

# Theoretical Approach of Downsizing 2L V6 Petrol Engine to 4 Cylinder Inline Engine

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**Abstract-** The paper discusses the concept, design and final results of downsizing 2L V6 Petrol engine to 4 cylinder inline (I4) engine. The basic architecture is retained and prime importance is given to meet the Indian market performance requirement, which was done by having strong focus on fuel economy, power & cost. The paper discusses the technologies which can be implemented for the purpose of downsizing so that the 4 cylinder inline engine has equal power or more power than the 2L V6 petrol engine. Mostly downsizing doesn't mean that just reducing the number of cylinders. Downsizing is done to reduce the capacity of engine, without affecting the power delivered by the engine. The paper discusses the theoretical calculations done for designing I4 engine & with the use of proposed technologies we can create a downsized I4 engine as good as a V6 engine.

**Index Terms-** *Petrol Engine, Downsizing*

## 1. INTRODUCTION

The purpose of this project is to produce a downsized 4 cylinder inline engine from a 2L V6 petrol engine. As diesel is cheaper, we can develop a downsized 4 cylinder inline diesel engine suited to Indian market performance. But we are going to present the theoretical concept of developing the engine based on the same architecture of a 2L V6 petrol engine. Hence, we will be developing a downsized 4 cylinder petrol engine. The main problem raised was whether we can achieve the same or better performance by integrating a smaller engine into our machines. This is the fundamental question that underpins the steady increase in Original Equipment Manufacturers (OEMs) looking at engine downsizing as a way of improving the cost-effectiveness of their operations.

With a growing number of OEMs choosing to install more compact and efficient engines into their machines, the benefits of engine downsizing are becoming more apparent. By integrating a smaller displacement engine, operators can benefit from a reduction in fuel burn and lower greenhouse gas emissions, while higher power density helps to improve the overall efficiency of smaller engines. If a car has a smaller capacity engine than its predecessor, but can still do the same job or has even better performance, then we call it 'downsizing'.

Engine downsizing is the use of a smaller engine in a vehicle that provides the power of a larger engine, through the use of recent technologies.

Mostly downsizing doesn't mean that just reducing the number of cylinders. Downsizing is done to reduce the capacity of engine, without affecting the power delivered by the engine.

It is the result of car manufacturers attempting to provide more efficient vehicles that emit less emission.

Many manufacturers are reducing engine capacity and number of cylinders. By adding a boosting device (turbocharger or supercharger) and direct injection technology, they provide a powerful engine with similar performance to a much larger engine, but with much improved efficiency and reduced carbon emissions.

A smaller engine is also often lighter, so the car can be lighter and therefore nimbler. Reducing the number of cylinders also reduces the amount of friction in the engine, increasing the efficiency.

Downsizing by adding a turbocharger or tuning the engine to have better exhaust system, racing air filters and remapping ECU to inject more fuel, so it's a petrol engine, you can use better racing spark plugs.

One of the best-selling examples of 'downsizing' is Ford's 1.0-litre EcoBoost petrol engine, which is available with outputs of 99bhp, 123bhp and 138bhp, meaning it effectively replaces 1.4, 1.6 and even some 1.8-litre engines from the past. It's also fitted in small, lightweight models like the top-selling Fiesta.

**2. COMPARISON TABLE  
(BENCHMARKING)**

Specifications	Ford Ecosport	Volkswagen Golf V	Toyota Corolla XI (E170)	Renault Fluence	Nissan Cefiro A32
Engine Model	DURATEC Ti-VCT	1.4 TSI	1.6 Valvematic	1.6 16V	VQ20DE
Bore	79mm	76mm	80.5mm	79.5mm	78mm
Stroke	81.4mm	75.6mm	78.5mm	80.5mm	69.7mm
No. of cylinders	4 (inline)	4 (inline)	4 (inline)	4 (inline)	6(V engine)
Displacement	1499cc	1390cc	1598cc	1598cc	1995cc
Compression Ratio	11.0:1	10.0:1	10.7:1	9.8:1	9.5:1
Maximum Power	112hp@ 6300rpm	140hp@ 5600rpm	132hp@ 6400rpm	110hp@ 6000rpm	155hp@ 6400rpm
Maximum Torque	140N.m@ 4400rpm	220N.m@ 4000rpm	160N.m@ 4400rpm	151N.m@ 4250rpm	186N.m@ 4400rpm
Top Speed	172kmph	210kmph	200kmph	185kmph	227kmph
Mileage	12.3kmpl (city) 19.2kmpl (highway)	12kmpl (city) 19.6kmpl (highway)	12.5kmpl (city) 20.4kmpl (highway)	12kmpl (city) 14kmpl (highway)	10kmpl(city) 14.1kmpl (highway)
0-100 acceleration (sec)	13.3	8.8	10	11.5	9.2
Transmission	5MT	6MT	6MT	5MT	5MT
No. of gears	6	7	7	6	6

