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Performance Study of Wind Friction Reduction Attachments for Van Using Computational Fluid Dynamics

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ABSTRACT
Road transport is the key factor as it is the major method to connect places through land. Along with wide use of internal combustion engines for this purpose comes the massive consumption of fossil fuels by vehicles. Most of the research today is toward making efficient machines. This paper mainly deals with providing attachments to existing models of vehicle to make it more efficient. An assessment of the impact of aerodynamic drag and its relationship to energy consumption presented. A few models are designed and analysed for reducing drag with the help of Attachments. Solid works is used to model and ANSYS Fluent is used for CFD analysis.
The results of Cd of various configuration is analysed, 0.427 being the Cd for conventional Van is reduced to 0.234 for van with front and rear attachment.
Keywords: Computational Fluid Dynamics, Drag, Aerodynamics, Collapsible Attachments, Coefficient of Drag, ANSYS Fluent

I. INTRODUCTION

Main purpose of vehicle is the safe, comfortable, quick and efficient transportation of passengers and belongings. In growing economy vehicle plays a vital role in its growth. In today's vehicle we can clearly view the optimization in various energy consuming sections, in same story we can also account for partial aerodynamics for a significant fuel economy.

The layout of current commercial vehicle design is governed primarily by their functional requirements. They still have a lots of areas for proper improvements and optimization. It can also be seen that attention given to aerodynamic profile of a vehicle is conventional. By opening a new door of dynamically shape changing vehicle, we can explorer deep into it with significant outcomes. The collapsible aerodynamic design is mainly a dynamic solution for different modes of a vehicle. It provides a window of opportunity for the vehicle to have normal ride in city drive mode, and to have highly efficient drive with attachments in highways.

For the purpose of analysis, Vehicle body with and without attachments are modelled in Solidworks-14. The model thus prepared is directly applicable in ANSYS Fluent.Variant of Curved profile attachment is considered in simulation. Mainly there are 3 modifications and its combination for different calculation viz., pointed ends, truncated end and flat top

II. LITERATURE REVIEW

R. B. Sharma, Ram Bansal (2013) generated a generic model of typical passenger car, wind tunnel and applied boundary condition in ANSYS workbench, there after model was simulated and tested to gain baseline. Another model with tail-plate was also subjected to same configuration resulting the change in value of Cd and thus provided evidence that tail plate can improve aerodynamics and fuel economy of the vehicle. (Sharma & Bansal, 2013)

Damjanović, Darko et al., (2010) Used Ansys Fluent to simulate and analyze conceptual car for aerodynamic improvement. Car was designed using Autodesk 3ds Max 2010. Designed car was derived from freeform sketches through imagination. Final digital images were generated through Mental Ray rendering. External surface of the car was only modeled, and by the use of ANSYS FLUENT, 2D analysis of the side contour of the vehicle was done, further correction of exterior geometry was done in order to improve the design of vehicle in terms of reducing aerodynamic drag and air resistance. (Damjanović, 2010)

Chainani. A, Perera. N (2008) analysed the present state of art for racing vehicles. This study of air flow over the body shows that drag force unfavourably disturbs the accelerative motion of the car and there is an alteration in the pressure among the air flowing overhead and underneath the vehicle. This produces the vertical forces. Aerodynamic forces executing upon a car prominently reduces its effectiveness. If the car is redesigned to enhance these forces it could always generate better results. The paper deliberates various methods that have been castoff to restructure and optimise the aerodynamics of a radio control race car. (Chainani & Perera, 2008)

Kevin R. Cooper, Jason Leuschen (2005). Prepared 1:10 scale model of truck and tested in 2mx3m wind tunnel and a full scale tests on a Navistar 9200 Day Cab along with 40- foot trailer in the 9mx9m wind tunnel. These tests were targeted to develop the desired attachment devices for trucks. The outputs demonstrated highly effective fuel savings from a combination of a long cab extenders, trailer boat-tails, and that increased fuel economy as much as the contemporary aerodynamic cab packages. (Cooper & Leuschen, 2005)

S. Roy and P. Srinivasan (2000) Conducted full functioning research on aerodynamics of heavy trucks and high sided vehicles in significant interest of reducing accidents due to wind loading and to improve fuel efficiency. Realizing the limitations and drawbacks of conventional wind tunnel, Computational analysis for the same purpose is carried out for axial and cross flow wind loading to obtain airflow characteristics around the trucklike three dimensional bluff body. Results provides associated drag for the trucklike geometry including the effects of rear-view mirror. Research also suggest that modifying the External geometry has significant effects on Fuel economy of the vehicle. (Roy & Srinivasan, 2000)

