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Carbon Fiber Trailer Body Design & CFD Simulation to Check Aerodynamic Effects on Commercial Tractor Trailer

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Abstract— The idea of this research is to check and improve airflow around the commercial tractor-trailer so that it requires less effort during the driving condition. The trailer body material is carbon fiber because it is lighter and smoother surface as compare with steel, aluminum also it is stronger and more rigid than steel. According to CFD flow analysis of tractor-trailer some changes were found i.e. proper airflow, low pressure, decrease in lift and drag forces also decrease in wind noise near to wheel and body which provide better tractor-trailer stability at the different driving condition with load or unload goods.

Index Terms—*Tractor-Trailer, Flow analysis, Carbon fiber, Surface contrivance, Aerodynamic.*

I. INTRODUCTION

In Commercial vehicle section tractor-trailer plays an important role, this vehicle is used for long drive goods transportation purpose. A semi-trailer is commonly known trailer which is attached to tractor fifth wheel coupling.

Tata, AMW, Ashok Leyland, Eicher, Volvo, Mercedes (Daimler Motor), Bharat Benz, Volvo, Scania, MAN & Mahindra are famous commercial vehicle manufacturer in India. They also produce various types of tractor-trailer. [3]

There was much research done by these industries related to aerodynamics, body material, design, engine and many more. If we talk about aerodynamic and body material we can observe many changes like improving fuel efficiency, stability and decrease in aerodynamic pressure, forces, wind noise and good streamline body. [3]

Fig. 1.1 Semi-Trailer

As we see that most of the trailer body is made up of steel and aluminium and we also know that these two

materials were easily available and less costly. But these material is heavier, less rigid and less strong than carbon fiber.

By using Carbon fiber as a body material it provides proper aerodynamic stability and also a reduction on wind noise because of lightweight.

So this research is generally focused on the design or tractor-trailer body, add on devices (Surface Contrivance) and carbon fiber trailer material with flow analysis to see the flow of wind and wind noise.

This research highlight the improve tractor-trailer aerodynamic shape by using a carbon fiber material on a trailer body and surface contrivance that means changing the shape of body design of trailer as well as the tractor.

The design has been done by using a 3D modelling software after that computation fluid dynamics simulation carried out. For airflow simulation, the velocity of air was 80 kmph on an actual dimensioned tractor-trailer and by doing CFD there were many changes on trailer body like proper airflow, decrease in lift and drag forces also decrease in wind noise near to wheel and body. Changing the overall design lead to decreases aerodynamic forces by 33 % which thusly lead deprecation in fuel consumption by 2.7 %. It also provides better trailer stability in windy weather and crosses wind condition depends upon different driving condition.

The research mainly focused on changes of tractor-trailer body design, the following changes have been done:-

- Cab deflector
- Trailer side skirt
- Wheel cowling (Trailer)
- Cab underbody air dam (Center Fitted)
- Air shield gap air passage
- Wider tire
- Trailer underbody triangular fairing
- Curve trailer body
- Trailer tail with air vanes
- Tractor corner vanes
- Extended cab panel with air vane (Tractor & Trailer Gap Filling)
- Internal air passage (rotating wheel air)
- Arc shape trailer frontal
- Tractor rear Spike (Pressure & Noise Decreaser)

II. DESIGN DETAILS

The figure shows the design detail of arc shape trailer frontal, Tractor rear spike, Tractor internal air passage, Tractor underbody air dam, Curve trailer body, Trailer side skirt, Curve trailer rear corner, Trailer tail with air vanes and Internal air passage for rotating wheel.

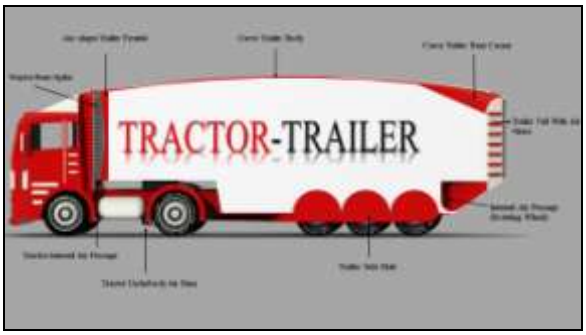

Fig. 2.1 Side View Name Indication
(Tractor-Trailer)

The figure shows the design detail of internal air passage for rotating wheel, wider tire and Tractor corner triangular vane.

