

# Impact of Profile Modifications and Rear View Mirror on Aerodynamics and Fuel Economy of Goods Carrier

Ganesh Raut\*, M. Chilbule Chaitanya, Awadhesh Upadhyay and Mohan Jagadeesh Kumar

Department of School of Mechanical and Building sciences, Automotive Division,  
VIT University, Vellore (632014), Tamil Nadu, India;  
ganesh.df@gmail.com, cmchilbule@gmail.com, erawadheshupadhyay@gmail.com

## Abstract

This paper focuses on the improvements to the truck trailer aerodynamics this can be achieved by the aerodynamic drag reduction devices. The Devices are used on the truck and trailer undergone aerodynamic analysis, CFD evaluation, fuel economy assessment, these modifications provide combined fuel saving 15% at an average velocity of 30 m/s, the improvement in fuel economy correlates the equivalent drag reduction of 21%. CFD analysis shows that addition of these modification on truck trailer has no negative impact on the stability, the effect of exterior rear view mirror on the truck trailer aerodynamic drag is analysed. Result shows that modification intruck trailer geometry can reduce the drag and fuel consumption.

**Keywords:** Aerodynamics, Aerodynamic Drag, CFD, Fuel Consumption, Rear View Mirror. Truck-trailer

## 1. Introduction

The freight industry number one operational cost is the fuel consumption and the rising fuel prices added to this cost for the industry. The aerodynamics design modification of truck and trailer having a potential to improve the fuel economy correlates the equivalent drag reduction. The present study are concerned with the classical truck-trailer and used as aerodynamic tool to reduce the drag force on the truck-trailer profile using the CFD to simulate the profile of truck-trailer, initially analysis has been done on the basic model of the practical robust commercial truck and analyzed for the truck and trailer and identified the potential region to reduce the drag and this initial analysis shows the trailer part, truck cabin and annular space between truck and trailer shows lots of modification required to reduce aerodynamic drag.

Design modifications for truck and trailer geometry are:

Wind deflector is used on the roof of the truck to make the flow more streamlined and deflect the flow over the

roof to prevent trapping of flow and wake formation. The estimated contribution of wind deflector in the drag reduction is around

5 percent, which is a considerable amount of drag reduction is caused by the wind deflector on roof of the cabin.

Vortex trap is provided at annular space between truck and trailer, here the six panel vortex trap is provided the edges of this vortex trap is aerodynamically sharp at the leading edge of each adjacent surface. At the leading edge flow separates and this separated flow form the vortex in the spacing between skirts and these vortex trap in these spacing and each vortex imparts the low pressure on forward facing surface of the trailer and it reduces the wake formation in the annular space.

Vortex stake is provided at rear of the vehicle at an angle 30 on both sides of rear trailer to separates streamlined flow and directs the flow to the rear over the frame extension and reduces the vortex formation at the rear of the vehicle. The vortex stake contribution in the drag reduction is around 3 percent of the total reduction

\*Author for correspondence

The Mini-Skirt (MS) device was developed to provide a large ground clearance without sacrificing drag reduction of the trailer undercarriage. A double skirt device is located laterally near the two outside edges of the trailer and positioned longitudinally between the trailer rear wheels and the landing gear. The two-panel design makes use of vortex to control and capture flow entering the undercarriage of a trailer. The outer panel generates a vortex that turns the incoming flow upward where the inner panel captures the vortex induced up wash field and redirects the captured low stream wise. In comparison single panel skirt with double panel skirt we can provide more ground clearance.

Frame extension is provided at end of the trailer to detach the flow smoothly at end of vehicle by providing Aerovolution which double boat tail design which reduces turbulence at rear and hence it avoid sharp flow detachment due to its oval profile and it lower wake formation at the rear and hence reduction in the vortex formation at rear of trailer and its contribution in the reduction of drag is around the 5 % of total drag.

## 2. Literature Review

In this field of aerodynamics of heavy vehicles many research has been done experimentally and theoretically. Many values are taken as reference value because they are well optimized.

