American Journal of Mechanical and Industrial Engineering
2023; 8(4): 90-98
http://www.sciencepublishinggroup.com/j/ajmie
doi: 10.11648/j.ajmie.20230804.11
ISSN: 2575-6079 (Print); ISSN: 2575-6060 (Online)

Numerical Analysis of Drag Reduction Using Aerodynamic Designs in a Passenger Bus

Md. Rezaul Karim Sikder, Mohammad Zoynal Abedin*

Department of Mechanical Engineering, Dhaka University of Engineering and Technology, Gazipur, Bangladesh

Email address:
20103001@student.duet.ac.bd (Md. Rezaul Karim Sikder), abedin.mzoynal@duet.ac.bd (Mohammad Zoynal Abedin)
*Corresponding author

To cite this article:
Md. Rezaul Karim Sikder, Mohammad Zoynal Abedin. Numerical Analysis of Drag Reduction Using Aerodynamic Designs in a Passenger Bus. *American Journal of Mechanical and Industrial Engineering*. Vol. 8, No. 4, 2023, pp. 90-98. doi: 10.11648/j.ajmie.20230804.11

Received: July 18, 2023; **Accepted**: August 14, 2023; **Published**: October 12, 2023

Abstract: The vehicles are used such as cars, passenger buses, trucks and heavy vehicles. The drag reduction is directly effect on the fuel saving as well as the efficiency of the vehicle. Due to higher prices, limited supply and negative impacts on the environment by fossil fuel, automobile industries have directed their concentrations in reducing the fuel consumption of vehicles to achieve the lower aerodynamic drag. As a consequence, numerous researches have been carried out throughout the world for getting the optimum aerodynamic designs with lower drag and decreases fuel consumption. Hence, for the analysis, a Computational Fluid Dynamic (CFD) analysis has been done using ANSYS^{R}19.0 workbench. Three demo base models are considered for the analysis namely model-1 made of a plastic body, model-2 made of metal body and model-3 of BD bus that runs on the Bangladeshi roads. Some extensive modifications are done in the bus body such as the front and rear side area which helps to reduce the aerodynamic drag of the bus. The analyses for the drag forces and drag coefficient have been done for model-1, 2 & 3 as well as for their respective modified models. For base model-1, the drag force is reduced as 0.027 N, the drag coeffic1qient, Cd is reduced as 0.30. For base model-2, the drag force is reduced as 0.062 N, the drag coefficient, Cd is reduced as 0.37. On the other hand, the CFD values at a velocity of 110 km/h for base model-3 the drag forces are reduced for base model modified-1, base model modified-2 as 1987.20 N, and 2499.80 N, respectively. The drag coefficients, Cd is reduced for base model modified-1 and base model modified-2 as 0.16, 0.26, respectively.

Keywords: Aerodynamics Drag Reduction, Drag Force, Drag Co-efficient, Fuel Saving, CFD, ANSYS

1. Introduction

Due to the global climate change of today the automotive industry invests significantly in reducing the fuel consumption of their products. The companies are, at first hand, pushed by the governments and legislations to reduce the emissions of their vehicles. There are many approaches to reduce the emissions and all of them are of importance for the automotive industry. One way is to switch to a more environmental friendly fuel or base the power train on other technologies such as electric or hybrid. A lot of work is put into making existing technology more efficient, for example reduction of internal friction, optimize combustion e.g., direct injection, spark timing as well as downsizing and turbo charging of internal combustion engines [1].

Aerodynamics is the part of fluid dynamics that is focused apparently on the motion of air, primarily when a solid object moves or through in a fluid or path. A long time study and researches of aerodynamic to understanding and improving the aerodynamics of a vehicle has considerable effects on the maximum velocity the vehicle can reach, but also on the environmental impact due to fuel consumption of the vehicle [2]. When the design of the bus body is very flat the resistance is more and hence the researchers gave attention to the design of the bus body. It is said that about 60-70 percent of the total wind-averaged drag of a bus is attributed to pressure loads acting on the vehicle for body making it the principal area for drag reduction [3].

The aerodynamic drag force significantly affects the vehicle's performance, fuel consumption, acceleration properties, handling characteristics, environmental pollution, noise and comfort. Moreover, aerodynamic drag coefficient is increased proportionally with the square of the speed. This status makes more important aerodynamic structure of buses which perform a large part of the transportation out of the city at high speeds. The fuel consumption reduces about 1% when the coefficient of drag of a vehicle reduces by 2% at high speeds [4].

Buses are one type of the heavy vehicles that consume much fuel. They are road vehicles designed to carry passengers in different applications. Buses can have a capacity as high as 300 passengers. The most common type of buses is the single-decker rigid bus. The larger loads are carried by double-decker buses and articulated buses. The smaller loads are carried by midi-buses and minibuses. Coaches are used for longer distance services. Bus manufacturing is increasingly globalized with the same design appearing around the world. Buses may be used for scheduled bus transport, scheduled coach transport, school transport, private hire, tourism, etc. Promotional buses may be used for political campaigns and others are privately operated for a wide range of purposes [5].

