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Engine Design Computational Analysis

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***Abstract:** In this research, different methods are developed to vary intake length. Various methods like ram effect tuning and geometric devices are researched in literature review to increase engine performance. Ricardo WAVE simulation software is used to simulate 4-cylinder engine. Main aim behind simulation is to study how induction manifold length tuning affects the inline 4-cylinder engine. Volkswagen cabriolet engine specifications are used to set parameters including stroke, bore, and clearance height etc. From simulation results, it is clear that by varying intake manifold length power and torque of the engine is increased, while fuel consumption is improved and therefore engine performance is improved.*

Keywords: Ricardo Wave Build, Engine Design, Intake Manifold, Power & Torque

1. Introduction

SI (Spark Ignition) engine performance can be improved by making adjustments in the operating parameters. Factors such as CR (compression ratio), air-fuel ratio, timings of spark advance fuel injection ignition and valve at different load conditions have an effect. The effects of operating parameters further exploited by using technologies like TDCI (Turbo Diesel Common Rail Injection), Quadra jet, DTSi (Digital Twin Spark Ignition), triple and twin spark. Inertial ram and acoustic effects require additional extra fuel and regulating devices to increase engine torque and engine performance. At certain speeds, opening and closing of valves create airflow through intake manifold and runner which results in resonance of airflow. Most conventional intake manifolds have static intakes and fixed airflow geometry. For a specific rpm, the static intake manifold can be optimized and for a given engine, this rpm corresponds to maximum torque. Generally, engines operate within large speed ranges so it is necessary to broaden the curve of a torque and this is achieved by varying the intake length. [1]

2. Literature Review

M A ceviz performed some experiments to understand how engine performance and emission affects with the variation of intake plenum volume. In this experiment author mainly focused on coefficient of variation in indicated mean effective pressure, Brake and indicated engine performance characteristics. Finally, author came to conclusion that, by varying intake plenum volume continuously performance of the engine can be improved. [4]

M.A. Ceviz and M. Akin researched on spark-ignited engine with electronic fuel injector. In this research, they mainly concentrated on how performance of this type of engine affects by intake plenum volume. Characteristics of SI engine improved in case of multipoint fuel injection system when compared to carbureted system. From results, it was clear that at low engine speed and high load, efficiency of engine i.e. fuel consumption was improved with the variation of plenum length. [5]

Two-stage variable intake system was designed especially for formula type of FSAE (Formula Society of Automotive Engineers) car. Control system used here was Flap control system. Where, the main function of flaps was to switch between two different runners. [1]

2.1 Intake tuning theory

Compression and rare faction waves play important role in increment of volumetric efficiency of the engine. Rare faction wave is also known as suction wave. More than 100% of volumetric efficiencies can be achieved at certain RPM's, ultimately which increases engine performance and torque output. When intake valve closes momentum of the airflow halts suddenly, which cause to generate compression wave and this wave reciprocates (travels) along the length of closed intake runner. Corresponds tuning is achieved by carefully adjusting the length of closed intake runner, which helps to arrive pressure wave exactly at the time when inlet valve opens. This effect is known as inertial ram effect and Chryslers ram theory is used to find out the length. [1]

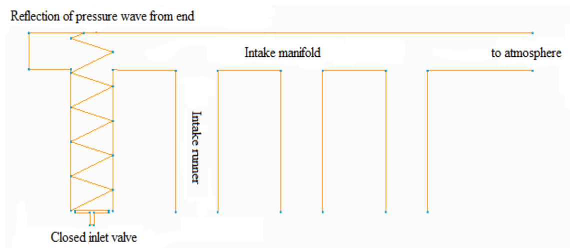

Figure 1: Chrysler's Ram Theory [1]

While, during the time of suction stroke of the engine suction wave is generated. This wave travels upstream to airflow and after reflecting from inlet boundary it will acts like high-pressure wave. While, it travels towards downstream side of the combustion space. Local density of inlet flow can be increased, if compressive wave made to arrive at proper time by designing intake manifold length properly. This effect is known as natural or acoustic supercharging and Resonance theory or Acoustic Theory of Piping is used to find out the length. [1]

