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ORIGINAL ARTICLE

Application of Box-Behnken Analysis on the Optimisation of Air Intake System for a Naturally Aspirated Engine

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ABSTRACT – Fuel price crisis has caused people to demand a car that is having a low fuel consumption without compromising the engine performance. Designing a naturally aspirated engine which can enhance engine performance and fuel efficiency requires optimisation processes on air intake system components. Hence, this study intends to carry out the optimisation process on the air intake system and airbox geometry. The parameters that have high influence on the design of an airbox geometry was determined by using AVL Boost software which simulated the automobile engine. The optimisation of the parameters was done by using Design Expert which adopted the Box-Behnken analysis technique. The result that was obtained from the study are optimised diameter of inlet/snorkel, volume of airbox, diameter of throttle body and length of intake runner are 81.07 mm, 1.04 L, 44.63 mm and 425 mm, respectively. By using these parameters values, the maximum engine performance and minimum fuel consumption are 93.3732 Nm and 21.3695×10^{-4} kg/s, respectively. This study has fully accomplished its aim to determine the significant parameters that influenced the performance of airbox and optimised the parameters so that a high engine performance and fuel efficiency can be produced. The success of this study can contribute to a better design of an airbox.

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KEYWORDS
Airbox, Box Behnken, Response surface methodology, Naturally aspirated engine

INTRODUCTION

An engine which aspirated naturally solely depends on the ambient air pressure within and around the engine in order to carry out combustion. It is very crucial to ensure the charged air that entered the combustion chamber is sufficient for oxygen so that the complete combustion will take place. Most cars are naturally aspirated up until the year of the 1990s when the researchers came out with a turbocharger [1]. Until today, the naturally aspirated engine is still relevant to use because of the cost-efficiency in manufacturing it. There are many researches done in order to improve the performance of a naturally aspirated engine. However, the natural aspirated cannot fully match the performance of a downsized-turbocharged engine or hybrids cars due to some limitation of processes that can be carried out by a naturally aspirated engine [1].

An air intake system is a crucial part of the engine since it provides a good quality of air and can cater a sufficient amount of oxygen to promote complete combustion of the fuel [2]. This air would then be mixed with the fuel in order to be burned completely in the combustion chamber. The ambient air will be guided to pass through the air intake path. In some modern automobiles, the turbocharger is used to add filtered warm air into the engine due to the high pressure coming from the compressor [3]. The use of bends that separates the external air with coarse particles helps in reducing pressure loss. When the pressure loss is increasing until it exceeds the backpressure limits, the performance of the engine decreased [4]. In a study carried out by Aradhye and Bari, they stated that the operating parameters and control methodologies are crucial in improving engine performance [5]. In a spark-ignition engine or a gasoline engine, the airflow through the intake manifold is increasing as the engine speed in revolution increasing. Therefore, it will allow the engine to burn more fuel. Hence, it will produce more power [5]. However, the increment in engine performance can lead to a high rate of fuel consumption. The performance of an engine can be improved by increasing the volumetric efficiency of the airbox [6]. Up to this date and our knowledge, there is no research done on optimising an airbox design and air intake system in the engine. From that gap, we focus on studying the design of airbox with a purpose to increase the volumetric efficiency as well as promote a lower rate of fuel consumption. Based on the trends of previous researches, it is discovered that the relationship between fuel consumption and engine performance is inversely proportional. When the engine performance or the brake torque is improved, the fuel consumption is large in amount [7].

One of the most important components of an engine to ensure the air to enter the combustion chamber, is an airbox. An airbox will filter all the unwanted particles in the incoming dirty air. This is due to the existence of the air filter in the airbox. After the air has been filtered, it will be guided into cylinders through intake plenum, intake manifold and intake port [8]. In recent years, many great efforts have been made by the researchers in order to study the design of airbox. The improvement of airbox can lead to the improvement of volumetric efficiency. If the volumetric efficiency is high, the

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engine performance can be improved, eventually. [6]. In a study carried out by Shahriman et al., they found out that engine performance can be improved when the airbox is redesigned [9]. The airbox can be designed depending on several conditions. Some applicable conditions that lead is affecting the airbox design are the limited space that is provided in the engine, type of engine and the airbox's structural resistance such as materials and geometries [10, 11]. Most modern vehicle nowadays only focusing on designing an airbox as a tool to feed in the air into the combustion chamber without specific measurement. It is a need to have an airbox, however, due to the lack of conscience in designing a well-performed airbox has led to just get the airbox to be well-fitted into the compartments of the air intake system of the engine [12].

The evolution of airbox design as well as air intake system keeps on being studied due to its major role in providing sufficient amount of air that needed to be mixed with fuel to perform complete combustion in combustion chambers. Therefore, this study intends to determine the significant parameters that influence the performance of an airbox and air intake system. The optimisation should take place in order to find the optimum values of parameters that need to be designed so that it can produce an airbox as well as an air intake system that have a high engine performance in terms of brake torque and low fuel consumption. In this study, the engine performance was indicated by using engine brake torque while fuel consumption was measured from the fuel mass flow rate.

MATERIALS AND METHOD

Development of Engine Model

The engine used in this project is a 1.6 L engine with a bore size of 76 mm, as shown in Table 1. It was designed by using AVL Boost software which is highly reliable to invent or design a more complicated and advanced engine [13]. This is due to its capability to simulate a real time-based engine simulation [13]. The engine model was validated in order to ensure it can simulate real engine performance [14]. The developed engine model is shown in Figure 1.

