel exhaust particles number, especially at the engine speed of 2000 r/min [1]. At some special engine conditions, that is heave-load and low-speed, the reduced emissions of HC and NOx can be observed at high altitudes.

Kevin Norman et al. (2009), suggested clogging the air filter has no significant effect on the fuel economy of the newer vehicles (all fuel injected with closed-loop control and one equipped with MDS) [2]. The engine control systems were able to maintain the desired AFR regardless of intake restrictions, and therefore fuel consumption was not increased. Acceleration performance on all vehicles was improved with a clean air filter.

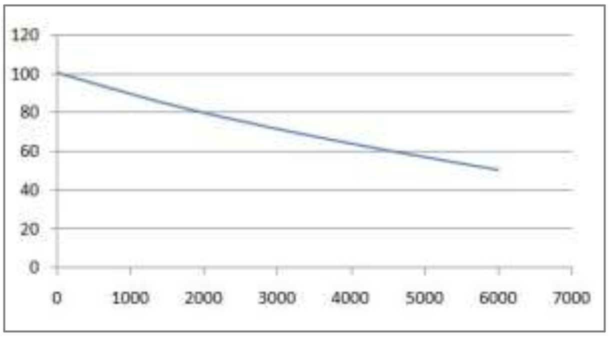
Nik Rosli Abdullah et al.(2013),analyzed the impact of air intake pressure on engine performance and emission characteristics of an SI engine [3]. This study will encourage the vehicle users to ensure their vehicle's air filter is always in clean and good condition. Ensuring clean and good condition of air filter will maintain higher air intake pressure and absorption of polluted particles through air filter. Clogged and dirty air filter reduces the air intake pressure and thus the engine performance and fuel economy.

II. PROBLEM DEFENITION AND BACKGROUND

In India the road conditions ranges from sea level conditions to around 6000m. As altitude increases the atmospheric pressure and air density decreases. This decrease in properties will reduce the performance of the engine at higher altitudes greatly affects volumetric efficiency. Even though there is a system to provide air at higher pressure to engine in order to improve the performance of the engine this is possible only when the engine rpm is above 1750. Up to this much of time engine gets only thin air so there by the engine performance obtained is undesirable. The lag noticed in boosting of air pressure accordance with engine rpm is called turbo lag.

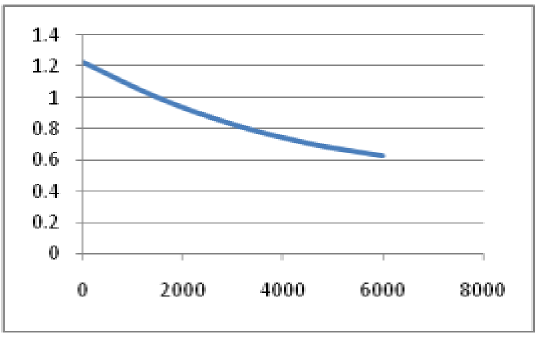
So our prime aim is to avoid turbo lag that is to create a situation at higher altitudes where engine gets required pressurized air at normal speed to obtain this condition. In order to obtain that we are modifying intake system of an engine, by providing an additional passage with an electric supercharger at one end and connected to existing intake manifold. The mass flow rate and volumetric efficiency of existing system and proposed system has been studied and compared. Engine performs well at atmospheric condition so our aim is to provide sea level conditions at higher altitude.

Supercharger is controlled with help of microcontroller governed by pressure and altitude sensors. When we reach an altitude of 1000m the supercharger is switched on. This system operates with in the turbo lag period.



X axis- altitude (m) Y axis-pressure (kPa)

Fig. 1: Pressure variation with altitude



X axis-altitude (m) Y axis-density (kg/m^3)

Fig. 2: Variation of air density with altitude

From the above two Figures, we can see that as we going to higher altitude there is a considerable decrease in atmospheric pressure and air density. The density of air decreases about 7% for every 1000m altitude. The Indian road conditions ranges between 0 to 6000m. We can see that for top road conditions performance decreases about 50%.