Nissan Cefiro A32 has Bosch double platinum spark plugs, 4 valves per cylinder (2 for inlet & 2 for exhaust). It has a Double OverHead Camshaft (DOHC) with Variable Valve Timing (VVT). Multi Point Fuel Injection (MPFI) system is equipped in this car.

The above mentioned I4 cars have a total of 16 valves (4 valves per cylinder). Multi Point Fuel

Injection (MPFI) system is equipped in almost all of them. Toyota Corolla XI (E170) has 1 spark plug per cylinder & the rest of the models have 2 spark plugs per cylinder each. All models have turbocharger but Volkswagen Golf V has both turbocharger & supercharger.

### 3. DESIGN OF PARAMETERS

Let

Car 1 = Ford Ecosport

Car 2 = Volkswagen Golf V

Car 3 = Toyota Corolla XI (E170)

Car 4 = Renault Fluence

Car 5 = Nissan Cefiro A32

We have Bore Diameter, d

We have Stroke Length, L

Displacement volume of single cylinder,

$$V = V_s = (3.14/4) * d^2 * L$$

Total displacement volume of 4 cylinders,

$$V_t = V_s * 4 * V$$

We have Compression Ratio, CR

$$CR = (V_c + V_s) / V_c$$

where  $V_c$  = Clearance Volume

&  $V_s$  = Stroke Volume

We get the value of  $V_c$  from above equation.

By following the above procedure, we get the values of  $V$ ,  $V_t$ ,  $V_c$  for the mentioned cars.

Table 1: Volumes of cars (in cc)

	Car 1	Car 2	Car 3	Car 4	Car 5
<b>V</b>	398.99	342.95	399.53	399.59	333.05
<b>V<sub>t</sub></b>	1595.96	1371.8	1598.12	1598.36	1332.2
<b>V<sub>c</sub></b>	39.89	38.10	41.19	45.41	39.18

We took the average of  $V_c$  of 4 cars.

We get  $(V_c)_{avg} = 41.14$

Based on  $(V_c)_{avg}$  value, we find the value of CR.

Table 2: Compression ratio of cars

	Car 1	Car 2	Car 3	Car 4
<b>CR</b>	10.69	9.34	10.71	10.71

We select the precise value, i.e., CR = 10.71

$$\text{Brake Power} = (2 * 3.14 * N * T) / 60$$

1 hp = 746 W Therefore, 1 W = (1 / 746) hp

Table 3: Break horse power of cars (in hp)

	Car 1	Car 2	Car 3	Car 4	Car 5
<b>bhp</b>	86.47	123.53	98.82	90.08	114.88

We take the average of the brake horse power (bhp) of the 4 cylinder inline petrol engine cars. We get

$$(bhp)_{avg} = 99.59 \text{hp} \sim 100 \text{hp} = 74600 \text{W}$$

We select the values closer to Volkswagen golf V because the bhp of this car is maximum among the other three 4 cylinder inline petrol engine cars.

We take the following values for the design of a downsized 4 cylinder inline engine:

Bore Diameter, d = 77mm

Stroke Length, L = 76mm

$$V = V_s = (3.14/4) * d^2 * L$$

We get  $V = V_s = 353.90 \text{cc}$

$$V_t = V_s * 4 * V$$

We get  $V_t = V_s * 4 * V = 1415.6 \text{cc} \sim 1416 \text{cc}$

Thus, we downsized the 2L V6 petrol engine to 1.4L 4 cylinder inline petrol engine.

Compression Ratio, CR = 10.71

$$CR = (V_c + V_s) / V_c$$

We get  $V_c = 36.45 \text{cc}$

Torque is inversely proportional to rpm. Hence, we take  $\text{Torque} * \text{rpm} = \text{Constant}$ .