Table 1. Engine details specification.

Engine type	four cylinder, in-line, naturally aspirated
Displacement (cc)	1597
Bore × stroke (mm)	76 × 88
Maximum torque (Nm / rpm)	137.33 Nm / 3500 rpm

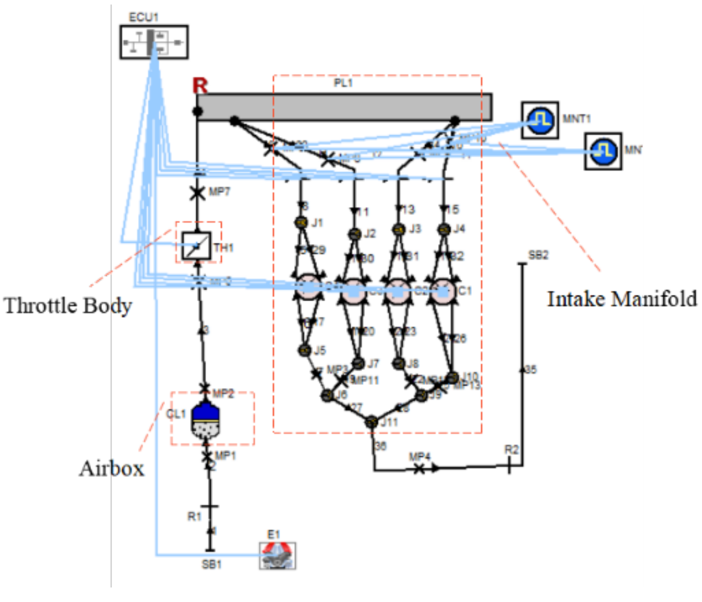


Figure 1. Engine model.

Determination of Significant Parameters

Significant parameters that were used to simulate the behaviour of the engine were obtained via literature review since this project is involving the simulation process. There are many factors that can be included; however, most researchers used these parameters that seem to be significantly influenced the performance of engine and fuel consumption. The snorkel helps in transporting the air into the airbox. In order to suck more air that can promote the complete burning of the fuel, the diameter of the snorkel plays an important role [15]. In order to achieve a good performance of the engine, the volume of airbox should be improved [16]. This is due to the increment of the volumetric efficiency of an engine. Moreover, the previous study has stated that the volume of airbox has a significant influence on the volumetric efficiency of an engine.[17]. The amount of air that is entering the combustion chamber is controlled by a throttle body. It opens up as the force is applied in the accelerator pedal to allow air to enter the combustion chamber and closes when the pedal is released. The high diameter of the throttle body helps in reducing energy loss which eventually improving the engine performance [18]. The intake runner is used to enable the air to pass through the intake plenum. Said stated that the higher the intake runner, the higher the rake torque that can be produced by the engine [19].

Factors and Levels of Significant Parameters

The factors and levels of the geometry of an airbox were obtained via findings from previous researches due to the project is related to simulation. The levels were categorised into three levels which are low (-1), centre point (0) and high (+1) as shown in Table 2. These levels were set as the upper and lower limit for modelling in Design-Expert software.

Experimental Design

Box-Behnken design

A Box-Behnken experimental design, with four variables, was used to study the response pattern and to determine the optimum parameter values that would give the combination of the best performance of the engine as well as the lowest fuel consumption. A three-level reaction was used, resulting in a total of 29 runs were conducted separately in order to get the desired responses. The application of the Box-Behnken method is carried out in order to minimise the number of runs that needed to be simulated [20–22]. The factors are shown in Table 2.

Table 2. Significant parameters

Symbol	Parameters	Unit	Levels		
			Low (-1)	(0)	High (+1)
A	Diameter of inlet/snorkel	mm	43.60 [9]	70.24	96.88
B	Volume of airbox	litre	0.47	1	1.53 [9]
C	Diameter of throttle body	mm	38 [23]	50	62
D	Length of intake runner	mm	425	800	1175 [24]

Steepest descent method

Steepest descent step was carried out in order to find the range of parameters that needed to be run by using Central Composite Design in the Design-Expert software. Steepest descent method intends to move the plot to an optimum region by using the most effective route, which requires less number of experiments. In this study, this method was used in order to find the lowest possible value of fuel consumption. This method is only applicable for fuel consumption since we cannot find any lowest optimum point of the fuel consumption by adopting the Box-Behnken method only. The equation that was used to find the step size as follows, where Δx indicates the step size and β is the highest coefficient of coded value in the mathematical model of ANOVA analysis.

$$\frac{\Delta x_i}{\beta_i} = \frac{\Delta x_j}{\beta_j} \tag{1}$$

In order to simulate the real value of the parameters, equation (2) was used to find the actual step size of the parameters.

$$Coded\ Step\ Size = \frac{Actual\ Step\ Size - Mean}{Half\ of\ Range} \tag{2}$$

The factors that were further evaluated from the Box-Behnken analysis were the volume of airbox and diameter of throttle body due to the significant effect in resulting the lowest fuel consumption in terms of fuel mass flow rate as shown in Figure 8. However, the data was stopped at 32 mm due to size constraint. The minimum size available in the industry is 32mm [25]. Table 3 indicates the data obtained by using the steepest descent method. The experimental matrix data for Box-Behnken analysis is shown in Table 4.

Table 3. Steepest descent.

Run	B	C	Remark
Standard Range	0.47	38	
1	0.441	37	
2	0.413	36	
3	0.384	35	
4	0.355	34	High Level
5	0.326	33	Center Point
6	0.298	32	Low Level

Table 4. Experimental matrix data for BBD.