- The 'Aerodynamic of Road Vehicles' by WHHucho, describes the data regarding wind tunnel Specification. The minimum blockage ratio for the wind tunnel testing for ground vehicle is less than 5% to get accurate result<sup>1</sup>.
- Cress Well and Hertz analyzed the aerodynamic of heavy vehicles for different frontal design and for this study we taken the information cd for the frontal area  $A = 0.45\text{m}^2$  should be in the range of 0.7 for a typical truck and trailer<sup>4</sup>.
- SRAhmed analyzed experimentally of Ahmedsimplified geometry for different rear slant angle and its corresponding variation on the value of coefficient of drag and this results can be used to validate methodology used in simulation<sup>3</sup>.
- In 'External flow analysis of a truck for drag reduction' by Subrato Roy shows the empirical relation between fuel consumption and aerodynamic drag force, which is obtained by performing several aerodynamic experiments on diesel powered truck.

$$\frac{L}{100} = 0.008051 \times F_D$$

The above formula is referred for correlating aerodynamic drag force with fuel consumption of given truck<sup>5</sup>.

## 3. Geometrical Specification

Truck and trailer geometry are taken from the catalogue of 'MAN XL-sleeper' truck<sup>6</sup>. The estimated dimensions are as follows.

|                                    |                     |
|------------------------------------|---------------------|
| Overall length                     | 14.9 m              |
| Overall height                     | 4.335 m             |
| Overall width                      | 2.64 m              |
| Trailer length                     | 12 m                |
| Trailer height                     | 2.7 m               |
| Total height to cabin height ratio | 1.3 m               |
| Minimum ground clearance           | 0.375 m             |
| Frontal area                       | 5.56 m <sup>2</sup> |

The front lateral edges are designed according to this empirical formula which is proposed by Antoine Devesa and Thomas Indinger<sup>7</sup>;

$$r_{min} \approx 1.3 \times 10^5 \frac{\nu}{U_{\infty}}$$

A critical radius  $r_{min}$  for the flow around these rounded areas can be estimated according to the incoming flow velocity and the viscosity of the air. The above formula is referred for correlating Minimum lateral radius.

## 4. Modified Profile Specification

Following are geometrical specification that have used for this analysis of practical robust commercial truck.

Vortex trap: 8.76% of trailer width.

Double mini skirt: 60% of ground clearance.

Frame extension; depend upon length of trailer and wake region.

## 5. Wind Tunnel and Truck Model

Wind tunnel is designed accordingly to keep blockage ratio less than 5%, as per Wolf-Heinrich Hucho specification, L is the overall length if the prototype.

- Distance between inlet of tunnel to the front of vehicle: 2L
  - Collector region: 4L
  - Width of Tunnel: 1.52L
- These specifications used to avoid frontal and collector blockage in the wind tunnel.

The Figure 1 shows the basic truck-trailer model and in Figure 2 shows model with modified profile.

## 6. Computational Fluid Dynamic

ANSYS *fluent* is used for this present simulation of aerodynamic modification of truck and trailer. Meshing is done by opting 'body of influence' mesh insert technique

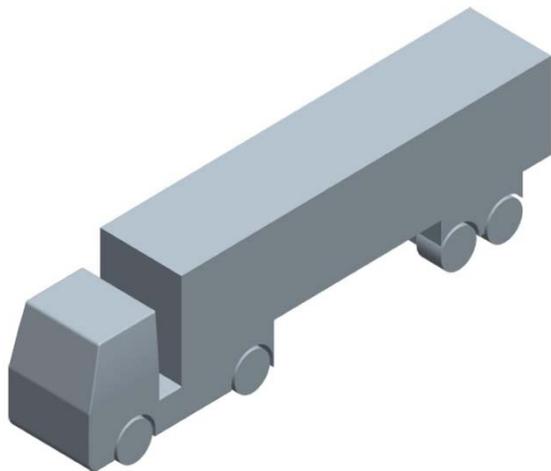


Figure 1. Basic truck-trailer model.