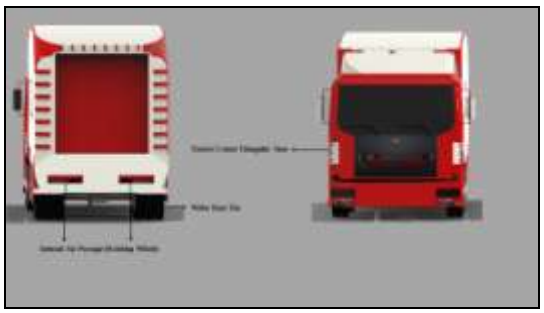

Fig. 2.2 Rear & Front View Name Indication (Tractor-Trailer)

The figure shows the design detail of internal air passage, trailer underbody triangular fairing, tractor cabin deflector and extended tractor panel with air vanes (tractor & trailer gap filling.

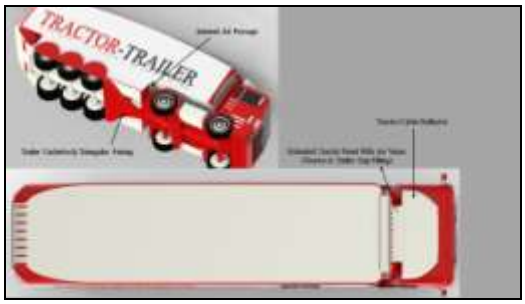

Fig. 2.3 Top & Bottom View Name Indication (Tractor-Trailer)

III. Body Material & Design

By using Carbon fiber as a body material it provides proper aerodynamic stability and also a reduction on wind noise because of lightweight. So this research is generally focused on the design or tractor-trailer body, add on devices (Surface Contrivance) and carbon fiber trailer material with flow analysis to see the flow of wind and wind noise.

But the main disadvantage or obstacle is cost because it is more costly with steel and aluminum.

If we talk about the advantage of carbon fiber then this material containing very thin fibers, thinner than human hair, about 0.005-0.010 mm in diameter and composed typically of carbon atoms. Carbon fiber is a composite material which is weighing significantly less than steel, comparable strength and rigidity. On the other hand, aluminum is significantly lighter and more corrosion-resistant than steel. However, aluminum usually costs more, although recent market conditions have significantly narrowed the gap. The disadvantage to aluminum is that it's not as strong or durable as steel and is often more expensive to repair.

Compared to aluminum and steel carbon fiber is lighter corrosion-resistant capabilities, more durable with a strength.

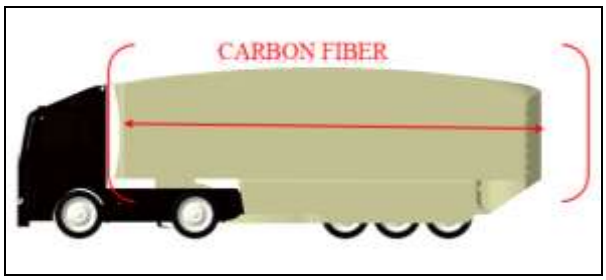

Fig. 3.1 Trailer Body Design & Material

3.1 CAB AIR DEFLECTOR

Roof Deflector is an add-on device which is design to deflect or spoil the air which is directly contacted with the tractor frontal area. It is also created a shield between tractor and trailer to improve airflow around the trailer body. The Gap between tractor-trailer creates uneven pressure and air turbulence due to which yawing moment will occur and this direct effects on steering handling mechanism. Another main work of air deflector is to reduce aerodynamic drag so that fuel efficiency of vehicle will improve.
So to avoid this a cab air deflector is needed.

Fig. 3.2 Cab Air Deflector

3.2 TRAILER SIDE SKIRT

The trailer side skirt is used to decrease aerodynamic drag caused by wheel & tire air turbulence, due to this there is less chance of wind noise and also there is proper stability during crosswind condition. It is also helpful for improving fuel economy up to 3%.