Standard order	Factor 1, A	Factor 2, B	Factor 3, C	Factor 4, D
1	-1	-1	0	0
2	1	-1	0	0
3	-1	1	0	0
4	1	1	0	0
5	0	0	-1	-1
6	0	0	1	1
7	0	0	-1	-1
8	0	0	1	1
9	-1	0	0	0
10	1	0	0	0
11	-1	0	0	0
12	1	0	0	0
13	0	-1	-1	-1
14	0	1	-1	-1
15	0	-1	1	1
16	0	1	1	1
17	-1	0	-1	-1
18	1	0	-1	-1
19	-1	0	1	1
20	1	0	1	1
21	0	-1	0	0
22	0	1	0	0
23	0	-1	0	0
24	0	1	0	0
25	0	0	0	0
26	0	0	0	0
27	0	0	0	0
28	0	0	0	0
29	0	0	0	0

Central composite design

The central composite design was used in order to find the lowest possible fuel consumption with an optimum value for the significant parameters. This step was taken after the steepest descent method was applied. The central composite design was chosen due to its high reliability in furthering the investigation from previous experiments [26]. In the steepest descent method, the parameters were further investigated as shown in Table 5. The data in Table 6 were used to run the simulation by using AVL Boost software in order to proceed with the optimisation process, which is using the central composite design.

Table 5. Factors and level for CCD.

Symbol	Parameter	Unit	Level		
			Low (-1)	Centre Point	High (+1)
B	Volume of airbox	litre	0.298	0.326	0.355
C	Diameter of throttle body	mm	32	33	34

Table 4. Experimental matrix data for CCD.

Standard Order	Factor 1 B	Factor 2 C
1	-1	-1
2	1	-1
3	-1	1
4	1	1
5	-1.189	0
6	1.189	0
7	0	-1.189
8	0	1.189
9	0	0
10	0	0

RESULT AND DISCUSSION

In this study, the process will be resulting in two different responses which are having an inversely proportional relationship. By using the AVL software, the engine brake torque can be obtained directly from the simulation of the developed engine model. However, fuel consumption needs to be calculated by using Eq. (3).

$$Fuel\ Consumption = \ (Fuel\ Mass\ Flow\ Rate)(4)(\frac{2500}{60})/2 \tag{3}$$

The data that was collected from the simulation has been analysed by Design-Expert software. The analysis included the analysis of variance (ANOVA), mathematical model equation, normal and residuals plot, and contour and 3D surface plot. The optimised parameters were obtained after the analysis was done. Table 7 shows the result obtained from the simulation for Box-Behnken Analysis.

Table 5: Data for engine brake torque and fuel mass flow rate for Box-Behnken analysis.

Std.	Factor 1 A	Factor 2 B	Factor 3 C	Factor 4 D	Fuel mass flow rate $\times 10^{-4}$ (kg/s)	Engine brake torque (Nm/rpm)
1	43.6	0.47	50	800	21.4878	92.4059
2	96.88	0.47	50	800	21.3479	92.7767
3	43.6	1.53	50	800	21.6723	94.1792
4	96.88	1.53	50	800	21.5853	94.712
5	70.24	1	38	425	21.2139	92.0251
6	70.24	1	62	425	21.5723	94.2846
7	70.24	1	38	1175	21.6621	92.8504
8	70.24	1	62	1175	21.8453	95.9501
9	43.6	1	50	425	21.4058	93.3696
10	96.88	1	50	425	21.4952	93.9318
11	43.6	1	50	1175	21.5982	94.3998
12	96.88	1	50	1175	21.6987	95.2727
13	70.24	0.47	38	800	21.0086	90.5962
14	70.24	1.53	38	800	21.2959	92.5351
15	70.24	0.47	62	800	21.41275	93.3665
16	70.24	1.53	62	800	21.667	95.3807
17	43.6	1	38	800	21.1804	91.7853
18	96.88	1	38	800	21.264	92.3784
19	43.6	1	62	800	21.5784	94.6278
20	96.88	1	62	800	21.6278	95.0744
21	70.24	0.47	50	425	21.268	92.432
22	70.24	1.53	50	425	21.5346	93.9121
23	70.24	0.47	50	1175	21.42131	93.2208
24	70.24	1.53	50	1175	21.7068	95.2981
25	70.24	1	50	800	21.5688	94.5334
26	70.24	1	50	800	21.5688	94.5334
27	70.24	1	50	800	21.5688	94.5334
28	70.24	1	50	800	21.5688	94.5334
29	70.24	1	50	800	21.5688	94.5334

Engine Performance

Analysis of variance (ANOVA)

The models stated in the ANOVA analysis are generated by the software due to their significance. The model row indicates the value of response variation of the data which includes the total models that were tested for the test of significance. Meanwhile, the terms included in the table has been tested independently by varying the factors A (diameter of snorkel), B (volume of airbox), C (diameter of throttle body) and D (length of intake runners). For example, term BD indicates that the factor B and D are varied while factor A and C are being kept constant. The same concept is applied to the other terms.

The Model F-value of 611.98 shows that the model is significant due to the Prob>F value. In addition, the values of “Prob>F” is less than 0.05 indicates that the model is significant. This indicates that the model terms which are A, B, C, D, BD, CD, A2, B2, and C2 are significant. The values for R-Squared and Adj R-Squared are 0.9975 and 0.9958, respectively. Both values are quite high and reasonable. This indicates the model is significant. The mathematical equation for this model is generated via ANOVA analysis as shown in Eq. (4) and (5).