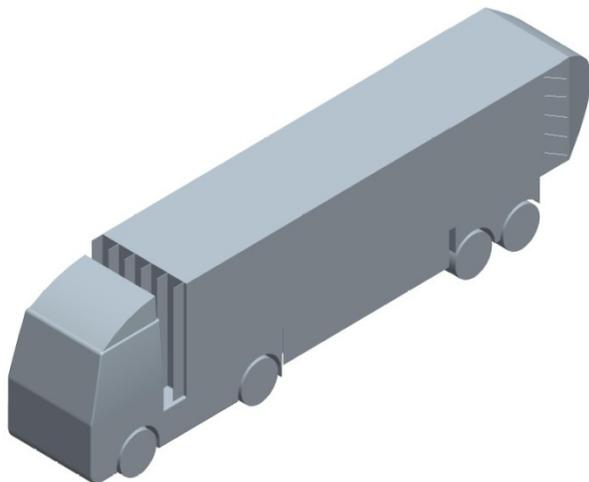


Figure 2. Modified profile truck-trailer model.

to vary the element size in air domain in wind tunnel, which is fine mesh size near to prototype and coarse size away from the prototype. Element selection is tetrahedron method, for this nodes are 814262 and elements are 3303674.

Methodology opted: In ANSYS *fluent* SST turbulence model has chosen which is very appropriate for aerodynamic analysis of vehicle.

SST: shear stress transportation turbulence modeling is used for present study. SST is appropriate model for the aerodynamic analysis because it uses two turbulence technique at near the aerodynamic interface it uses k-w turbulence model and rest of area it uses the k-epsilon turbulence model.

SST gives clear picture of wake formation because it is omega component which shows the vorticity.

The governing equations of fluid flow are the incompressible Navier-Stokes equations which Comprise of the mass, momentum and energy.

## 7. Validation of Methodology

The validation of present simulation is done with comparing the experimental result obtained by SR Ahmed for simplified geometry for different rear slant angle (with the CFD result).

The following graph shows the drag coefficient ( $c_d$ ) vs. slant angle (of Ahmed body, which is obtained by experimentally).

Following table shows the difference between results of  $c_d$  obtained by Experiments and present CFD simulation, and the simulation results are close to the experimental results shows the present methodology of simulation is valid

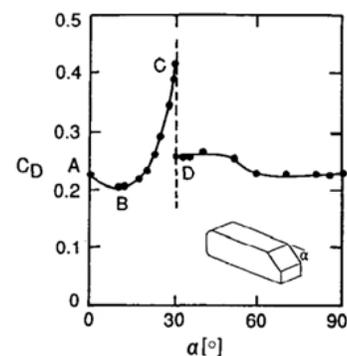


Figure 3. Experimental comparison  $c_d$  vs. by SR Ahmed<sup>3</sup>.

