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Enhancement of Aerodynamic Efficiency of Truck-Trailer

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ABSTRACT: The CFD (Computational Fluid Dynamics) analysis is the well known analysis which is done to parameters of the interface between the body and the fluid. Fluid flow around the body is major topic of concern so the CFD is held. These analyses will helping in minimize the fuel consumption of a freight vehicle, Truck-trailer and increase its stability while at work. One parameter on which the whole project depends is the Drag coefficient of the body which is being determined in the project further. The analysis is done in ANSYS software and Coefficient of Drag is obtained. A truck-trailer as a ground vehicle is considered. The project will be dealing with the air flow around the body at high speed of 30 m/s. Analysis will be done by considering the Menter's SST (Shear Stress Transition) model as standard. Simulation would be done on different cases with some improvements on the body and comparing them. Velocity contours and vector fields will be obtained along with the Coefficient of drag. A single modified device or body is analyzed at a time and there COD are to be noted for improvements.

KEYWORDS: CFD, Coefficient of drag, Heavy commercial vehicle, Profile modification, Truck-Trailer analysis.

I. INTRODUCTION

The world is participating in the race of efficient and economic productions with the ideas which are revolutionizing the sense of determining the pros and cons of the existing Designs and Mechanisms. In this context, the Automobile sector is one of the most revolutionized entities of the world. As it is a gigantic sector, it opens the doors for massive number of research topics to make an impact upon. Aerodynamics is one of the vastest field to work upon and it never give up providing new challenges to researchers, in other words researchers never get enough of it.

In the current study, we focused on understanding and analysing the aerodynamics of the Truck-trailer, which is a little less touched aerodynamic topic if compare with other transportation devices like cars, bikes and other four wheelers.. Fuel consumption is one of the main factors which increase the operating cost of the freight industry, operating cost further increases with day to day increase in fuel prices. Therefore, improving the fuel economy by modifying the aerodynamics design of an automobile is one of the potential areas of research interest. The present study is concerned with the classical truck-trailer model and numerical analysis was carried out considering it as an aerodynamic tool to reduce the drag force which resists the body to move forward, on its structure. As a fright transportation device, the vehicle is much heavier and loaded and larger than other vehicles which may reach to the length and weight up to 25 m and 55 tons respectively. Larger the body is, larger the negative force or Drag force will be experienced by the body. The project comprises the optimization of the current features and periphery of the body and the stability of the air around it, increasing the stability of the vehicle and reducing the Drag force to it.

II. PROJECT BACKGROUND

Truck companies all over the world are not leaving a single card unturned to make the vehicle more efficient than its earlier version as ascending fuel prices and the environmental issues are enforcing them to do so. This project is thought and performed for a little contribution to the work done on the topic till now. The aerodynamics of the Truck-trailer is the main focus of the project in which the optimization of the profile of the body will be done and some

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method of improvement will be contributing in the Drag force reduction and stability of air on the periphery of the body as we know that more unstable the air is, more chances are there that there would be the separation of air over body which may lead to the creation of drag.

Many devices have been introduced which make the air flow according to them. For example: Air deflector on the roof, air deflector on sides, side plates (down fairing), bumper modifications etc. In this project some more possible devices and modification have been done on both the truck and the trailer for making the vehicle more aerodynamically appealing. The project can't be possible without using the fluid flow equations such as Navier-Stokes equation, as numerical analysis is necessary, for this k - ε model is used which will help us to calculate the parameters required for the work. Air which is at room temperature and having Mach number below 0.3, also called incompressible fluid. So the Navier-Stokes equations of mass, moment and energy will come into play.

III. METHODOLOGY

Geometry: A basic 3d model of the freight vehicle was designed with a simple cuboidal shaped trailer with sixteen tyres on the trailer and four tyres under the truck body. CAD software NX8 Unigraphics is used for the design of the 3d models and its modifications. The 3d model has four wheels (Tyres) on the Truck body and 16 wheels on the trailer body with no drag reducing device mounted except a roof deflector. This is the model taken as a reference which will compared to the modified ones for aerodynamic efficiency.

