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Improvement in Fuel Efficiency by Changing Coefficient of Drag in an Existing Automobile

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Abstract:
Automobile business is very competitive with there are hundreds of companies and that spend billions of dollars on R&D to give their products that crucial advantage, which will help them win at the market place. Fuel consumption plays a major role in deciding whether the vehicle will be successful or not. This is the scenario across the board. Be it Cars two wheelers or commercial vehicles. Actually, in commercial vehicles this acquires the maximum significance. Fuel efficiency of vehicles have following implications:

Financial for the bus operator.

Unlike a personal vehicle cost of fuel is cost of production for the operator. He has to generate surplus from the operations so that he is able to pay the EMI for the vehicle. Fuel being close to 50% of cost of operation in India, is very important factor when he makes the buying decision. This one aspect will decide if the vehicle is able to generate enough surplus so that it is able to meet its EMI and other commitments. Volvo is a big bus and has a fuel efficiency of only 2.2 Kms/Liter of diesel [1]

Environmental for the society

Last financial year India consumed 72.72 Million Tons of diesel. [2] Out of this 9.55% is for bus operations.[3] Which is a big chunk of the total diesel consumed. Every liter of Diesel produces 2.62 grams of CO2 [4] a greenhouse gas along with other pollutants like CO, HC, NOx and particulate matter [5]. Every year during winters we see huge fog in several parts of the country and automobile pollution is a major contributor for the same. [6].

Balance of payment Issue for the country

India imports 82% of its crude oil requirements. It the single largest item in our import basket. Contributing to 21.6% of total imports. All this purchase has to be in dollars which has geopolitical ramifications as this dependence can reduce the bargaining power of the country, more so in case of War or sanctions.

Thus, it's good to reduce the overall consumption of fossil fuels any which way we look at it.

In this study we have taken a Volvo bus and have tried to carry out modifications such that we are able to reduce the aerodynamic drag and thus improve the fuel efficiency. A Volvo bus is a very well-designed product by a multinational company, where it would have been optimized for aerodynamics too. If we are able to get some improvement in the same similar modifications in other locally built buses would certainly have more significant improvement. As bus operations consume big chunk (9.55%) of diesel in the country even a small improvement in fuel efficiency will go a long way.

Key Words: *CFD (Computational Fluid Dynamics), Automotive Sector, Fuel Efficiency etc. Aerodynamics, Drag*

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I. Introduction

Fuel efficiency of a vehicle is very important in deciding whether the vehicle will be successful in the marketplace or not. The cost of fuel in India is very high as compared to several countries in dollar term. Secondly our currency is weaker and thus as an Indian we pay much higher price in purchasing power parity. This makes our markets more and more sensitive to the cost per kilometer. We all remember Maruti Suzuki's campaign that focused on "Kitna Deti Hai". It was a hit campaign and helped in boosting their sale. That is one of the reasons why they hold close to 50% market share in a market that has more than 12 players.

Another aspect of fuel consumption is related to environment. The more fuel we consume as a whole, the more we pump Carbon Dioxide (CO2) which is a Green House Gas which causes global warming. Vehicle's tailpipes also emanate following hazardous gases; like

1. Carbon Monoxide,
2. Oxides of Nitrogen,
3. Sulphur Dioxide,

4. Particulate matter
5. Hydro Carbons [5]

Our country unfortunately has the distinction of having 3 of the world's 10 most polluted cities [7]. Automobiles are responsible for substantial part of the same. Despite the fact that our country has only 22 car per thousand people, the pollution levels are very high, it means substantial part of this should be coming from Commercial Vehicles. That is the reason why the Supreme Court ordered for conversion of entire fleet to CNG from diesel as early as 1998 [8]

Thus, this paper deals with improvement of Coefficient of drag in commercial vehicles, especially buses.

So, any which way we look at it, be it commercial, environmental or foreign exchange point of view, the importance of fuel efficiency improvement, more so, in commercial vehicles cannot be overstated.

