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Use of Aerodynamic Lift in Increasing the Fuel Efficiency of Heavy Vehicles

J.Sita Priyadarshini[1], A.V.S.Abhinav[2], B.Sharath Chandra[2] and R.S.Swathi[2]
([1]Assistant Professor, Department of Mechanical Engineering, MVSR Engineering College,Osmania University, Hyderabad, Telangana-501510, India)
([2]Student, Department of Mechanical Engineering, MVSR Engineering College,Osmania University, Hyderabad, Telangana-501510, India)

Abstract:*The ever increasing fuel costs and automobile emissions have called for attention of the automotive fuel economy and the climatic changes evidenced nowadays. The use of alternative materials such as aluminum, magnesium and polymer matrix composites (PMCs) instead of steel is sought to reduce weight of the vehicle, but they face technical and economic hurdles which limit the possible elaborate advancements in such light-weight materials. The concept of reducing the resultant downward force by using aerodynamic lift is being studied in the present work. This lift is induced by a series of wings attached on the top of the vehicle. To validate the proposed method 3D model of one medium duty vehicle is modelled using SOLIDWORKS. 3D external flow analysis is performed using ANSYS FLUENT, with and without the addition of the wings. The results of Lift and Drag are compared from the two setups. The values of lift are converted to virtual weight reduced and the reduction in fuel consumption is calculated. The results show that there is a considerable reduction in fuel consumption for these vehicles. Further research on the aerofoil profiles which can generate more lift and reduce drag will help reduce the fuel consumption even further.*

Keywords:*3D External flow,Aerodynamics,Fuel consumption,k-epsilon model,Turbulent flow,Fluent.*

I. Introduction

So many new vehicles are being produced these days and it is hard to ignore environmental issues associated with road-vehicle transportation. As a result of the combustion process traditional passenger vehicles produce emissions and most importantly carbon dioxide (CO2), which is an important greenhouse gas. It is considered to be responsible for anthropogenic climate change in terms of causing global warming. Even though road transportation is only accountable for 15.9% of man-made CO2 emissions, there is a huge pressure on vehicle manufacturers to produce more environmentally-friendly cars.

Since it is obvious that vehicle emissions have to be reduced, automotive manufacturers are looking for ways to achieve this goal. One of them is decreasing fuel consumption. Together with the increased fuel price this has resulted in a “green race” within automotive companies in order to stay competitive, and the development of fuel efficient products has escalated.

On-highway consumption is majorly dominated by the freight carriers and inter-state transport vehicles. Reducing the fuel consumption of these vehicles is thus necessary.

II. Fuel consumption

Vehicle weight reduction is a well-known strategy for improving fuel consumption in vehicles, and presents an important opportunity to reduce fuel use in the transportation sector. By reducing the mass of the vehicle, the inertial forces that the engine has to overcome are less, and the power required to move the vehicle is thus lowered.

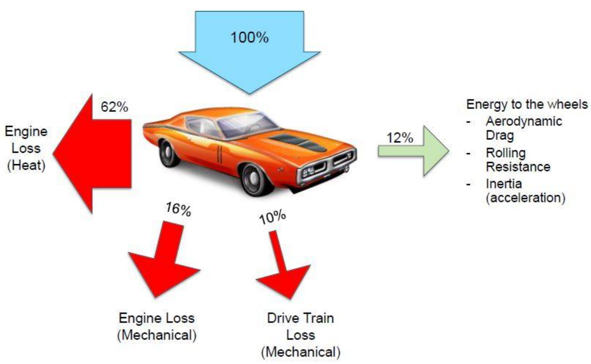


Fig. 1. Vehicle energy distributions

We know that mass affects tractive forces - Rolling resistance, inertial forces. But the relationship between mass and energy consumption is complicated by a variety of factors
–Averages/fleet mix
–Mass compounding
–Vehicle design
–Powertrain resizing
–Material energy content
(reference [7])

2.1 Effectiveness of Vehicle Weight Reduction

The simulations shown in "On the Road in 2035 - MIT Energy Initiative-Chapter-3" revealed that leaving vehicle acceleration performance and size unchanged, for every 100 kg weight reduction, the adjusted, combined city/highway fuel consumption could decrease by 0.40 L/100km for cars, and 0.49 L/100km for light trucks in the United States. In other words, for every 10% weight reduction from the average new car or light truck's weight, the vehicle's fuel consumption reduced by 6.9% and 7.6%, respectively.