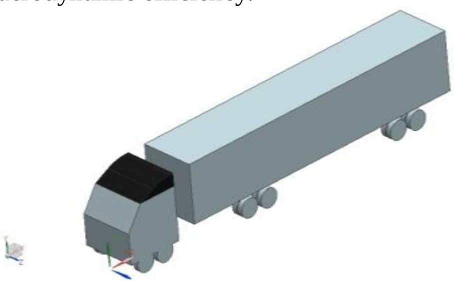

Fig1: Reference 3d model designed in NX 8

Numerical solution: Computational fluid dynamics (CFD) consists of many turbulence methods to determining the dynamics of the turbulent fluid. Some of them are: Reynolds-Averaged Navier-Stokes (RANS), Large Eddy Simulation (LES), Direct Numerical Simulation (DNS) and Lattice Boltzmann method (LBM). RANS method is most commonly used for a fluid dynamic simulation and the same method will be used in the project. RANS uses the Navier-Stokes equations as starting point and aims solving them. Navier-stokes equations system is a 3 equation system with the following euation

$$\nabla V = 0$$

$$\rho(\partial V/\partial t) = -\nabla p + \mu \nabla^2 V + \rho g$$

$$\rho c_p\,(dT/dt) = k\nabla^2 T + \phi$$

ANSYS 15 is the software used for the meshing of the domain, project simulation and results evaluation and the obtained results are described in further topics.

Boundary conditions: The setup consists of a 'velocity-inlet' through which the air enters in the system and a 'pressure outlet' to determine pressure gradients at the rear part of the body. Turbulent kinetic energy and Turbulent dissipation rate is taken 'Second order Upwind' to gain better results.

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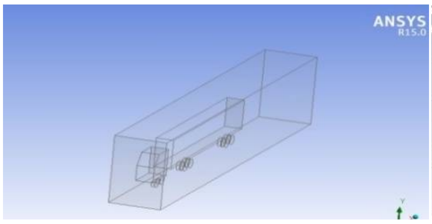


Parameters	Type	Quantity
Inlet	Velocity Inlet	30 m/s
Outlet pressure	Pressure Outlet	1 atm.
Truck-trailer	Stationary wall with no slip	0 m/s
Road	Moving with no slip condition	30 m/s
Inside the wind tunnel	Symmetry	--

(a) (b)

Figure 2: (a) Body in wind tunnel; (b) Table of Boundary conditions.

Gap Improvements

In this improvement, the gap between the truck and the trailer is treated or optimized to make the body more aerodynamically efficient. Some of the improvements introduced in the body are as follows:

- **Coanda Device:** The Coanda device which is used in the project happens to experience a phenomenon which is the effect of balancing between centrifugal force and the pressure force in a wall bounded jet. Control of airfoils is the area where this adherence effect is widely used. A fluid jet has the tendency to stay attached to a convex periphery of the body whether it is liquid or gas. This effect may contribute in drag reduction [Fig. 3 and 4].

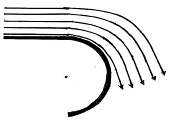
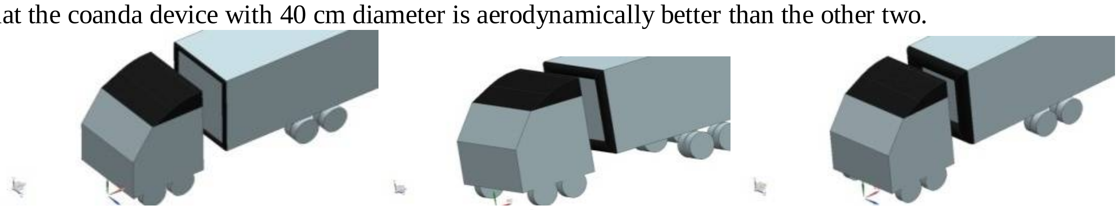


Fig 3: Coanda effect: air is bending along the convex curved surface.

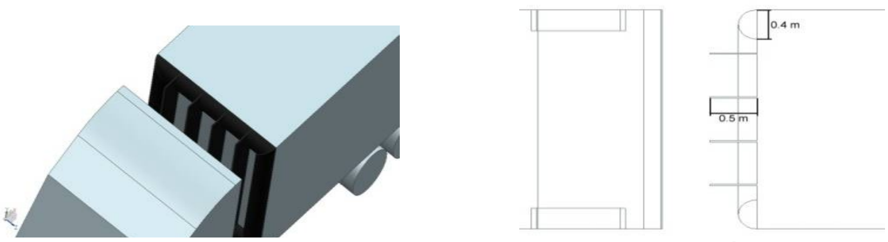
For the sake of optimality, three cross-sections were taken for the coanda device which are 20, 40 and 60 cm. it was found that the coanda device with 40 cm diameter is aerodynamically better than the other two.



