Commercial Vehicle Aerodynamic Drag Reduction: (Tipper Truck)

Prakash Shakti[1], Sachin Patel[2,] Satyavrat Patel[3]
[1](Assistant Professor Automobile Department, KJIT Vadodara, India)
[2](Assistant Professor Automobile Department, KJIT Vadodara, India)
[3](Assistant Professor Automobile Department, KJIT Vadodara, India)
Savli, Vadodara India

Abstract- *The main objective of this work is to design best roof deflector for tipper truck according to Indian truck market. The all work is done by 3D design and simulation software. By improving the tipper aerodynamic or drag force we can get better fuel efficiency, better tipper stability, improved road holding and reduction in wind noise level.*

Keywords — *Roof deflector, Tipper, Aerodynamic, Drag, Wind tunnel, Streamline, Fuel efficiency.*

I. INTRODUCTION

The truck population in India has grown at a rate of 7.2% per annum between 1950-51 to 1990-91. At this moment in time, there are over 1300 trucks per million population and the consumption of trucks is around 70,000 kms/year. The trucking industry is a very significant performer in goods movement, carrying over 54% of the tonne km.

According to India market a such type of tipper truck having 5883 CC Engine with maximum power and torque, 177.68 bhp @ 2400 rpm and 675 Nm @ 1500 rpm which carry load of 18550 kgs and give a maximum of 3 km per litter mileage that is not much suitable for any truck owner.

Fig. 1 Tipper Used In India

The consistent requirement for better fuel efficiency, more prominent vehicle performance, Decrease in wind noise level and enhanced road holding and stability for a vehicle rolling, has elevated vehicle maker to examine the way of air resistance or drag for various body shapes under different working conditions. Aerodynamic is the investigation of a strong body traveling through the climate and connection which takes bind between the body surface and the encompassing air with changing connection speeds and wind course.

Many Indian Trucks for example Tata, Mahindra, AMW, Bharat Benz, Ashok Leyland and Volvo has Container or dump type body which is connected with cabin and the drag pressure increases in between the cabin and dump due to the a long plate which cover the roof of the cabin and that is attached with dump. An air turbulence occurs in between dump and cabin. This tipper trucks take a 3 to 4 running round per day covering 600 to 800 km per day with or without load. So they need more power and require more fuel to run. Thus keeping this all data a research has done for better fuel efficiency for such truck by improving aerodynamic shape and a better streamline air flow over the tipper cabin and body.

Aerodynamic drag is generally immaterial at low vehicle speed yet the size of air resistance gets to be distinctly impressive with rising velocity.

Heavy duty Commercial vehicles are considered efficiently wasteful contrasted with other ground vehicles due to their un-streamlined body shapes. A large commercial vehicle going at 75 km/h consumes about around 47% of the overall fuel to give energy to defeat the Aerodynamic drag. Interestingly, a traveller auto under a similar driving conditions, devours around 4 times less to beat drag. For the most part, an overwhelming commercial vehicle's yearly mileage can change between 120,000 km and 150,000 km. In this way, any reducing of Aerodynamic drag will bring about huge fuel saving funds. In spite of the fact that a critical exertion was made by specialists over the decade to create different fuel saving device for heavy commercial vehicles, there are still extensions to additionally decrease the aerodynamic drag.

Right now most trucks are furnished with different fuel Saving device or additional items utilizing streamlined shapes in front as well as various parts of the truck to limit drag. Without out changing the anticipated frontal range of the truck, it is conceivable to change the states of the truck incorporating the holder confine a more streamlined way. These outside connections can limit streamlined drag in view of their outer shapes, sizes and positions

Aerodynamic drag (*D*) depends on the size of a vehicle (projected frontal area, *A*),
The drag coefficient (*CD*) which is a measure of the flow quality nearby the vehicle, and the square of the vehicle speed (*V*) as expressed in Eq. (1).

$$D_A = \frac{1}{2} ev^2 C_D A \qquad \text{eq. 1}$$

where,*p* is the air density.
Aerodynamic drag with a tipper truck typically accounts for about 70-75% of the total resistance to motion at 75 km/h. Therefore, reducing aerodynamic drag contributes significantly to the fuel efficiency of a tipper truck. Therefore, the essential goal of this work is to explore the potential outcomes for further reduction of aerodynamic drag utilizing streamlined fairings with different blends keeping in mind the end goal to build its viability.