Fuel efficiency depends of many parameters of vehicles including engine design, aerodynamic drag, weight, fuel type and driving skills etc. Indian automotive sector is the fourth largest petroleum consumer after china and USA also increased 5.3% petroleum products in this year.

Our country did not have good roads till a few years ago or had automobiles capable of running at higher speeds. This resulted in a very modest average kilometers per hour even on highways. But the scene is fast changing on both counts.

Recently Mr. Nitin Gadkari, the Minister of Road Transport and Highways of India (MoRTH) announced that the country is developing highways @ 40 kilometers per day (and the highways as against 2 earlier) will have maximum permissible speed of 140 Km/Hour [9]. This means that the vehicles will be travelling at much higher speeds. Thus, aerodynamics becomes a major factor in improvement in fuel efficiency, as can be seen in the table below.

Table 2.1

Vehicle Speed	Aerodynamic Drag	Rolling & Accessory Drag
20 mph (32 kph)	28%	72%
33 mph (53 kph)	33%	66%
40 mph (64 kph)	36%	64%
50 mph (80 kph)	50%	50%
60 mph (96 kph)	62%	38%
65 mph (105 kph)	67%	33%
70 mph (113 kph)	70%	30%

Relative magnitude of drag components. [10] CSTT, 2012

With better roads and more powerful automobiles aerodynamics can go a long way in improving fuel efficiency. While this will result in savings to the operator of the bus, it will reduce pollution and help in conserving precious foreign expense because we import 82.5% of our needs of crude oil close to 100 Billion USD and is the single largest item comprising of 25.2% of the total import [11].

Aerodynamics is as old as cars themselves, but it did not acquire great significance in early evolution of automobiles because the fuel was cheap and the speeds were low. However, lot of research was done in aeronautical science as the countries needed faster and faster planes not only to transport people and goods but also to win wars. The lessons learnt from aeronautics were later applied to racing cars and then to regular automobiles so that the drag could be minimized resulting in increased speeds and reduced fuel consumption.

Drag can be analytically calculated with the following formula:

$$F_D = \frac{1}{2} \rho v^2 C_D A$$

where

F_D is the **drag force**,

ρ is the density of the fluid,[11]

v is the speed of the object relative to the fluid,

A is the cross sectional area, and

C_D is the drag coefficient – a dimensionless number.

Here density of air remains constant (@ sea level 1.225 kg/m3 at 15 Degree Celsius [12]), Cross sectional area is dictated by usage and styling of the vehicle. We would want to drive at higher speeds [8] to save time, and then we are left with only Cd to play around with, to reduce the drag in order to improve the fuel efficiency.

There are only 2 ways to find out the value of drag. One is through wind tunnel experimentations. With scaled models and then with full scale models. And the second one is through Computational Fluid Dynamics where large number of software's like Ansys Fluent, Solid Works etc. are available that can simulate the wind tunnel testing and give fairly accurate results. As can be see testing in wind tunnel can be expensive and time consuming, more so when one considers large number of iterations before the design is finalized.
There are some enhancement techniques to improve airflow around the vehicle thus improving the Coefficient of drag Cd.

a) Creating a round edges at front of the vehicle
b) Experiment with front fascia grill shape
c) Design of rear spoiler to reduce lift value.
d) Design a side skirts for airflow around the vehicle.
e) Aerodynamic wheel shape

II. Objective

An improvement in fuel efficiency is good for individuals, countries and the environment and every effort should be made to achieve this.
In this study we are going to attempt to reduce fuel consumption of a bus by altering its external profile so that we can improve its coefficient of drag (Cd) and thus reduce aerodynamic drag.

III. Methodology

The primary objective of this research work is to improve fuel efficiency of a bus by reducing the aerodynamic drag. This will be performed through Computational Fluid Dynamics (CFD) analysis of a bus body shell and reduction of the drag force value by changing its shape. Which may reduce the fuel consumption and improve the efficiency of the vehicle. In this research we started our work with previous research on the same field. Firstly, we performed a CFD analysis of a Volvo bus and then modified the same to improve drag coefficient value.