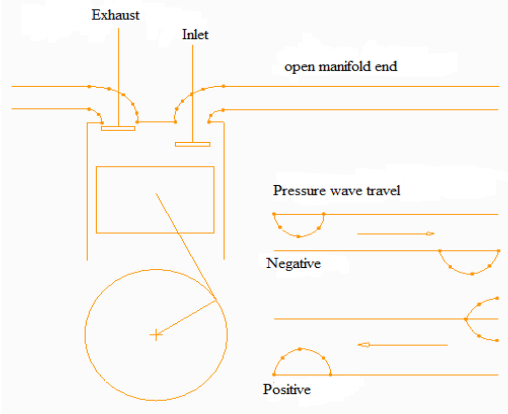

Figure 2: Acoustic Tuning Theory [1]

For multi cylinder engines with common intake manifold, during suction stroke suction waves are generated and which can be tuned by using acoustic theory. While, Chrysler method is used for the tuning of compressive wave by deciding individual length of the intake runner. For single cylinder engines, there is no plenum end and as the intake manifold and inlet runner are the same. Suction wave reflects back as a compression wave when it reaches to the inlet end. To obtain maximum torque increase, arrival time of this wave have to be matched with maximum piston velocity time. By changing crossectional area of pipe or altering the inlet pipe, arrival time can be altered. Compression waves can be tuned by using Helmholtz resonator, as shown in Figure 3. [1]

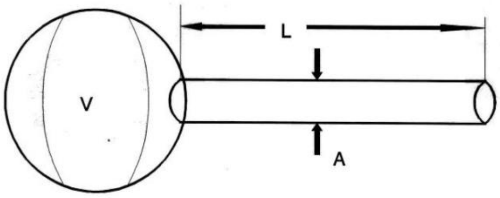

Figure 3: Helmholtz Resonator [1]

For Helmholtz Resonator frequency (f) is given by following formula,

$$f = \frac{C}{2\pi}\sqrt{\frac{A}{L*V_{eff}}} \quad \text{.........................} \textbf{Equation 1}.[1]$$

Where,
c is speed of sound, V_{eff} is effective velocity and L = l+0.3d (d and l are diameter and length of the pipe)
Piston velocity is maximum at mid-stroke. Therefore, to calculate effective velocity(V_{eff}), the cylinder volume with the piston at mid-stroke position is considered.

$$V_{eff} = \frac{V_D\,(CR+1)}{2(CR-1)} \quad \text{......................................} \textbf{ Equation 2}.[1]$$

Substituting value of V_{eff} in Equation 1,

$$f = \frac{C}{2\pi}\sqrt{\frac{A*2(CR-1)}{L*V_D\,(CR+1)}} \text{................} \textbf{ Equation 3}.[1]$$

Where,
V_D= Swept volume
CR= Compression Ratio

3. Research Methodology

Wave is software package from Ricardo software and it is ISO approved. This software is one of the leading 1D engine & gas dynamics simulation software available in market. Wave software mainly used in industrial sectors like, motorcycle, motorsport, car, truck, power generation and locomotive. Simulations of combustion, intake and exhaust can be done very easily by using this software. [2]