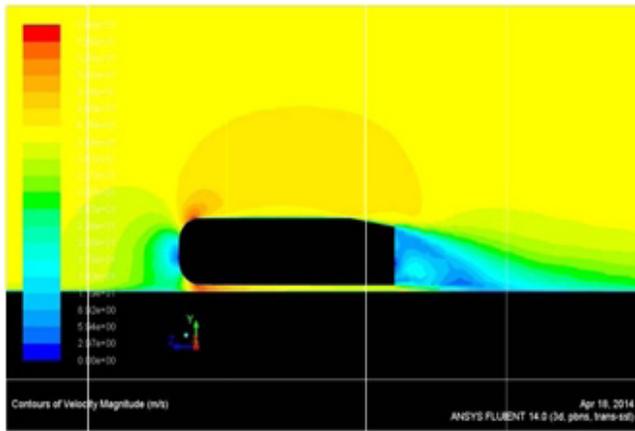


Figure 4. Velocity contour on Ahmed body with slant angel 10°

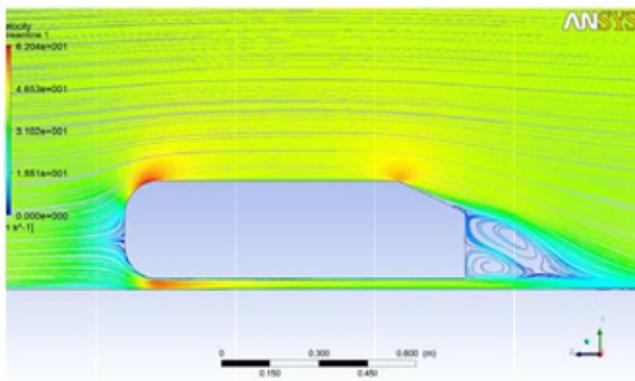


Figure 5. Velocity streamline on Ahmed body with slant angel 20°

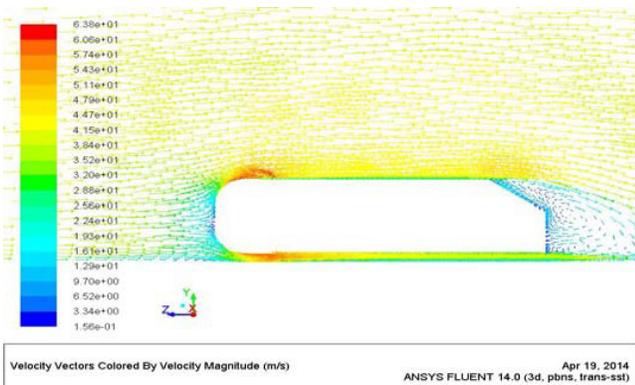


Figure 6. Velocity vector on Ahmed body with slant angel 30°

| Slant Angle (°) | $C_d$<br>(Experimental<br>by S.R Ahmed) | $C_d$ |
|-----------------|---|-------|
| 10°             | 0.2                                     | 0.18  |
| 20°             | 0.280                                   | 0.29  |
| 30°             | 0.39                                    | 0.325 |

These are result obtained for simplified Ahmed body using SST turbulence model at 10°, 20° and 30° slant angle ( $\alpha^\circ$ )

## 8. Boundary Condition

The boundary condition are given as air velocity inlet at 30 m/s, outlet at standard atmospheric pressure, truck-trailer has no slip wall condition and moving road at same velocity as that of inlet air. The sides of wind tunnel given as symmetry, since the sides of wind tunnel are far away from the prototype and have no significant influence on truck and trailer.

## 9. Result

The following figures are showing the contours and vector results obtained by CFD simulation.

## 10. Discussion

Drag assessment of  $C_d$  is done for basic and modified model of truck and trailer is obtained 0.76 and 0.6 respectively, this show that significant reduction in aerodynamic drag is achieved by profile modification.

Coefficient of lift ( $C_L$ ) is obtained for basic and modified model are-0.07 and 0.05 respectively, therefore the comparative lift increased by 3.3% that much increase in  $C_L$  is obtained because of reduction in the Reynolds number undercarriage of truck and trailer geometry of aerodynamic model.

Coefficient of drag ( $C_d$ ) assessment is done for exterior rear view mirror of truck trailer and it is found that there is increase of 3.22% in relative  $C_d$  value.

Variation in Coefficient of pressure with respect position is analysed for modified and basic model of truck trailer geometry and it is found that more uniform pressure variation is obtained due to aerodynamic

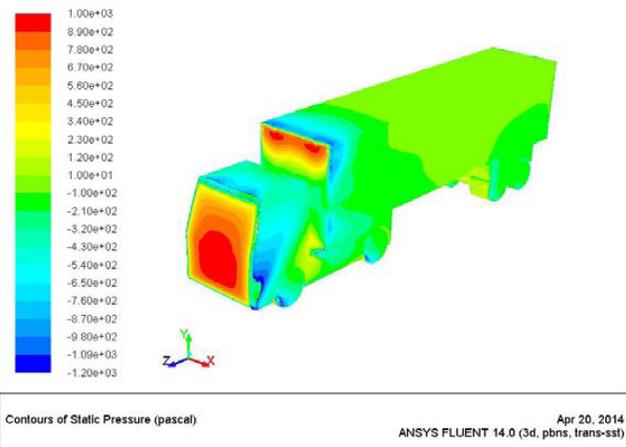


Figure 7. Static pressure contour on basic truck-trailer model.