Wolf-Heinrich Hucho (1993) analysed various parts and compared them to catagorise different standard lookalike shapes of vehicles and forwarded the coefficient of drag value. This resulted into the ability of general prediction of coefficient of drag to a vehicular shape in real case situation. Report also forward the possible theoretical shapes of vehicle and their respective value of coefficient of drag. Research also analysed the different standard flow pattern seen in generally obtained corners, edge and shapes around the vehicle and was able to propose ideas to remove such drag sources from the vehicle surfaces. (Hucho, 1993)

Randall L. Peterson (1981) disclosed that use of boatlike attachment on the box like vehicle results into an average of 31 percentage of reduction in aerodynamic drag, which is significant. Research also showed that there is slight increment in drag when boattail apex is cut out, thus it also suggested that boat tail can retain its aerodynamic effects without tip and thus reduces the overall length of vehicle with attachment. Hence truncated boattail attachment is efficient as well as effective to use. (Peterson, 1981)

III. III.CFD ANALYSIS OF DIFFERENT MODELS

1. Model A

This is baseline for vehicular calculation. Simple vehicle design is used without attachments for this computation. This will provide the scenario of present state of art. Model A is the main vehicle design with a vast area of improvement, we'll only be manipulating the vehicle body drag. Thus the model which we have doesn't have provision for windows and other accessories vents.

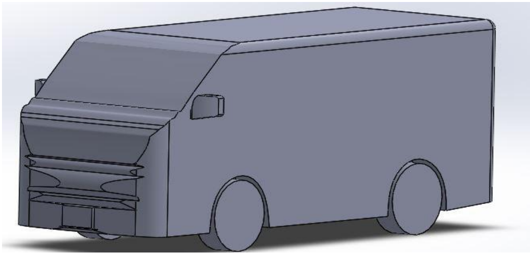

Figure 1: Detailed diagram of Model A

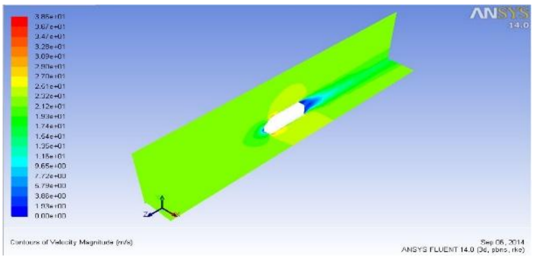

Figure 2 : Velocity Contour of Model A

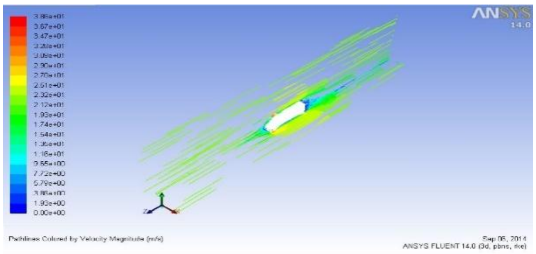

Figure 3 : Particle path line of Model A

Coefficient of Drag (Cd) :0.42716
Coefficient of Lift (Cl) :-0.10387

2. Model B

This model possess front and back attachment with flat top. For the ease in driving we have omitted the wind shield part from the attachment thus driver can have single layer of transparent material to view from.

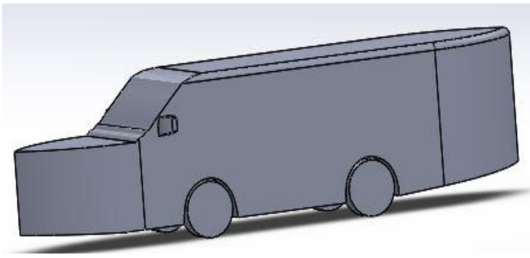

Figure 4 : Detailed diagram of Model B

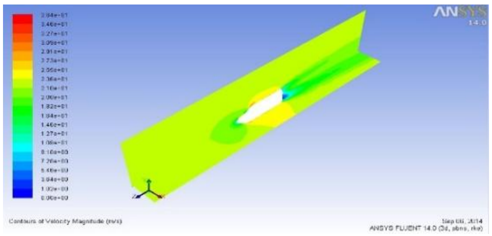

Figure 5 : Velocity Contour of Model B

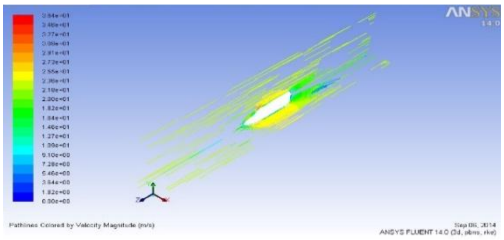

Figure 6 : Particle path line of Model B

Coefficient of Drag (Cd) : 0.33316
Coefficient of Lift (Cl) :-0.085285

3. Model C

This model possess front attachment with curved top and back attachment with pointed end. We have selected the top portion of attachment to be curved s that we can have smooth transition between wind shield and the attachment body. It is also essential for the driver to view portion of road top in a range while driving.