Table 6: ANOVA analysis for engine performance in terms of engine brake torque.

Source	Sum of squares	DF	Mean Square	F Value	p-value Prob > F	
Model	42.2244	9	4.6916	611.9800	< 0.0001	significant
A	0.9511	1	0.9511	124.0672	< 0.0001	
B	10.4890	1	10.4890	1368.2038	< 0.0001	
C	19.6257	1	19.6257	2560.0100	< 0.0001	
D	3.2376	1	3.2376	422.3166	< 0.0001	
BD	0.0892	1	0.0892	11.6304	0.0042	
CD	0.1835	1	0.1835	23.9366	0.0002	
A^2	0.2467	1	0.2467	32.1825	< 0.0001	
B^2	2.4723	1	2.4723	322.4888	< 0.0001	
C^2	2.8763	1	2.8763	375.1916	< 0.0001	
Residual	0.1073	14	0.0077			
Cor Total	42.3318	23				

Std. dev.	0.08756	R-squared	0.9975
Mean	93.6853	Adj R-squared	0.9958
C.V. %	0.0935	Pred R-squared	0.9932
PRESS	0.2895	Adeq precision	93.9630

Coded Factors:

$$\begin{aligned} &Engine\ Brake\ Torque \\ &\quad = 94.4867 + 0.2815A + 0.9349B + 1.3957C + 0.5669D + 0.1493BD + 0.2686CD \\ &\quad - 0.2366A^2 - 0.7429B^2 - 0.7732C^2 \end{aligned} \tag{4}$$

Actual Factors:

$$\begin{aligned} &Engine\ Brake\ Torque \\ &\quad = 70.2101 + 0.0574A + 6.4949B + 0.6055C - 0.0022D + 0.0008BD + 5.96967E \\ &\quad - 005CD - 0.0003A^2 - 2.6659B^2 - 0.0054C^2 \end{aligned} \tag{5}$$

Model adequacy verification for engine brake torque in terms of engine performance in BBD

The normal probability plots of residuals and the plots of residuals versus the predicted response are shown in Figure 2 and Figure 3, respectively. The plots in Figure 2 that the errors of the data are normally distributed along the straight line. Since they are normally distributed along the straight line, we can say that there are no abnormalities that can affect the data. From Figure 3, we can observe that there is no unusual structure apparent. The model is correct and all the assumptions are satisfied due to the data are randomly scattered according to the prediction of the response of the experiment.

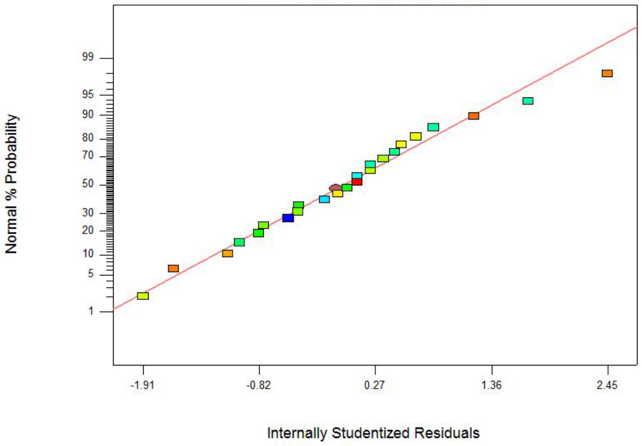


Figure 2. Normal plot for engine performance.

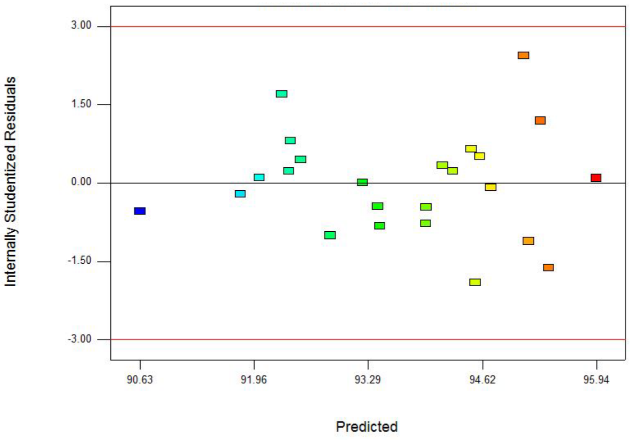


Figure 3: Residuals vs predicted plot for engine performance.

3D surface graph and contour plot for engine brake torque in terms of engine performance in BBD

The purpose of a 3D surface graph and contour plot is to show the effect of the parameters. Figure 4 shows the contour plot of the engine brake torque while the 3D surface graph of the same plot is shown in Figure 5. The maximum predicted values were indicated by the surface-confined in the elliptical shapes. The smallest the ellipse, the higher the performance of the engine with the suggested values for both volume of the airbox and the diameter of the throttle body. These graphs were drawn by imposing the other significant parameter at their zero level. The parameters that were set at zero level were the diameter of snorkel and length of intake runner. However, as we can see, when the volume of airbox and diameter of throttle body were over the optimum value, the engine performance started to drop and decreasing its value. Hence, we can say that the optimum point has been obtained. The value of the diameter of inlet/snorkel, the volume of airbox, the diameter of throttle body and length of intake runner are 90.49 mm, 1.13 L, 58.86 mm and 1093.4 mm, respectively.

