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Research Paper

CFD ANALYSIS OF AERODYNAMIC DRAG REDUCTION AND IMPROVE FUEL ECONOMY

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The rising fuel price and strict government regulations makes the road transport uneconomical now a days. The exterior styling and aerodynamically efficient design for reduction of engine load which reflects in the reduction of fuel consumption are the two essential factors for a successful operation in the competitive world. The bus body building company's precedence's are outer surface and structure of the bus and ignore the aerodynamic aspect. The present intercity buses have a poor aerodynamic exterior design. This project aims to modify the outer surface and structure of the bus aerodynamically in order to reduce the effect of drag force of the vehicle which in turn results in reduction of fuel consumption of the vehicle. The Two prototype bus body has been modeled by using CFD to reduce the drag force. These are namely model 1 and model 2. Model 1 is existing Volvo intercity bus model and model 2 is modification of existing Volvo intercity bus. Model 2 is to modify and analyze by using CFD to reduce the drag force, which results in increased performance and reduced the fuel requirement. The overall reduction in aerodynamic drag force is 10%.

Keywords: Aerodynamics, Drag reduction, Fuel consumption, Computational Fluid Dynamics, Bus

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 etc., as well as downsizing and turbo charging of internal combustion engines. However one of the most effective approaches is to reduce the

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driving resistance of the vehicle. For a vehicle the following expression can be determine as the required force to propel the vehicle.

$$Freq = F_d + F_r + F_a + F_g \quad ...(1)$$

Where,

F_d = 1/2 * V2 is the aerodynamic drag force

F_r = force due to rolling resistance

F_a = force required to accelerate the vehicle

F_g = Wsin is the climbing resistance due to gravity.

Hence the mass, the rolling resistance and the aerodynamics are the parameters left for the automotive industry to improve.

Still in general for a typical passenger vehicle the rolling resistance and aero-dynamic resistance are equal in around 100km/h and at highway velocities the aerodynamic drag is the main source of driving resistance whereas the rolling resistance stays more or less constant.

OBJECTIVE

The objective of this project is to conduct a thorough analysis of current Omni bus aerodynamics through computer modeling and provide recommendations for improve-ment.

- To model an existing Omni bus, as a baseline model using solid works CAD modeling software.
- To perform the flow analysis on the baseline model using CFD tool fluent.
- To design new model of bus such that drag force is reduced.
- Perform flow analysis on the new models.
- To achieve better fuel efficiency by reducing the drag force.

A. Modal Development

Most of the researches were focused only on the race car, sedan aerodynamics rather than the heavy vehicles. This is mainly due to market forces at work and consumer preferences. However there were few researches, (Sachin Thorat and G Amba Prasad Rao, 1999) conducted an research on “Computational Analysis of Intercity Bus With Improved Asthetics And Aerodynamic Performance On Indian Roads” and reduced the drag force by 30%. (Edwin j Saltzman and Robert R Meyer, 2007) carried out studies on reducing the drag of trucks and buses. The final model equipped with rounded horizontal and vertical corners, smoothed under body and a boat tail achieved Cd value of 0.242. (Peterbilt Motors Company, 2009) presents a white paper on Heavy vehicle aerodynamics and fuel efficiency. This paper reviews the aerodynamics drag losses which make the vehicles to utilize large capacity engines. (G Buresti, 2007) carried out a research on Methods for the drag reduction of bluff bodies and their application to heavy road- vehicles in which they stated that in order to reduce the bluff body drag, boat- tailing has been applied & this reduced the base drag to about 5% to 10% respectively. Further to reduce the drag force Tractor – Trailer gap has been occupied by a device so that both drag reduction and also the trailer can turn easily around the turns without any clashing. Also fairings and flow-deflection devices have been provided in the pressure drag not only of the axle but also of the trailer base. This paper also points out the wheels of the road vehicles are, in general, a source of considerable aerodynamic drag, therefore in order to reduce such drag wheel housings have been provided. It has also been said clearly that optimization.

