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Experimental investigation for reducing aerodynamic drag and fuel consumption in a passenger bus

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Abstract
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, experimental investigation has been done for various passenger bus models using a wind tunnel. Two demo base models are considered for the analysis namely model-1 made of a plastic body and model-2 made of metal body. 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 experimental analysis for the drag forces, drag coefficient and fuel consumption have been done for model-1 & 2 as well as for their respective modified models. For base model-1, the drag force is reduced as 0.027 N, the drag coefficient, Cd is reduced as 0.30 and fuel savings 19.50%. For base model-2, the drag force is reduced as 0.062 N, the drag coefficient, Cd is reduced as 0.37 and fuel savings 22.20%.

Keywords: Aerodynamics drag, drag force, co-efficient of drag, bus, CFD, ANSYS

1. Introduction

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 CD coefficient of a vehicle reduces by 2% at high speeds [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. While in the past, the ambition of products more aerodynamic vehicles was increasing the top cruising speed of the vehicle. Today, the focus is no longer on the speed of the vehicle but energy conservation due to the limitation of fossil fuel. Decreasing the fuel consumption of vehicles is particularly need when looking at commercial vehicles, due to a large portion of the total fossil fuel consumption used every day. More fuel consumption implies even more emissions, which have a direct effect on the environment [2]. Drag is the most significant force that occurs when air motion around a solid body is studied. Drag is important in a way that it directly opposes the direction of the body and a great amount of energy and power is required to overcome it, causing it to be a highly undesirable force. Automotive manufacturers try to factor in this force when designing automobiles. Drag force affecting a body in motion is usually calculated and represented by using a value called the drag coefficient (Cd) [3].

There are various types of drag forces acting on a vehicle namely: Parasitic drag, lift, induced drag and wave drag. Parasitic drag is further sub divided into form, skin friction and interference drag. These individual drags are very difficult to calculate and hence most people are concerned in finding the overall drag coefficient of a vehicle [5].

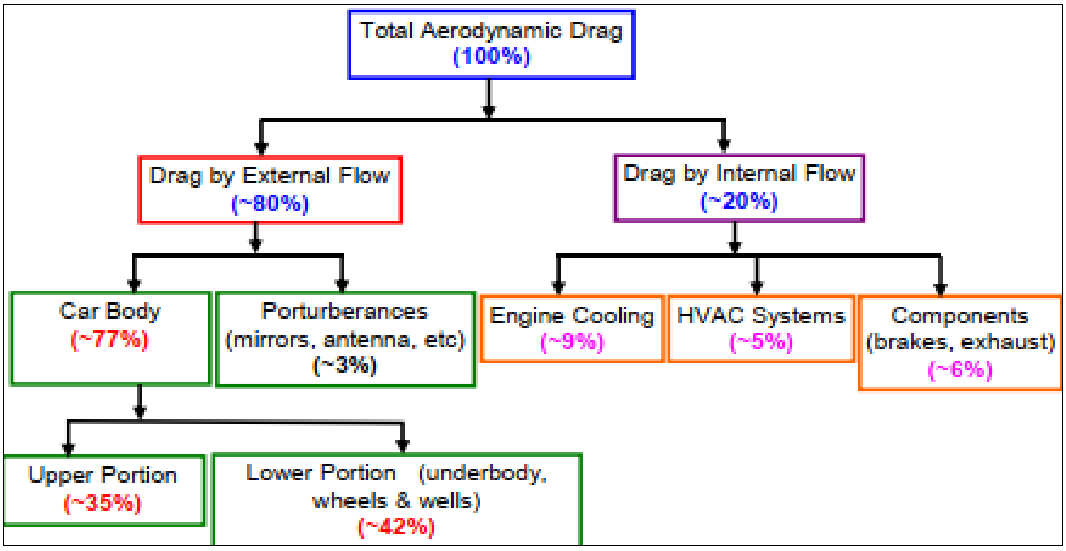

Fig 1: Breakdown of passenger car aerodynamic drag [4].

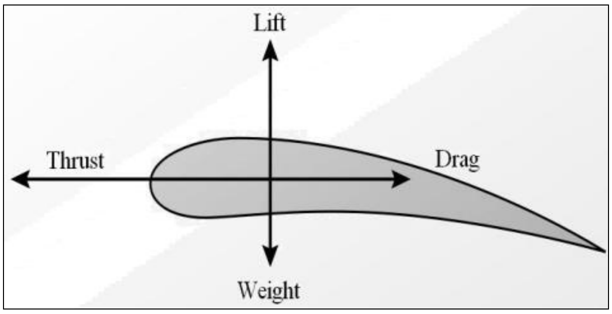

Fig 2: Different forces acting on body [6].