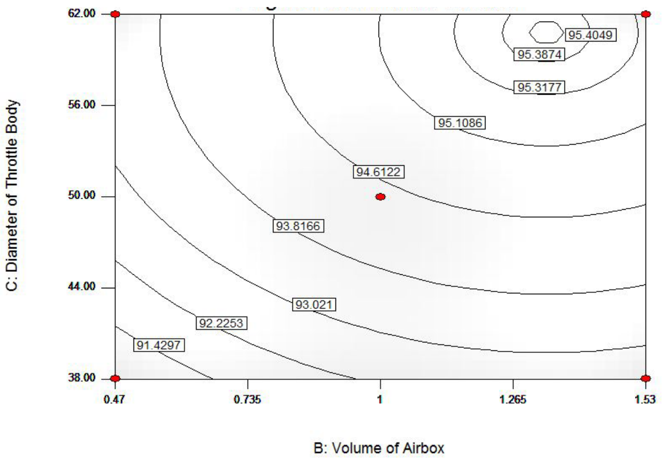


Figure 4. Contour plot for engine brake torque.

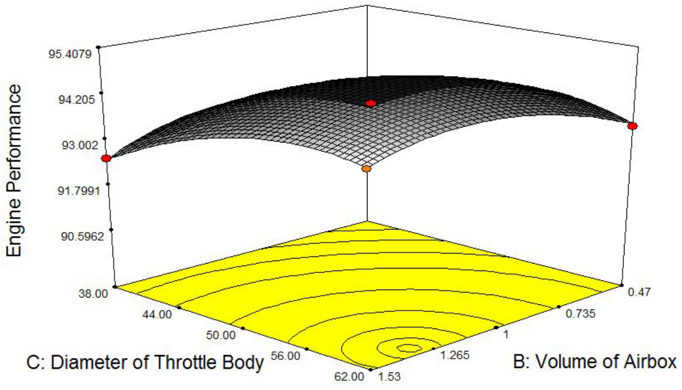


Figure 5. 3D surface graph.

Fuel Consumption

Analysis of variance (ANOVA)

The models stated in the ANOVA analysis are generated by the software due to their significance. The model row indicates the value of response variation of the data which includes the total models that were tested for the test of significance. Meanwhile, the terms included in the table has been tested independently by varying the factors A (diameter of snorkel), B (volume of airbox), C (diameter of throttle body) and D (length of intake runners). For example, term B indicates that the factor B is varied while factor A, C and D are being kept constant. The same concept is applied to the other terms

Table 7: ANOVA analysis for fuel consumption in terms of fuel mass flow rate (BBD)

Source	Sum of squares	DF	Mean square	F Value	p-value Prob > F	
Model	0.8284	4	0.2071	42.9704	< 0.0001	significant
B	0.1914	1	0.1914	39.7142	< 0.0001	
C	0.4466	1	0.4466	92.6540	< 0.0001	
D	0.0877	1	0.0877	18.1910	0.0004	
C^2	0.0694	1	0.0694	14.3938	0.0012	
Residual	0.0916	19	0.0048			
Cor Total	0.9110	23				

Std. Dev.	0.0694	R-squared	0.9005
Mean	21.4774	Adj R-squared	0.8795
C.V. %	0.3232	Pred R-squared	0.8332
PRESS	0.1535	Adeq precision	20.8056

The Model F-value of 49.9704 shows that the model is significant due to the Prob>F value. In addition, the values of “Prob>F” is less than 0.05 indicates that the model is significant. This indicates that the model terms which are B, C, D, BD, and C2 are significant. The values for R-Squared and Adj R-Squared are 0.9005 and 0.8795, respectively. Both values are quite high and reasonable. This indicates the model is significant. The mathematical equation for this model is generated via ANOVA analysis which is shown in the following.

Coded factors:

$$Fuel\ Mass\ Flow\ Rate = 21.5224 + 0.1262B + 0.2033C + 0.0901D - 0.1084C^2 \tag{6}$$

Actual factors:

$$Fuel\ Mass\ Flow\ Rate = 18.3619 + 0.2383B + 0.0923C + 0.0002D - 0.0008C^2 \tag{7}$$

Model adequacy verification for fuel mass flow rate in terms of fuel consumption in BBD

The normal probability plots of residuals and the plots of residuals versus the predicted response are shown in Figure 6 and Figure 7, respectively. No abnormalities can affect the data since they are normally distributed along the straight line as shown in Figure 6. The plots in Figure 7 are randomly scattered according to the prediction of fuel consumption. No unusual apparent structure can be found. Hence, the model is correct, and all assumption are satisfied.

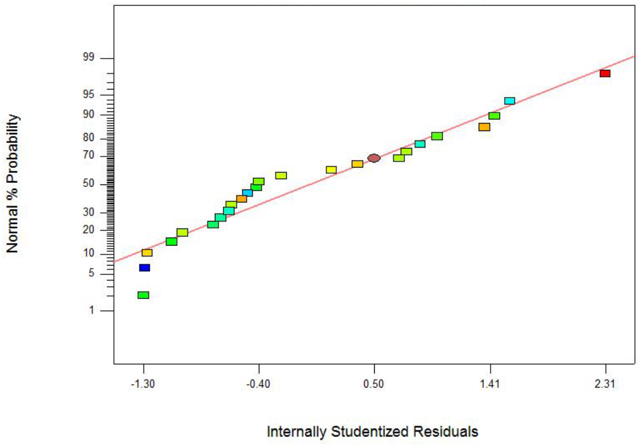


Figure 6. Normal plot for fuel consumption in BBD.