(a) (b) (c)

Fig 4: Coanda Devices: (a) Coanda device with cross section of 20 cm of diameter; (b) 40 cm and (c) 60 cm.

- **Coanda device and cross-flow trap together:** In this device, Coanda device will try to make the flow at the edges smoother on the edge of the vehicle and the cross-flow trap will work for pressure compensation and to create vortices at top of the body. Cross-flow trap is a device with strips or plates mounted on the front part of the trailer and are called cross-flow vortex trap device. It is also called as vortex stabilizers as it may contribute in the compensation of the pressure behind the trailer body, hence stabilizing the fluid flow [Fig. 6].



(a) (b)

Fig 5: (a)Coanda device with cross-flow trap; (b)Dimension of cross-flow trap and coanda device.

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Base improvements

In this improvement the base of the trailer of the back of the trailer is treated. Massive amount of study is available on the base improvement and taking reference to the studies, the trailer base improvement is designed. The trailer improvements used in the project are given below:

- **Coanda device at the base of trailer:** Coanda effect do not lets the air separate the body at the end in other words, it delay the air separation time and reduce the wake region behind the body [Fig 7].

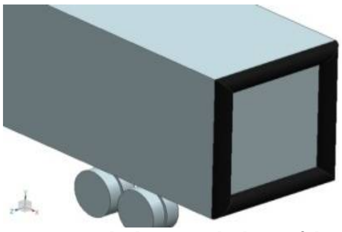


Fig 6: Coanda device at the base of the trailer.

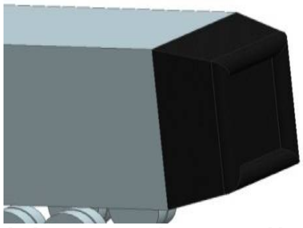


Fig 7: Coanda device mounted on a tapered base.

- **Coanda device with expended tapered base of the trailer:** The device consists of a Coanda device mounted on the 15° tapered 1 meter extended portion of the trailer which is used to reduce the drag force and increase the stability of air [Fig 8].
- **Modified base edges of the trailer:** 40 cm fillet is provided at the edges at back of the trailer and vortex stabilizers are mounted to stabilize the air behind or to compensate the low pressure behind the freight vehicle [Fig 9]. The sharp edges of vortex stabilizers generate vortices so that air flow tries to reduce the size of wake (low pressure) region by minimizing the pressure differences.

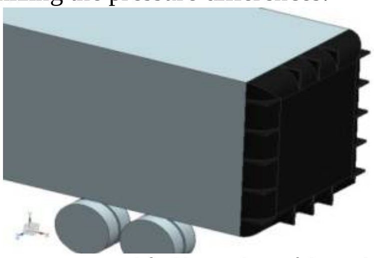
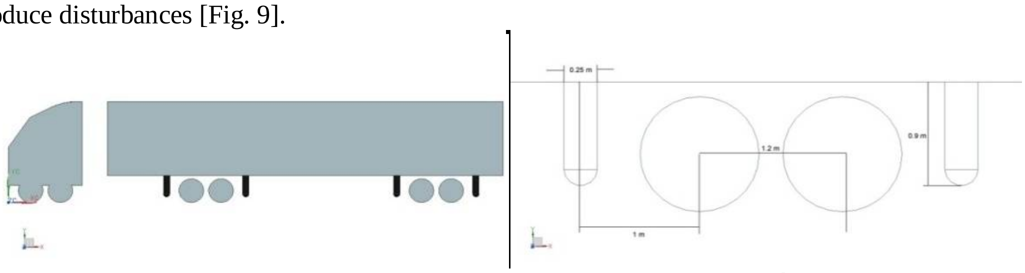


Fig 8: Modified base edges of the trailer

Undercarriage improvements

The improvements describe some attempts to minimize the instability and drag in the freight body. Region below the body is one of the most drag producing and instability regions when it comes to aerodynamics. Most unstable part is wheel mounting because there could be found the flow with a high Reynolds number which carries high turbulence. Following are the improvements done for reduce the drag from the wheel area Fig. 9 & 10 shows some undercarriage improvements performed on the body.