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: Reduce the frontal area of the vehicle to decrease the impact area of air. Aerodynamic improvement to reduce the drag coefficient (C_d) [7].

Figure 3 shows that the vehicle body moved in airflow. Drag force is created and moves in the opposite direction of the vehicle. In the front and rear sides of the body pressure drag is created. On the sides of the body, skin friction is activated which causes minor drag and also moves to the opposite direction of the vehicle. Magnitude can be measured and amplified by creates flow separation of geometry [8].

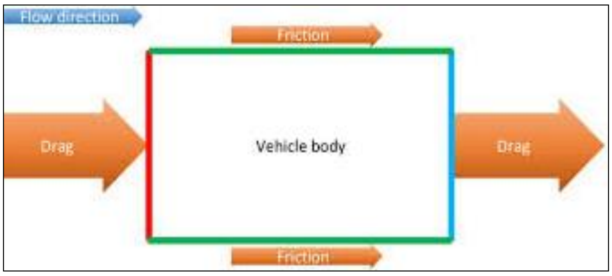

Fig 3: Primary Concept of Vehicle Aerodynamics on high way roads [8].

There are many literatures review published in the field of aerodynamic drag of the vehicles. The additional purposes of the review papers are comparing among the papers and to investigate the outcomes of the results.

Roy and Srinivasan [9] the aerodynamics bus and various high-speed buses have the target and significant to reduce the road accident and improve the fuel consumption of the bus by aerodynamic drag reduction. To study the aerodynamic drag and provide the exterior rearview mirrors also equipment set up with the body. Modifying the bus geometry, can reduce aerodynamic drag and to obtain the fuel economy.

Thorat and Rao [10] showed that slight modification in exterior bus design and frontal area with improved aesthetic, drag can be reduced significantly. Newland [11] aimed the passenger bus to develop and obtain fuel consumption. The function of fuel consumption is based on the relationship executed in the literature review. To compare the fuel consumption between the reference bus model and various passenger bus operating characteristics.

Abinesh and Arunkumar [12] aimed to modify the outer surface and structure of the bus aerodynamically to reduce the effect of drag force of the vehicle which in turn results in reduction of fuel consumption of the vehicle. Two prototype bus body were modeled by using CFD to reduce the drag force. As a result, they increased performance and reduced the fuel consumption. The reduction in aerodynamic drag force was 10%.

Rodrigues *et al.* [13] shows that small changes in vehicle geometry has been possible to achieve a reduction of almost 20% of drag coefficient which results in fuel saving of about 10%. Carr [14] the effects of fluid flow of the front and rear side of the rectangular vehicle is investigated in ground proximity. In the experimental results the coefficient of drag value is calculated with low leading edge is 0.21.

Shankar G *et al.* [15] carried out both numerical and experimental studies on sedan car model using active airflow modification technique for reducing aerodynamic drag coefficient and lift coefficient. The analysis was performed with three delta shaped vortex generators mounted at the roof end of sedan car model where the flow separation initiates from the exterior surface of the car. The experimental results show that 4.53% and 2.55% reduction of drag coefficient and lift coefficient respectively.

Abdel Gawad and Abdel Aziz [16] the effect of the front shape of buses is investigated numerically and experimentally of the characteristic of fluid flow. Also, the rear side of the bus considered the heat transfer in driving tunnels. Three bus models are considered with modification of the front side as flat, inclined and curved. The modification shape affects the aerodynamic drag when vehicles run on the road. It's observed that the modification of inclined and curved on front side of the vehicle is better than the aerodynamic drag of modification flat by about 20%.

Belman *et al.* [17] illustrated the fuel consumption by vehicles accounts for over 30% of CO2 and other greenhouse gas emissions. Moreover, most of the usable energy from the engine goes into overcoming the aerodynamic drag (53%) and rolling resistance (32%); only 9% is required for auxiliary equipment and 6% is used by the drive-train. 15% aerodynamic reduction at highway speed of 55 mph can result in about 5–7% in fuel saving.