At present automobiles employ supercharging and turbocharging systems that rely only on engine speed. They are capable of providing sufficient boost at high rpm. But at normal speeds the boost is so low. Thus for normal speeds the need for pressure boost is needed, the system must be independent of engine speeds but depend on the altitude of operation and manifold pressure. This will allow us to provide the sufficient boost at normal speeds based on altitude only.

III. METHODLOGY ADOPTED

For starting every work we should find out a problem, the topic was selected by us by counting difficulties faced in driving at higher altitudes. When we go to higher altitudes vehicle pulling power is found to be decreasing this will increase driving difficulties. Technically speaking as we go to higher altitudes the volumetric efficiency of the engine is found to be decreasing. So our first step towards this project is to verify the problem. We discussed in team, guide and heavy vehicle drivers. Our next step was to find key factor that cause these problems. Then we notice that as altitude increases the atmospheric pressure and air density is found to be decreasing. Then we studied the effect of decrease in atmospheric pressure and air density in the performance of the engine. To make analysis simpler we chosen different altitudes, 0m, 1500m, 3000m, 4500m, 6000m. Our next step to find out atmospheric pressures and air densities at above mentioned altitudes. Various atmospheric pressure and densities as shown in Table I and Table II.

Pressure at various altitudes obtained by using the relation,

$$P=100\{ [44331.514-Z] / 11880.516 \}^{5.255}$$

Variation of density with altitude using the relation,

$$P = \rho RT$$

Temperatures at different altitudes find out Gay Lusacc's law, then substituting in above equation, we get densities as shown in Table II.

Table I: Variation of Atmospheric Pressure with Altitudes

ALTITUDE, Z (m)	PRESSURE(kPa)
0	101.325
1500	85
3000	72
4500	61
6000	51

Table II: Variation of Density with Altitudes

ALTITUDES (m)	DENSITY (kg/m^3)
0	1.225
1500	1
3000	0.83
4500	0.71
6000	0.635

We calculated volumetric efficiencies of the engine at different conditions for speed of 1500 rpm. We compared the volumetric efficiency of the proposed system with that of existing one at a speed of 1500 rpm. The flow pattern, static pressure and velocity profile has been analyzed using ANSYS 15.

The Figures 3 and 4 shows the turbulence produced at different inserting positions. To identify the optimum position to insert secondary passage, we considered two cases in which the secondary passage given perpendicular to main inlet and in other case the secondary passage given at an inclined angle (45^0).

It is observed that in first position the mass flow rate found to be lesser than that of second case. And observed that the turbulence kinetic energy also found to be lower than that of second case. So the undesirable effect cavitation can be reduced in second case. So second position considered.