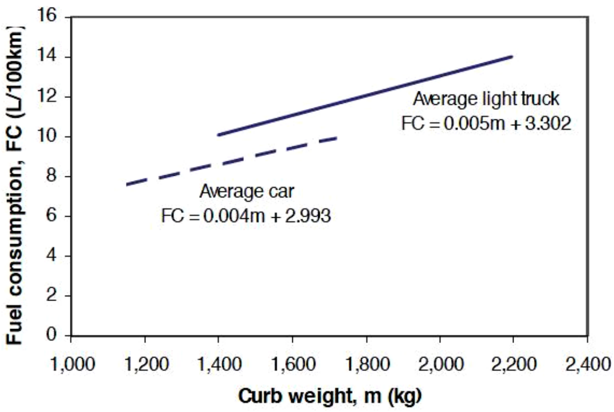


Fig. 2. Simulation results: curb weight-fuel consumption relationship for today's vehicles

Platform for Aerodynamic Road Transport conducted several simulations and wind tunnel tests on various drag reduction devises and found out that for every 10% increase in drag fuel consumption was increased by 1L/100km.

III. Proposed method

To reduce the resultant downward force by using aerodynamic lift induced by attaching a series airfoil wings of sufficient wingspan over the top of the vehicles.

3.1 Case Study
Trainer jet: Cessna 152
Weight: 780kgs
Take-off speed: 100kmph
Wing aerofoil profile: NACA 2412
Chord length: 1.63m
Wing span: 9.2m

The vehicles under study travel at an average speed of 100km/h on the highways. Thus the aerofoil profile used should be of low speed type. The NACA 2412 aerofoil profile is used for the Cessna 152 trainer jet which takes off at a speed of 100km/h. Thus this profile is chosen for the present study.

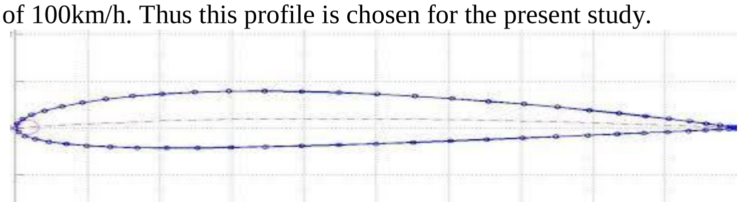
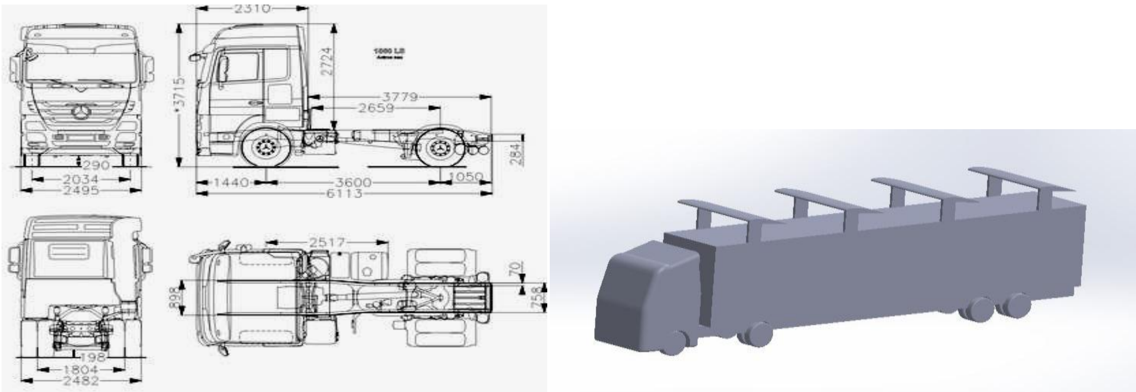


Fig. 3. NACA 2412 Profile

IV. Modelling And Simulation

4.1 Modelling

Modelling was done in Solid Works. The heavy vehicle modelled was a truck. The model was simplified for faster meshing and simulation.