When an object is placed in a flow or moving in a fluid, forces are applied to its surface. These forces, due to shear stress, try to decrease the speed of movement; thus, energy is dissipated. The most two factors to reduce the drag of the vehicles are as follows:

1) Reduce the frontal area of the vehicle to decrease the impact area of air.
2) Aerodynamic improvement to reduce the drag coefficient (C_d) [1].

The following figure 1 shows that the power required to overcome the aerodynamic drag is greater at the high velocity of the vehicles. Also, rolling friction and accessories are directly affected to slow the motion of the vehicles. The red color curve indicated the aerodynamic drag and the blue color curve indicated the friction losses. Both are increased as increased the speed of vehicles [2].

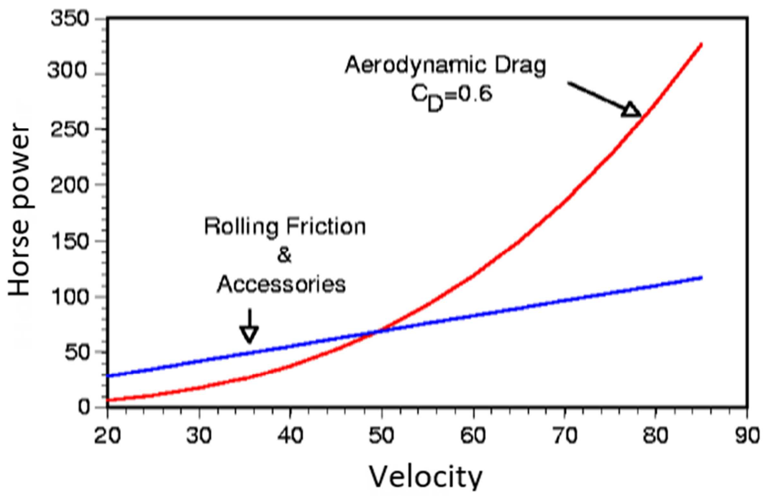


Figure 1. *Horsepower required overcoming aerodynamic drag and rolling friction [6].*

There are many literature reviews published in the field of aerodynamic drag of the vehicles.

Roy and Srinivasan [7] illustrated the reducing aerodynamic drag, the aerodynamic bus and various high-speed buses aim to reduce traffic accidents and enhance the bus's fuel efficiency. The exterior rearview mirrors are also equipment set up with the body to study aerodynamic drag. Changing the geometry of the bus can improve fuel efficiency by reducing aerodynamic drag.

Carr [8] investigated in close proximity to the ground, the front and rear sides of the rectangular vehicle's fluid flow are studied. The coefficient of drag value, which was calculated using a low leading edge, is 0.21 in the experimental results.

Abdel Gawad and Abdel Aziz et al. [9] illustrated the influence of a bus's front shape on fluid flow characteristics is researched numerically and experimentally. The bus's rear side took into account heat transfer in driving tunnels as well. With the front side modified to be flat, inclined, or curved, three bus models are taken into consideration. When vehicles are running on the road, the modification shape has an impact on aerodynamic drag. It has been noted that the aerodynamic drag of a flat modification on the front of the vehicle is inferior by about 20% to that of an inclined and curved modification.

A. Muthuvel et al. [10] provided the aerodynamic exterior body design of a bus was the name of the experiment, which was carried out in a wind tunnel with numerical testing to determine the efficacy of the new design model. It has been established that the aerodynamic drag force is estimated using experimental data and is between 30 and 40 percent of the bus's current value. Additionally, every 100 kilometers of travel, less fuel is used roughly 6-7 liters.

Chowdhury, et al. [11] developed the aerodynamic components to lower heavy vehicles' drag coefficients. By altering the design of the spoiler, reducing the distance between the truck and trailer, and adding some components to lessen drag brought on by the wheels, they were able to achieve an average aerodynamic improvement of 26.1%. The spoiler's design may increase drag by 17.6%.

Yelmule and Kale [12] illustrated the comfort provided by airflow due to motion in open-window buses is studied experimentally and numerically. They claimed that by altering the bus's exterior body, an overall drag reduction of about 30% at 100 km/h can be achieved.

Patil et al. [13] considered using the CFD technique, the flow pattern around a bus model. To reduce the drag force of the bus model, three models were created. In their investigation, they discovered that the bus's base model's CD coefficient was 0.53. By changing the front and back surfaces of the bus, they were able to lower the CD coefficient to 0.49. They were able to lower the CD coefficient to 0.39 by adding the side panel and 0.40 by adding the rear spoiler. As a result, their aerodynamic performance improved by 6.57%, 25.82%, and 24.42%, respectively.