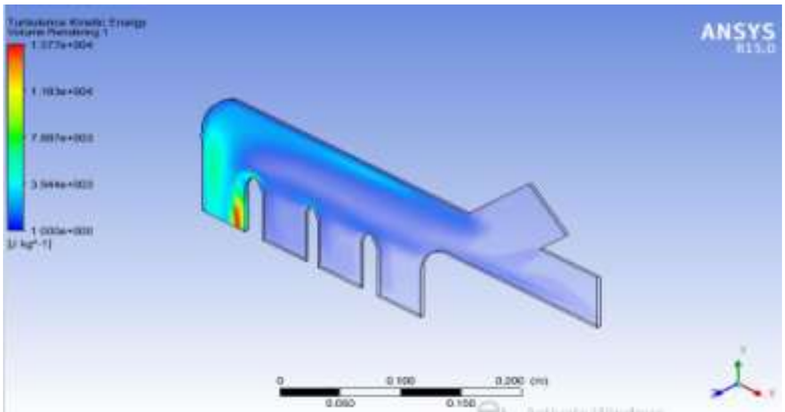


Fig. 3: Turbulence effect for the given position

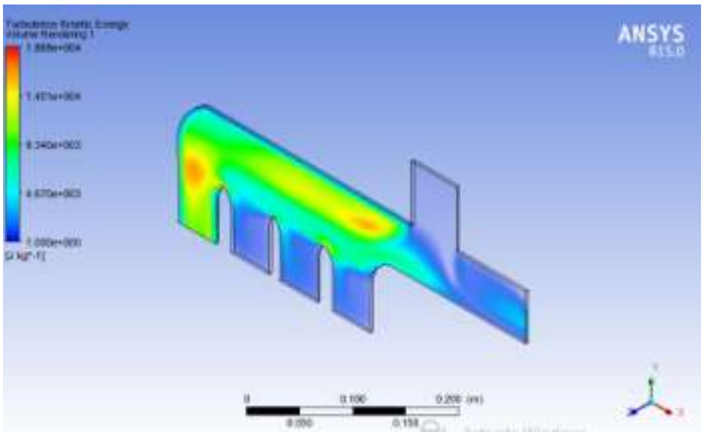


Fig. 4: Turbulence effect for the given position

IV. HIGH ALTITUDE AIR FLOW REGULATOR

In order to create model first of all we need to select an engine to get dimensions for modelling of intake manifold. The most popular Hyundai i20 CRDI 1.4 l diesel engine selected. The engine specification given below,

- 4 cylinder 4 stroke diesel
- Swept volume 1336 cc
- Maximum torque 220 Nm
- Bore 2.95”
- Stroke 3.11”
- Maximum power 89 bhp

In order to provide air at a higher pressure we use a turbocharger which will come in to operation when engine rpm gets beyond 1750 rpm. The turbocharger placed in main passage which will compress the air to required pressure. But this is not sufficient at higher altitudes at normal speeds due to lack of boost pressure at lower rpm.

The Figures 5 shows catia model of existing manifold and Figure 6 shows catia model of proposed system. In order to avoid the problem faced in higher altitudes we introduce a secondary passage which runs parallel to main passage. The secondary passage gives sufficient air flow to the manifold with the help of supercharger fitted at one end.

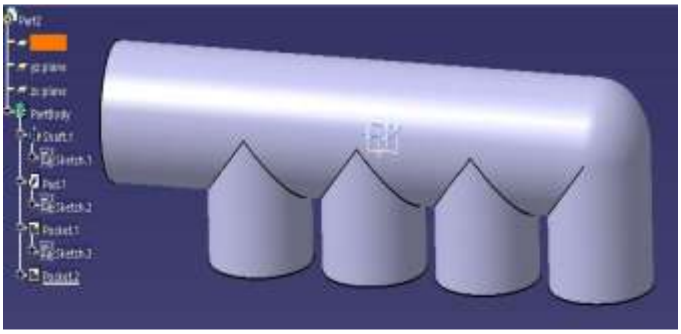


Fig. 5: Existing model

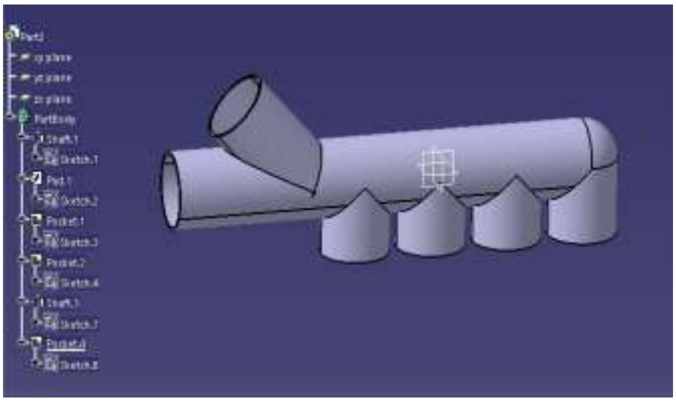


Fig. 6: Proposed model

Table III: Mesh Details

Nodes	2279
Elements	2120
Mesh size	0.05mm
Equation used	K and epsilon
Analysis type	Steady state

Table III shows mesh details of ANSYS analysis. First we had obtained the various inlet and exit values of the manifold. We are considering a steady state analysis of the manifold with a single cylinder in open condition. Thus a suction pressure is provided at the cylinder and different air pressures are provided at inlet. The main two pressure losses are due to friction losses and filter losses. The friction losses occurring in the intake system is assumed to be a constant whose value is around 8.5 kPa. The other main loss is filter losses, it is around 1.5kPa. So the total loss is around 10 kPa, which is a constant. Figure 7 shows air pressure filter losses in intake manifold.