II. Pressure Distribution tipper Body

The diagram of **fig**.1 show the dominant percentage drag regions on a tipper truck which are the tipper front face ,cabin-Container gap, under carriage/wheels, and tipper base.

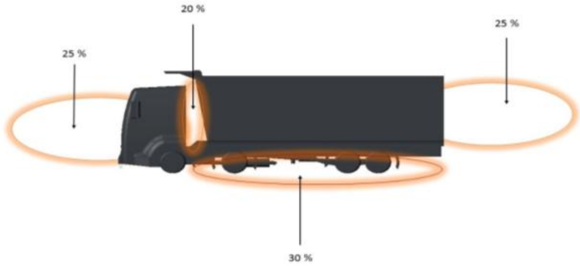

Fig 2. Drag Percentage

The frontal and rear area of tipper has 25% of drag and 30% drag occur undercarriage and 20% in between the cabin and Container body and this all cause in high pressure on a tipper which effect the fuel economy of the vehicle.
To better understand the technical challenge of drag reduction, it is important to understand the distribution of the drag between the cabin and Container, see figure 2.

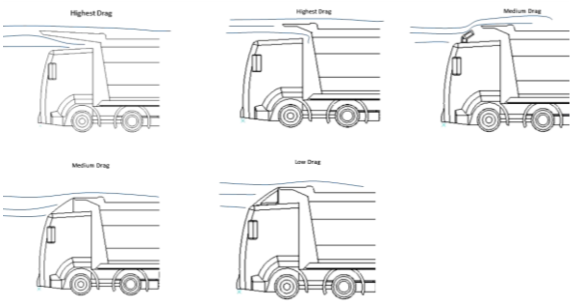

Fig 3. Air flow separation on tipper

As can be seen the pressure dispersion demonstrates a positive pressure district air spread over the uncovered front face of the tipper body with its most extreme force simply over the level of the roof, this difference the negative weight created wind stream in the forward locale of the tipper roof brought on by the wind stream isolated turbulence.
By fitting a cabin roof deflector the patter of wind current is occupied upward and over the top of tipper body, there being just a slight level of stream partition at the front end of the tipper body roof. Here there is three types of deflector is outlined and utilized.
Therefore the wind current moves specifically between the cab roof redirector and the top of the tipper body, it in this manner cause the air pressure in the cab to trailer crevice to reduction this negative weight being more articulated on the uncovered upper vertical face of the tipper subsequently the front face upper district of the tipper will really lessen that part of drop delivered by the uncovered frontal zone of the tipper, on the other hand the negative weight made by the wind stream over the main edge of the roof bombs quickly, showing early wind stream re connection.

III. Drag force (Air Resistance)

- Drag is the largest and most important aerodynamic force.
- Drag force is defined as the force acting in the opposite direction of vehicle motion.
- Aerodynamic drag is defined by the following equation

$$D_A = \frac{1}{2} ev^2 C_D A$$

Where,
C_D = Coefficient of aerodynamic drag
A = Frontal area of the vehicle (m^2)

- Drag force is a function of vehicle drag's coefficient C_D and frontal area and velocity V.
- Drag occur specially at higher speed (especially higher than 70 km/hr.)
- Overcoming drag uses approx. 60% of the fuel used when loaded and 40% when empty.
- Sharp corners, racks and parts that stand out will include "parasitic drag", additionally lessening fuel effectiveness.
- Aerodynamic drag is influenced by the vehicle shape, frontal region and speed. The more noteworthy the frontal area of a vehicle or the higher its speed, the more noteworthy the Aerodynamic drag will be.

Amount of drag depends:-

i. Size and shape of vehicle: - A thick body's body vehicle cause drag their streamlined body.

ii. Vehicle Surface: - Rough surface cause more drag than a smooth polished one.

iii. Vehicle Speed: - Aerodynamic drag increase as the square of speed. In general it is observed that 60% of the power required in cruise at highway speed is used to overcome (minimizing) drag translate in to improved fuel efficiency.

iv. Frontal area- Drag force is directly proportional to the frontal area more frontal area cause more drag.

v. Inclined Windshield: - Drag also depends upon the position of wind shield. Inclined wind shield gives good streamlined shape hence reducing the drag force.