We find the torque values of all the mentioned cars at 4400rpm.

Table 4: Torque of cars (in N.m)

	Car 1	Car 2	Car 3	Car 4
<b>Torque</b>	140	200	160	145.85

We took the average value of the torque of the first 4 cars. We get

Average Torque = 161.46 N.m

$$\text{Brake Power} = (2 * 3.14 * N * T) / 60$$

We get bhp = 99.72hp

Thus, the theoretically obtained bhp of a 4 cylinder inline petrol engine is 99.72hp.

Theoretically obtained bhp of 2L V6 petrol engine is 114.88hp.

The value of the brake horse power of 4 cylinder inline engine (before downsizing) is very much closer to the brake horse power of a 2L V6 petrol engine. Now, after equipping some better technologies, we can further increase the power of the 4 cylinder inline petrol engine.

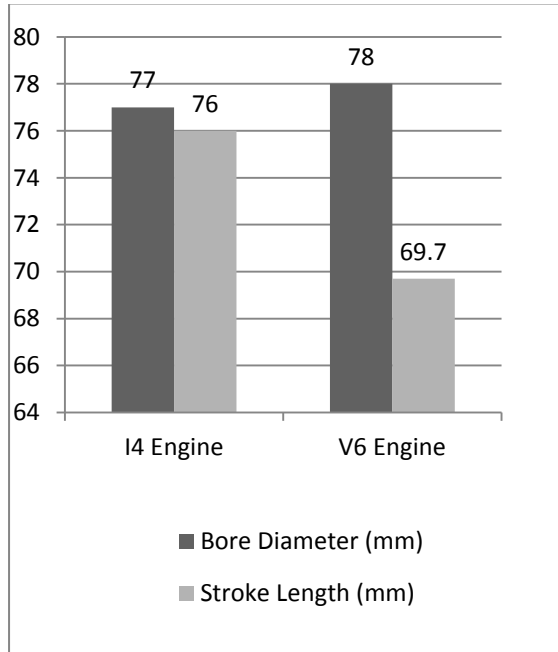


Fig. 1: Bore diameter (mm) & Stroke length (mm) of I4 & V6 engine

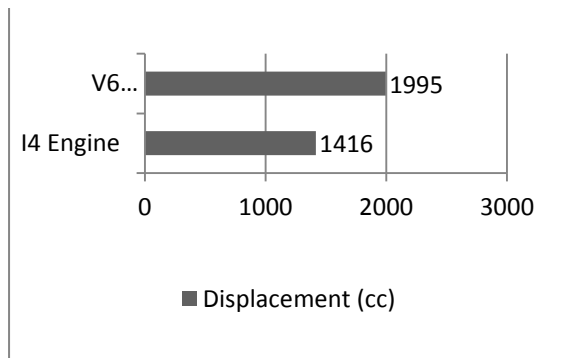


Fig. 2: Displacement volume (cc) of I4 & V6 engine

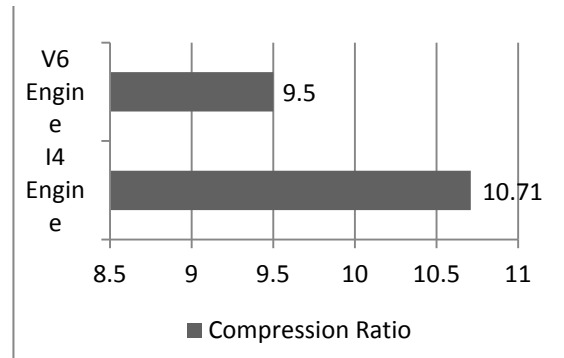


Fig. 3: Compression Ratio of I4 & V6 engine

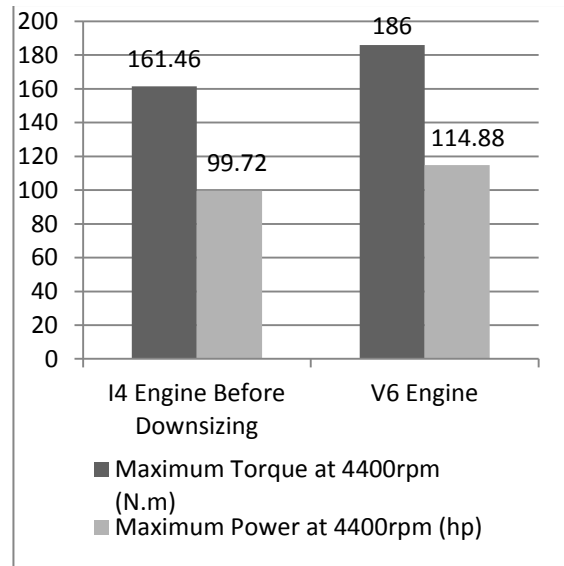


Fig. 4: Maximum torque (N.m) & maximum power (hp) of I4 engine before downsizing & V6 engine at 4400rpm

#### 4. PROPOSED TECHNOLOGIES

##### 4.1. Fuel Injection Technologies:

##### 4.1.1. Gasoline Direct Injection (GDI):

In non-Diesel internal combustion engines, Gasoline Direct Injection (GDI), also known as Petrol Direct Injection, Direct Petrol Injection, Spark Ignited Direct Injection (SIDI) and Fuel Stratified Injection (FSI), is a variant of fuel injection employed in modern two-stroke and four-stroke gasoline engines. The gasoline is highly pressurized, and injected via a common rail fuel line directly into the combustion chamber of each cylinder, as opposed to conventional multi-point fuel injection that injects fuel into the intake tract, or cylinder port. Directly injecting fuel into the combustion chamber requires high pressure injection whereas low pressure is used injecting into the intake tract or cylinder port.

In some applications, gasoline direct injection enables stratified fuel charge (ultra-lean burn) combustion for improved fuel efficiency, and reduced emission levels at low load.

#### **4.1.2. Multi Point Fuel Injection (MPFI):**

MPFI is a fuel injection technique used in gasoline engines. MPFI injects fuel into the intake ports of each cylinder's intake valves, rather than at central point within an intake manifold like in spark plugs.

Direct Injection has a lot of advantages over the MPFI or port injection and it's the way of the future.

- Direct injection improves mileage through a stratified charge engine process.
- Lower emissions.