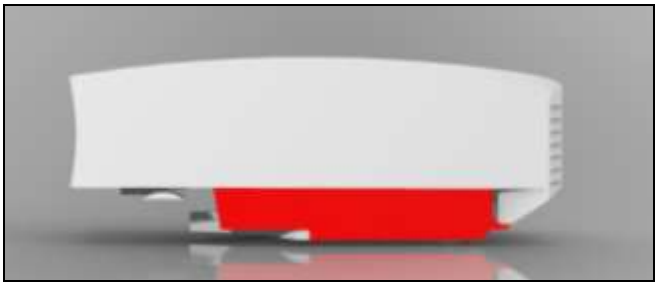

Fig. 3.3 Trailer Side Skirt

3.3 CAB UNDERBODY AIR DAM (CENTER FITTED)

The underbody air dam is designed and located in the tractor body, it is used to deflect the oncoming air. By the use of this, there is less lift force and there is less pitching moment. The function of an air dam is to deflect the air or we can say that it spoils the air.

Fig. 3.4 Cab Underbody Air Dam

3.4 TRAILER UNDERBODY TRIANGULAR FAIRING

Underbody triangular fairing is design and mounted under the trailer body and the purpose of this is to create proper airflow below the trailer body and also to decrease the lift force.

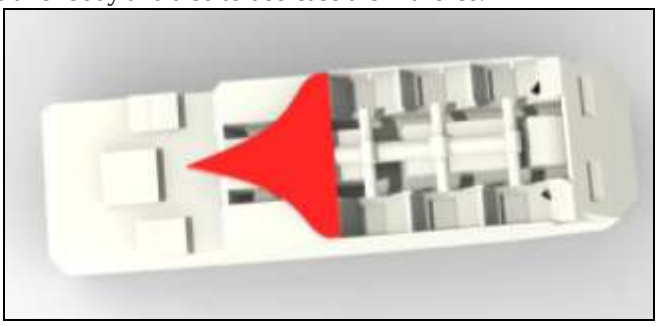

Fig. 3.5 Trailler Underbody Triangular Fairing

3.5 TRACTOR CORNER VANES

Tractor corner vanes are designed to flow wind in the proper direction and basically, it is used for the frontal. It is one of the best methods to reduce the frontal body drag on the tractor. It also decreases the frontal pressure because the wind flows in between the vanes toward the rear end of the trailer.

Fig. 3.6 Tractor Corner Vanes

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3.6 EXTENDED CAB PANEL WITH AIR VANE
(TRACTOR & TRAILER GAP FILLING)

Extended cab panel is with air vane is design and mounted near the roof deflector which is used to fill the top gap between the tractor and trailer. Due to this, the air will not travel between the tractor and trailer. It is also used to decrease turbulence and noise.
The air vane provides a smooth airflow above the trailer surface.

Fig. 3.7 Extended Cab Panel With Air Vane

3.7 INTERNAL AIR PASSAGE (ROTATING WHEEL AIR)

In the area between the front and rear wheels of the truck, a very complex phenomenon of turbulence will be formed because of the long distance between its front and rear wheels. The complex turbulence will greatly increase air resistance, which affects the truck trailer speed and greatly increases fuel consumption.

To improve the smoothness of the airflow at the bottom of the truck, a kind of drag reduction structure at the bottom of the truck is presented. The device, located at above the rear wheels of a trailer which is an airflow passage that flows out the rotating wheel air directly rear side of the trailer.
The rotating wheel creates maximum turbulence due to its rotation and also the tire noise increases, so to avoid that an internal air passage is given.