The gross flow over the body of a vehicle is governed by the relationship between velocity and pressure expressed in Bernoulli's Equation.

$$P_{static} + P_{dynamic} = P_{total}$$

$$P_S + ½\, p\, V^2 = P_t$$

Where,

p = Density of air

V = Velocity of air

vi. The fuel utilization of a vehicle running over a specific timeframe T is normally characterized as the proportion:

$$B = \frac{\int_0^T \dot{b}\,dt}{\int_0^T V dt}$$

Where b is the volume fuel rate and the denominator is basically the separation gone in T seconds.

The fuel utilization is normally measured in L/100 km.

IV. Result and Discussion

The Wind Tunnel Testing was used in simulation software to measure the aerodynamic drag on the tipper truck model design. The maximum speed of air is 75 km/h.

A detail of Wind tunnel test setup is given bellow:

TABLE 1. WIND TUNNEL DIMENSION FOR TEST

Length (x)	17500 m
Height (y)	3725 m
Width (z)	2500 m

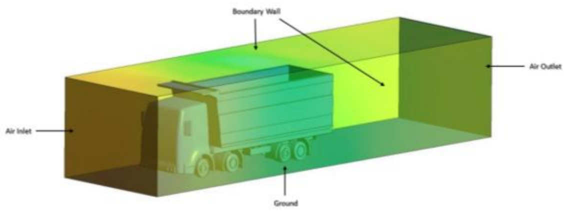

Fig 4. Wind tunnel simulation setup

In this work there have plan a model of wind tunnel whose measurements are offered by facilitate framework. Area is a prerequisite for outer streams analysis. It is a case loaded with liquid and has limits. These limits are given conditions and the liquid is given a movement.

Wind tunnel testing was connected to vehicles, not such a great amount to decide streamlined strengths but rather more to decide approaches to decrease the power required to move the vehicle on roadways at a given speed. In these reviews, the association between the street and the vehicle assumes a critical part, and this connection must be mulled over when translating the test outcomes. In a real circumstance the roadway is moving in respect to the vehicle yet the air is stationary with respect to the roadway, yet in the wind tunnel the air is moving in respect to the roadway, while the roadway is stationary in respect to the test vehicle.

TABLE 2: BOUNDARY CONDITION FOR TESTING

S.No	Objects	Property	
1.	Type	Air Ideal Gas	
2.	Reference Pressure	1.0000e+00 [atm]	
3.	Heat Transfer Model	Isothermal	
4.	Fluid Temperature	2.5000e+01 [C]	
5.	Turbulence Model	k epsilon	
6.	Flow Regime	Subsonic	
7.	Turbulence	Medium Intensity and Eddy Viscosity Ratio	
8.	Mass And Momentum (Inlet)	Cartesian Velocity Components	
9.		U	7.5000e+01 [km hr^-1]
		V	0.0000e+00 [km hr^-1]
		W	0.0000e+00 [km hr^-1]
10.	Mass And Momentum (Outlet)	Average Static Pressure	
11.	Pressure Profile Blend	5.0000e-02	
12.	Ground	Sand Grain Roughness Height 2.0000e-02 [m]	

TABLE 3. BOUNDARY FLOWS FOR CFX

Location	Mass Flow	Momentum		
		X	Y	Z
Inlet	4.6094e+02	1.6341e+04	-2.2230e-04	8.6493e-07
Outlet	-4.6139e+02	-1.0892e+04	6.7131e+02	-4.0630e+01
Road	0.0000e+00	-6.5446e+02	-3.2592e+03	-7.0425e-01
Tipper	0.0000e+00	-4.6547e+03	3.2720e+02	1.0934e+01
Wall	0.0000e+00	-3.1854e+02	2.5695e+03	2.2967e+01

A. Analysis of Non Roof Deflector 1

According to first non-roof deflector design it is found that in such type of tipper there is more drag which cause effect on fuel economy of the vehicle. Figure 5 (a) and (d) shows the pressure distribution of frontal and in between the gap of cabin and Container. Figure (b) shows the streamline or air flow motion on the tipper were figure 5 (c) show the turbulence inside the Container. Figure 5 (e) shows the drag graph and figure 5 (f) shows the velocity of air.