To perform a computational fluid dynamic analysis, we used Ansys 18.1 as a pre-processor and fluent as a solver. So, we need to import CAD data into Ansys Design modeler and develop enclosure as specified dimensions then export this data in to mesh modeler where we mesh it. Start with simple tetra meshing using .5mm size, import patch conforming method then import body sizing and body sizing to re-mesh it. At last import inflation on bus surface with first layer first layer thickness .3mm. assign boundary condition names like inlet, outlet bus surface and wall. Import this data into fluent launcher with double precision option and consider 4 processors

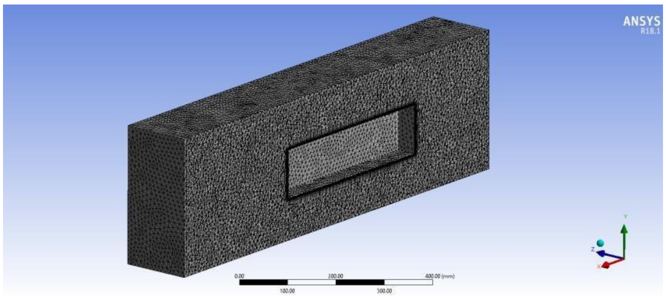


Figure 4.1

In fluent solver setup the desk as per analysis.

Setup → Models → Energy → On

Setup → Models → K-Epsilon → Realizable→ Standard wall function

Setup → Material→ Air →Density (1.225 Kg/m3) →Viscosity (1.7E-05 Kg/m-s)

Setup → Boundary Condition→ Inlet →Velocity (33.34 m/s or 120 KM/Hr)

Solution initialization → Hybrid initialization

Run Calculation _ Table 4.

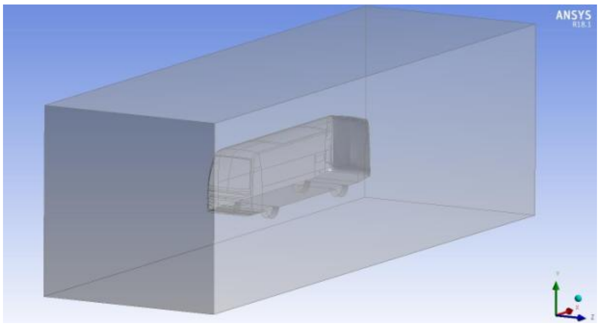
iter	continuity	x-velocity	y-velocity	z-velocity	k	epsilon	drag	lift	time/iter
1	1.0000e+00	2.3712e-03	2.0867e-03	2.2281e-03	1.2513e-01	2.0264e-01	4.5366e-01	7.2388e-03	0:36:29 199
2	1.0000e+00	1.4873e-03	1.0740e-03	1.1776e-03	1.3397e-01	1.2431e+00	1.3709e+00	2.0092e-02	0:36:18 198
3	4.0015e-01	1.0205e-03	7.0570e-04	7.7629e-04	9.4512e-02	3.4564e-01	2.1282e+00	-3.5259e-02	0:34:09 197
4	3.6640e-01	7.6894e-04	4.8865e-04	5.3899e-04	7.8702e-02	2.3690e-01	2.0812e+00	-2.8875e-02	0:31:45 196
5	2.5101e-01	6.6206e-04	3.6226e-04	4.0489e-04	6.5776e-02	3.3010e-01	2.0552e+00	-2.2224e-02	0:31:07 195
6	2.3009e-01	6.5769e-04	3.3023e-04	3.6830e-04	5.2740e-02	3.3734e-01	1.9487e+00	-2.7307e-02	0:29:57 194
7	1.7272e-01	6.0782e-04	2.8655e-04	3.1960e-04	4.6225e-02	2.8267e-01	1.8468e+00	-2.3480e-02	0:28:59 193
8	1.6568e-01	5.8259e-04	2.6937e-04	2.9882e-04	3.7927e-02	3.2911e-01	1.8087e+00	-2.5022e-02	0:28:11 192
9	1.3675e-01	5.5282e-04	2.4759e-04	2.7451e-04	3.1835e-02	3.6012e-01	1.7836e+00	-1.9031e-02	0:28:09 191
10	1.3135e-01	5.3993e-04	2.4011e-04	2.6391e-04	2.5836e-02	3.3650e-01	1.7756e+00	-2.0403e-02	0:28:07 190

IV. Result

In this research process we start the analysis of a Volvo bus and subject the same to CFD analysis.