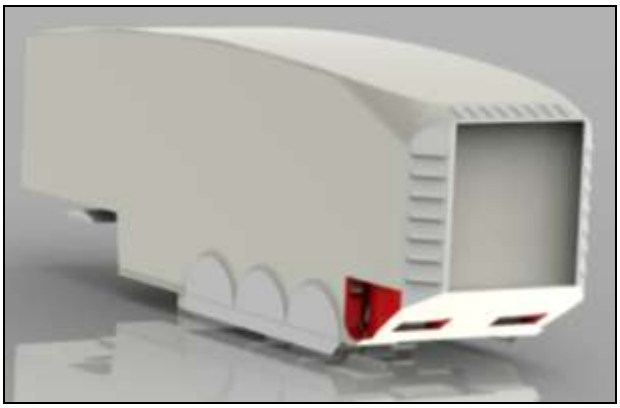


Fig. 3.8 Internal Air Passage

3.8 TRACTOR REAR SPIKE PRESSURE & NOISE DECREASER

Tractor rear spike designs and used to decrease the pressure as well as noise because when the wind will flow in

between the spike the flow pressure will decrease and at the same time the noise will also decrease.

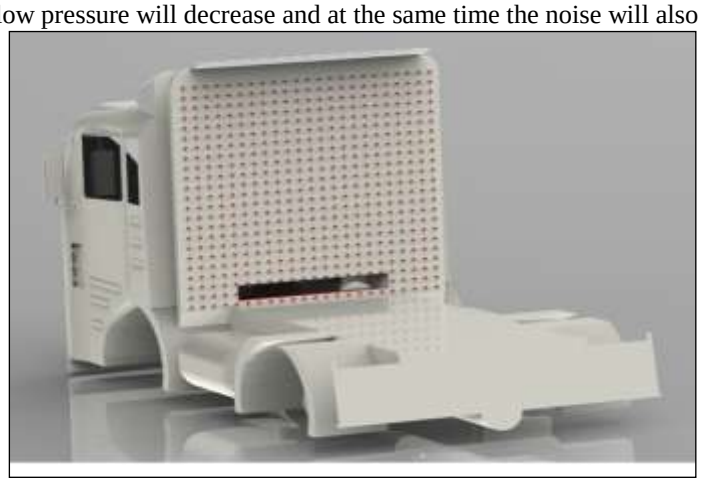


Fig. 3.9 Tractor Rear Spike

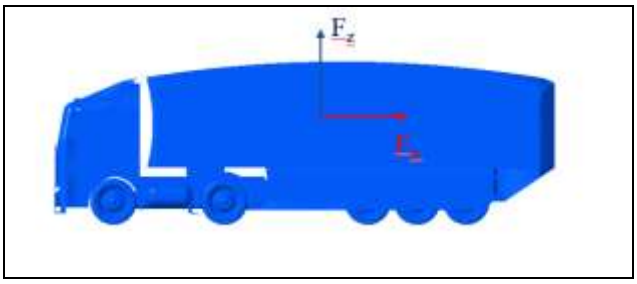
3.9 WIDER REAR TIRE

The use of a wider tire may decrease the air noise in between the two tires also it will decrease the turbulence which is created by the tire gaps. So in this tractor-trailer design, there is a wider tire which will decrease the tire noise, turbulence and pressure drag as well as rolling resistance.

Fig. 3.10 Wider Rear Tire

IV. AERODYNAMIC ANALYSIS – 3D MODEL

Based on the computational fluid dynamics analysis of the tractor-trailer, aerodynamic devices are installed at tractor-trailer respectively to reduce resistance and fuel consumption.



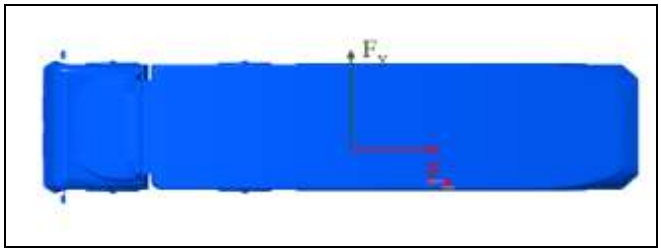


Fig. 4.1 Forces Acting on Tractor Trailer

4.1 FORCES ACTING ON TRACTOR TRAILER

Fx - Is force which generated along the direction of the wind which is called as the "drag" force

Fy - Is force which is generated perpendicular and horizontal to the direction of the wind and it is called as the "lateral" force