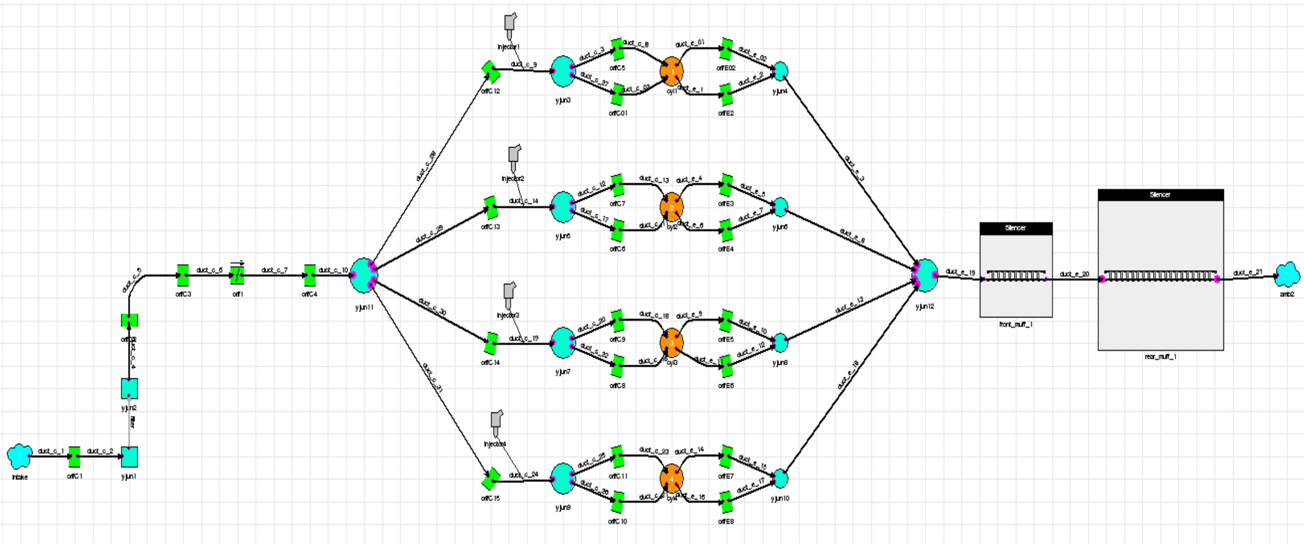

Figure 4: Wave Model

3.1 Wave Model

Above figure 4 shows, wave model of inline 4 cylinders, 4 stroke, spark ignition engine designed in Ricardo WaveBuild simulation software. This engine consists of 4 DI (Direct Injection) fuel injectors to inject fuel in cylinders (one in each cylinder) and each cylinder has 4 valves (two inlets and two exhausts). Using Y-junction intake manifold lengths are connected to inlet valves of cylinder, as shown in figure 5.

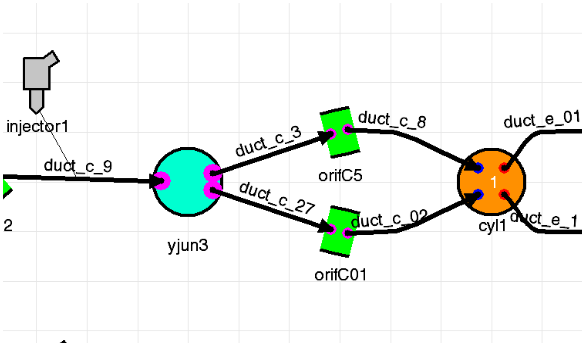

Figure 5: Simple Y-Junction

3.2 Volkswagen cabriolet engine specifications

In current report, the main aim is to investigate tuning effects of induction manifold length on 4-cylinder engine. Design parameters are referred from Volkswagen cabriolet engine, as this engine is of 4-cylinder type. [3]

DX code Engine
Engine type: 4 cylinder
Bore = 81mm
Stroke= 86.44mm
Clearance height= 2mm
Compression ratio= 10:1
Horsepower= 112 at 5800rpm
Torque (lb.ft) = 113 at 3500rpm