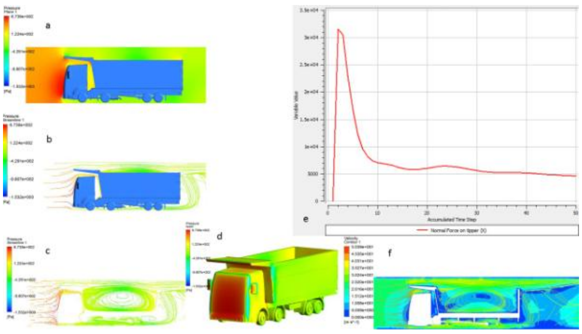

Fig. 5 Non Deflector Analysis 1

TABLE 4: FORCES AND TORQUE ON TIPPER NON DEFLECTOR 1

Type	X	Y	Z
Pressure Force	4.5936e+03	-3.2074e+02	-1.0759e+01
Viscous Force	6.1170e+01	-6.4633e+00	-1.7640e-01
Total Force	4.6547e+03	-3.2720e+02	-1.0936e+01
Pressure Torque	-1.6236e+01	3.4249e+01	-1.3070e+04
Viscous Torque	-3.5811e-01	2.0008e+00	-1.1847e+02
Total Torque	-1.6594e+01	3.6250e+01	-1.3188e+04

B. Analysis of Non Roof Deflector 2

According to second non-roof deflector design it is found that in such type of tipper there is more drag which cause effect on fuel economy of the tipper. Figure 6 (a) and (c) shows the pressure distribution of frontal and in between the gap of cabin and Container. Figure 6 (b) shows the streamline or air flow motion on the tipper. Figure 6 (e) shows the drag graph.

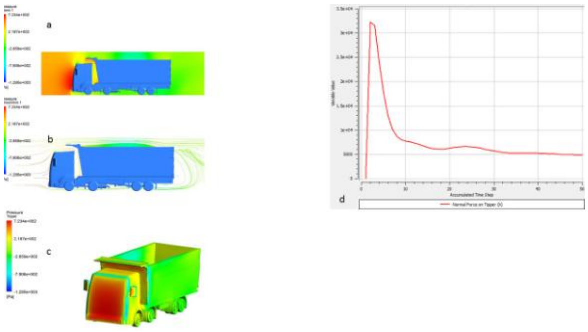

Fig. 6 Non Deflector Analysis 2

TABLE 5: FORCES AND TORQUE ON TIPPER NON DEFLECTOR 2

Type	X	Y	Z
Pressure Force	4.8264e+03	8.4624e+01	-3.0128e+01
Viscous Force	6.0886e+01	-7.0159e+00	-2.5642e-01
Total Force	4.8873e+03	7.7609e+01	-3.0385e+01
Pressure Torque	-3.4713e+01	1.4151e+02	-7.9144e+03
Viscous Torque	-1.4753e-01	2.2773e+00	-1.1798e+02
Total Torque	-3.4860e+01	1.4378e+02	-8.0324e+03

C. Analysis of Roof Deflector 1

According to first roof deflector design it is found that in such type of tipper there is medium drag which cause not more effect on fuel economy of the vehicle. The design of deflector is shown. Figure 7 (a) and (d) shows the pressure distribution of frontal area of the tipper. Figure 7 (b) shows the streamline or air flow motion on the tipper were figure 7 (c) show the turbulence inside the Container. Figure (e) shows the drag graph and figure 7 (f) shows the velocity of air.

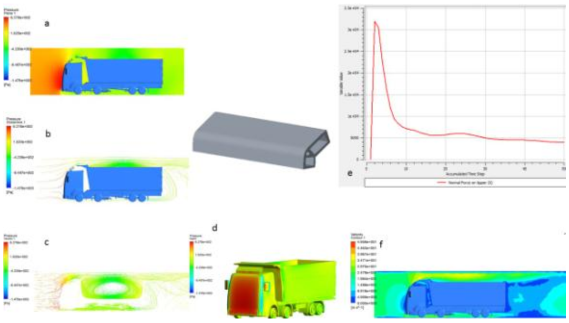

Fig. 7 Deflector Analysis 1

TABLE 6: FORCES AND TORQUE ON TIPPER DEFLECTOR 1

Type	X	Y	Z
Pressure Force	3.9277e+03	- 5.2042e+02	1.7911e+01
Viscous Force	6.8158e+01	8.4152e-01	-3.1215e-01
Total Force	3.9958e+03	- 5.1958e+02	1.7599e+01
Pressure Torque	2.2679e+01	5.3939e+01	- 8.0480e+03
Viscous Torque	2.7678e-01	4.9259e+00	- 1.0098e+02
Total Torque	2.2956e+01	5.8864e+01	- 8.1490e+03