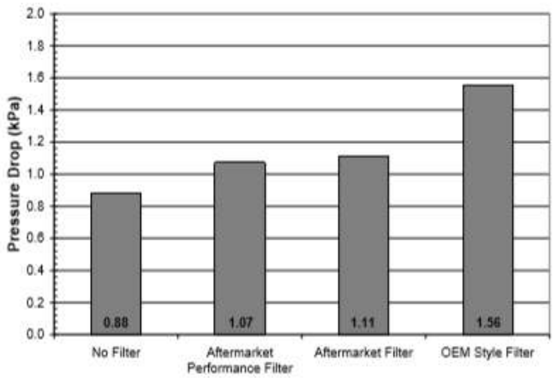


Fig. 7: Air filter losses

Table IV: Boundary Conditions For Existing System

INLET PRESSURE (kPa)	ALTITUDE (m)	OUTLET PRESSURE (kPa)	DENSITY (kg/m^{3})
91	0	-10	1.225
75	1500	-10	1
62	3000	-10	.82
51	4500	-10	.71
41	6000	-10	.635

To improve the performance we runs a secondary passage parallel to main intake ,the secondary passage connected to main to a point before the region of turbulence to avoid cavitations. The secondary passage consist of an electric super charger ,an MAP is placed in main passage. When going to higher altitude then air density decreases at this time the electric super charger placed in secondary passage starts working and compress the air to a higher pressure corresponding to altitude, that is this system always trying to maintain sea level conditions. When the pressure reaches sea level conditions the electric super charger get switch off. Tables IV and V shows the boundary conditions of existing and proposed systems.

Table V: Boundary Conditions of Proposed System

Primary inlet pressure (kpa)	Secondary inlet pressure (kpa)	Altitude (m)	Outlet pressure (kpa)	Density (kg/m^3)
91	91	0	-10	1.225
75	109.47	1500	-10	1
62	96.47	3000	-10	0.83
51	85.47	4500	-10	0.71
41	75.47	6000	-10	0.635

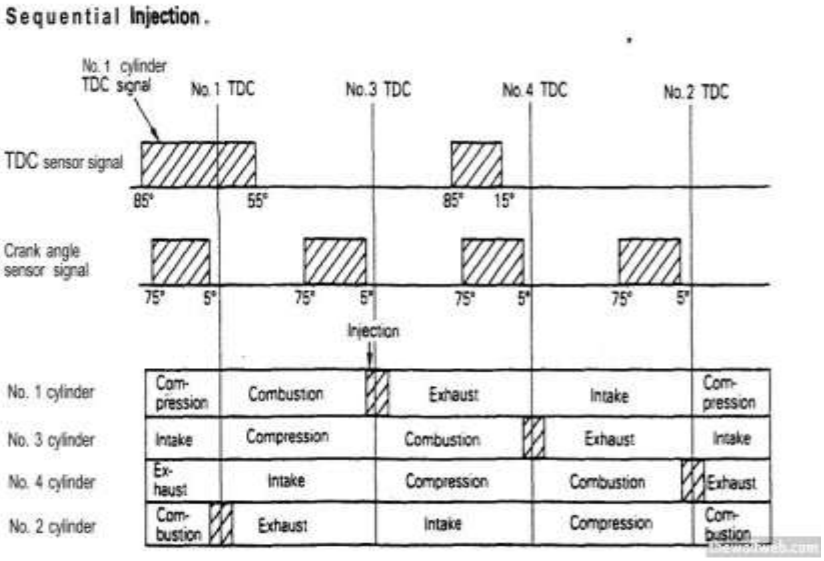


Fig. 8: Valve timing diagram of 4 stroke engine

Even though the flow condition is transient we did our analysis on steady state condition. By noticing the above Figure 8 we can see that in every point on every stroke of engine there is suction taking place in one of four cylinders. So we can infer that the effect produced when one cylinder is opened for a period of time is equal to actual working condition. To get transient values we took rms values of steady state analysis.