Design 1 (Base Design Original Volvo Bus)

Fig.4.2 Design 1



Results – Drag Coefficient – 0.35904 and Drag Force – 2.010

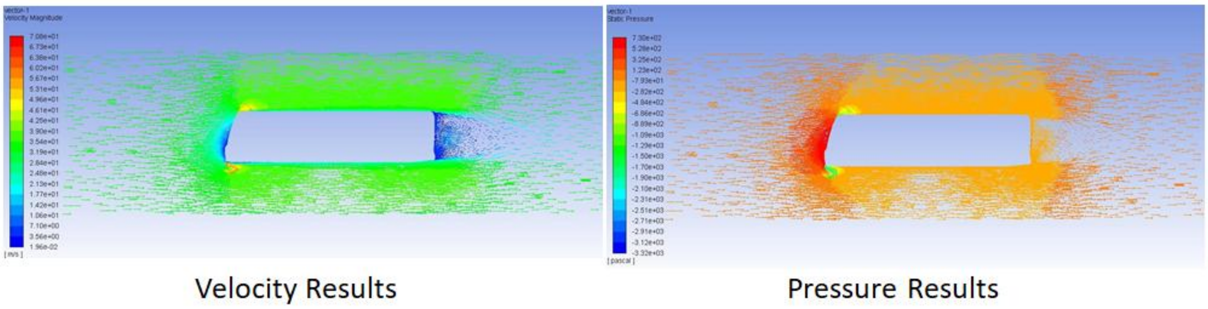


Fig.4.3 Result

Design 2 – We made the roof curved hoping to get the better flow of air and hence lower Cd and subjected the same to CFD analysis.

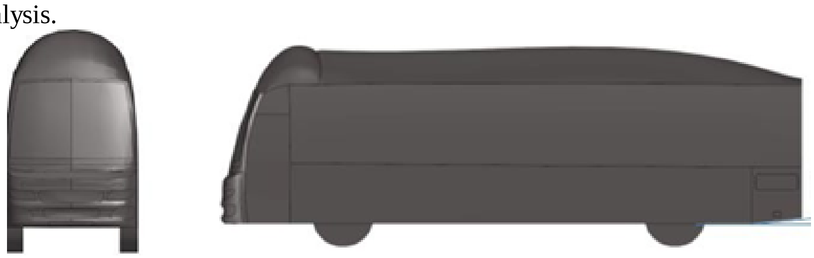


Fig.4.4 Design 2

Results – Drag Coefficient – 0.38193 and Drag Force – 2.5353

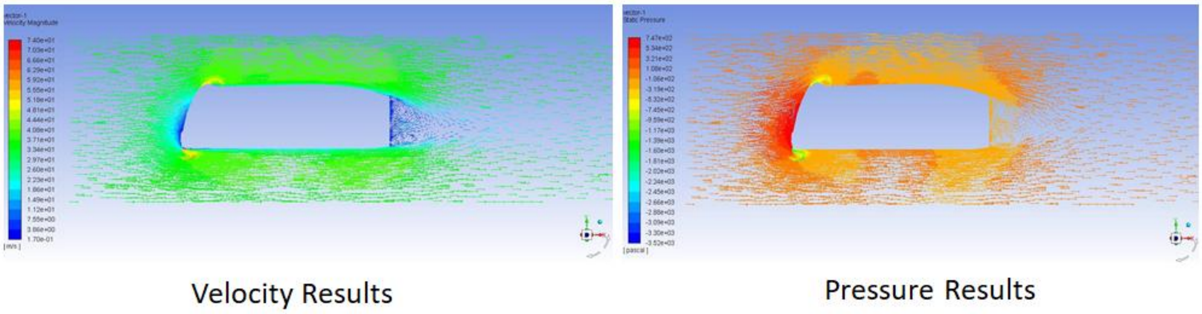


Fig.4.5 Result

Design 3 – Another iteration we tried was by increasing the angle of departure 17°.