D. ANALYSIS OF ROOF DEFLECTOR 2

According to second roof deflector design it is found that in such type of tipper there is medium drag which cause not more effect on fuel economy of the vehicle. The design of deflector is shown. Figure 8 (a) and (d) shows the pressure distribution of frontal area of the tipper. Figure 8 (b) shows the streamline or air flow motion on the tipper were figure 8 (c) show the turbulence inside the Container. Figure 8 (e) shows the drag graph and figure 8 (f) shows the velocity of air.

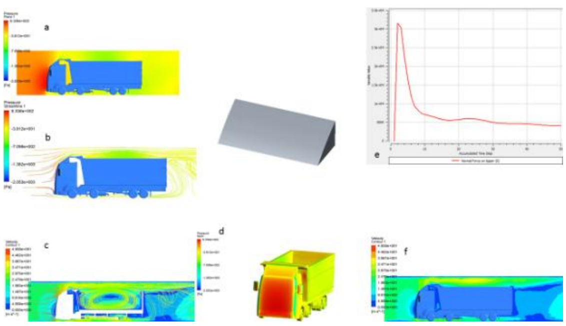

Fig. 8 Deflector Analysis 2

TABLE 7: FORCES AND TORQUE ON TIPPER DEFLECTOR 2

Type	X	Y	Z
Pressure Force	3.9883e+03	- 4.1847e+02	2.9108e+01
Viscous Force	6.9661e+01	2.2116e+00	-2.4368e-01
Total Force	4.0579e+03	- 4.1626e+02	2.8864e+01
Pressure Torque	5.3659e+01	- 5.3118e+01	- 7.5319e+03
Viscous Torque	-4.3448e-01	3.4860e+00	- 1.0401e+02
Total Torque	5.3225e+01	- 4.9632e+01	- 7.6359e+03

E. ANALYSIS OF ROOF DEFLECTOR 3

According to third roof deflector design it is found that in such type of tipper there is low drag which beneficial for fuel economy of the vehicle. The design of deflector is shown. Figure 9 (a) and (d) shows the pressure distribution of frontal area of the tipper. Figure 9 (b) shows the streamline or air flow motion on the tipper were figure 9 (c) show the turbulence inside the Container. Figure 9 (e) shows the drag graph and figure 9 (f) shows the velocity of air.

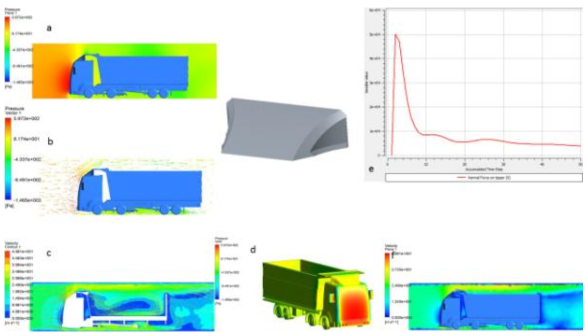

Fig. 9 Deflector Analysis 3

TABLE 8: FORCES AND TORQUE ON TIPPER DEFLECTOR 3

Type	X	Y	Z
Pressure Force	3.9085e+03	- 3.9533e+02	8.0827e+01
Viscous Force	7.3201e+01	2.6265e+00	-2.0946e-01
Total Force	3.9817e+03	- 3.9270e+02	8.0617e+01
Pressure Torque	1.2184e+02	- 1.7882e+01	- 7.3807e+03
Viscous Torque	- 1.0874e+00	3.0311e+00	- 9.7350e+01
Total Torque	1.2076e+02	- 1.4851e+01	- 7.4780e+03

F. COMPARISON OF ANALYSIS RESULT

From the above analysis the drag force on a tipper is given as well as lift and side forces which is tested on 75 km/h wind speed.