A. Muthuvel *et al.* [18] the name of the experiment is Aerodynamic exterior body design of bus executed a wind tunnel with numerical test and to obtain the effectiveness result of the new design model. It has been proved that from the experimental result and the aerodynamic drag force is considered about 30-40% from the existing value of the bus. Also, fuel consumed is reduced by about 6-7 liters every 100 km.

2 Experimental Setups

In studies on vehicle aerodynamics, geometric, kinematic and dynamic similarity conditions have to provide between prototype and model car. To provide geometric similarity, model vehicle drawn in CAD program and produced in 3-D printer using this drawing data. So, first similarity condition was obtained. In kinematic similarity depends on blockage ratio factor. It was provided in wind tunnel tests. Finally, to provide dynamic similarity Reynolds number independence was used as stated in the literature for wind tunnel experiments. The aerodynamic drag coefficient CD is the function of the drag force (FD), density (ρ), free flow velocity (V) and front view area (A) and it was presented equation 1. As a results of the wind tunnel tests, the drag force was measured in different free stream velocities and the CD coefficients were calculated [19].

(a) L=180 mm, W = 58 mm, H = 60 mm. (b) L = 200 mm, W = 80 mm, H = 85 mm.

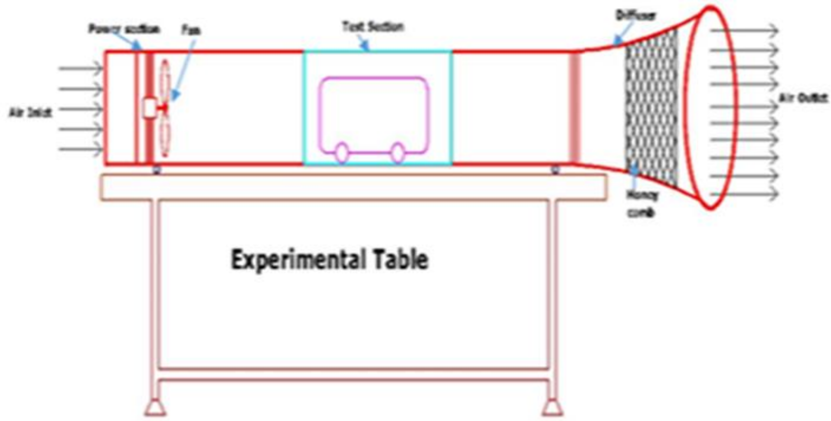

Fig 4: Setup in Experimental wind tunnel for base model-1 & 2

Fig 5: Setup in experimental wind tunnel for base model modified-1 & 2

3. Standard and modified model confirmations

The standard model of the bus was set up in the test section to take parameters of the drag force. The drag components of force impact on the models during the testing period are balanced by sliding weights parallel the arms of the balance until a state of zero position or null deflection is achieved. A digital spring weight scale is attached in the test section for precious reading of drag force. Multiple data were set and collected at each speed. The speed ranges up to 10 m/s under 0^0 yaw angle and the results were average, minimizing possible errors in the experimental data. Yaw angle is vital parameter that directly affects drag force and is considered that 0° angles.

3.1 Experimental Data Analysis

The experimental data as like pressure, temperature, the density of air and area of the frontal view of the bus are considered constant. The velocity of the air is rapidly changes depend on the blower speed. To obtain aerodynamic drag force from the experimental result then calculated coefficient of drag. The experimental result and simulated result have a little bit of deviation which is ignored due to some limitations in the experimental tunnel and model.

3.2 Experimental Aerodynamic Drag Calculation

The Aerodynamic parameters are important to help find out the aerodynamic efficiency among different vehicles. There are some parameters are drag coefficient (C_d), drag force (F_d), vehicle speed (V), area of the front view of vehicle (A) and density (ρ) [20]. 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, $\Delta C_d = C_{d\text{−specific case}} - C_{d\text{−reference}}$

3.3 Fuel saving of the models

The fuel system is the vital points which directly effect on efficiency and costing of the vehicles. There are many systems are developed to reduce the fuel consumption of the vehicles. The following equation are derived that the fuel savings calculated in percentage (%). This equation executed the relation between the fuel savings and the coefficient of drag in specific case and reference case of vehicle.

$$F.S\ (\%) = \frac{\Delta Cd\ .16}{30}$$

Above the formula is used in the experiments for a long-distance vehicle of bus weight almost 40 ton and multiplying factor considered 16. The denominator 30 is executed the fuel consumption of 30Liters/ 100 km during experiments. The equation can be simplified by converted as the following equation.

$$F.S\ (\%) = \Delta Cd \ x\ 1/1.88$$

4 Results and Discussion

Figures 6 and 7 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.