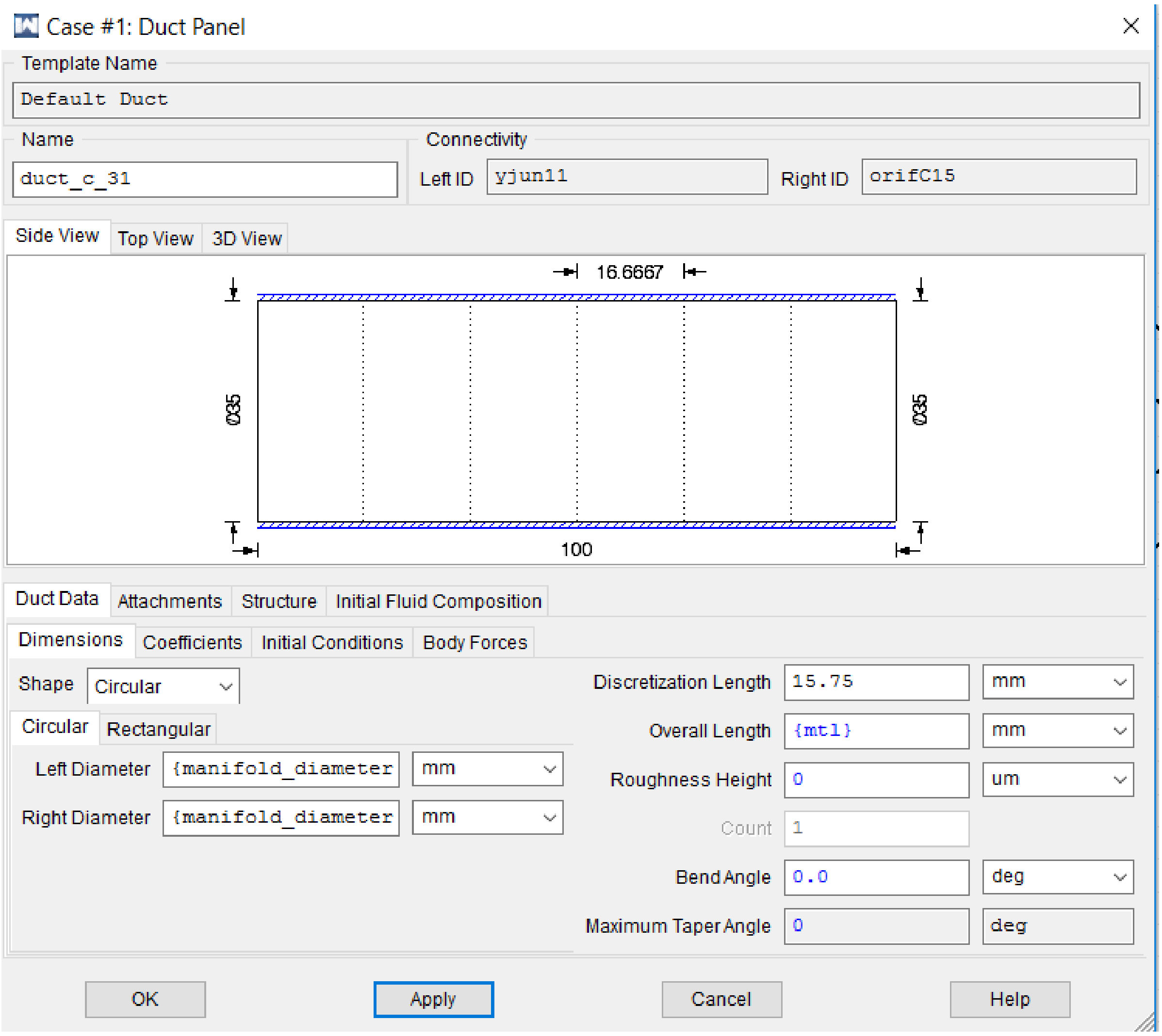

Figure 6: Intake manifold length

As shown in figure 6, Overall length of all intake manifold lengths was designated as {mtl} and added to constants table as {mtl}. The main feature of constants table is that, by changing first case value, remaining all case values are automatically updated and changed to same value as first case value. In current model six different intake manifold lengths 100, 200, 300, 400, 500 and 600 are used for tuning to improve engine performance. The simulation model was run six times for six intake manifold lengths by just changing value of {mtl} in constants table (refer figure 7).