- **Wheel air deflector1:** The device is a cylindrical in appearance and mounted on both front and back side of the wheels. It deflects the air smoothly over and around the wheels so that air do hit the wheels directly and produce disturbances [Fig. 9].



(a) (b)

Fig 9: (a) Mounting of the wheel air deflector 1; (b) Dimensions of the wheel air deflector.

- **Wheel air deflector 2:** This device is similar to the earlier one and does perform the same operation but it is different in its physical appearance and is found to be a considerable example of stabilizing the air around the wheel periphery [Fig. 10].

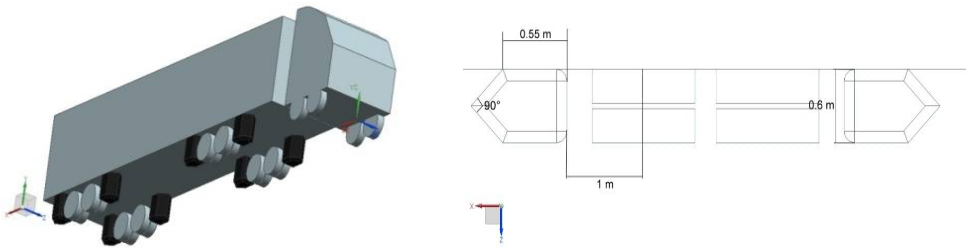
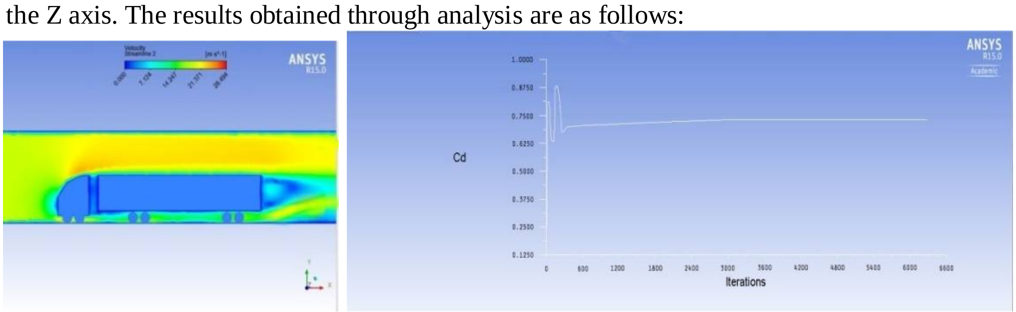


Fig10: (a) Wheel air deflector 2 mountings; (b) Dimensions of the device.

IV. RESULTS

Numerical simulation was done on both reference [REF] body and the body with improvements and results from each modification is obtained. The result is obtained in the form of velocity contours and graphs obtained in the simulation which are representing the coefficient of drag of a particular body. Velocity contours may help to determine the nature of flow over the body and this velocity contour is obtained on the symmetric plane of the domain which is a XY plane on middle of the Z axis. The results obtained through analysis are as follows:



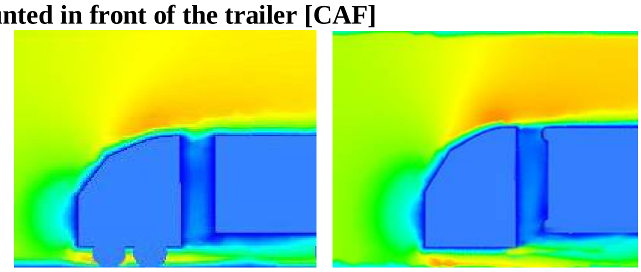
(a) (b)

Fig 11: (a) Velocity contour of reference body; (b) Graph showing Coefficient of drag.

Fig. 11(a) is a velocity contour of the reference body which is showing the areas to be worked upon for the aim achievement. The figure also shows the coefficient of drag graph obtained in the analysis which shows that the drag coefficient of the reference body is 0.7332.