Mc Callen (2004) in their experiments found out removal of rear view mirror alone will bring down the drag of the vehicle by 4.5%. Any gap in the vehicle body will result in flow separation and flow circulation. This investigation revealed a reduction in drag value until the front leading edge radii value reaches 150mm.

Panu Sainio (2007) from aalto University conducted a research on aerodynamics possibilities for heavy vehicles and they came out with a conclusion that boat tail approach is known to be a good solution in terms of aerodynamics. The classical boat tail may increase the length of the vehicle significantly, but by using trailing edge blowing there might be possibilities to shorten the solution and still to have the full aerodynamically performance of the long boat tail.

E Selvakumar (2013) conducted research on "Aerodynamic exterior body design of bus" experimental numerical tests have been conducted in wind tunnel to prove the effectiveness of the new concept design. It is evident from the test result, that there has been a considerable reduction in drag force of about 30 – 40% from the existing bus to the new concept and 6 to 7 liters of fuel is consumed for the every 100 km.

B. Methodology

In this study numerical simulations of different vehicle configurations are performed. Starting with evaluating the results of the baseline simulation, configurations of interest can be identified. For each configuration the CFD-process described below is performed. The CFD-process can be divided into three steps; pre-processing, solving and post-processing.

C. Boundary Conditions

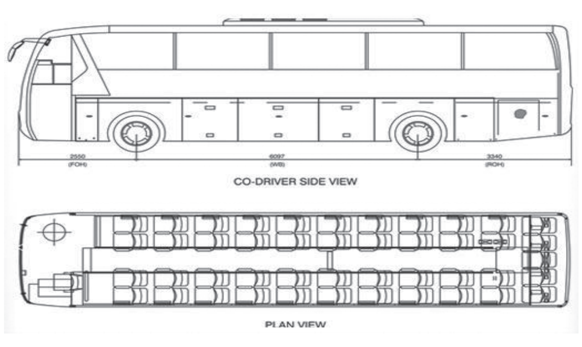
Boundary conditions were applied on the meshed model. In the simulation only straight wind condition was considered at different vehicle speeds up to 100 Km/hr. Constant velocity inlet condition was applied at the inlet to replicate the constant wind velocity conditions same as wind tunnel tests. Zero gauge pressure was applied at the outlet with operating pressure as atmospheric pressure.

MODELLING

This baseline model is one of the models of Volvo intercity bus shape. The body of bus was designed to actual Volvo bus dimensions which are almost common to the actual design.

Normally for aerodynamic analysis they will consider only the overall body shape, but in this we considered every projection such as side mirrors, window panels, AC vents etc. Also it is taken as a constraint such that the shape & size of the body remains unaltered.

Figure 1: Outer Dimensions



A. Baseline Model

This model is the baseline model that means the actual Volvo intercity bus model design in presence.

Figure 2: Baseline Model

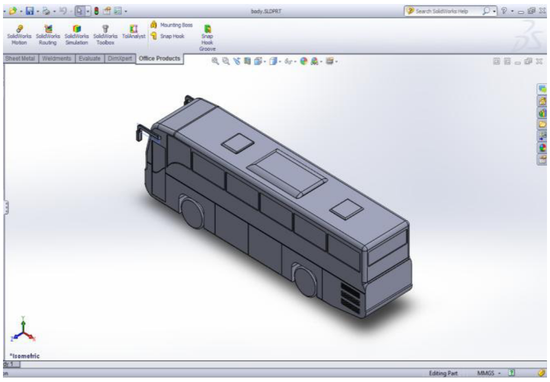
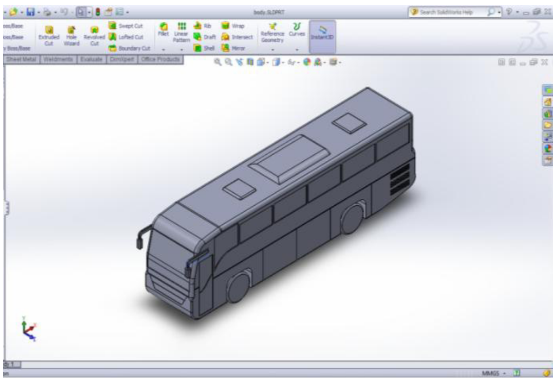