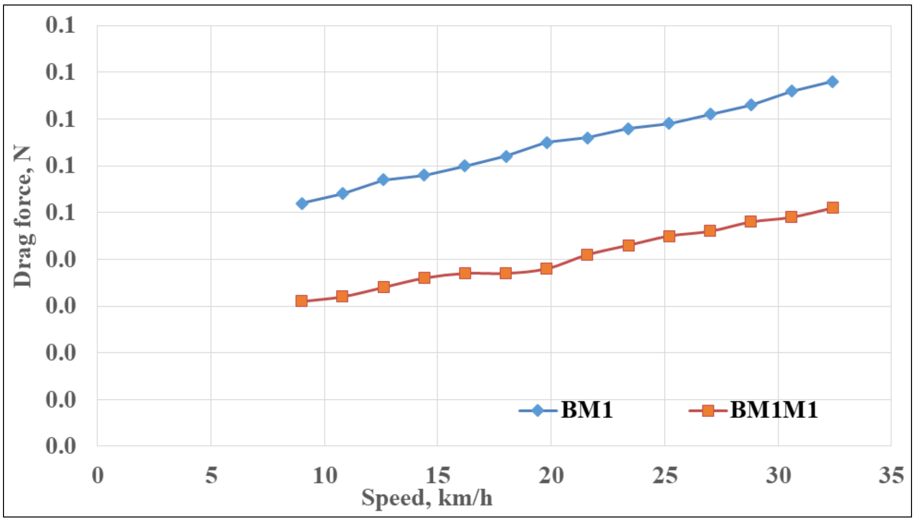

Fig 6: Drag Force versus speed of base model-1 & base model modified-1.