Gap Improvements

- **Coanda device mounted in front of the trailer [CAF]**



(a) (b)

Fig12: Airflow comparison at front of the trailer: (a) Velocity contour without Coanda device; (b) Velocity contour with Coanda device.

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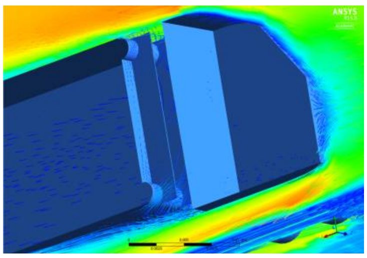
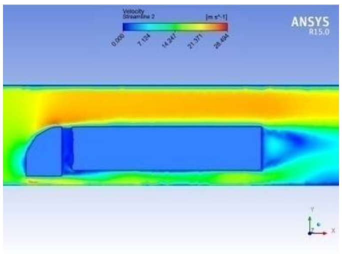
The change in the movement of the air both upper and lower region of the front trailer can be seen. It's been proved that the separation has reduced and a low pressure zone at down side of the trailer with Coanda device is reduced which is a good sign for the improvement of the drag [Fig. 12].

- **Coanda device and cross-flow trap mounted together [CCFT]**

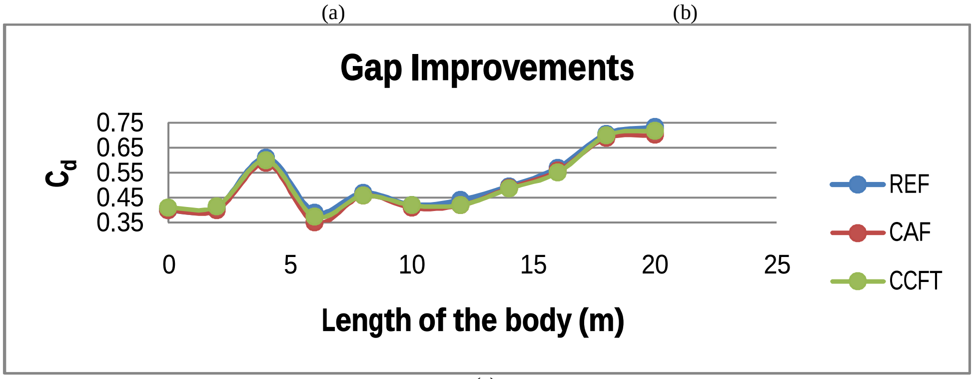
The gap between the trailer and the truck shows [Fig. 13] that unwanted low pressure zone is denser in the body mounted with cross-flow trap device. It is due to increment of pressure on trailer front. When the air fills the gap between the truck and the trailer, it remains trapped by these vortex stabilizers hence pressure in the region increases. The device may be some good use when the body in at some yaw angle, because then it'd be able to compensate the low pressure zones with generating vortices when air leaves it.



(a)



(b)



(c)

Fig13: (a) Vortices getting trapped in the gap region; (b) Velocity contour; (c) Graphical curve showing COD along the length of the body (Where, REF: Reference Body; CAF: Coanda at Front trailer; CCFT: Coanda and Cross-flow trap).

Above figures [Fig. 13(b) & (c)] shows the velocity contour and coefficient of drag curve along the length of the body per 2 meters. It can be seen that in comparison with the velocity contour of the reference body, the air flow around the body is almost same as it was with the coanda device only. The analysis shows that the cross-flow trap is a better in a body facing cross wind or which is at some yaw angle.

Base Improvement

Base of the freight body carries the most of the potential to minimize the drag force on the vehicle. The above discussed suggestions are analysed through simulation and following results are obtained:

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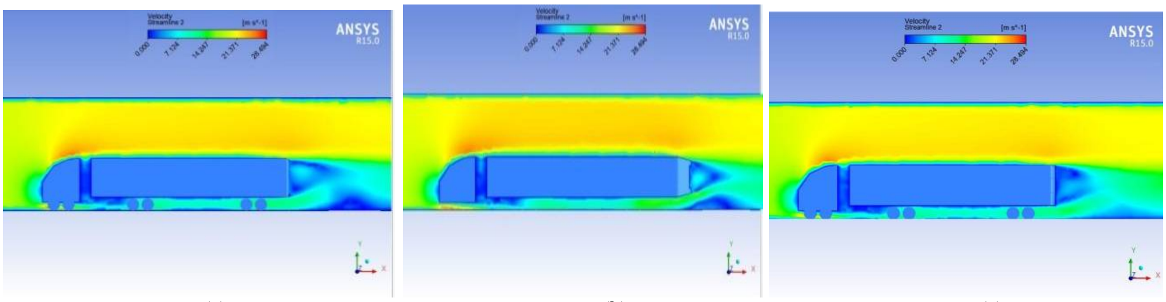