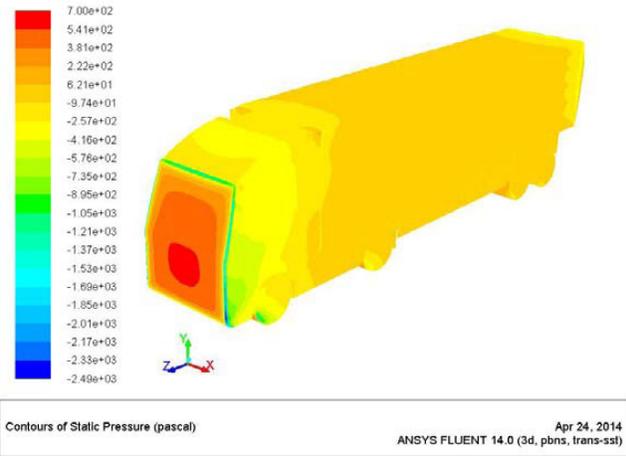


Figure 8. Static pressure contour on modified truck-trailer model.

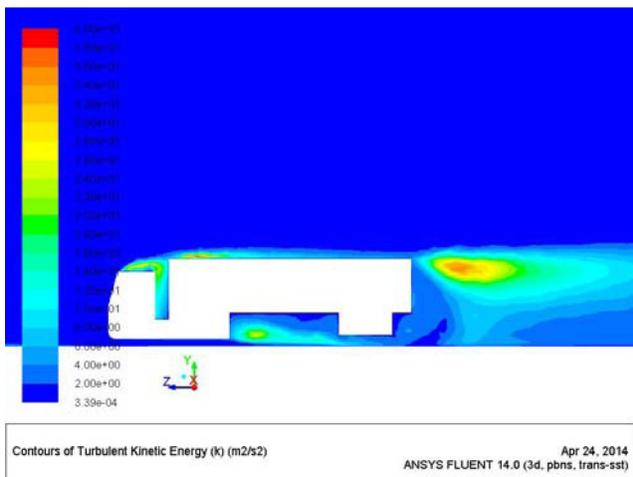


Figure 9. Turbulence kinetics energy contour on basic truck-trailer model.

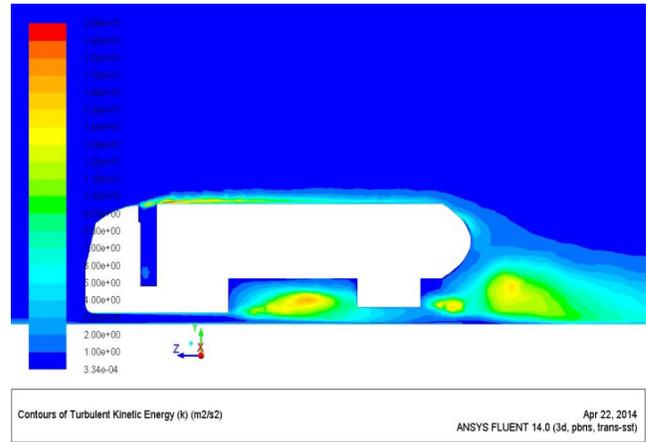


Figure 10. Turbulence kinetics energy contour on modified truck-trailer model.