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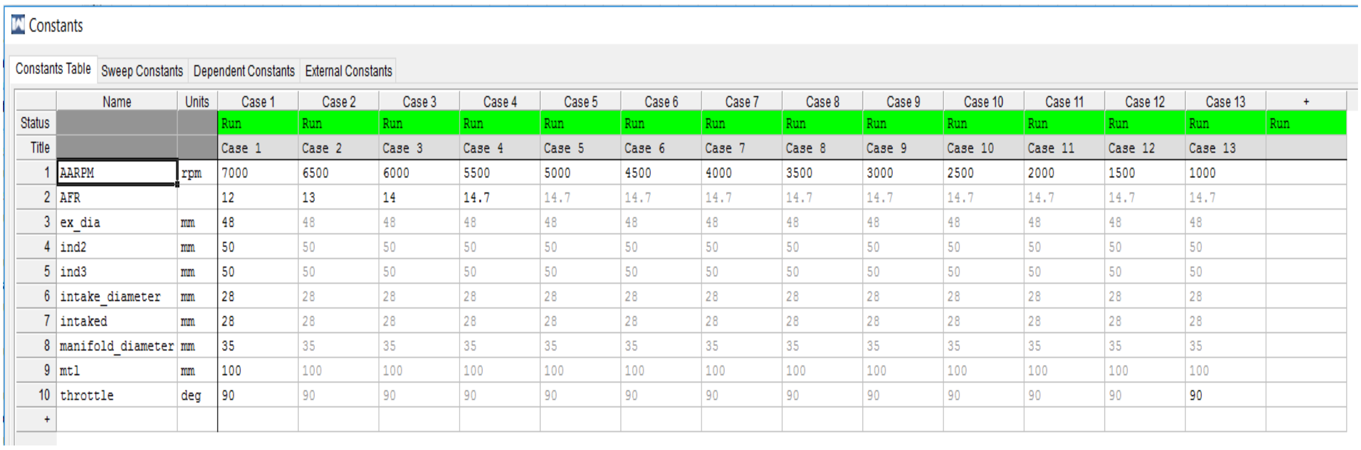


Constants

Constants Table | Sweep Constants | Dependent Constants | External Constants

	Name	Units	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11	Case 12	Case 13	+
Status			Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run	Run
Title			Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11	Case 12	Case 13	
1	AARPM	rpm	7000	6500	6000	5500	5000	4500	4000	3500	3000	2500	2000	1500	1000	
2	AFR		12	13	14	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	
3	ex_dia	mm	48	48	48	48	48	48	48	48	48	48	48	48	48	
4	ind2	mm	50	50	50	50	50	50	50	50	50	50	50	50	50	
5	ind3	mm	50	50	50	50	50	50	50	50	50	50	50	50	50	
6	intake_diameter	mm	28	28	28	28	28	28	28	28	28	28	28	28	28	
7	intaked	mm	28	28	28	28	28	28	28	28	28	28	28	28	28	
8	manifold_diameter	mm	35	35	35	35	35	35	35	35	35	35	35	35	35	
9	mtl	mm	100	100	100	100	100	100	100	100	100	100	100	100	100	
10	throttle	deg	90	90	90	90	90	90	90	90	90	90	90	90	90	
+																

Figure 7: Constants table

4. Results & Discussion

After running the simulation model for six different intake manifold lengths. In wave post for each intake manifold length, graphs of Engine speed (RPM) against Brake Power (KW), Brake Torque (N.m) and BSFC (Brake Specific Fuel Consumption) in kg/kW/hr was plotted. Finally, graphs of all these intake manifold lengths are combined for tuning of intake manifold length.