TABLE 9. DRAG FORCE ON TIPPER

Tipper Deflector	Drag Force (N)	Lift Force (N)	Side Force (N)
Non-Deflector 1	4654.73	-3727.19	-10.935
Non-Deflector	4887.29	77.607	-30.391
Deflector 1	3995.85	-519.577	-17.603
Deflector 2	4057.92	-416.254	28.861
Deflector 3	3981.61	-392.706	80.616

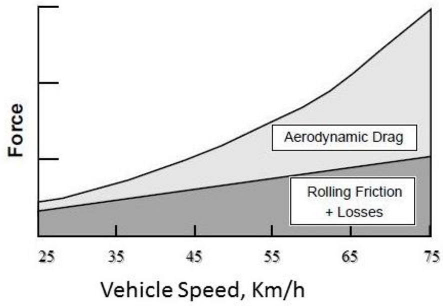

Fig. 10 Vehicle speed and drag force

From the above analysis it is observed that in non-roof deflector tipper truck the pressure is increasing when the truck speed is at 75 km/h and in roof deflector 3 the pressure is low due to low drag formation.
The different type of tipper design is shown below on which the analysis has been done.

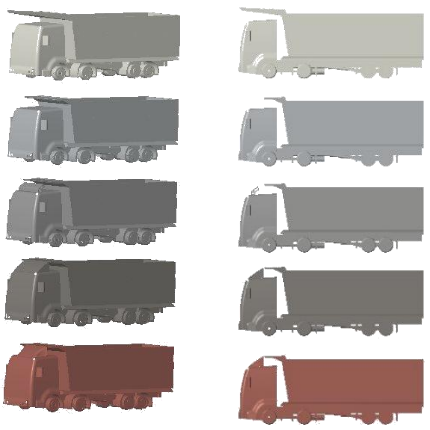

Fig 11. Different types of tipper truck model for testing.

These cabin roof deflector are beneficial in reducing the head on air flow.

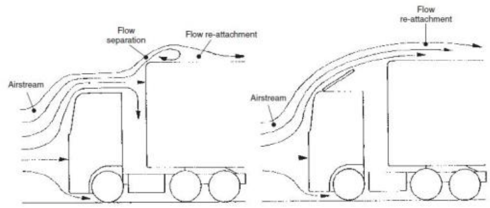

Fig. 12 Air Streamline on Truck Roof

Many investigations of Heavy Commercial Vehicles for long removed high way applications have demonstrated that critical extent of fuel losses were because of aerodynamic drag. Taken a cost down tests have demonstrated that at speed over 70 km/h, the aerodynamic drag represent 60% and rolling resistance causes 40% of total drag. In this manner outer optimal design study and recreation of Heavy commercial vehicle to diminish the aerodynamic drag accept significance in this time of high fuel costs. Heavy commercial vehicles, for example, trucks, tipper and buses have large bluff bodies without over all streamlined shape which causes solid wakes and trailing vortexes bringing about genuine streamlined drag at rapid cruising.
Speed unmistakably is a vital piece of the condition (additionally take note of that wind conditions are not thought about). At unpredictable rates, optimal design has little effect on fuel productivity, however the quicker you go it makes a difference a considerable measure. At 70 km/h, you have four circumstances the constrain conflicting with your vehicle that you had at 35 km/h (Increasing pace from 55 km/h to 65 km/h for instance builds drag by around 40 percent, bringing about a 10 to 15 percent expansion in fuel utilization).

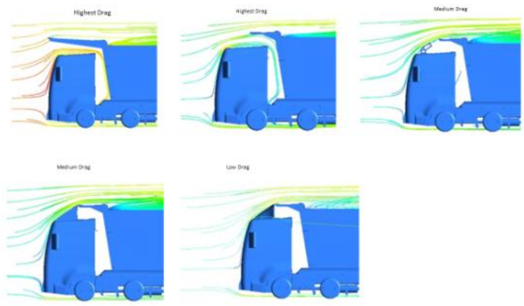

Fig.13 Streamline over tipper

Adjustable Height is produced and surveyed utilizing CFD reproduction of 3D turbulent stream around the truck, cab and container shown in figure 13. Also, the wind pressure load on air fairing were mapped on structural finite element model and the tipper deflector design was evaluated for durability.
The aerodynamic drag can be separated into two segments: viscous drag and pressure drag. For over over heavy vehicles at highway speed the Reynolds number is sufficiently larger with the viscous forces can be safely ignored. Therefore drag experienced