Fz - Is force which is generated perpendicular and vertical to the direction of the wind so it it known as the "Lift" Force

4.2 GRID AND GEOMETRY INFORMATION:

4.2.1 Data used for simulation:-

Velocity of wind: - 30 m/s or 108 km/hr
Temperature: - 28 °C
Density [kg/m³]:- 1.225
Tractor Trailer: - Stationary Position

Number of Cells: 972353
Number of Faces: 4044173
Number of Nodes: 2044604

Lower Bound [m]
X: -10.2284 [m]
Y: 0.383022 [m]
Z: -2.32915 [m]

Upper Bound [m]
X: 32.4413 [m]
Y: 6.34621 [m]
Z: 2.32915 [m]

Surface Info:
Number of Faces: 10098061
Lower Bound [m]
X: -4.13274 [m]
Y: 0.383022 [m]
Z: -1.66368 [m]
Upper Bound [m]
X: 8.05861 [m]
Y: 4.35848 [m]
Z: 1.66368 [m]

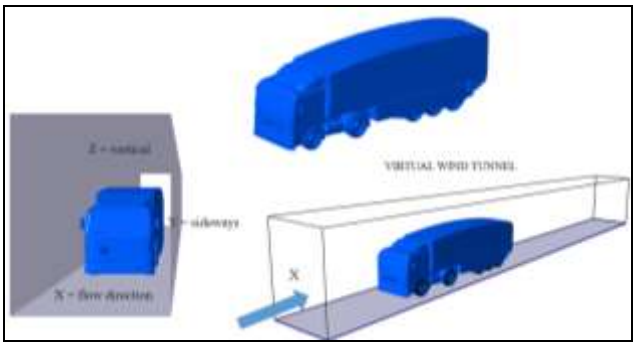


Fig. 4.2 Geometry Information

4.3 FLOW ANALYSIS (CFD)

With a CFD analysis, we can understand the flow throughout a design process. The basic methodology for any engineering CFD analysis is based on a few procedures:

- Understanding Flow separations, transient effect, and physical interactions.
- Proving Experimental results validation, parametric studies, structural simulations;
- Model optimizing — reducing pressure drops, flow homogenization, improving laminar and turbulent flow.

Without numerical simulations of fluid flow, it is very difficult to imagine how vehicle designers can improve aerodynamic characteristics.

4.3.1 SURFACE PRESSURE DRAG

When the air attack at the frontal surface of the tractor, the pressure builds up, so that produces a force. At the rear of the trailer, the air is dragged along, dropping the pressure, creating a wake due to turbulence of air which is flowing above and below of the body behind the trailer. While calculating the pressure over the whole surface of the tractor-trailer, the total force acting on the tractor-trailer body can be obtained. To know the drag only we have to find out the component of the total force that is directed along the wind direction and this phenomenon is known as pressure drag.

A high pressure acting on the front of tractor-trailer will push it back, producing aerodynamic drag. Frontal facing surfaces with facing upstream of the air have positive pressure, or backward facing surfaces with facing downstream of the air have negative pressure that produces aerodynamic drag. On another hand forward-facing surfaces with negative pressure, or backward facing surfaces with positive pressure help in reducing aerodynamic drag. Here the maximum pressure is 101863.79 Pa and minimum 99226.383 Pa