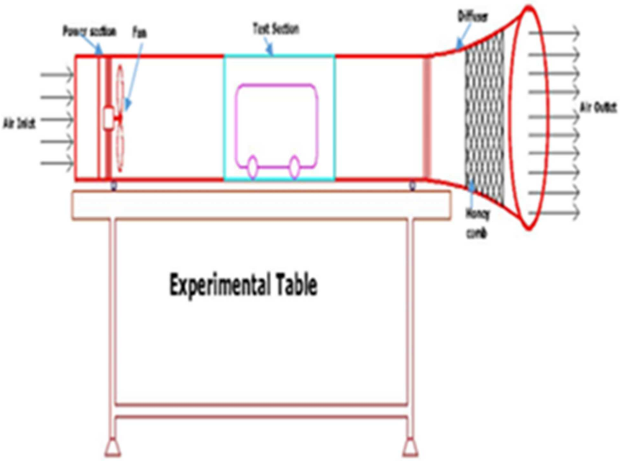
2. Experimental Setups

The experimental wind tunnel is suction type. The testing area measures 50 x 50 x 200 cm. The frequency inverter is used to regulate the fan motor's rpm. The frequency inverter controls a 600 mm diameter, 6 kW powered axial fan and operates in the 0-50 Hz range with a 0.1 Hz step. In experimental studies, a Honeywell Model 41 load cell was used to measure the drag force with an accuracy of 0.1%. This load cell has an output voltage range of 0 to 5 Vdc and measures forces ranging from 5 lb to 400,000 lb. The drag force was calculated by averaging the 20000 data points that were collected during the 20 second, 1000 Hz data acquisition period at each free flow rate. Figure 1a and Figure 1b show the view of the test apparatuses and wind tunnel, respectively.

(a) L=180 mm, W = 58 mm, H = 60 mm. (b) L = 200 mm, W = 80 mm, H = 80 mm

(c) L-11275mm, W -2950 mm, H -3090 mm

Figure 2. *Setup in Experimental Wind Tunnel for (a) Base Model 1 (b), Base Model 2 (c) & Base Model 3.*



(a)

(b) (c)

Figure 3. *Setup in Experimental Wind Tunnel for (a) schematic view. (b) Base Model Modified 1 (c) Base Model Modified 2.*

3. Aerodynamic Drag Calculations

The results are performed by ANSYS[R]19.0 CFD software which is calculated by the following equation. The value of the total drag force,

Total drag = Friction drag + Pressure drag

The equation defined that, the relation among the drag force *(F_d)*, drag coefficient *(C_d)*, frontal area of the bus *(A)*, Velocity of the bus *(V)* density (ρ) of the fluid which through the bus [14].

The equation of the Aerodynamic drag calculation is given as-

$$C_d = \frac{F_d}{\frac{1}{2}\rho.A.V^2}$$

The yaw angles are considered as 0° and 5° for bus simulation. The weighted value of the coefficient of drag expresses the following equation and results found in a crosswind angle of approximately 3.1^0.

$$Cd\text{−}weighted = {}^{1}/3 \cdot Cd\text{−}0deg + {}^{2}/3 \cdot Cd\text{−}5deg$$

The aerodynamic drag is normally presented by drag counts (DC). It's defined between the reference model and the existing model. Drag counts are calculated by the following equations.

$$DC = \Delta C_d \cdot 1000$$

Where, $\Delta C_d = C_{d\text{−}specific\ case} - C_{d\text{−}reference}$

The bus is subjected or faced by the different cross wind during run the vehicle on the road. The boundary conditions is the vital point for aerodynamic drag force calculation of the cross wind. In generally it's defined as the surrounding of the vehicle body to contact with air during run on the road. There are many parameters were consists as inlet and outlet of the air flow. The dimension and boundary condition of the base model is given following.

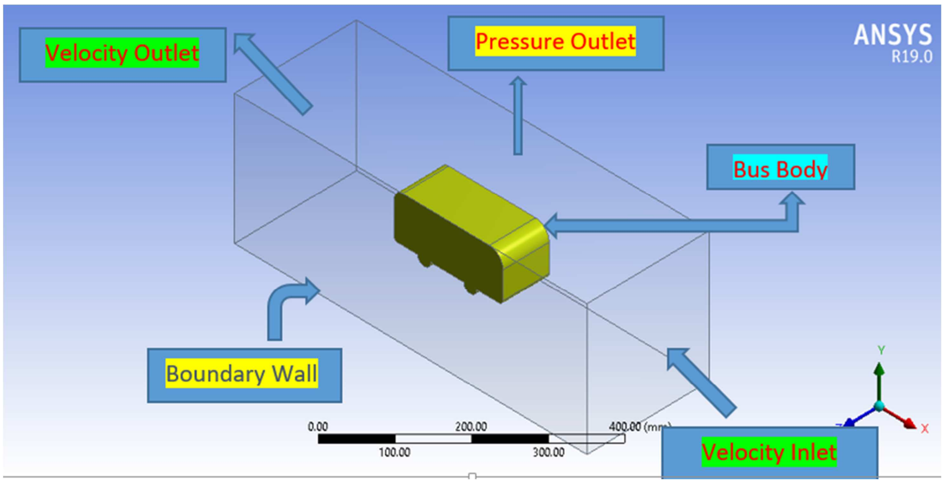


Figure 4. *Dimension and Boundary Condition of the Base Model.*

4. Results and Discussion

Figures 4 and 5 show the drag force (N) vs. speed (km/h) for base models 1 and 2 along with the y and x axes, respectively. When the speed is increased, the drag force also increases and vice versa for the base model and the modified base model. Base model modified 1 and 2 have lower drag forces than base models 1 and 2.