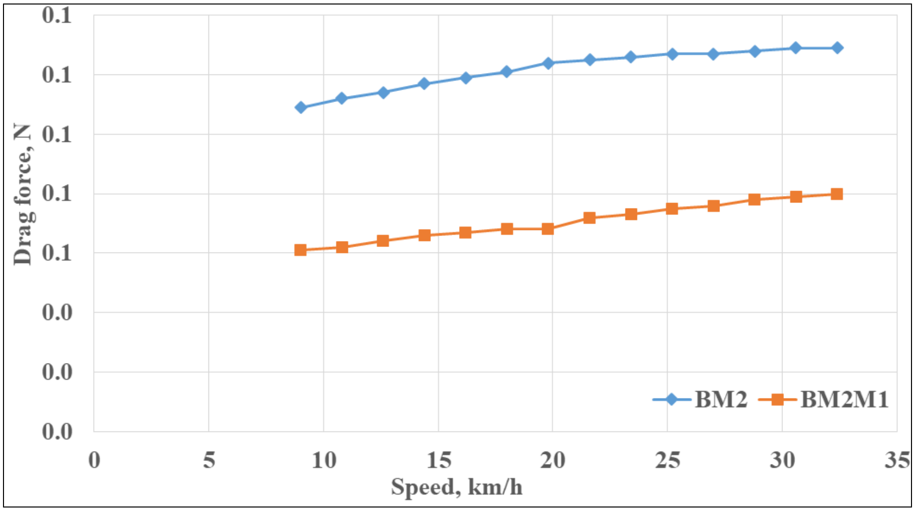

Fig 7: Drag Force versus Speed of Base Model-2 & Base Model Modified-1

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

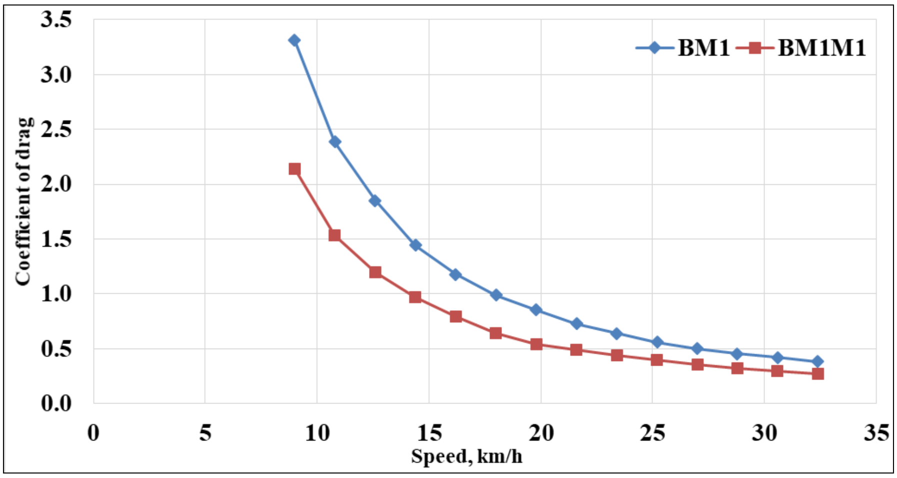

Fig 8: Co-efficient of drag versus Speed of Base Model-1 & Base Model Modified-1.

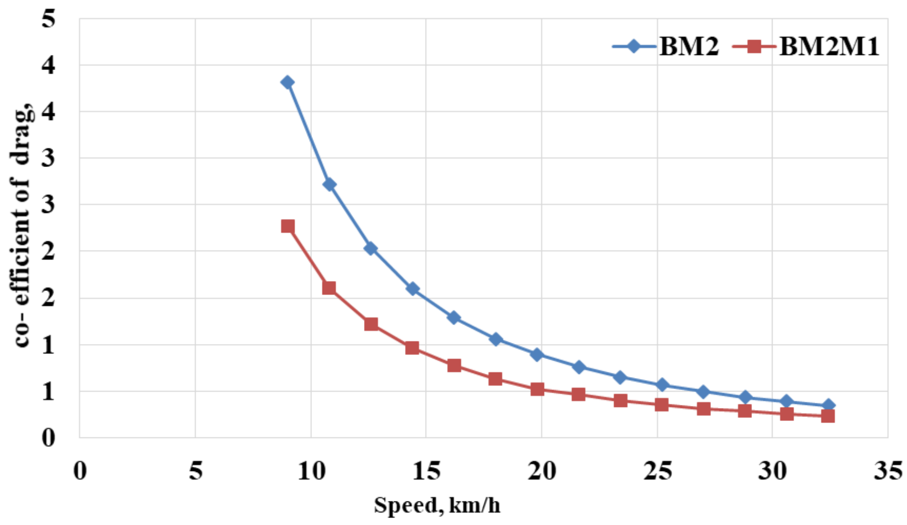

Fig 9: Co-efficient of drag versus Speed of Base Model 2 & Base Model Modified 1.

Figure 10 represents the drag reduction in percentage (%) and Fuel saving in percentage (%) with velocity for base model-1 & 2. Drag reduction and fuel saving indicated by Y axes and speed indicated by X axis. For base model 1 & 2, drag reduction and fuel saving slightly decreased with respect to speed.

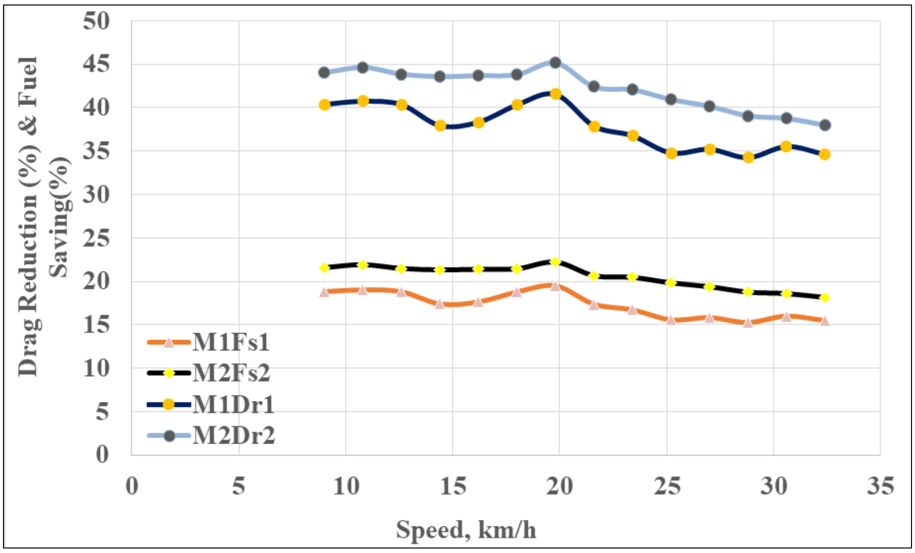

Fig 10: The results of drag reduction and Fuel saving with velocity for Model-1 & 2.