(a) (b) (c)

Fig14: Velocity contours obtained in analysis: (a) Coanda mounted at base of trailer, (b) Tapered base with coanda and (c) Modified base edges.

Above are some figures which are velocity contours of all the base improving devices with the freight body. Nature of air can be seen changing in every device and is much better than that of the reference body.

- **Coanda device at the base of trailer [CAB]**

The device stands good in reducing drag force on the body, the fluid flow curved along the Coanda device curve and helps delaying the separation [Fig. 14(a)]. The device is 7.65% better than reference model.

- **Coanda device with expended tapered base of the trailer [TBWC]**

Tapered base may be a big help in reducing drag. The device made the body 8.3% more efficient than the reference body [Fig. 14(b)]. Wake region behind the trailer drastically minimized and has become more aerodynamic. Two devices combined proved a good drag reducing agent. The device is little bit less practical because it reduces the cross-sectional area of the trailer through which good are entered, so it'd only be able to import only the goods with small size due to its small entrance.

- **Modified base of the trailer [MB]**

This is about no add-on device but a modification on the edges of the trailer. Edges are modified so that the area of contact between the air and the body increased, which will allow more air to be attached to the body, which may minimize the separation. As modification has sharp edges, it generates the vortices which contribute in drag reduction on large scale [Fig. 14(c)].

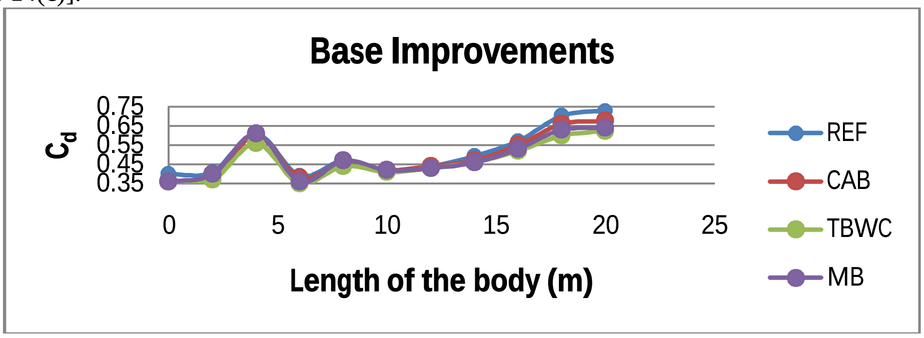

Fig 15: Graphical representation of Coefficient of drag along the length of the bodies of base improvements and reference body (Where, CAB: Coanda at Base; TBWC: Tapered Base with Coanda; MB: Modified Trailer).

Undercarriage Improvements

In this section some undercarriage improvements are suggested which may help reducing the coefficient of drag (COD) and make air-flow smoother around the wheel house.

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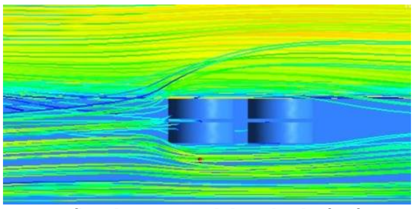
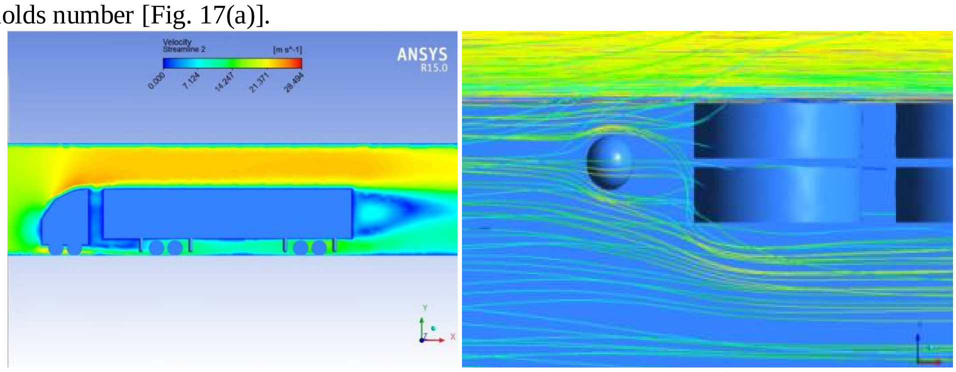