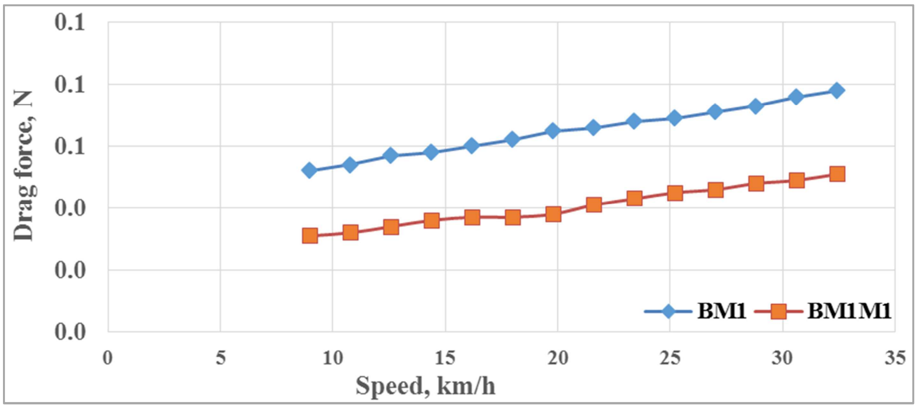


Figure 5. *Drag Force versus Speed of Base Model 1.*

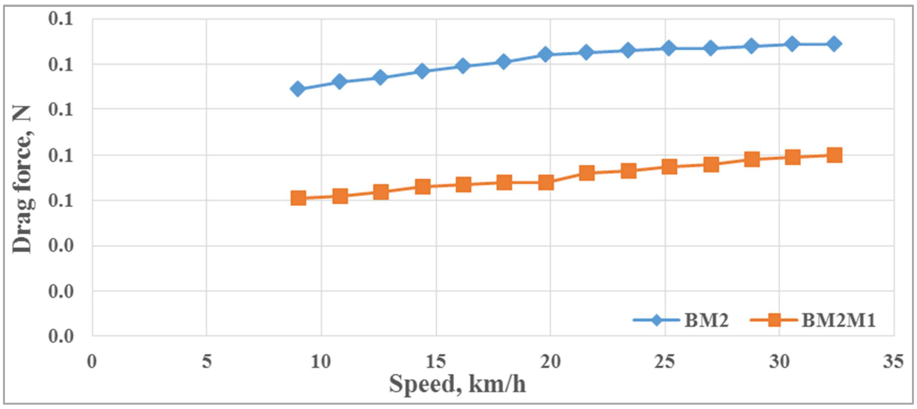


Figure 6. *Drag Force versus Speed for Model 2.*

Table 1. *Drag Force at various speeds for Base Model Modified 1 & 2 with Sunlong China Bus 1 & 2 [15].*

Velocity, Km/h	Drag Force, Fd0 (BM-3)	Drag Force, BM3M1	Drag Force, BM3M2	Drag Force, Sunlong China Bus-1 [10]
80	2218.60	1600	1436.50	1366.06
90	2806.60	2016	1820.50	2264.12
100	3462.20	2466.1	2180.70	2913.11
110	4977.00	2989.8	2477.20	3978.14

Figure 7 illustrates the relationship between drag force (N) and speed (km/h) for the Sunlong China bus 1 and 2 and base model 3. The y axis represents drag force (N), while the x axis represents speed (km/h). For the base model 3 and Sunlong China bus, the drag force increases as the speed increases and vice versa. In comparison to Sunlong China buses 1 and 2, the base model modified has lower drag forces.

Figures 8 and 9 illustrate the coefficient of drag vs. speed (km/h) for base models 1 and 2 along with the y and x axes, respectively. For the base model and the modified base models 1 and 2, the coefficient of drag decreases as the speed is increased. Base model modified 1 and 2 have less coefficient of drag than base models 1 and 2.