Using above given values steady state analysis of the manifold using ANSYS workbench 15.0.The values obtained were compared and plotted. The micro controlled based governing system has been proposed along with analysis. The governing system consist of manifold absolute pressure sensor and an altitude sensor for real time data acquisition. The values obtained are passed through micro controller which governs the running of supercharger.

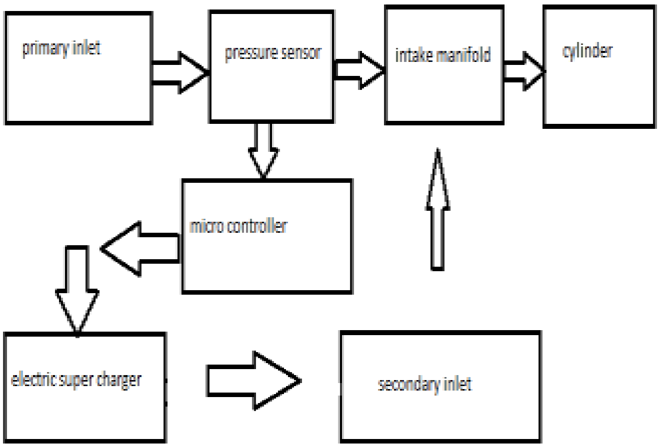


Fig. 9: Diagram of proposed intake

The flow diagram of proposed system is shown in Figure 9, that there is an electrical control module with in which a barometric pressure sensor is placed. This will sense the pressure variation with altitude. The air pressure in main duct can be measured by MAP. We can set a suitable pressure value in control module which is close to sea level conditions. As the vehicle going to higher altitude the difference between MAP and barometric reading increases. When the difference goes beyond the limit the supercharger placed in secondary passage will activated. So mass flow of air can be improved. When MAP reads sea level condition the secondary duct will cut off automatically.

Our prime aim is to improve the volumetric efficiency,

$$\eta_{vol} = \frac{3456 \times CFM}{CID \times RPM}$$

CID = NOC x 0.7854 x bore^2 x stroke

CID = 4 x 0.7854 x 2.95 x 3.11 x 2.95

=85.08 in^3

The mass flow of air of existing and proposed system studied and compared. After that the improvement in volumetric efficiency checked.

Table VI: Comparison of Mass Flow Rate

Altitude (m)	Mass flow of existing system (kg/s)	Mass flow of proposed system (kg/s)
0	2.40	2.4
1500	1.94	2.2
3000	1.64	1.89
4500	1.39	1.65
6000	1.20	1.44

From the Table VI we can see that the mass flow rate of air is increased as compared to existing system. By in cooperating additional passage to existing passage it will definitely improve the mass flow rate. It is seen that the mass flow rate increase about to 20% to 30%.

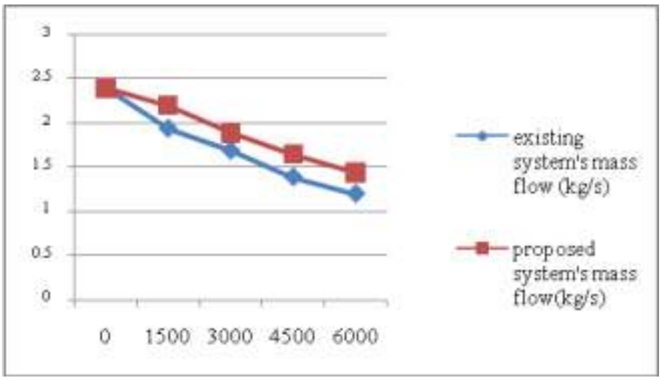
Table VII: Comparison of Volumetric Efficiency

Altitude(m)	η_{vol} existing system (%)	η_{vol} proposed system (%)
0	78.56	78.56
1500	64.8	72.04
3000	53.7	65.85
4500	45.73	57.47
6000	39.02	49.977

From the above Table VII we can see that the volumetric efficiency of proposed system is higher than existing system. When the mass flow rate increases it will definitely increase the volumetric efficiency. With proposed system the volumetric efficiency can be increased to 8 % to 12 %.