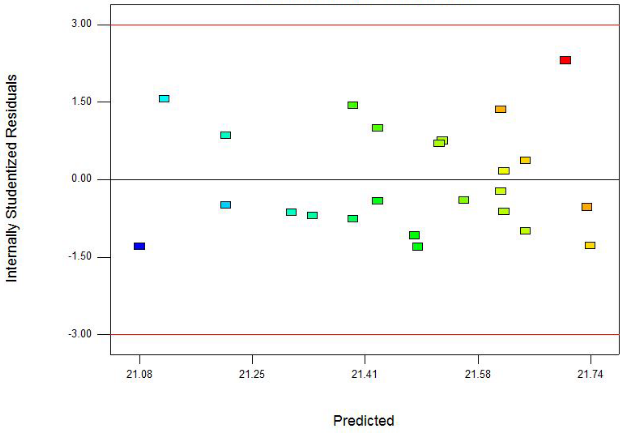
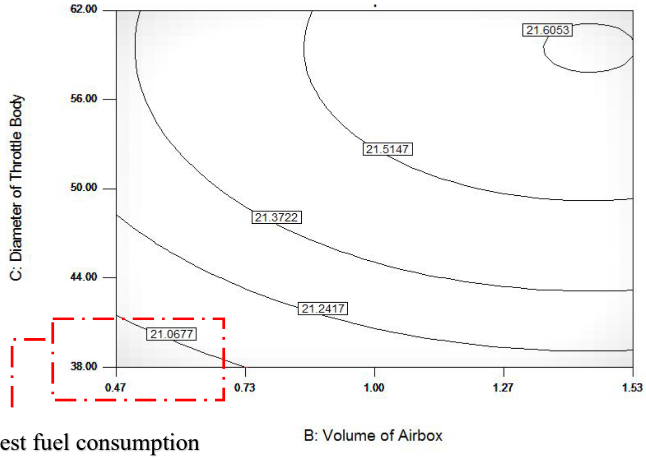


Figure 7. Residuals vs predicted plot for fuel consumption in BBD.

3D surface graph and contour plot for fuel mass flow rate in terms of fuel consumption in BBD

From the figures, it can be found that the smaller the ellipse, the higher the fuel consumption with the suggested values for both volume of the airbox and the diameter of the throttle body. The parameters that were set at zero level, which is being kept at their mid values were the diameter of snorkel and length of intake runner. However, the desired response is not the highest fuel consumption. The fuel mass flow rate needs to be in the lowest value so that it has the lowest fuel consumption, which can satisfy the aim of this study. Therefore, the study was furthered by applying the steepest descent method and later adopting Central Composite Design as it is highly reliable to be used in continuing the optimisation process from the previous method.



Lowest fuel consumption

Figure 8: Contour plot for fuel consumption in BBD.

Steepest descent method

From the contour plot and 3D surface graph shown in Figure 8 and Figure 9, it is known that the significant parameters that are needed to be extended by calculating their step size are volume of airbox and diameter of the throttle body. The calculation of data was stopped until the diameter of the throttle body is 32mm due to the size constraint. The smallest size of the diameter of the throttle body that can be found in the industry is 32mm [25]. Figure 10 indicates that the smaller the volume of airbox will resulting in the smaller the diameter of the throttle body.

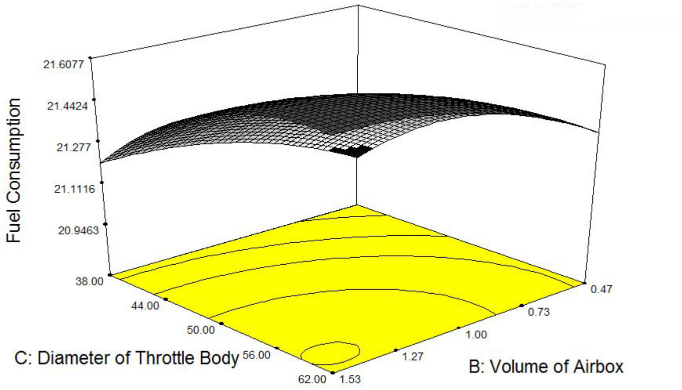


Figure 9: 3D surface graph for fuel consumption in BBD

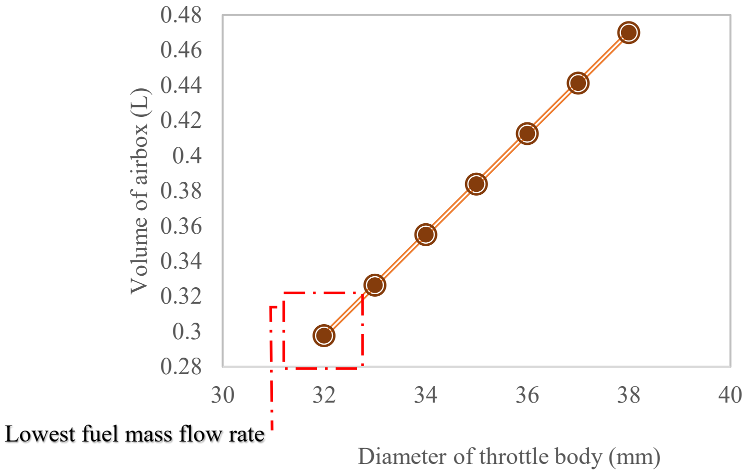


Figure 10. Graph of the volume of airbox vs diameter of the throttle body.