Fig 16: (a) Air flow lines around the wheel of reference body

When air directly hit the wheels, there is occurrence of high turbulence in air flow. This uneven flow of air causes the production of drag force due to air and body separations. The reference model which is taken is most basic and simple model but in actual wheel house there are numerous drag producing agents and there are many devices mounted which create turbulence in air. Figure above shows the turbulence in the reference model and its cure are discussed further [Fig. 16].

- **Wheels air deflectors 1[WD 1]**

The device is a cylindrical in appearance and mounted on both front and back side of the wheels. It deflects the air smoothly over and around the wheels so that air doesn't strike it directly and produce disturbance. The device may be the good example of the drag reduction and minimizing disturbances as it has shown 5.26 % of improvement due to reduction in Reynolds number [Fig. 17(a)].



(a) (b)

Fig 17: (a) Velocity contour of the body with wheels air deflector 1; (b) Air flow around the wheels.

Fig. 17(b) shows the changed pattern of air due to the presence of the wheel air deflector 1. The device has minimised the direct air hitting to the wheels which has helped the drag to be reduced.

- **Wheel air deflector 2 [WT 2]**

The device has played a considerable role in drag reduction. It can be seen in the Fig. 17(b) that the flow has become smoother over the wheels. The body is 6.38 % more efficient than the reference body. Both the improvements showed the improvement but, improvement under the trailer means the smoother flow of air and smoother flow of air may create some lift on the body or reducing down force [Fig. 18].

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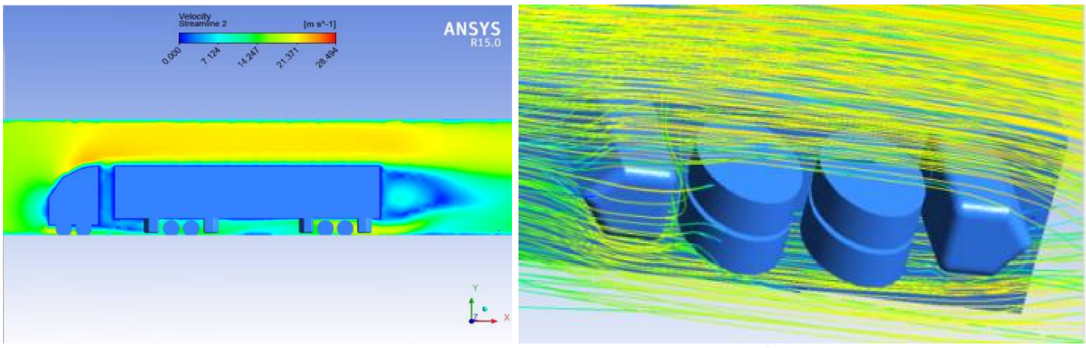

(a) (b)

Fig 18: (a) Velocity lines in Wheels deflector 1; (b) Air flow around the wheels.

Wheel air deflector 2 turned out to be better device than earlier undercarriage modification. Triangular edge of the device has helped the air to divert around the tyres preventing the direct hit of the air. This diversion of air has helped in the reduction of the Reynolds number of the air and reduced its turbulence to some extent.