by a truck is principally because of weight drag which is comprises of weight constrain that exist on front and back of the vehicle. The front end is demonstrated precisely which comprise of cab, bumper, wheels and wheel arcs along with container body. Despite the fact that compartment body is ridged however for the model simplicity and size it is considered as plain box. The container body height differs so in order to get improved aerodynamic performance on all containers adjustable roof deflector is considered. Since this is a similar review with or without air deflector, for effortlessness different parts of the vehicle like mirrors, couple of under body segments are not considered.

Range of drag constrain with vehicle speed Later wind weight load on air deflector is separated and utilized for supporting strength with inertia load conditions. Correlation of stress forms with and without wind loads are appeared in the three dimensional turbulent stream around truck and the change in streamlined attributes brought about by roof fairing were numerically examined.

V. ANALYSIS RESULT IMAGES

The given image shows the Mass and Momentum on tipper truck, velocity stream line, turbulence of air inside the container of tipper and streamline of air.

Non-Roof Deflector Design 1

It is having higher pressure at its frontal area i.e. 4.6547e+03.
Drag Force (x) is 4654.73 N or 474.6504 kg force
Lift Force (y) is -327.196 N or -33.3647 kg force
Side force (z) is -10.9355 or -1151 kg force

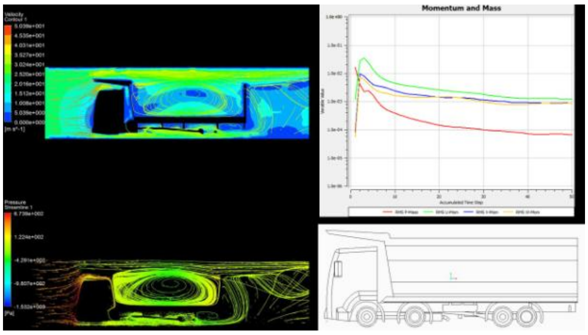

Fig. 14 Pressure and Momentum & Mass

Non-Roof Deflector Design 2

It is also having more pressure at its frontal area i.e. 4.8264e+03.
Drag Force (x) is 4887.29 N or 498.3649 kg force
Lift Force (y) is 77.6077 N or 7.9138 kg force
Side force (z) is -30.3912 or -3.099 kg force
Speed of Sound is 3.4621E+02 (Wind Noise)
Reynolds Number is 8.6428E+06
Momentum and Mass and Turbulence KE is 1.84E+03 66.5 %

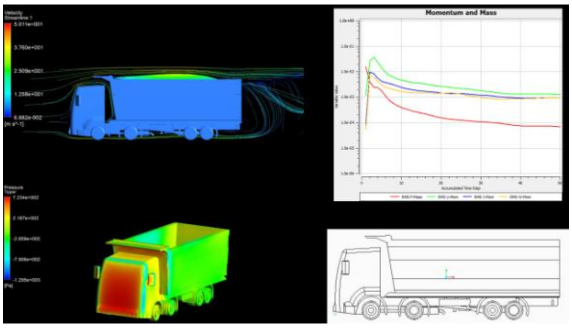

Fig. 15 Pressure and Momentum & Mass

Deflector Design 1

It is having medium pressure at its frontal area i.e. 3.9277e+03
Drag Force (x) is 3995.85 N or 407.4633 kg force
Lift Force (y) is -519.577 N or -52.9821 kg force
Side force (z) is -17.6033 or -1.795 kg force
Speed of Sound is 3.4621E+02 (Wind Noise)
Reynolds Number is 8.8358E+06
Momentum and Mass and Turbulence KE is 1.89E+03 65.7 %