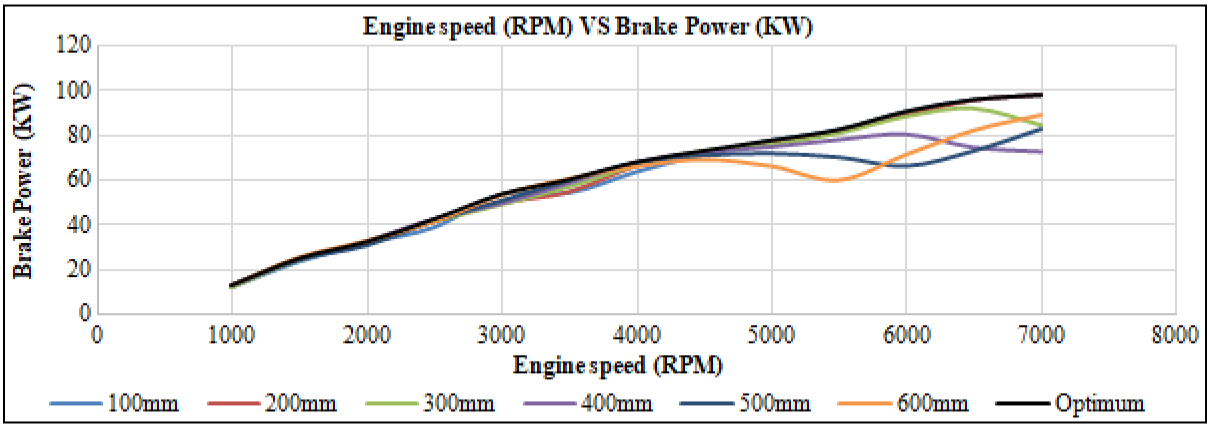
4.1 Engine speed (RPM) VS Brake Power (KW)

Table 1, shows values of brake power obtained at different intake manifold lengths for corresponding values of engine speed. For each engine speed out of all brake powers of intake manifold lengths, maximum value was taken as optimum brake power.

Table 1: Values of Brake Power (KW) at different manifold lengths against Engine Speed (RPM)

Engine speed (RPM)	Brake Power (KW)						
	100mm	200mm	300mm	400mm	500mm	600mm	Optimum
7000	97.969	97.9356	84.5189	72.9251	83.0918	88.7871	97.969
6500	95.8832	95.5984	91.91	74.86	73.3001	81.9191	95.8832
6000	90.6101	89.0606	88.3718	80.7514	66.5678	71.1085	90.6101
5500	82.5299	81.8225	80.958	78.3066	70.4724	59.7079	82.5299
5000	77.7008	76.6663	75.9248	75.1585	72.1964	65.9673	77.7008
4500	71.6025	72.4523	73.1096	72.5737	71.288	68.8954	73.1096
4000	63.7728	66.1667	66.651	68.0881	67.8714	65.8998	68.0881
3500	54.4957	54.4965	57.0951	58.7518	60.0474	60.2423	60.2423
3000	53.7131	49.4757	49.1455	49.547	51.0051	53.0089	53.7131
2500	39.0495	41.3583	41.7468	42.5862	41.9186	41.078	42.5862
2000	32.1721	31.701	32.1941	32.4883	30.9667	32.4463	32.4883
1500	23.8887	24.4989	24.5844	24.5409	24.5412	25.1042	25.1042
1000	12.4071	12.6112	12.3584	12.634	13.0894	12.6077	13.0894

Graph 1, shows engine speed against brake power, where Engine speed is varied from 1000 to 7000 while lines represents intake manifold lengths (100,200,300,400,500 and 600). From graph 1, it is clear that brake power was increased by increasing engine speed. Black line curve represents optimum values of brake power at corresponding engine speeds. Engine performance can be improved by increasing brake power, Therefore, here higher values of brake torque are chosen as optimum values, which are obtained due to tuning of intake manifold lengths.