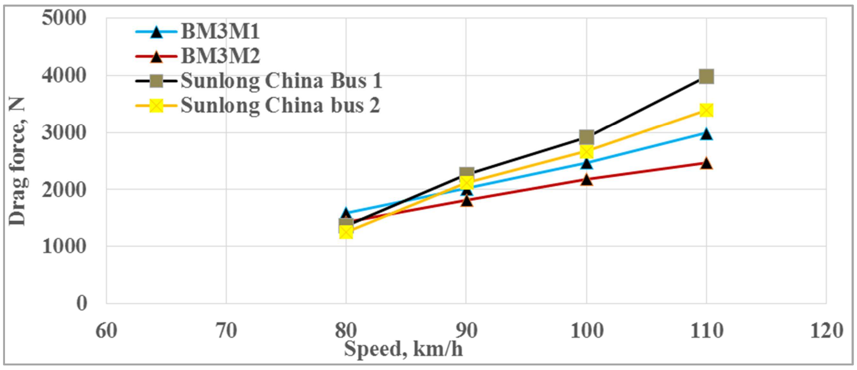


Figure 7. *Drag Force for Base Model Modified 1 & 2 with Sunlong China Bus.*

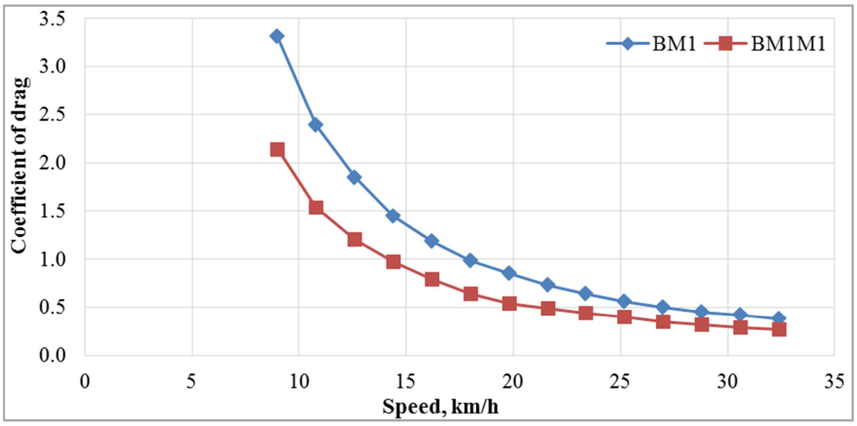


Figure 8. *Coefficient of drag versus Speed of Model 1.*

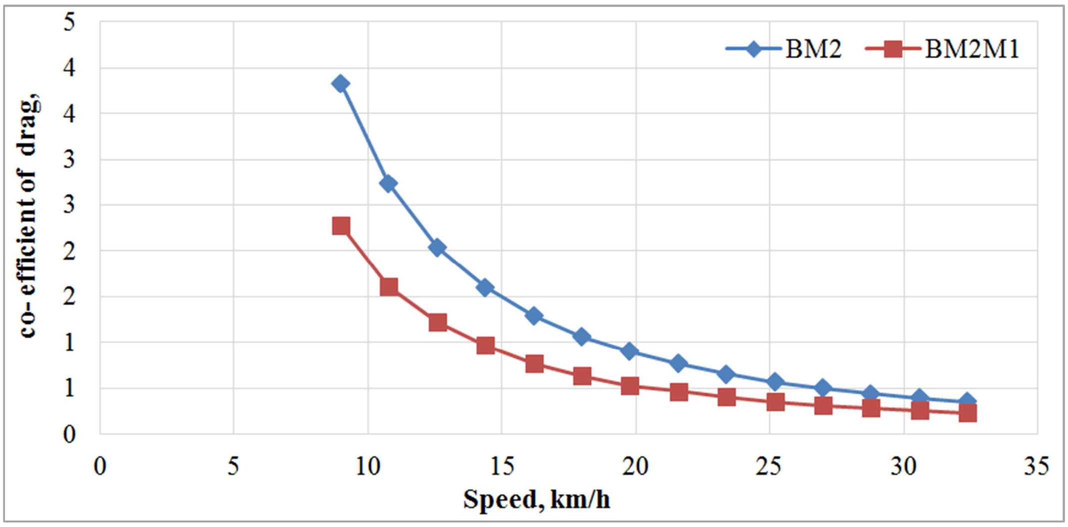


Figure 9. *Coefficient of drag versus Speed of Model 2.*

Figure 10 shows the drag coefficient vs. speed (km/h) for base model 3 with base model modified 1 & 2. The y axis represents coefficient of drag while the x axis represents speed (km/h). As speed is increased, the coefficient of drag also slightly decreases and vice versa. The coefficient of drag of modified 1 & 2 are less than of base model 3.

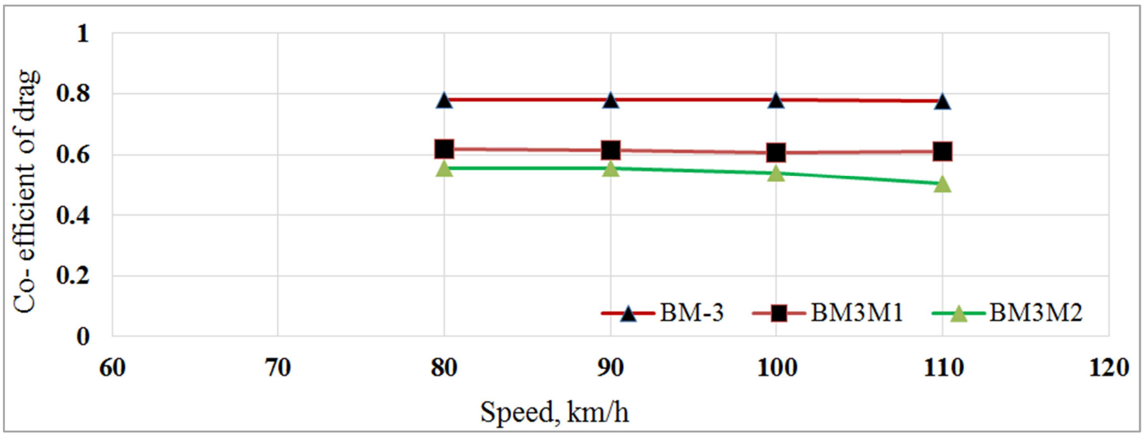
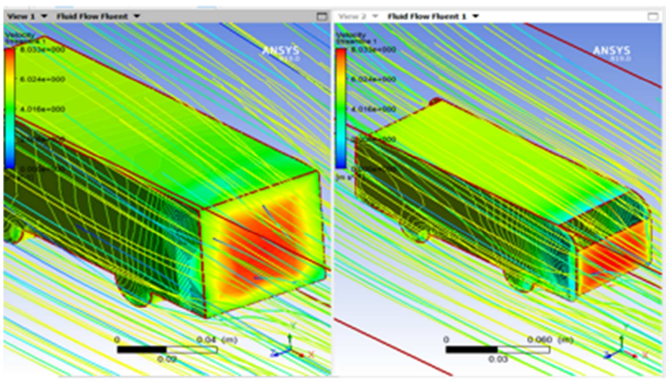
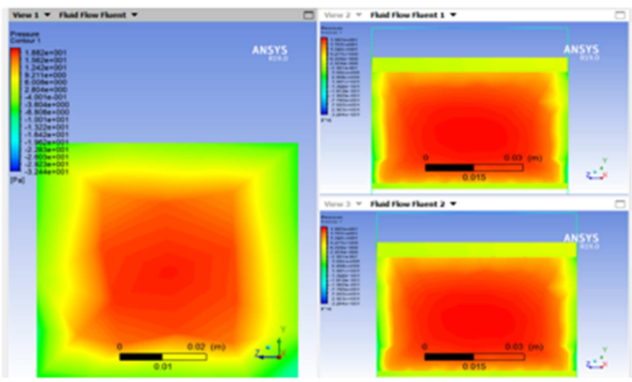