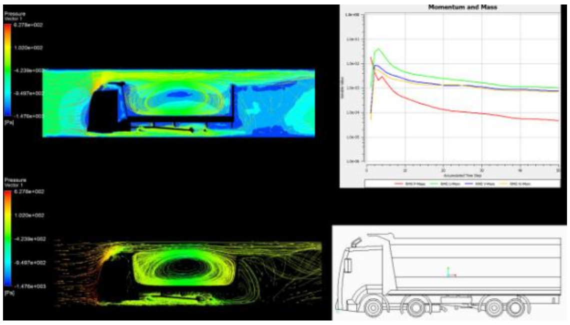

Fig. 16 Pressure and Momentum & Mass

Deflector Design 2

It is also having medium pressure at its frontal area i.e. 3.9883e+03.
Drag Force (x) is 4057.92 or 413.7927 kg force
Lift Force (y) is -416.254 or -42.4461 kg force
Side force (z) is 28.861 or 2.943 kg force
Speed of Sound is 3.4621E+02 (Wind Noise)
Reynolds Number is 8.7682E+06
Momentum and Mass and Turbulence KE is 1.67E+03 66.0 %

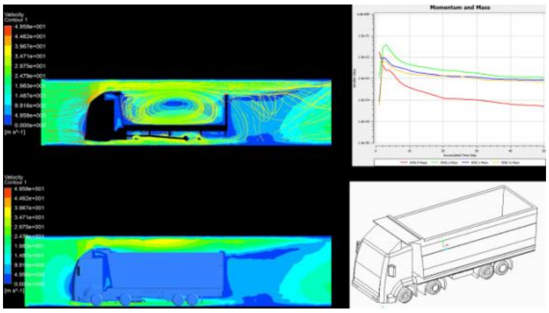

Fig. 17 Pressure and Momentum & Mass

Deflector Design 3

It is having low pressure as compare to other at its frontal area i.e. 3.9817E+03.
Drag Force (x) is 3981.67 or 406.0173 kg force
Lift Force (y) is -392.706 or -40.0449 kg force
Side force (z) is 80.619 or 8.4248 kg force
Speed of Sound is 3.4621E+02 (Wind Noise)
Reynolds Number is 8.8404E+06
Momentum and Mass and Turbulence KE is 2.08E+03 70.9 %

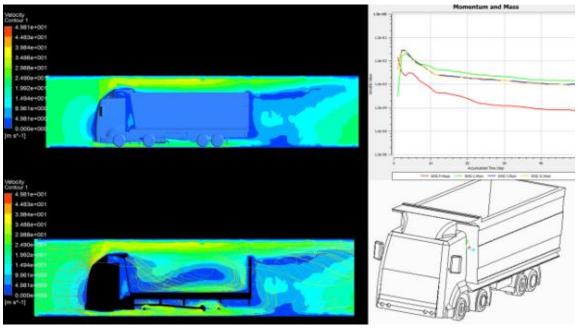

Fig. 18 Pressure and Momentum & Mass

VI. Conclusions

The Aerodynamic analysis of a tipper truck with roof deflector 3 Drag Force (x direction) is 3981.67 or 406.0173 kg force results (3.9 N) in an efficient drag coefficient as compare to non-roof deflector or other roof deflector design for tipper truck and in which the fuel consumption can be improved as there would be less opposing force acting on its frontal area and on a Container body.

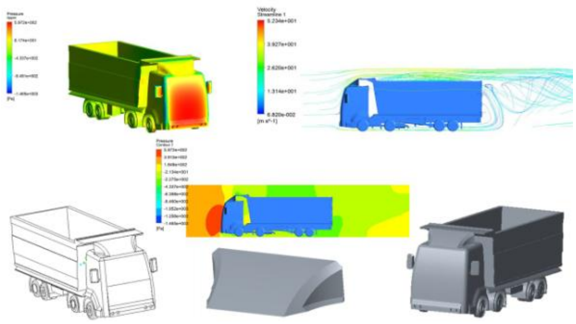

Fig. 19 Final roof deflector for tipper trucks

Contributions to power consumption from drag and rolling resistance for a tipper truck. Relationship between changes in drag and changes in fuel consumption

Power = D×U + RR×U + AuxP
Fuel Consumption ≡ FC = (bsfc) × Power

Keeping roof deflector over Tipper level roof cabin with holder decreases aerodynamic drag by 22 % which thusly lead diminishment in fuel utilization by 1.5 to 2 %. It was accommodated that Wind weight impact the auxiliary durability of air deflector mounting section.

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