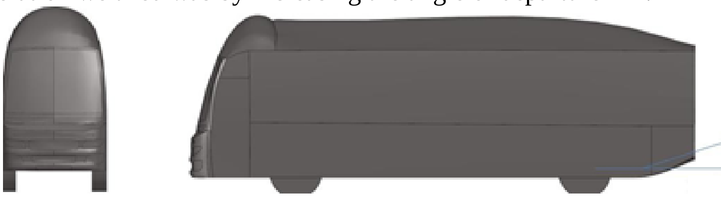


Fig.4.6 Design 3

Results – Drag Coefficient – 0.38360 and Drag Force – 2.5231

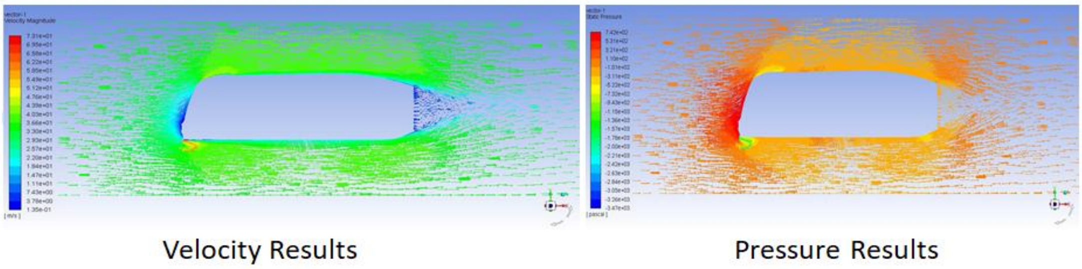
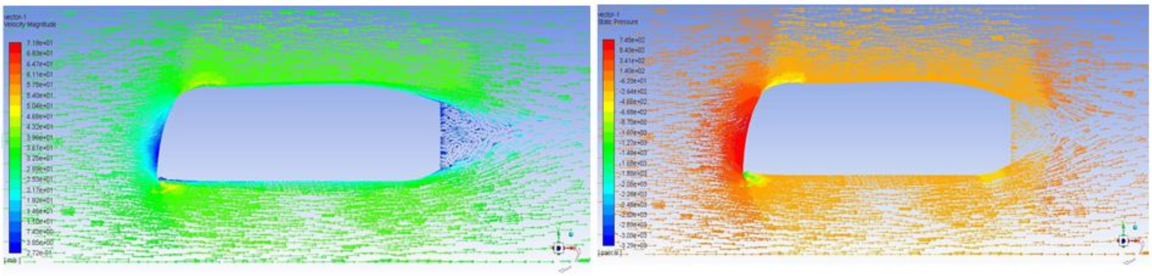


Fig.4.7 Result

Design 4 – As shown in the figure we increased the front angle to 11 and subjected the design to CFD analysis

Fig.4.8 Design 4

Results – Drag Coefficient – 0.432 and Drag Force – 2.872



Velocity Results Pressure Results

Fig.4.9 Result

Design 5 – After so many iterations we decided to take a totally different approach. We added a spoiler to the original Volvo design & subjected to CFD analysis. The results came out to be encouraging.