Figure 10. *Co-efficient of drag Versus Speed of Base Model-3 and Base Model Modified 1 & 2.*

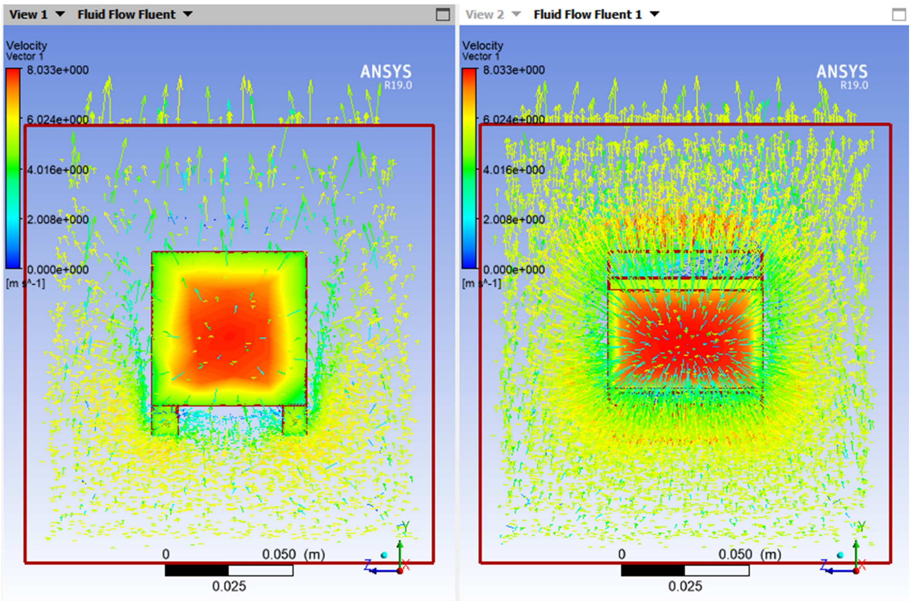
The following figure of Pressure contour, velocity streamline and velocity vector with velocity for base model and modified model. The highest density of red color indicated that highest air resist by vehicle body. Fluid streamline indicated that the direction of air movement which flow the opposite vehicle movement.