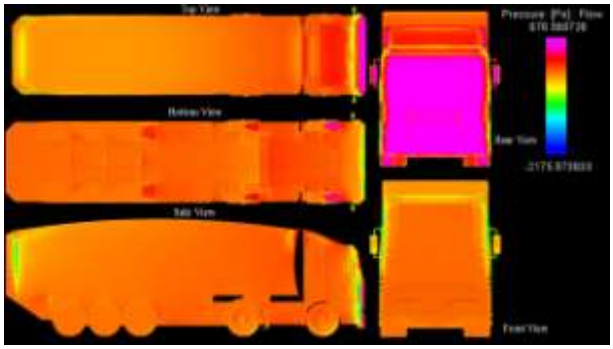


Fig. 4.3 Surface Pressure

5.3.2 STREAMLINE FLOW

Streamlines provide various understandings. First of all, by the use of streamline, we can observe the changes like laminar flow zones (steady streamlines) to turbulent zones (swirling streamlines). The changeover from laminar to turbulent frequently occurs when the airflow is incapable to follow the surface of the tractor-trailer, because of the "negative angle". Due to this there is increased aerodynamic drag. Also, there is the observation of incompressible air, speed up and slowing of air which depends upon the velocity of the wind.
In this, the maximum velocity of wind goes till 40.642 m/s or 146.3112 km/h due to the geometry design which is almost better for decreasing drag because the wind will directly contact with the air which comes below the trailer body.

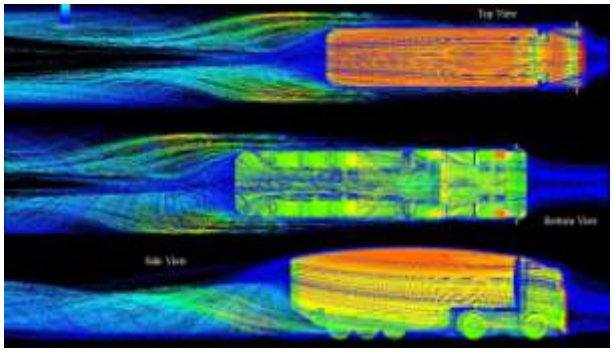


Fig. 4.4 Streamline Flow

4.3.3 TURBULENCE EFFECT

The pressure distribution around the tractor-trailer gives more hints on the details for the drag change with the introduction of upstream turbulence. The turbulence on a trailer body many effects in various way such as an increase in wake region, drag coefficient also un proper stability.

So to improve this here is design change that reduces the turbulence energy. The major changes are trailer rear tail vanes and curve trailer body also by adding tractor and trailer gap-filling vanes.

By using rear wider tire also reduces the turbulence on a tractor-trailer.

At last the overall 12% of tractor-trailer efficiency will increase by improving the turbulence area and this leads to increasing the fuel efficiency, tractor stability and wind noise.

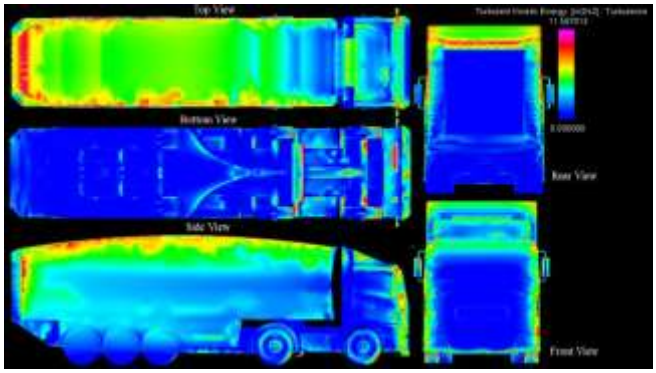


Fig. 4.5 Turbulence Energy

V. RESULTS

The figure showing the frontal wind effect and in different condition like pressure, turbulence & pressure.