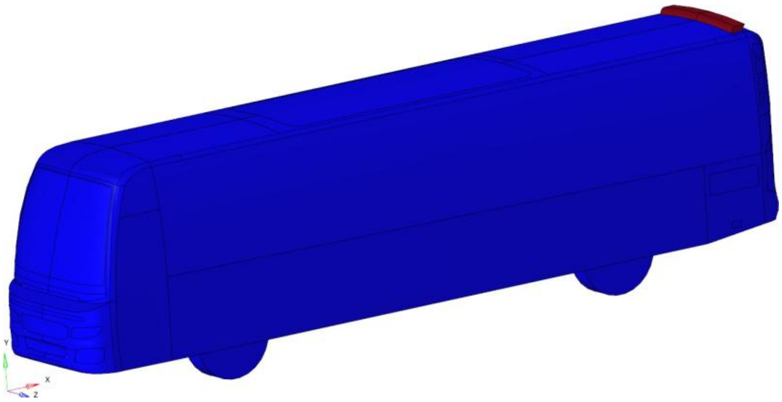
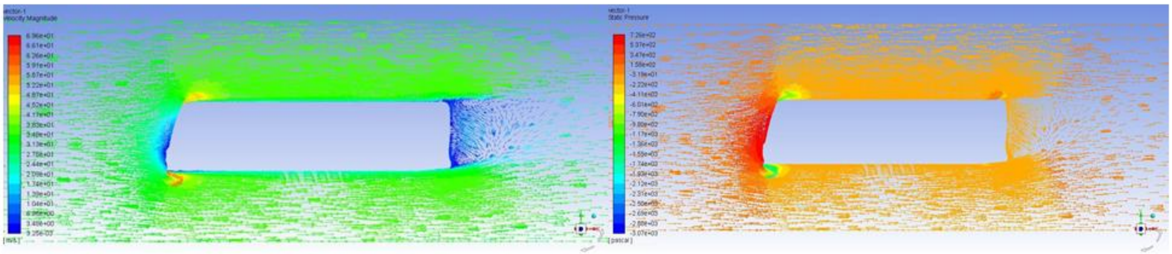


Fig.4.10 Design 5

Results – Drag Coefficient – 0.32900 and Drag Force – 1.84677



Velocity Results Pressure Results

Fig.4.11 Result

V. Conclusion

The aim of this research was to improve vehicle efficiency by reducing the drag force. In computational fluid dynamics analysis, we can easily predict drag coefficient and lift value which helps engineering team to design aerodynamic shape of the vehicle.

Design1

This initial design as based on a Volvo bus. They have very well-developed R&D setup and would have optimized the design for functionality, Comfort and Aerodynamics. This is a far cry from the ones boxy shapes that are made in the country by local body builders on a drive away chassis by OEMs. Though there is a Bus Body design code approved by ARAI (AIS-052) but it doesn't delve in to aerodynamics [13]. Cd and drag values are actually very low. This makes our job tougher.

Design2

In this design the front top end of the bus was given an oval shape, and it was expected that this should ease the flow of the air as compared to the flat roof and should result in lower Cd values. However, when the design was subjected to CFD analysis the Cd and drag values actually went up.

Design3

In this design the rear end of the bus was given a taper of 17° at the rear end. This did not have any significant change in the values.

Design4

We tried another iteration by giving entry chamfer of 11° at the bottom. This did have some effect and the values came down a bit but were still higher than the original design.

Design5

Till now whatever designs we tried the results were not favorable so we decided to abandon that approach and tried new tried something totally different i.e. a spoiler at the back.

Table.5.1 Results Comparison

Concept	Cd	Dag CFD	% Change	Between
D1	0.35904	2.0105494		
D2	0.38193	2.5262781	25.65	D1 & D2
D3	0.38360	2.5231310	25.49	D1 & D3
D4	0.36514	2.4011301	19.43	D1& D4
D5	0.32900	1.8467764	-8.15	D1 & D5

Consolidated results of all iterations are there in Table 5.1. As can be seen the first 4 iterations did not result in lowering of the drag. However the 5th one was different and we were able to achieve 8.15% reduction from the original one. Considering that we could expect 60% of this to translate in to improvement in fuel efficiency. A Volvo gives 2.2 kms /liter of fuel with this improvement it can be expected to give 2.3075 kms/liter. Which is a good improvement and should lead to substantial savings to the bus operator as well as reduction in greenhouse gases by similar percentage.

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