- Prevents engine knocking/detonation.
- Better control of the engine since before GDI it was only possible to manipulate valve timings in real time operation to change the efficiency/power characteristics of the engine, now since you can vary the fuel pressure, amount, there are a whole lot of possibilities to explore.
- GDI engines are built sturdier compared to MPFI engines and last longer.
- Better power output compared to MPFI.

The ultimate advantage of GDI is that through this technology everything happening inside the engine can be precisely controlled by the electronics and nothing is left to chances. For example in MPFI, some amount of fuel can be left over inside the injectors though not causing an issue, causes slight variation in every stroke but when you move over to GDI, it's like a German train time table. It will always be perfect. Hence, we are implementing GDI technology.

#### **4.2. Valve Operating Mechanisms:**

There are various technologies available in the market for valve opening & closing mechanism as follows:

- VVT: Variable Valve Timing
- VTVT: Variable Timing Valve Train
- VVTi: Variable Valve Timing with intelligence
- iVTEC: Intelligent Valve Lift Technology

& many more similar technologies.

The above mentioned technologies are used mechanically. Hence, there are friction losses.

Brake Power = Indicated Power – Friction Losses

Hence, to increase the brake power, we need to reduce the friction losses. To reduce friction losses, we are implementing an electronically operated solenoid valve for operating intake & exhaust valves. As we use a hydraulic system, there is no need to use cam shaft & timing belt or timing chain.

#### **4.3. Turbocharger:**

There are various types of turbocharger.

Some of them are as follows:

- Normal Turbocharger
- Variable Nozzle Turbocharger
- Waste Gate Turbocharger
- Two Stage Turbocharger
- Three Stage Turbocharger

We are implementing a Two Stage Turbocharger (Twin Type Turbocharger) in a 4 cylinder inline petrol engine along with an intercooler in between because with the help of such kind of arrangement, we can send more amount of air inside the cylinder. Turbocharger will suck the atmospheric air in its first stage. Then the pressure air rises, & according to Charles law, pressure is directly proportional to the temperature. Thus, temperature rises & then the density also rises. Now, if we pass this pressurized air into the intercooler, then its density will decrease. Again pass the air to the second stage of compressor & then ultimately send it to the IC engine. Thus, we can send more amount of air by this arrangement. This ultimately results in efficient combustion of fuel.