Figure 3: Baseline Model



B. Modified Model

This model has modified at its outer design. This model is design under the consideration of aerodynamic aspects and parameters.

Modified aspects:

Frontal area
AC vents inbuilt in front hoods
Rear shape
Side view mirror shapes

Figure 4: Modified Model View1

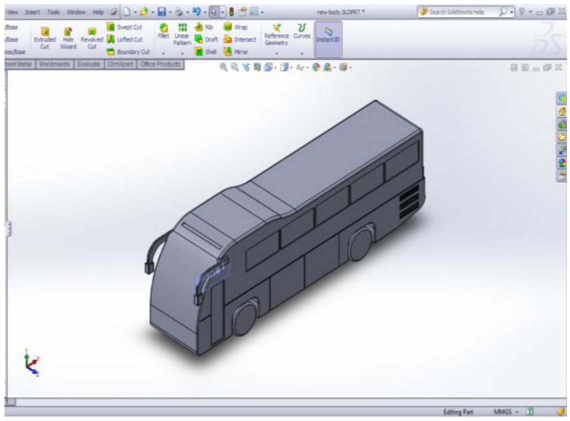


Figure 5: Modified Model View2

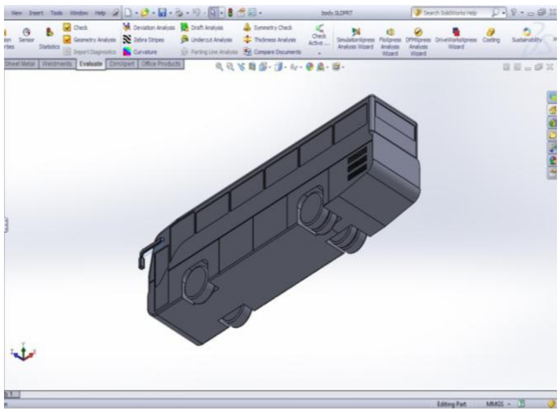
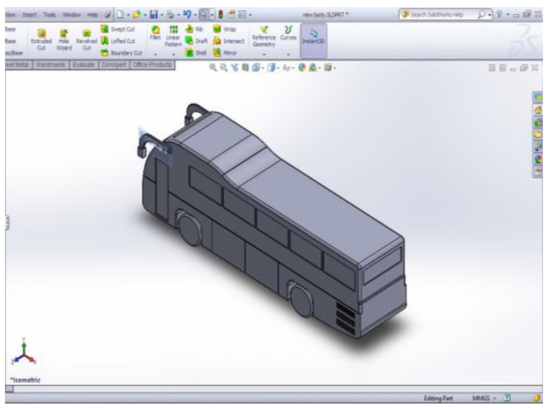


Figure 6: Modified Model View3



MESHING

The computational domain is designed to lead to a free with neglect able blockage, which essentially means a box that consists of an inlet, an outlet, two sides, a roof and a ground Surface. The size of the domain is taken approximately such that the real-time road conditions were satisfied.

The surface mesh was created on the geometry of the vehicle as well as on the surface of the domain. Between the surface of the vehicle and the domain the computational grid was generated. To capture certain areas of interest (where separation might occur and where the degree if turbulence is high) the cells have to small enough to solve all irregularities and achieve a robust solution. The grid has been redefined around the bus, at the rear and especially underneath the vehicle since this study is focusing on the underbodies influence on the flow field. These refinement zones can be seen figure.