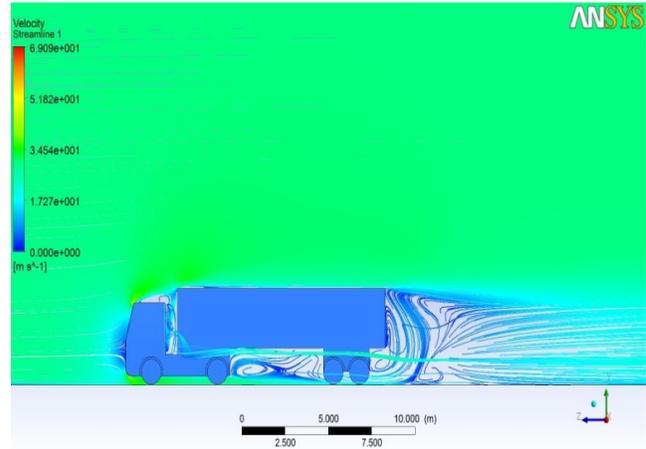


Figure 11. Velocity streamline on basic truck-trailer model.

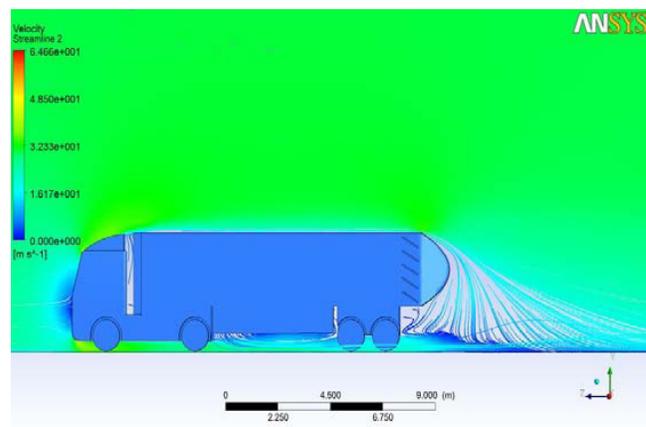


Figure 12. Velocity streamline on modified truck-trailer model.

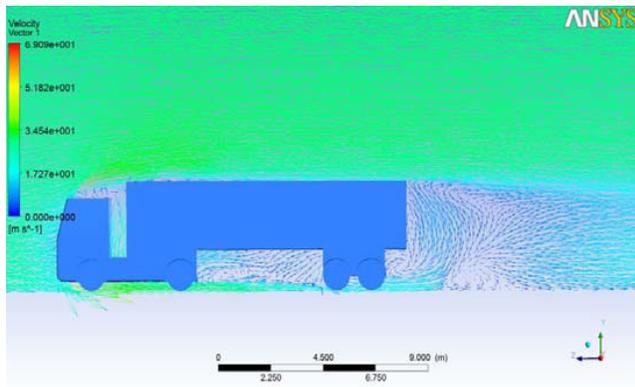


Figure 13. Velocity vector on basic truck-trailer model.

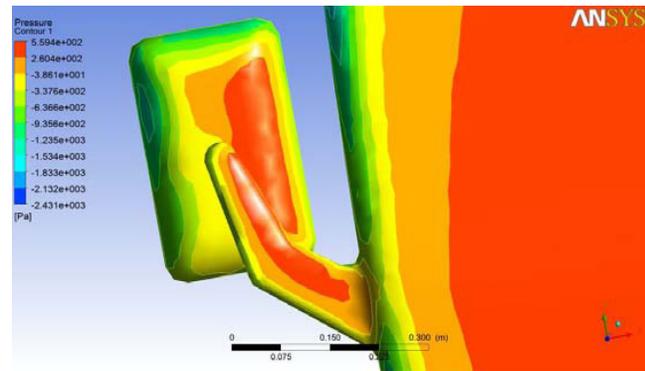


Figure 16. Pressure contour on rear view mirror.