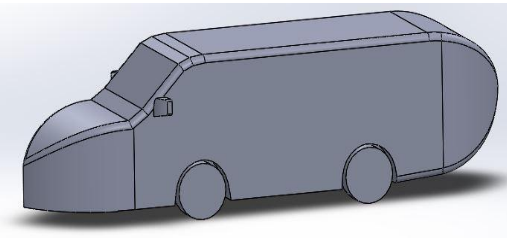

Figure 7 : Detailed diagram of Model C

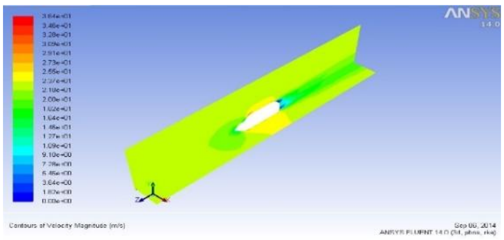

Figure 8 : Velocity contour of Model C

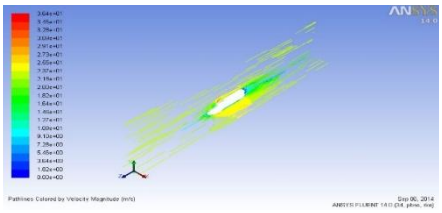

Figure 9 : Particle path line of Model C

Coefficient of Drag (Cd) :0.26155
Coefficient of Lift (Cl) :-0.1181

4. Model D

This model possess front and back attachment with all four side curved. The advantage of having this profile is that the air is pushed away from vehicle in all directions. Pointed tip of vehicle provides a better view of the road for driver thus might have advantage over other designs.

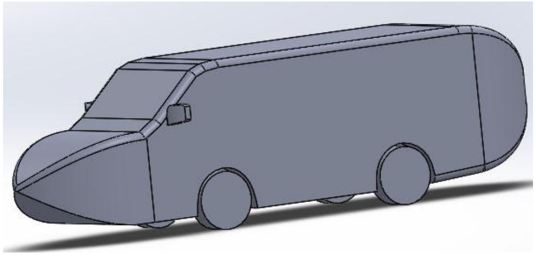

Figure 10 : Detailed diagram of Model D

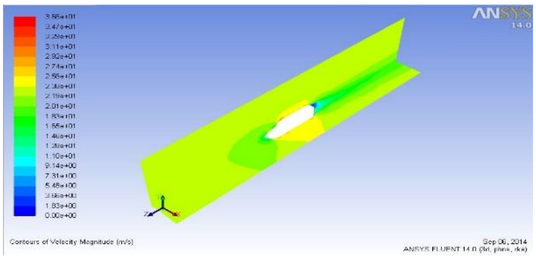

Figure 11 : Velocity Contour of Model D

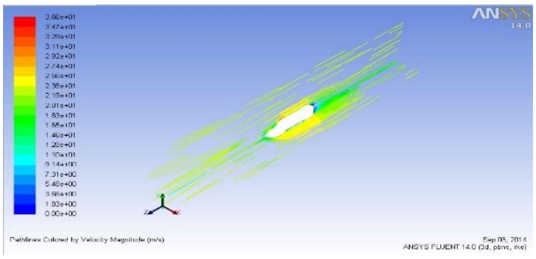

Figure 12 : Particlepath line of Model D

Coefficient of Drag (Cd) :0.24377
Coefficient of Lift (Cl) :-0.082539

5. Model E

The latter portion of the attachment doesn't have much effect on the wake. Thus we can omit the latter segment of the vehicle. This truncation of the attachment provides with advantage of reduction in length of attachment with better curvature.