Figure 7: Meshing Model 1

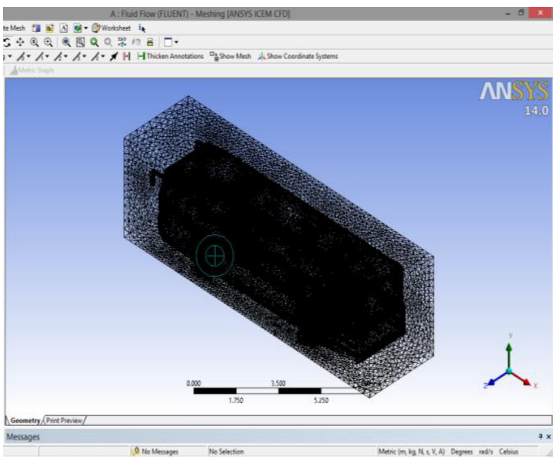
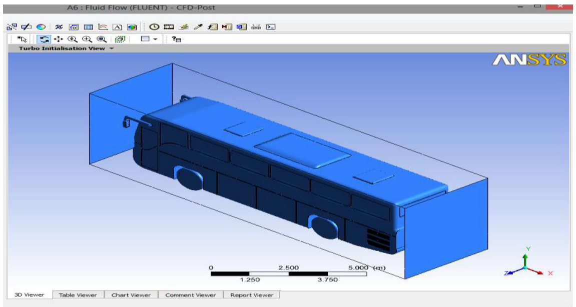


Figure 8: Meshing Model 2



In previous sections it has been mentioned how the air act when flowing past a surface and create a boundary layer. To capture these floe phenomena a refinement region around the exposed surface must be created, this refinement area is called a prism layer.

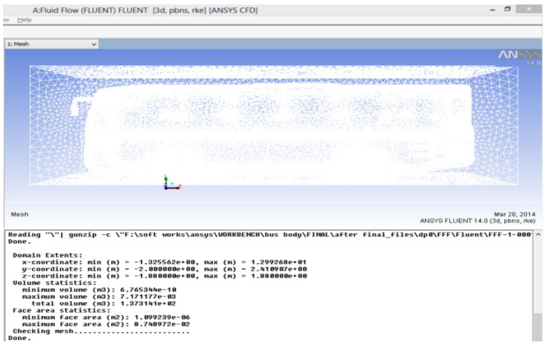
It's important to define the orientations of the surfaces in order to make the prism layer to grow in the direction of normal vectors. The prismatic layer is needed to predict the flow more accurate since the highest gradi-ents are located near the wall.

A. Baseline Model

Element Details:

- 4854947 tetrahedral wall faces, zone 3, binary.
- 318920 triangular interior faces, zone 1, binary.
- 9538150 triangular interior faces, zone 2, binary.
- 420 triangular velocity- inlet faces, zone 6, binary.
- 520 triangular pressure- outlet faces, zone 7, binary.
- 23628 triangular wall faces, zone 8, binary.
- 897720 nodes, binary. ? 897720 node flags, binary.

Figure 9: Baseline Model Meshing

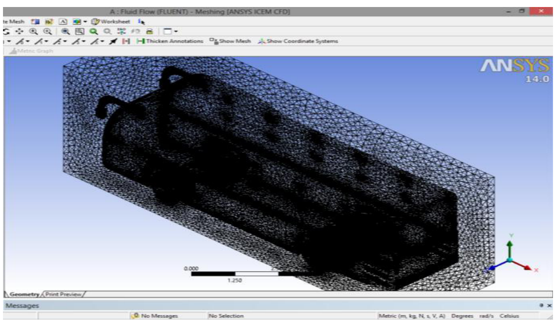


B. Modified Model

Element Details:

- 5358491 tetrahedral cells, zone 3, binary.
- 337748 triangular wall faces, zone 1, binary.
- 10536449 triangular interior faces, zone 2, binary.
- 642 triangular velocity- inlet faces, zone 6, binary.
- 749 triangular pressure- outlet faces, zone 7, binary.
- 21927 triangular wall faces, zone 8, binary.
- 985931 nodes, binary.
- 985931 node flags, binary.