Graph 1: Engine speed (RPM) VS Brake Power (KW)

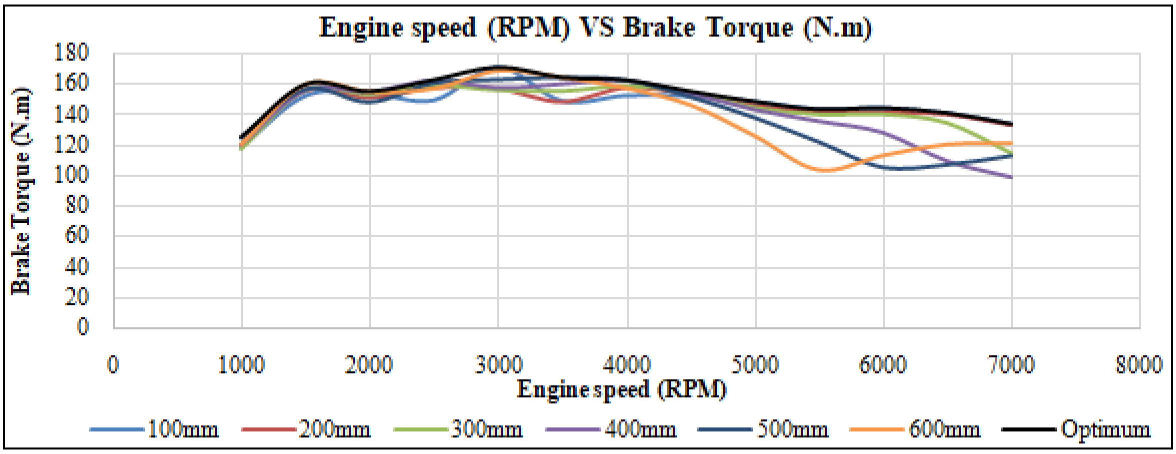
4.2 Engine speed (RPM) VS Brake Torque (N.m)

Table 2, shows values of brake torque obtained at different intake manifold lengths for corresponding values of engine speed. For each engine speed out of all brake torque of intake manifold lengths, maximum value was taken as optimum brake torque.

Table 2: Values of Brake Torque (N.m) at different manifold lengths against Engine Speed (RPM)

Engine speed (RPM)	Brake Torque (N.m)						
	100mm	200mm	300mm	400mm	500mm	600mm	Optimum
7000	133.648	133.603	115.3	99.4837	113.353	121.123	133.648
6500	140.865	140.447	135.027	109.979	107.687	120.35	140.865
6000	144.211	141.745	140.649	128.52	105.946	113.173	144.211
5500	143.292	142.064	140.563	135.959	122.357	103.667	143.292
5000	148.398	146.423	145.006	143.543	137.886	125.989	148.398
4500	151.946	153.749	155.144	154.007	151.278	146.201	155.144
4000	152.247	157.962	159.118	162.549	162.032	157.325	162.549
3500	148.685	148.687	155.777	160.297	163.832	164.364	164.364
3000	170.975	157.487	156.436	157.714	162.355	168.733	170.975
2500	149.159	157.978	159.462	162.668	160.118	156.907	162.668
2000	153.611	151.362	153.716	155.121	147.856	154.92	155.121
1500	152.081	155.965	156.51	156.233	156.234	159.818	159.818
1000	118.48	120.429	118.015	120.647	124.995	120.395	124.995

Graph 2, shows engine speed vs brake torque, where Engine speed is varied from 1000 to 7000 while lines represents intake manifold lengths (100,200,300,400,500 and 600). From graph 2, it is clear that brake torque was increased and then decreased by increasing engine speed. Black line curve represents optimum values of brake torque at corresponding engine speeds. Engine performance can be improved by increasing brake torque, Therefore, here higher values of brake torque are chosen as optimum values, which are achieved due to tuning of intake manifold lengths.



Graph 2. Engine speed (RPM) VS Brake Torque (N.m)