(a) (b)

Fig. 4. (a)Dimensions of Truck (b) Solid model of Truck with wings

No of wings	:	4
Chord length	:	2m
Span	:	3m
Total span	:	12m

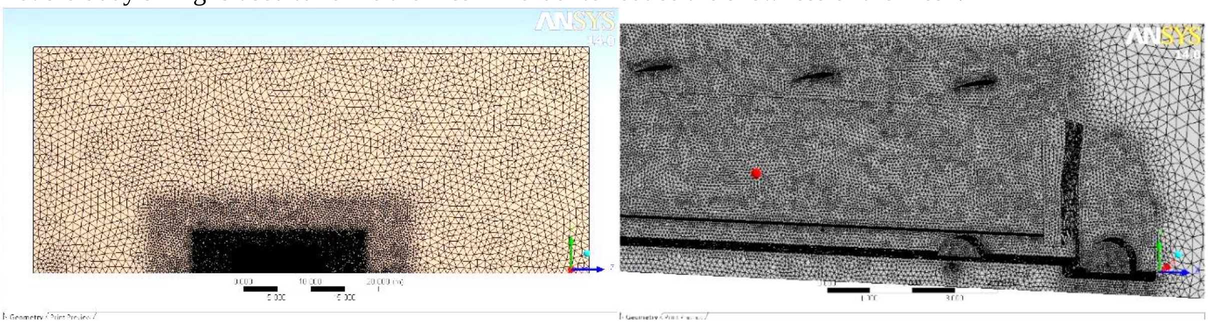
Angle of attack for the wings on the vehicle was set to 11degrees as it was found to be suitable for having reasonable lift with minimum drag for NACA 2412.

To capture the real flow behavior around the truck 3-D analysis has to be done. The vehicles modelled using SOLIDWORKS were imported to Ansys Workbench for further CFD analysis where an enclosure is created to it as air domain in Design Modeller.

4.2 Meshing

Meshing is done using different sizing options.

Double body sizing is used to refine the mesh in order to reduce the skewness of the mesh.



(a) (b)

Fig. 5. (a) Mesh with body sizing (b) Magnified view of Truck's Mesh

4.3 Setup and solution

To create realistic environment for simulation all the bounding planes are set up as symmetry planes except for the bottom plane, which acts as the road and contributes to shear. This is a close approximation of the real situation than setting the bounding planes as walls, which is similar to wind tunnel testing.

Here k-epsilon with non-equilibrium model walls is used. All the boundary conditions applied are used from the settings specified by the developers of ANSYS fluent.

V. Results

Table 1. results from simulations

	WITHOUT WINGS	WITH WINGS	DIFFERENCE
LIFT	-769N	3334N	4103N
DRAG	3112N	3513N	401N

Lift = 4103 N
Weight reduction = 4103/9.8 = 418.6kgs

VI. Calculation of fuel efficiency

Weight reduction	= 418.6 kgs
Reduction in fuel consumption per 100km	= 418.6 x (0.32/100) = 1.34 L/100km
% increase in drag	= 12.8%
Fuel consumed	= 1L/100km
Resultant reduction in fuel consumption	= 0.34 L/100km
Average annual distance travelled	= 67000 miles = 107200 km
Total reduction in fuel consumption	= 107200 x (0.34/100) = 364.28 L
Cost per liter of fuel	= 1.4$
Total savings	= 510.27 $

6.1 Case Study
Deutsche Post DHL Group has 15000 trucks working throughout the year in various countries.
Total savings per year = 15000 x 510.27 = 7654050 $

VII. Conclusion

This study verifies the possibilities of improving the aerodynamic lift acting on a heavy vehicle in order to reduce the fuel consumption, and concludes that:

- Aerodynamic lift can be increased by the addition of wings over the top of the vehicle.
- Lift can be varied by the position of the wings on the top surface. Height, distance between successive wings, angle of attack, aerofoil profile etc. can be varied to increase or decrease the lift forces.
- Profiles used should add minimum drag otherwise the fuel consumption increases.
- By the addition of the wings to the vehicles considerable increase in the lift forces acting on the vehicle is observed. This lift acts as virtual mass reduction from the vehicle and increases the efficiency of the vehicles to a good extent.

Thus aerodynamic lift can be used to considerably increase the efficiency of heavy vehicles.

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