Figure 10: Modified Model Meshing



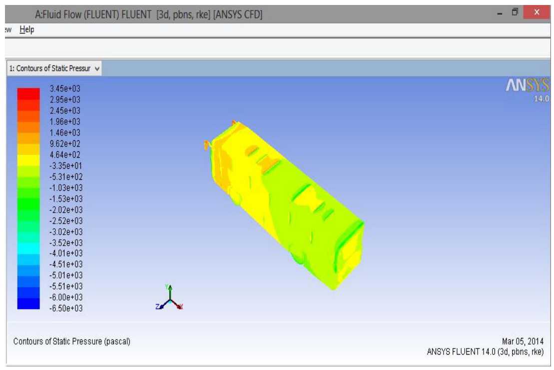
RESULTS AND DISCUSSION

In this we discussed on the analyzed results that is static pressure distribution on the vehicle, drag coefficient and velocity vector flow pattern for each case respectively.

Baseline Model

A. Static Pressure Plot

Figure 11: Static Pressure Plot



B. Drag Coefficient

From the analysis we have found the force in the X axis direction which is nothing but the drag force. Upon substituting the drag force value we can find the drag coefficient (Cd) value respectively.

$$C_d = 0.5^* \text{ drag force}/ \rho AV^2 \quad ...(2)$$

Where

C_d – Drag coefficient, ρ - Air density

A – Frontal area, V – Velocity in X direction

p = 1.225 (kg/m^3); A =12.68 (m^2); V= 27.77(m/s); Drag force = 19165.8(N)

p = 1.225 (kg/m^3); A =12.68 (m^2); V= 27.77(m/s); Drag force = 19165.8(N)

By substituting the value in the above equation we get the drag coefficient Cd as 0.8

C. Velocity Vector Plot

Figure 12: Velocity Vector Plot 1

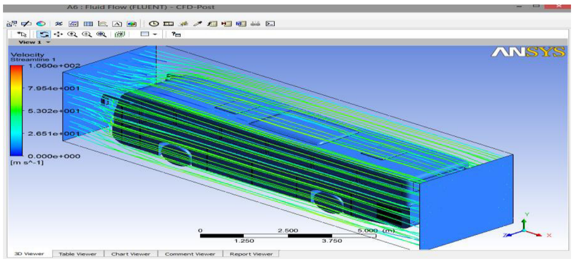
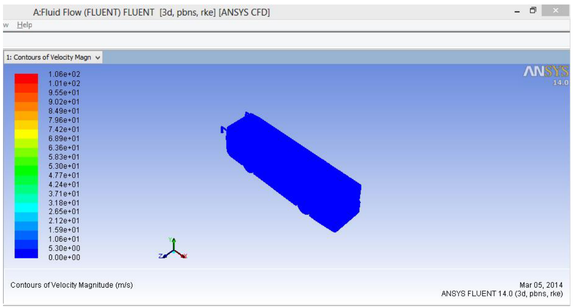


Figure 13: Velocity Vector Plot 2

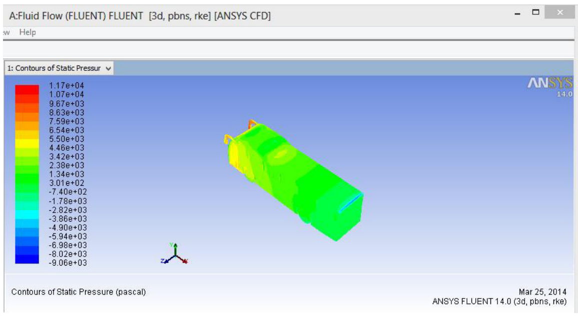


Modified Model:

A. Static Pressure Plot

Static pressure distribution plot of the bus body at the speed of 100 kmph reveals pressure concentration in front region of the vehicle as the air flow strikes at the front and brought momentarily to rest.