Figure 11 shows the velocity streamline, pressure contour and velocity vector of the base model 1 and base model modified 1. The drag forces and drag coefficient are directly affected on the fuel consumption reductions of the models. From figures, velocity streamlines of base model modified 1 are smoothly than base model. Pressure contours are highly concentrated in the center point than sides of both models. Velocity vectors of base model modified 1 are greater than base model 1.

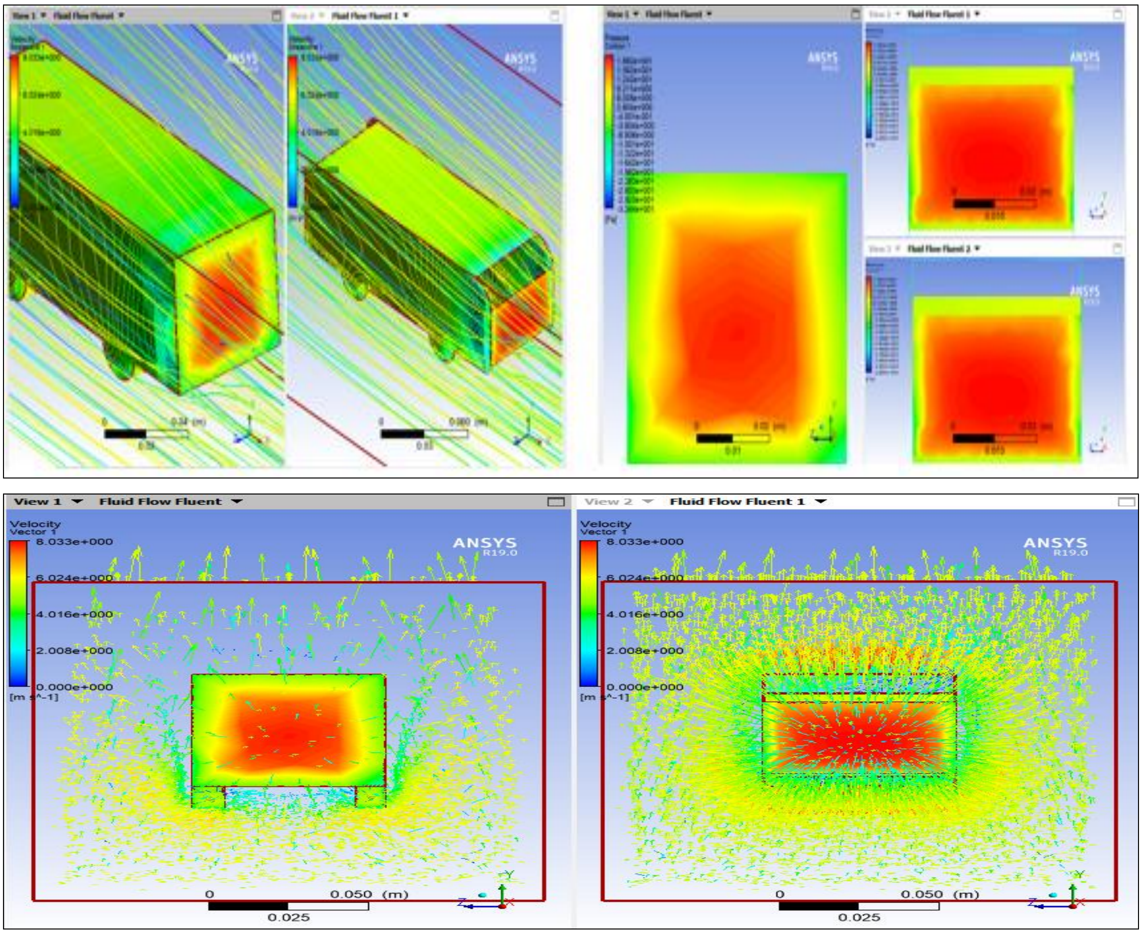

Fig 11: velocity streamline, pressure contour and velocity vector of the base model 1and base model modified 1.

Figure 12 shows the velocity streamline, pressure contour and velocity vector of the base model 1 and base model modified 1. The drag forces and drag coefficient are directly affected on the fuel consumption reductions of the models. From figures, velocity streamlines of base model modified 1 are smoothly than base model. Pressure contours are highly concentrated in the center point than sides of both models. Velocity vectors of base model modified 1 are greater than base model 1.