V. RESULTS AND DISCUSSION

It is seen that by adopting proposed system the volumetric efficiency can be improved to 8-15% from sea level to extreme high road conditions. Which is obtained by improving the mass flow rate to engine. So by referring to analysis report we can infer that our proposed system is a solution to get high volumetric efficiency in higher altitudes. Declined volumetric efficiency of current system is due to less air density in higher altitudes, this problem is rectified by providing a secondary passage with electric super charger. The supercharger is governed by micro controller.



X -altitude(m) Y-mass flow rate(kg/s)

Fig. 10: Mass flow rate comparison

We can see that the mass flow rate of air is increased as compared to existing system. In our proposed system there is an additional secondary passage which will come in to action when the air pressure in main duct falls below.

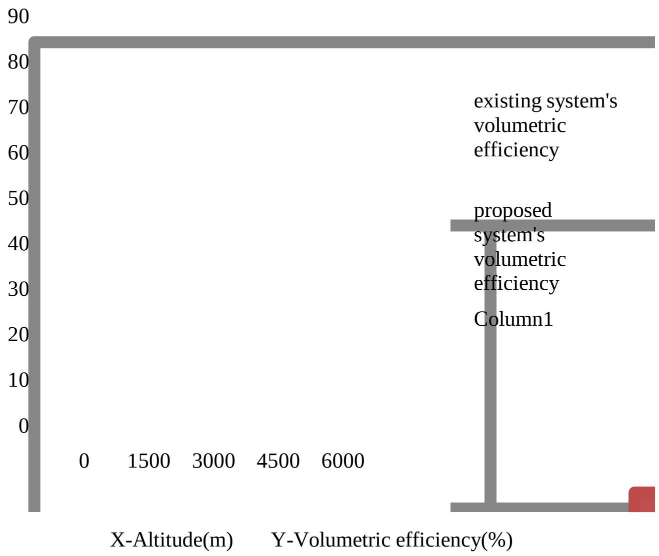


Fig. 11: Volumetric efficiency comparison

By in cooperating additional passage to existing passage it will definitely improve the mass flow rate. It is seen that the mass flow rate increase about to 20% to 30%. These variations are shown in Figures 10 and 11.

VI. CONCLUSIONS

It is seen that in existing automobiles when going to higher altitude mass flow rate found to be decreasing so that performance found to be inadequate. In order to improve the mass flow rate a secondary duct run parallel to main duct. This is provided with an electric super charger. This will come in to action when main inlet pressure falls under atmospheric pressure. The secondary duct helps to maintain pressure almost equal to sea level conditions. Improve the efficiency of the engine at normal speeds even at high altitudes. Proposed system the volumetric efficiency is found to be higher than that of existing system. The mass flow rate and volumetric efficiency of existing system and proposed system has been studied and compared. To provide sea level conditions at higher altitude. By doing so performance of the engine can be improved.

The proposed system will improve the volumetric efficiency of the engine by about 10% in all altitudes. This system is cost effective and can be successfully implemented in any given vehicle with minimal modifications. The best suitable position for fixing the secondary passage is in between the inlet manifold and inlet duct. The flow pattern will not get changed inside the manifold in addition of the secondary duct. Thus this flow will not affect the resonator design.

The flow pattern and the pressure developed in the manifold shows a improvement in flow rate at various altitudes. Air flow to engine is the only external factor that affects the engine performance at altitudes. The improvement in airflow will thus enhance the volumetric efficiency and in turn the overall efficiency of the engine.

With the improvement in air flow the combustion will be better and the emission characteristics of the engine. Thus the CO emission and particulate emission will also drops.

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