Figure 14: Modified Model Static Pressure Plot



- Static pressure occupies the frontal region which develops a huge resistance for the vehicle to move forward.
- Since the static pressure occupies a large area vacuum is created on the side of the vehicle that is the surface which is parallel to the flow.
- Rear wall of the bus experience low pressure compared to the front due to the flow circulation and separation. This pressure difference leads to high pressure drag on the body.

B. Drag Coefficient

From the analysis we have found the force in the X axis direction which is nothing but the drag force. Upon substituting the drag force value we can find the drag coefficient (Cd) value respectively.

C_d = 0.5* drag force/ ρAV^2 ...(3)

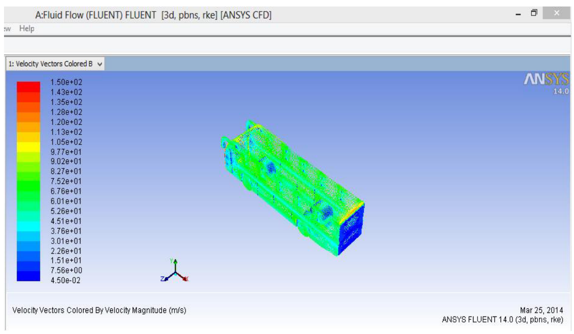
Where,

ρ = 1.225 kg/m^3; A =12.68 m^2; V= 27.77m/s; Drag force = 13926.57 N

By substituting the value in the above equation we get the drag coefficient Cd as 0.7

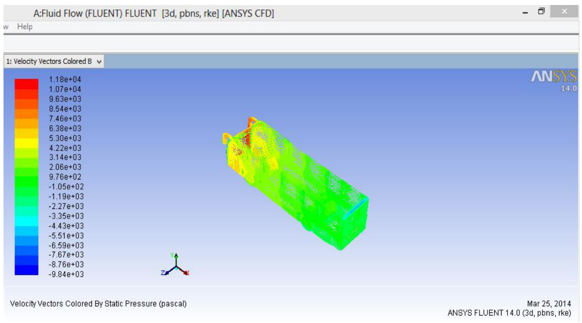
C. Velocity Vector Plot

Figure 15: Modified Model Velocity Vector Plot 1



- The velocity of the flow increases while crossing front faces edges respectively. This is because of the front face.
- Due to the presence of side wings the flow does not expose directly on the road wheels.
- Flow direction is diverted in the rear portion by the presence of the filleted edge in the rear.
- Hence the vacuum region created in the rear portion of the vehicle is controlled.

Figure 16: Modified Model Velocity Vector Plot 2



POWER & FUEL REQUIREMENTS

The power required to pull to pull the vehicle against the resistance in a leveled surface is calculated and their corresponding values for differential speeds were given below.

Table 1: Input Parameters for Power Requirement Calculation

Parameters	Baseline model	Model1
Air density in kg/m^3	122.5	1.225
Frontal area in m^2	10.8	10.8
Weight in kg (W)	30000	30000
Transmission efficiency (n_t)	0.9	0.9
Drag coefficient (C_d)	0.8	0.76

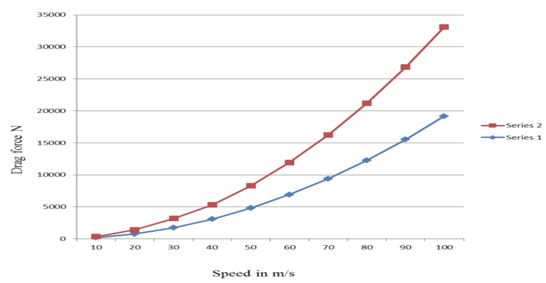
A. Forces (N)

$$F_d = pAV^2C_d / 0.5 \quad ...(4)$$

Table 2: Mesh Data for Data for 8th Stage Seals (Hub and Shroud)