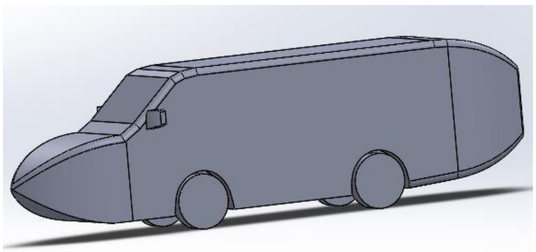

Figure 13 : Detailed diagram of Model E

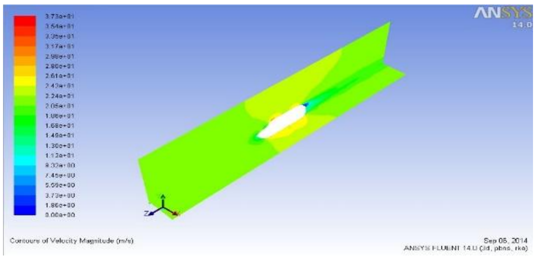

Figure 14 : Velocity contour of Model E

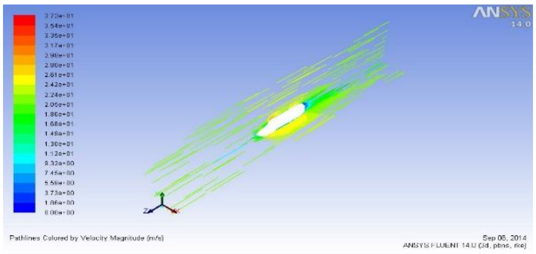

Figure 15 : Particle path line of Model E

Coefficient of Drag (Cd) : 0.23028
Coefficient of Lift (Cl) :-0.066855

6. Model F

This model possess front attachment with curved top and the rear attachment is truncated. It might not have the best performance but it sure have advantage in mechanism development of the attachments that can be further taken into future scope of the research presented.

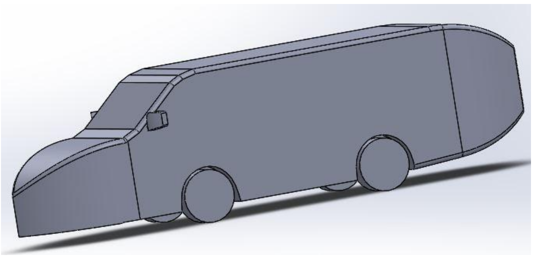

Figure 16 : Detailed diagram of Model F

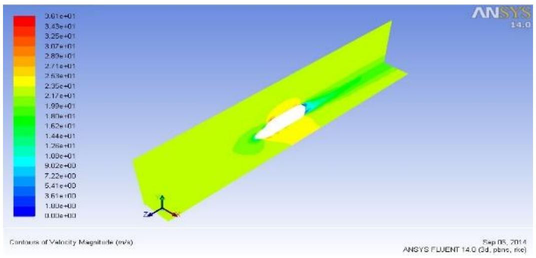

Figure 17 : Velocity Contour of Model F

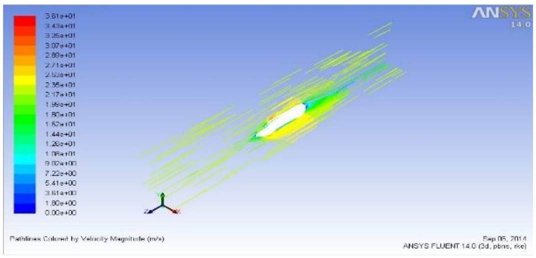

Figure 18 : Particle path line of Model F

Coefficient of Drag (Cd) : 0.24884
Coefficient of Lift (Cl) :-0.091885

Models in above simulation are provided with inflation layer instead of mapped mesh to accommodate the complex design. Inflation layer of 6 steps are used that can provide boundary effect for the air layer around the vehicle design.
Comparative study of all the models shows that for the models with lower value of Cd, there is less amount of wake behind the vehicle. It is also seen that those models also have less dispersion of air molecules around it. It signifies that the energy loss from vehicle to surrounding air just to propel forward. From the velocity contour it is visible that the effect of wake have high impact on the drag.
From the results it is seen that efforts have been made while designing the attachment to keep coefficient of lift unchanged or least changed. This indicates the vertical forces in vehicle is same as it was before implementing the attachments.