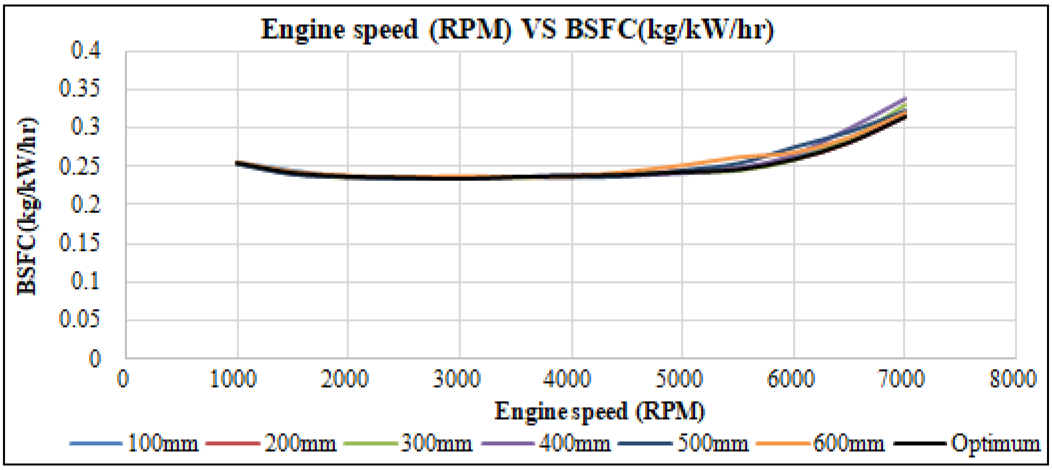
4.3 Engine speed (RPM) VS BSFC (kg/kW/hr)

Table 3, shows values of BSFC obtained at different intake manifold lengths for corresponding values of engine speeds. For each engine speed out of all BSFC of intake manifold lengths, minimum value was taken as optimum BSFC.

Table 3. Values of BSFC (Kg/kW/hr) at different manifold lengths against Engine Speed (RPM)

Engine speed (RPM)	BSFC(kg/kW/hr)						
	100mm	200mm	300mm	400mm	500mm	600mm	Optimum
7000	0.317407	0.31553	0.329817	0.338721	0.323505	0.319435	0.31553
6500	0.284462	0.281674	0.2861	0.30032	0.296351	0.287207	0.281674
6000	0.260582	0.259274	0.258832	0.265919	0.276033	0.267171	0.258832
5500	0.246945	0.247904	0.245084	0.248287	0.254709	0.261173	0.245084
5000	0.24156	0.244574	0.243314	0.241718	0.245909	0.250376	0.24156
4500	0.238673	0.239815	0.241116	0.238823	0.238248	0.24209	0.238248
4000	0.236997	0.236536	0.238453	0.239101	0.23669	0.236298	0.236298
3500	0.235658	0.236412	0.23563	0.236588	0.23764	0.235491	0.235491
3000	0.232752	0.234194	0.234896	0.234811	0.235365	0.236371	0.232752
2500	0.235451	0.234709	0.234557	0.234641	0.234874	0.235307	0.234557
2000	0.235921	0.236199	0.236009	0.236609	0.237132	0.236799	0.235921
1500	0.24366	0.242216	0.241179	0.240828	0.240692	0.24201	0.240692
1000	0.254674	0.254434	0.254624	0.254492	0.254085	0.254624	0.254085

Graph 3, shows engine speed vs BSFC, where Engine speed is varied from 1000 to 7000 while lines represents intake manifold lengths (100,200,300,400,500 and 600). From graph 3, it is clear that at lower engine speeds up to 5500rpm BSFC was almost steady and then started to increase at higher engine speeds. Black line curve in graph represents optimum values of BSFC at corresponding engine speeds. Engine performance can be improved by decreasing BSFC i.e. by improving fuel consumption. Therefore, here lower values of BSFC are chosen as optimum values, which are obtained due to tuning of intake manifold lengths.



Graph 3: Engine speed (RPM) VS BSFC (kg/kW/hr)

5. Conclusion

Inline 4 cylinders, 4 stroke, spark ignition Volkswagen cabriolet engine was designed in Ricardo WAVEBUILD simulation software. Simulations of various intake manifold lengths were performed on this engine. From results of graphs obtained from simulations, by considering optimum line curves, it was clear that Brake power and brake torque of the engine is increased while BSFC was improved. Therefore, it can be concluded that performance of the engine was improved due to tuning of intake manifold lengths.

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