Kmph	Speed m/s (V)	Baseline Model (Fd)	Modified Model
10	2.78	192.07	159.80
20	5.56	768.28	639.23
30	8.33	1724.5	1434.82
40	11.11	3067.63	2233.28
50	13.89	4794.90	3490.76
60	16.67	6906.31	5027.91
70	19.44	9392.21	6837.68
80	22.22	12270.53	8933.15
90	25	15533	11308.28
100	27.78	19165	13953.02

Figure 17: Drag Force Vs Speeds



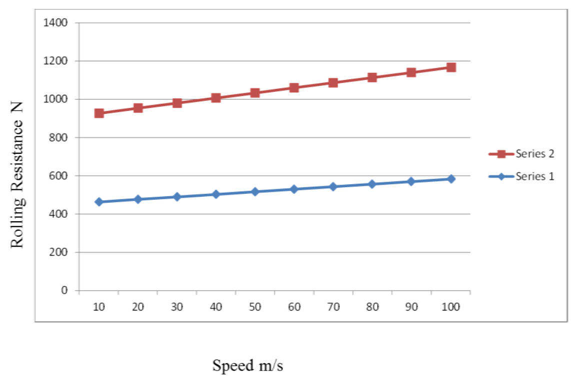
B. Rolling Resistance (N)

$$Fr = (0.015+0.00016V)\, W \quad ...(5)$$

Table 3: Rolling Resistance at Various Speeds

Kmph	Speed m/s (V)	Baseline Model (Fd)	Modified Model
10	2.78	456.344	456.344
20	5.56	476.688	476.688
30	8.33	489.984	489.984
40	11.11	503.328	503.328
50	13.89	516.672	516.672
60	16.67	530.016	530.016
70	19.44	543.312	543.312
80	22.22	556.656	556.656
90	25	570	570
100	27.78	583.344	583.344

Figure 18: Rolling Resistance Vs Speed



C. Total Resistance (N)

Ft = Fd+Fr ...(6)

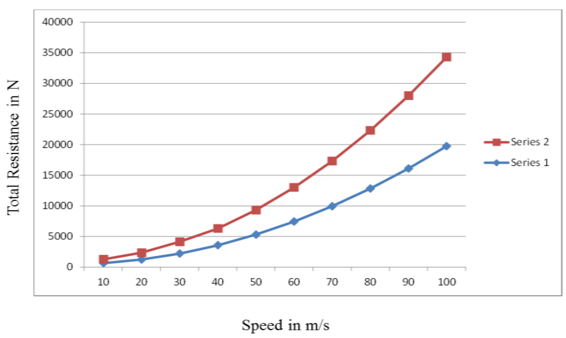
Fd - Drag force

Fr - Rolling resistance

Table 4: Total Resistance at Various Speeds

Kmph	Baseline Model	Modified Model
10	655.414	623.14
20	1244.96	1115.91
30	2214.484	1924.80
40	3570.958	2736.00
50	5311.572	4007.43
60	7436.31	5557.91
70	9935.522	7380.99
80	12827.186	9489.80
90	16103	11878.28
100	19748.344	14536.36

Figure 19: Total Resistance Vs Speeds



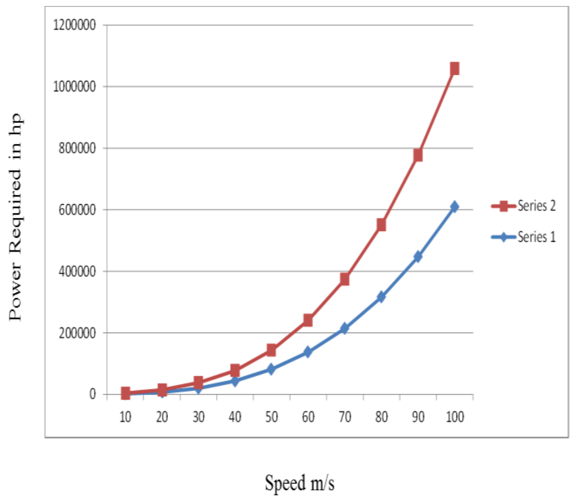
D. Power Required (hp)