#### **4.4. Camshaft & Cam Quantity:**

If the number of inlet & exhaust valves is 1 each in a single cylinder, then we can use a Single Over Head Camshaft (SOHC).

If the number of inlet & exhaust valves is 2 each in a single cylinder, then we can use a Double Over Head Camshaft (DOHC).

The more are the number of valves, the more are the number of cams required for operating the valves.

We are using 16 valves in total.

In case, if we use an electronically operated solenoid valve, then there is no need of a cam shaft. Hence, no need of DOHC. But the cost of this system is more.

In case, if we don't use electronically operated solenoid valve, then to get the required output power & efficiency like the V6 engine, we have to use iVTEC: Intelligent Valve Lift Technology along with Double Over Head Camshaft (DOHC).

#### **4.5. Exhaust Gas Recirculation (EGR):**

##### **4.5.1. High Pressure EGR:**

- Low EGR rates at lower engine speeds/loads
- Simple to calibrate
- Cheaper

##### **4.5.2. Low Pressure EGR:**

- Higher EGR rates
- Possible damage to engine
- Complicated to calibrate
- Expensive

##### **4.5.3. High + Low Pressure EGR:**

- Higher EGR rates
- More flexibility in control
- Complicated to calibrate
- Expensive

We are selecting High + Low Pressure EGR because according to the conditions, the respective EGR will process the exhaust gas.

#### **4.6. Spark Plug:**

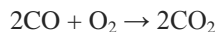
- Single Spark Plug
- Dual Spark Plug
- Triple Spark Plug – One Master Plug & Two Slave Plugs

When we are using all the advanced technologies, then there is no need to use a triple spark plug. Dual spark plug is sufficient enough to create complete combustion of the fuel inside the combustion chamber & cylinder. Hence, we use dual spark plug.

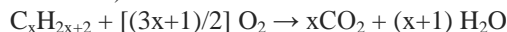
#### **4.7. Catalytic Converter:**

##### **4.7.1. Two way catalytic convertor: Reactions:**

Oxidation of carbon monoxide to carbon dioxide:

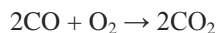


Oxidation of hydrocarbons (unburnt and partially burnt fuel) to carbon dioxide and water:

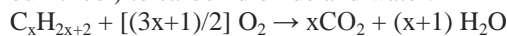


##### **4.7.2. Three way catalytic convertor: Reactions:**

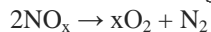
Oxidation of carbon monoxide to carbon dioxide:



Oxidation of hydrocarbons (unburnt and partially burnt fuel) to carbon dioxide and water:



Reduction of nitrogen oxides to nitrogen and oxygen:



We are using the three way catalytic convertor because it reduces nitrogen oxides also.

Alternative to this problem is that we can use 'Nano fluid' as a coolant which doesn't allow the production of NO<sub>x</sub> & SO<sub>x</sub> in the cylinder after combustion. Beyond a particular higher temperature (1100°C), NO<sub>x</sub> & SO<sub>x</sub> gases are produced. The Nano fluid (Alumina- Al<sub>2</sub>O<sub>3</sub>), as a coolant doesn't allow this temperature to be reached. So, there is no production of NO<sub>x</sub> & SO<sub>x</sub>.

## **5. CONCLUSION**

Thus, we are able to develop a 4 cylinder inline engine which has a closer value of brake power to that of a 2L V6 petrol engine. Later, to increase further the brake power of the 4 cylinder inline engine, we equipped the engine with various technologies. We installed a Gasoline Direct Injection (GDI) system, iVTEC valve operating mechanism, Two Stage Turbocharger, 4 valves per cylinder (2 inlet valves & 2 exhaust valves), Double Over Head Camshaft (DOHC), High + Low Pressure EGR, Double Spark Plug (Twin Spark Ignition System), Three Way Catalytic Converter, etc.

We can even install an electronically operated solenoid valve instead of iVTEC & DOHC so that friction losses occurring by the mechanical valve operating mechanism & Double Over Head Camshaft (DOHC) is reduced. The problem with this technique is the increase in cost of the engine. There is no need to install a supercharger. The above mentioned technologies are sufficient to downsize a 2L V6 petrol engine into a 4 cylinder inline petrol engine.

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