Central composite design

The central composite design was used to analyse the data obtained by the steepest descent method. Since the data only considered factor B and factor C, factor A and factor D are maintained at their standard measurement, which are 70.241 mm and 800 mm, respectively. Table 10 shows the factors and level, while Table 11 indicates the data obtained from the experiments that were conducted by using Central Composite Design which is consist of 10 runs with two centre points. The data were used to run the simulation by using the AVL Boost.

Table 8: Factor and levels for central composite design.

Parameter	Code	Low (-1)	High (+1)
Volume of airbox (Litre)	B	0.298	0.355
Diameter of throttle body (mm)	C	32	34

Table 9: Data for fuel consumption for central composite design.

Standard order	Factor 1, B	Factor 2, C	Fuel mass flow rate ($\times 10^{-4}$ kg/s)
1	0.298	32	18.0715
2	0.355	32	19.8108
3	0.298	34	18.074
4	0.355	34	19.9884
5	0.292	33	17.7847
6	0.361	33	20.0143
7	0.326	31.8108	19.1486
8	0.326	34.1892	19.4886
9	0.326	33	19.2705
10	0.326	33	19.2705

Analysis of variance (ANOVA)

As stated in the previous section, the modes are generated by the software due to their significance. The model row indicates the value of response variation of the data, which includes the total models that were tested for the test of significance. Meanwhile, the terms included in the table has been tested independently by varying the factors B and C. For example, term B indicates that the factor B is varied while factor C is being kept constant. The same concept is applied to the other terms

Table 10: ANOVA Analysis for Fuel Consumption in terms of Fuel Mass Flow Rate in CCD

Source	Sum of squares	DF	Mean square	F value	p-value Prob > F	
Model	6.1534	3	2.0511	432.7476	< 0.0001	significant
B	5.8220	1	5.8220	1228.3205	< 0.0001	
C	0.0500	1	0.0500	10.5532	0.0175	
B^2	0.2814	1	0.2814	59.3691	0.0003	
Residual	0.0284	6	0.0047			
Lack of Fit	0.0284	5	0.0057			
Pure Error	0.0000	1	0.0000			
Cor Total	6.1818	9				

Std. Dev.	0.0688	R-Squared	0.9954
Mean	19.0922	Adj R-Squared	0.9931
C.V. %	0.3606	Pred R-Squared	0.9858
PRESS	0.0880	Adeq Precision	51.1530

The Model F-value of 432.7476 shows that the model is significant due to the Prob>F value. In addition, the values of “Prob>F” is less than 0.05 indicates that the model is significant. In addition, the values of “Prob>F” is less than 0.05. This indicates that the model terms which are B, C and B2 are significant. The values for R-Squared and Adj R-Squared are 0.9954 and 0.9931, respectively. Both values are quite high and reasonable. This indicates the model is significant. The mathematical equation for this model is generated via ANOVA analysis which is shown in the equation.

Coded factors:

$$\text{Fuel mass flow rate} = 19.2905 + 0.9234B + 0.0856 - 0.2094B^2 \tag{8}$$

Actual factors:

$$\text{Fuel mass flow rate} = 31.5836 + 262.2057B + 0.0856C + -352.3297B^2 \tag{9}$$

Model adequacy verification for fuel consumption in terms of fuel mass flow rate in CCD

The normal probability plots of residuals and the plots of residuals versus the predicted response are shown in Figure 11 and Figure 12, respectively. The plots in Figure 11 indicates that the errors of the data are normally distributed along the straight line and resulting in no abnormalities that can affect the data. No unusual structure apparent in Figure 12, therefore, the model is correct, and all the assumptions are satisfied due to the data are randomly scattered according to the prediction of the response of the experiment.

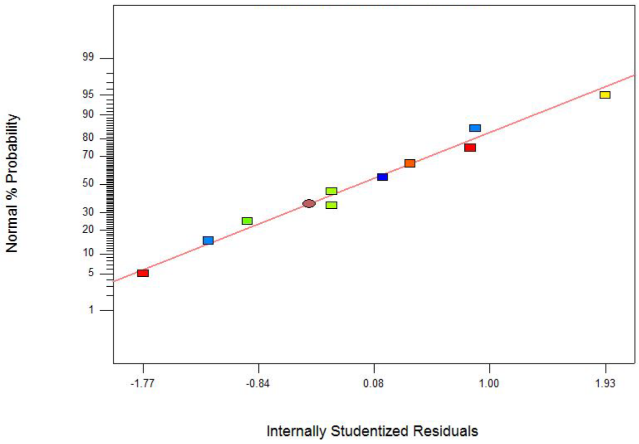


Figure 11: Normal plot for fuel consumption in CCD

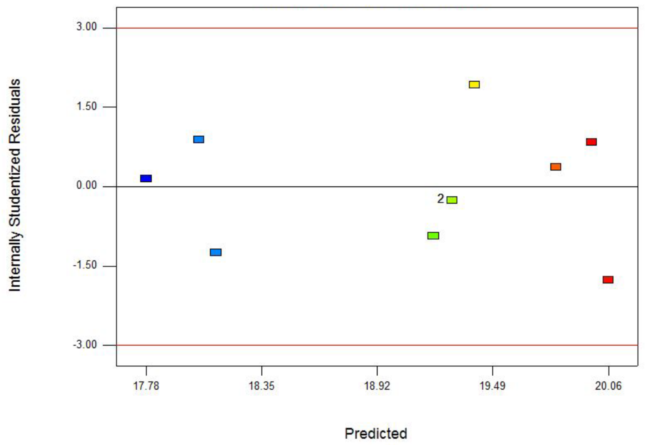


Figure 12: Residuals vs. predicted for fuel consumption in CCD

3D surface graph and contour plot for fuel consumption in terms of fuel mass flow rate in CCD

The predicted value should be indicated in the surface-confined in the elliptical shapes. However, the ellipses cannot be obtained due to the desired response is low fuel consumption as shown in Figure 13 and Figure 14. The peak of the graphs cannot be indicated since the study had to be stopped at 32mm diameter of the throttle body. Hence, the optimum value of this study should be taken from the lowest value of the parameters available. The optimum value for the diameter of inlet/snorkel, the volume of the airbox, diameter of throttle body and length of intake runner are 70.24 mm, 0.298 L, 32 mm and 800 mm, respectively.