$P = F_t V/\eta_t$ ...(7)

Table 5: Power Resistance at Various Speeds

Kmph	Speed m/s (V)	Baseline Model (Fd)	Modified Model
10	2.78	2024.50	1924.82
20	5.56	7691.13	6893.89
30	8.33	20496	17815.09
40	11.11	44081.49	33781.90
50	13.89	81975.26	61484.03
60	16.67	137736.86	10294.84
70	19.44	214607.27	159429.42
80	22.22	316688.96	234292.766
90	25	447305.55	329952.22
100	27.78	609565.551	448689.102

Figure 20: Power Resistance at Vs Speeds



The graph indicates power requirements at various speeds for baseline model and modified model respectively.

- The power required by the baseline model and modified model is almost equal therefore modified model has no major improvements.

E. Change in Fuel Requirements

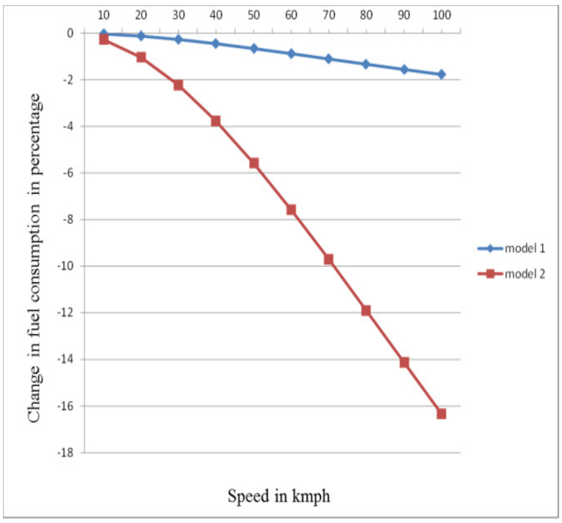
$$\text{Thermal efficiency} = \frac{\text{Brake horse power *33000}}{\text{Weight of used per min *heat value*0.778}}$$

Table 6: Change in Fuel Requirements When Compared With Baseline Model

Speed in Kmph	For Model 1	For Model 2
10	-0.0335	-0.2703
20	-0.1278	-1.0390
30	-0.2719	-2.2332
40	-0.4534	-3.7737
50	-0.6605	-5.5812
60	-0.8825	-7.5815
70	-1.1106	-9.7084
80	-1.3383	-11.9057
90	-1.5605	-14.1271
100	-1.7739	-16.3362

*Negative sign indicates the reduction

Figure 21: Change in Fuel Requirements Vs Speed



ANALYSIS OF RESULT

A three dimensional flow analysis has been performed on various models to predict the airflow characteristics around bus. The results provide the flow pattern and associated drag of the bus body.

Table 7: Comparison Between Two Models

Parameters	Model 1	Model 2
Drag Coefficient (C_d)	0.8	0.7
Change in fuel requirement in%	-1.77	-16.33

CONCLUSION

In the process of redesigning, exterior styling with improved aerodynamics of existing intercity bus plying on Indian roads, a detailed computational analysis has been done.

The Two prototype bus body has been modeled for performing numerical analysis using CFD software. Model No.1 is the existing Volvo intercity bus model and Model No.2 is that we altered and modified the existing model.

Velocity given to the fluent analysis is 100kmph. The resultant drag force of the baseline model is 0.8 and the modified model we get is 0.7.

By these modifications the coefficient of drag is reduced by approximately 10%.

We reduced the drag force, results in increased performance of the bus and reduced fuel requirement.

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