(a) velocity streamline

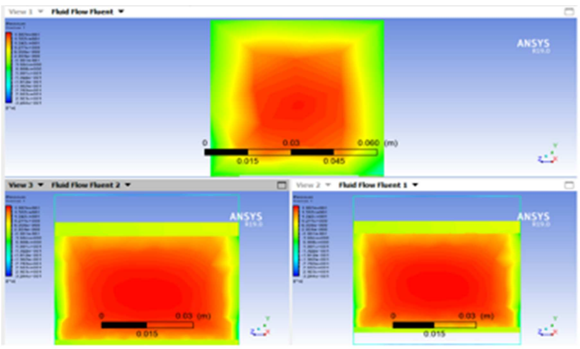


(b) pressure contour

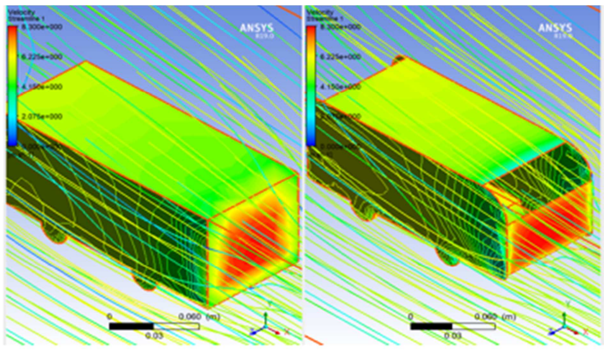


(c) velocity vector

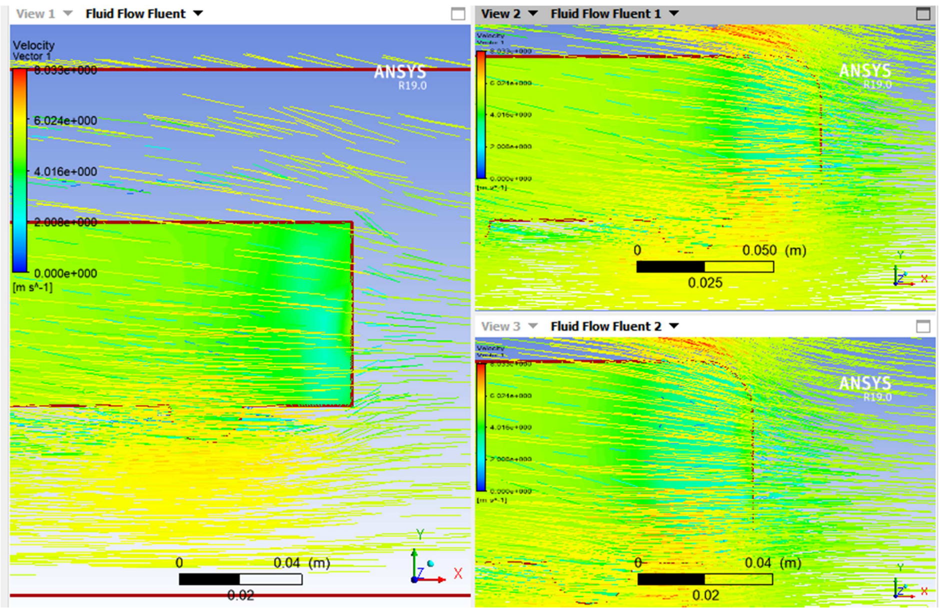
Figure 11. *(a) velocity streamline, (b) pressure contour, and (c) velocity vector of the base model1 and base model modified1.*



(a) pressure contour

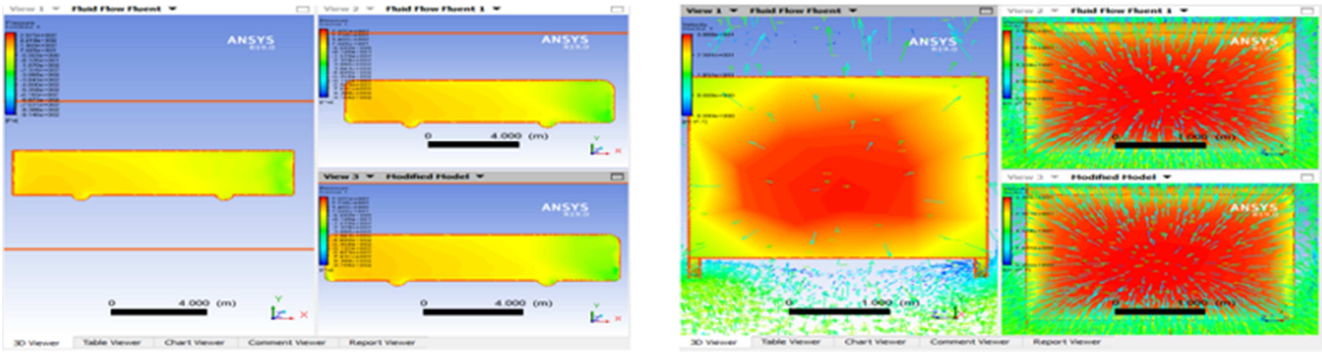


(b) velocity streamline

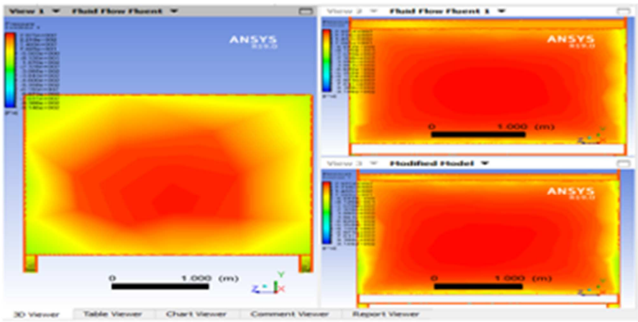


(c) velocity vector

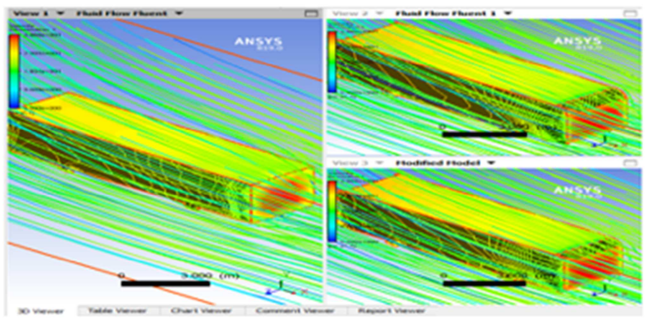
Figure 12. *(a) velocity streamline, (b) pressure contour, and (c) velocity vector of the base model2 and base model modified1.*



(a) velocity vector



(b) pressure contour



(c) velocity streamline

Figure 13. *(a) velocity Vector, (b) pressure Contour and (c) velocity streamline of the Base Model3 & Base Model Modified 1 & 2.*

5. Conclusions

It has been seen that the aerodynamic drag on a vehicle directly affects not only is fuel consumption but also the generation of carbon dioxide (CO_2) from the combusted fuel which directly affected on the environment. Drag force has been reduced and performance of bus gets increased due to the fuel consumption decreased and hence the efficiency of the bus increases. Other findings are provided in the following way.