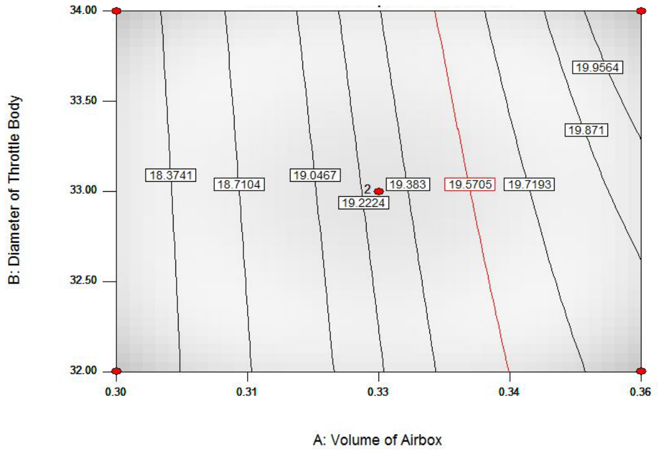


Figure 13. Contour plot for fuel consumption in CCD.

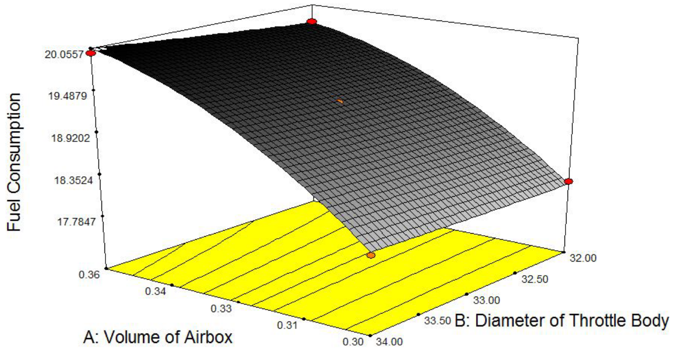


Figure 14. 3D surface graph for fuel consumption in CCD.

From the optimisation, we obtained the optimum setting for the value of the parameter must be set at certain points in order to achieve the desired responses which are maximum engine brake torque, minimum fuel mass flow rate, and maximum engine brake torque and minimum fuel mass flow rate, simultaneously. The optimisation process of obtaining optimum point for maximum engine brake torque was obtained by using Box-Behnken technique. Meanwhile, the optimum point for minimum fuel mass flow rate was carried out by using Central Composite Design since the result obtained from the primary technique which is Box-Behnken still insufficient to promote the lowest fuel mass flow rate.

In addition, the optimum point that will result in having both maximum engine brake torque and minimum fuel mass flow rate simultaneously was obtained during primary optimisation, which is the Box-Behnken technique.

Table 11: Summary of the optimised results.

	Diameter of inlet / snorke (mm)	Volume of airbox (litre)	Diameter of throttle body (mm)	Length of intake runner (mm)	Engine brake torque (Nm)	Fuel mass flow rate (10^{-4} kg/s)
Maximum engine brake torque (Nm)	90.49	1.13	58.86	1093.4	95.9887	-
Minimum fuel mass flow rate (10^{-4} kg/s)	70.24	0.298	32	800	-	18.0377
Maximum engine brake torque (Nm) & minimum fuel mass flow rate (10^{-4} kg/s)	81.07	1.04	44.63	425	93.3732	21.3695

CONCLUSION

From the study, all objectives have been achieved where due to the significant parameters in designing an airbox has been determined. The significant parameters in designing airbox geometry are the diameter of inlet or snorkel, the volume of the airbox, the diameter of the throttle body, and length of intake runner. Moreover, the engine model that had been developed by using AVL Boost software had been successfully utilised as simulation software that helped in obtaining the data that were needed for optimisation. The optimisation process was carried out by applying Box-Behnken method, which obtained maximum engine performance in terms of brake torque and maximum engine performance and minimum fuel consumption. The study was furthered by using the steepest descent method and later adopted Central Composite Design to find the lowest fuel consumption. The optimal setting for the engine that requires high engine performance and low fuel consumption that took place by using Design Expert software has been successfully obtained. The value of the optimum setting in order to produce an airbox that will enhance the performance of the engine brake torque as well as promoting low fuel consumption in terms of fuel mass flow rate is 81.07 mm diameter of inlet or snorkel, 1.04 L volume of airbox, 44.63 mm diameter of the throttle body and 425 mm length of intake runner which resulting the values of engine brake torque and fuel mass flow rate are 93.3237 Nm and 21.3695 x 10^{-4} kg/s, respectively. The success of this study can contribute to the new design of the air intake system and airbox, which can improve the engine performance in terms of brake torque and fuel mass flow rate.

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