Value of Cp is always high at the front face of the vehicle. The value changes around vehicle and is zero at the end of vehicle. Sudden changes in value of Cp signifies the irregularities in the surface of vehicle. This is mainly seen in the connection point of attachment and vehicle

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Geometry	Coefficient of Drag (Cd)	Coefficient of lift (Cl)
Model A	0.42716	-0.10387
Model B	0.33316	-0.085285
Model C	0.26155	-0.1181
Model D	0.24377	-0.082539
Model E	*0.23028*	*-0.066855*
Model F	0.24884	-0.091885

IV. ANALYTICAL CALCULATION

For the measurement of performance of attachment drag loss for the design is major factor. Drag is influenced by factors like shape, viscosity, boundary layer separation, compressibility,texture, lift (for induced drag), and so on. All these factors can be applied into single factorcoefficient of drag (*Cd*). Thus overall Drag Energy loss is given as half of product of density (ρ), the reference area (A),coefficient of drag (*Cd*) and velocity (v) squared.

$D=0.5 \times \rho \times A \times Cd \times v^2$

Equation 1: Drag loss

Drag loss (kW)				
Velocity(ms^{-1})		**8.33**	**22.22**	**36.11**
Model	**Coefficient of Drag**			
A	**0.43**	0.62	11.79	50.60
B	**0.33**	0.48	9.16	39.29
C	**0.26**	0.38	7.22	30.99
D	**0.24**	0.35	6.73	28.89
E	***0.23***	0.33	6.36	27.29
F	**0.25**	0.36	6.87	29.49

Rolling friction loss is another factor influencing engine power requirement. Rolling resistance is defined as the force required to maintain the forward movement of a loaded pneumatic tire in a straight line at a constant speed. The rolling resistance can be expressed as product of coefficient of rolling friction (μ), normal reaction of body (R) and velocity (v)

$Fr = \mu \times R \times v$

Equation 2: Rolling Friction Loss

Rolling Friction loss (kW)			
Velocity(ms^{-1})	**8.33**	**22.22**	**36.11**
All Model	1.70	4.53	7.37

For Computation of Mileage we use output as Total energy requirement and as an input we evaluate from the calorific value of fuel used. Evaluation is done using following relation whereCalorific value of fuel (Cv) and engine efficiency (η) Total energy loss (E) and velocity (v)

$$Mileage = \frac{\frac{Cv * \eta}{E} * v}{1000}$$

Equation 3: Mileage computation

Mileage (kmpl)		Velocity(ms^{-1})		
Model	**Coefficient of Drag**	**8.33**	**22.22**	**36.11**
A	**0.43**	10.8	12.2	4.65
B	**0.33**	11.5	14.6	5.8
C	**0.26**	12.1	17.0	7.0
D	**0.24**	12.2	17.8	7.4
E	**0.23**	12.4	18.4	7.8
F	**0.25**	12.2	17.5	7.3

Economical interpretation of this achievement can be done for a vehicle travelling 240km per day. For this only the baseline model and the model with least value of millage is considered.

Fuel Economy		
Diesel Cost	64.27	*Rs/Liter*
Distance travelled	240	*per day*
Vehicle Model	**A**	**E**
Coefficient of Drag (Cd)	0.427	0.230
Mileage (kmpl)	12.24	18.402
Fuel Consumption (l)	19.599	13.041
Cost (Rs.)	1259.66	838.183
Consumption Per Month	587.985	391.247
Cost Per Month (Rs.)	37789.8	25145.5
SAVINGS		
Fuel saved per day	6.55	*Litre*
Cost saved per day	421.47	*Rupees*
Fuel saved per month	196.73	*Litre*
Cost saved per month	12644.34	*Rupees*

V. CONCLUSION

In this paper presented to reduce the wind friction losses, collapsible wind friction reduction attachments are designed. These attachments are provided at front and back of vehicle body. This provided a smooth aerodynamically streamlined body for existing vehicle design. This aerodynamically improved model have highly reduces wind friction and is responsible for the reduction of coefficient of drag from **0.472 to 0.230**.

Addition of attachment makes the driving efficient, it doesn't have any alteration in rolling friction loss but the impact of attachment and this reduced coefficient of drag causes huge difference in wind friction loss. To propel a vehicle at the speed of 80 Kmph, value of energy loss changes from **16.232 kW to 10.801 kW**

The reduced coefficient of Wind Friction reduces the drag of vehicle at front and rare, resulting into increase in speed of the vehicle with same load conditions. This increase of speed helps to cover some extra distance with same consumption of fuel over the range of travel, hence better mileage is obtained. Numerically Mileage is increased form **12.240 KMPL to 18.402KMPL**.

Thus we can confirm that with reduced drag coefficient the performance of vehicle is increased by 41.72%. Direct result of this on a vehicle running 240Km per day is saving of **Rs. 12644.34 per month** (under standard conditions)

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