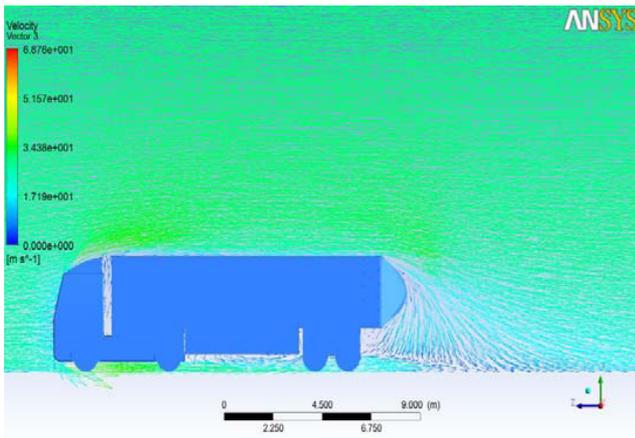


Figure 14. Velocity vector on modified truck-trailer model.

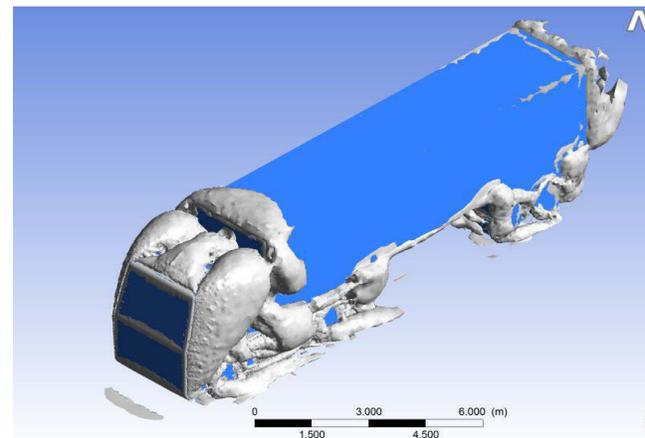


Figure 17. Swirling vortex on basic truck model.

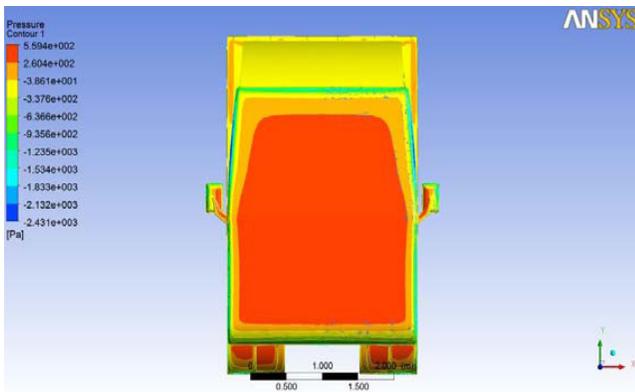


Figure 15. Pressure contour on modified truck with rear view mirror.