1) *Model-1*: The drag force at a velocity of 20 km/h for base model-1 is 0.065 N and for base model modified-1 is 0.038 N. Hence, the drag force is reduced as 0.027 N or 41.54 %. Therefore, the drag coefficient, C_d becomes for base model-1 as 0.85 and for base model modified-1 as 0.54. Hence, the drag coefficient, C_d is reduced as 0.31 or 36.53%.
2) *Model-2*: The drag force at a velocity of 20 km/h for base model-2 is 0.124 N and for base model modified-1 is 0.068 N. Hence, the drag force is reduced as 0.056 N or 45.16 %. Therefore, the drag coefficient, C_d becomes for base model-2 as 0.90 and for base model modified-1 as 0.52. Hence, the drag coefficient, C_d is reduced as 0.37 or 41.57%, 0.38 or 41.66%.
3) *Base Model-3*: The CFD values of the drag forces at a velocity of 110 km/h for base model-3, base model modified-1, base model modified-2 and Sunlong China Bus are 4977.0 N, 2989.8 N, 2477.2 N and 3389.8 N, respectively. Hence, the drag forces are reduced for base model modified-1, base model modified-2 and Sunlong China Bus as 1987.20 N or 39.93%, 2499.80 N or 50.53% and 3803.8 N or 46.8%, respectively. Therefore, the drag coefficients, C_d become for base model-3, base model modified-1, base model modified-2 and Sunlong China Bus are 0.77, 0.61, 0.51, and 0.59, respectively. Hence, the drag coefficients, C_d are reduced for base model modified-1, base model modified-2 and Sunlong China Bus as 0.16 or 21.60%, 0.26 or 35.0%, and 0.11 or 18.98% respectively.

References

[1] J Abinesh, J Arunkumar, CFD Analysis of Aerodynamic Drag Reduction and Improve Fuel Economy, 2278–0149, ijmerr, Vol. 3, No. 4, October, 2014.

[2] R. Brown, Analysis of Drag Reduction using Aerodynamic Devices on Commercial Buses by Computational Fluid Dynamic Simulation, Alfred Newyork, 2015.

[3] J. Godwin John, A. Muthuvel, N. Prakash, Numerical Analysis for Drag Reduction in Commercial Buses, IOSR-JMCE, PP-01-05, 2014.

[4] Cihan Bayındırlı, Mehmet Çelik, The Experimentally and Numerically Determination of The Drag Coefficient of a Bus Model, S, IJAET 7 (3), 117-123, 2018.

[5] E. A. Mohamed, M. N. Radhwi, A. F. A. Gawad, Computational investigation of aerodynamic characteristics and drag reduction of a bus model, Vol. 2 (1-1): pp. 64-73, 2015.

[6] F. Browand, Reducing Aerodynamic Drag and Fuel Consumption, Global Climate and Energy Project Workshop on Advanced Transportation October 10-11, 2005.

[7] S. Roy, and P. Srinivasan,"External Flow Analysis of a Bus for Drag Reduction'', International Bus and Bus Meeting & Exposition, Paper, 2000.

[8] Carr. G. W., "The aerodynamics of basic shapes of road vehicles, part 1, Simple rectangular bodies", MIRA report No. 1982/2.

[9] A. A. Abdel Aziz, and A. F. Abdel Gawad, "Aerodynamic and Heat Transfer Characteristics around Vehicles with Different Front Shapes in Driving Tunnels," Proceedings of Eighth International Congress of Fluid Dynamics & Propulsion (ICFDP 8), December 14-17, 2006.

[10] A. Muthuvel, M. K. Murthi, Sachin. N. P, Vinay. M. Koshy, S. Sakthi, E. Selvakumar, Aerodynamic Exterior Body Design of Bus, IJSER, Volume 4, Issue 7, 2013.

[11] Chowdhury, H. Moria, H. Abdulkadir, A. Khan I. Alam, F. and Watkins, S, A Study on aerodynamic drag of a semi-trailer truck. Procedia Engineering, 56, 201–205, 2013.

[12] M. M. Yelmule and S. R. Kale, A erodynamics of a Bus with Open Windows, Int. J. Heavy Vehicle Systems, Vol. 16, No. 4, 2009.

[13] Patil, C. N. Shashishekar, K. S. Balasubramanian, A. K. Subbaramaiah, S. V, Aerodynamic Study and drag coefficient optimization of passenger vehicle. IJERT, Vol 1 (7-8), 2012.

[14] H. Shiri, Aerodynamic Analysis of Drag Reduction Devices on the Simplified Body for Tractor and Bus by Using CFD, 2016.

[15] Optimum Aerodynamic Design of a High-speed China Sunlong Bus for fuel saved and carbon Dioxide reduction. Journal Paper for Automotive Engineering Vehicle Body Design and Aerodynamics. Department of Mechanical and Automotive Engineering Adama Science and Technology University. 2016.