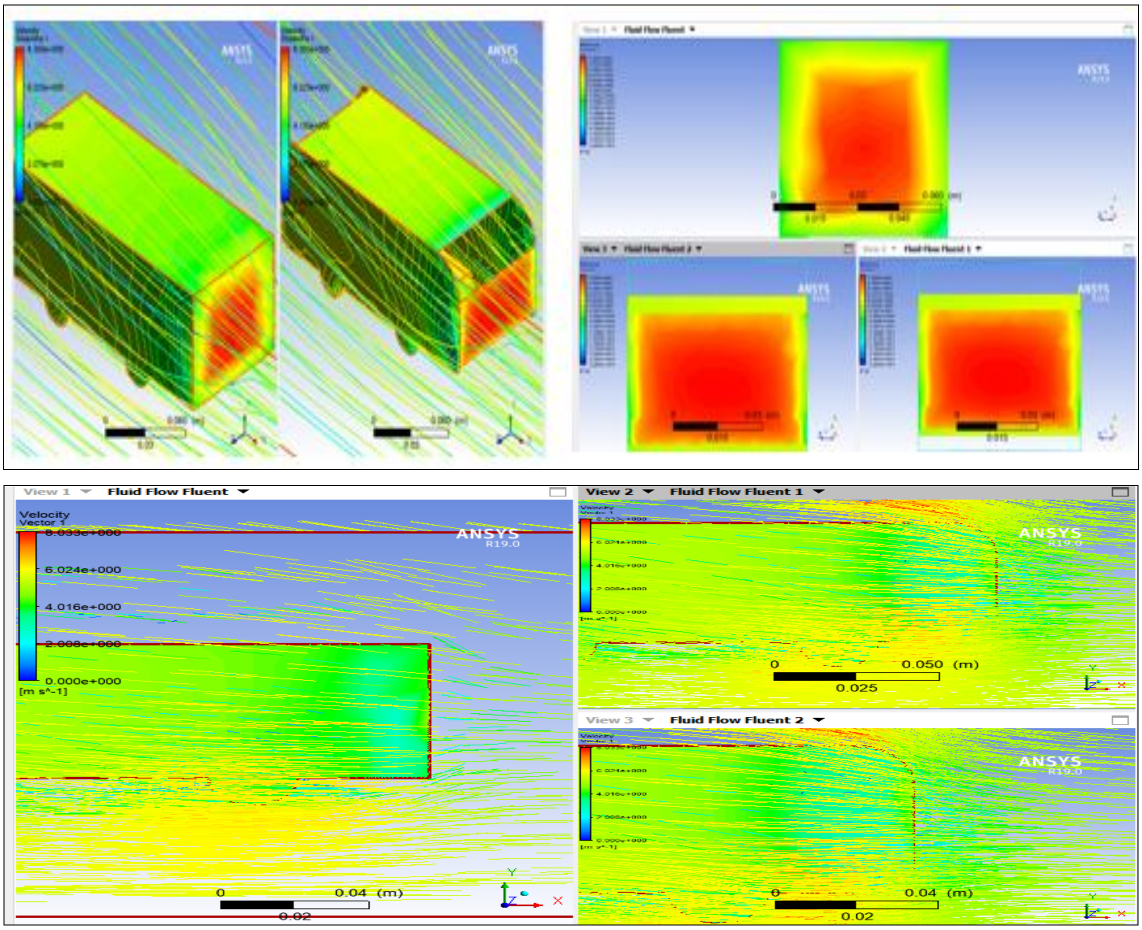

Fig 12: velocity streamline, pressure contour and velocity vector of the base model 2 and base model modified 1.

5 Conclusions

It has been seen that the aerodynamic drag on a vehicle directly effects on fuel consumption as well as 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.

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 co-efficient, C_d becomes for base model-1 as 0.85 and for base model modified-1 as 0.54. Hence, the drag co-efficient, C_d is reduced as 0.31 or 36.53%. In addition, the fuel consumption for base model modified-1 is 19.50 liters by EFD.

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 co-efficient, C_d becomes for base model-2 as 0.90 and for base model modified-1 as 0.52. Hence, the drag co-efficient, C_d is reduced as 0.37 or 41.57%, 0.38 or 41.66%. In addition, the fuel consumption for base model modified-1 is 22.20 liters by EFD.

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