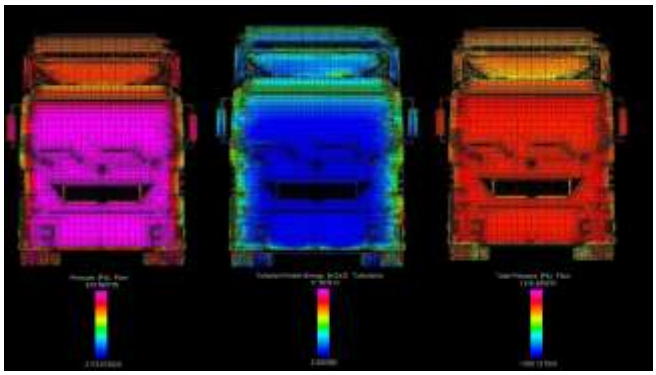


Fig. 5.1 Frontal Pressure, Turbulence, Total Pressure

5.1 FORCE ACTING ON TRACTOR

Maximum Force 155000 N at 40.642 m/s or 146.3112 kmph on tractor frontal area

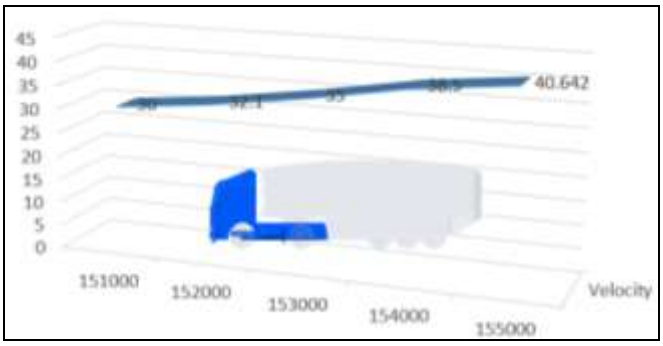


Fig. 5.2 Forces Acting on Tractor

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Force – N
Velocity - m/s

	151000	152000	153000	154000	155000
Velocity	30	32.1	35	38.5	40.642

Table. 5.1 Forces Acting on Tractor

5.2 FORCE ACTING ON TRAILER

Maximum Force 155700 N at 40.642 m/s or 146.3112 kmph on trailer body

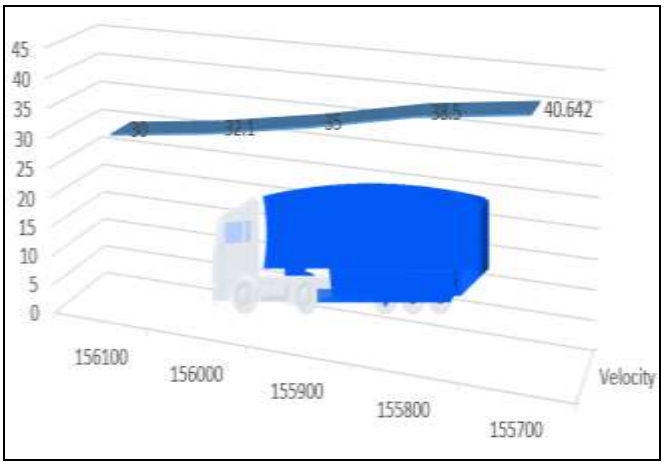

Fig. 5.2 Forces Acting on Trailer

Force – N
Velocity - m/s

	156100	156000	155900	155800	155700
Velocity	30	32.1	35	38.5	40.642

Table. 5.2 Forces Acting on Trailer

	Maximum	Minimum
Velocity	40.642 m/s (146.3112 Km/h)	37.354 m/s (134.4744 Km/h)
Turbulence	11.567 m2/s2	0

	Maximum	Minimum
Pressure	101863.79 Pa	99226.383 Pa
Friction	439.713 Pa	647.274 Pa
Total	102303.503 Pa	99873.657 Pa

Table. 5.3 Total Result

The above detail showing the result of the maximum velocity of wind when it hit the frontal area of the tractor. Also, it shows the maximum and minimum pressure rising on a tractor-trailer.
Surface friction pressure is also given.
The total pressure of the wind is also given in the table which is generated due to the hitting of wind on the body.

VI. CONCLUSION

The Aerodynamic analysis of a tractor-trailer with new changes in design is having a better drag coefficient reduction because it has low frontal pressure as compared to a normal tractor-trailer.
The fuel consumption will be improved as there would be a less opposing force acting on its frontal area and a trailer body.
Changing the overall design of tractor-trailer decreases aerodynamic drag by 33% which thusly lead diminishment in fuel utilization by up to 7% and also reduction of diesel CO2 emission.
The goal of this project is to design such a truck body or vehicle body that will experience minimal amount aerodynamic drag while the vehicle running at higher speeds, that will.

- Increase the fuel efficiency.
- Reduce the effect of wind noise.
- Better Tractor trailer stability on highway during windy weather and cross wind condition.
- Decreasing the drag forces.
- Decreasing the turbulence and wake generation.
- Providing good airflow around the vehicle.

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