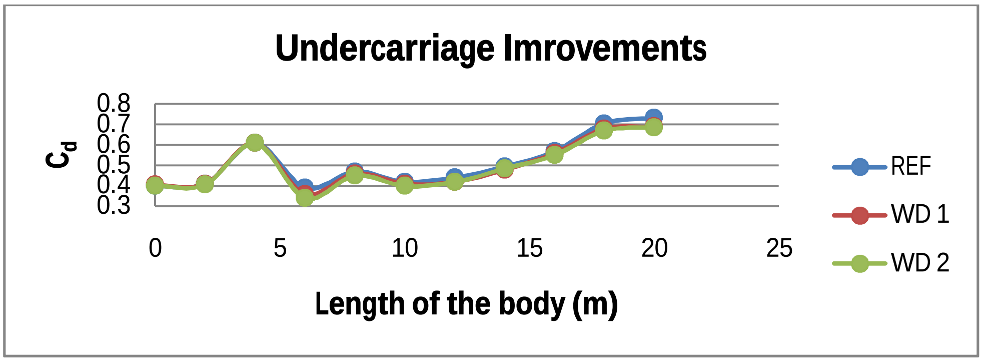

Fig 19: Graphical representation of Coefficient of drag along the length of the bodies of undercarriage improvement and reference body (Where, WD 1: Wheels air Deflector 1; WD 2: Wheels air Deflector 2).

There are 3 continuous curves present in the Fig. 19 which depicts the comparison between the two models or modifications with the reference model. It is the curve of coefficient of drag over the body per 2 meters. It was found that overall drag which was observed are 0.6902 and 0.6864 obtained from wheel air deflector 1 and wheel air deflector 2 respectively.

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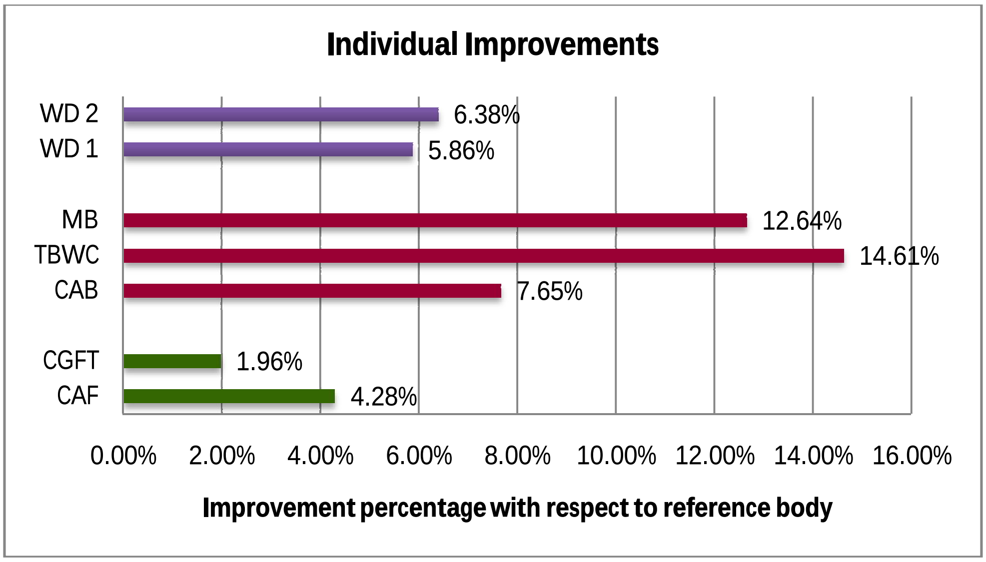

Figure 20: Individual improvements obtained in comparison with the reference body.

It was concluded that the base improvements which are suggested in the research work made the freight vehicle more efficient than any other improvements done on the body. Figure [Fig. 20] shows the comparison of all the improvements obtained by an individual device. TBWC (Tapered Back with Coanda device) is the most efficient device suggested in the project and had shown a good improvement in air-flow around the body at the base.

V. CONCLUSION

This paper confirms the possibilities of improvement of aerodynamics of a Truck-trailer in order to minimize the consumption of fuel. The project concludes that:

1. The trailer has great potential for the reduction of the negative forces which are called drag forces. If the trailer is compared with the tractor/truck, it has got more susceptibility for the aerodynamic improvements and hence has wide range of modifications to improve the vehicle's fuel efficiency.
2. Improvements on the base and Under-carriage of the truck-trailer have shown the greatest improvement in the freight body's aerodynamic efficiency when the regions are modified and mounted with some aerodynamic devices. Extended tapered base along with coanda device and the modified base are two base improvements which have shown a great potential to improve the flow in the regions and should be the topic of further researches and developments.

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