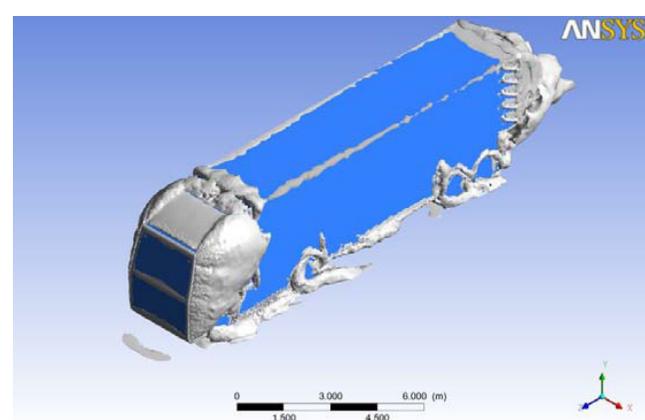
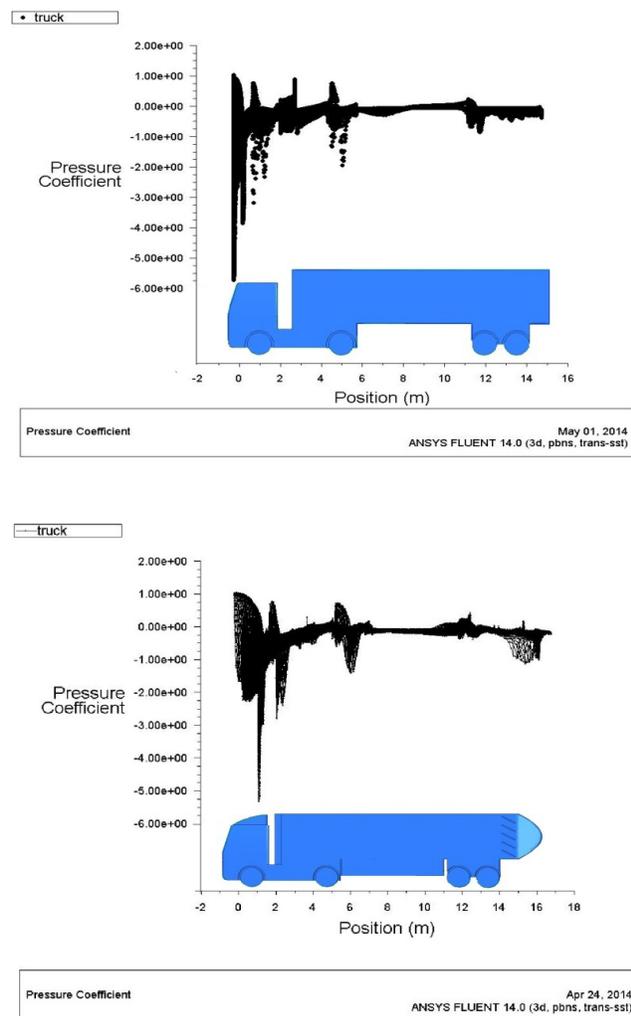


Figure 18. Swirling vortex on modified truck.



**Figure 19.** Pressure coefficient vs. truck position.

modification, pressure coefficient is reduce at the front and low pressure coefficient obtained at rear and annular space of truck trailer geometry, this variation reduces the tendency of wake formation.

Swirling vortex formation on the truck trailer geometry is shown in Figure 17 and 18 for basic and modified geometry respectively, these contours shows that intense vortex formation and sharp detachment of vortex in basic

truck trailer geometry in comparison modified one low intensity vortex formed and smooth detachment of vortex which reduces possibility of wake formation at rear and undercarriage of truck trailer geometry.

## 11. Conclusion

Aerodynamic modification leads to drag reduction of 21% on truck trailer and equivalent drag force reduction from 23kN to 18.14kN which leads improvement in fuel economy of 4.2 liters per 100 km at an average speed of 30m/s of truck.

Aerodynamic modification tends to the increase in lift by 3.3%, which is induced 151N upward lift force for 20 Ton truck, and this is reducing the traction force by 0.79 % which has very negligible effect on the tuck but provide significant reduction in rolling resistance.

Exterior rear view mirror on truck trailer geometry increased the drag by 3.22 % in relative comparison of with and without using the rear view mirror on truck.

## 12. References

1. Hucho W. Aerodynamic of Road Vehicles. Ostring 48, Schwalbach (Ts) Germany.
2. Perzon S, Janson J, Hoglin L. On Comparisons between CFD Methods and Wind Tunnel Tests on a Bluff Body. Volvo Truck Corp; SAE Paper No 1999-01-0805.
3. Ahmed SR. Influence of base slant on wake structure and drag of road vehicles. ASME J. 1984; 103:162–34.
4. Creswell H. The effect of different frontal design on value of Cd. SAE Paper No 920202-1992.
5. Roy S, Srinivasan P. External Flow Analysis of a Truck for Drag Reduction. Kettering University. SAE Paper No 2000-01-3500.
6. TGX Cab Specification Trucknology delivers. MAN-India XL Sleeper.
7. Devesa A, Indinger T. Fuel Consumption Reduction by Geometry variations on a Generic Tractor-Trailer Configuration. SAE 2012-01-0105.