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Study Of Air Flow Over The Truck Using OpenFOAM

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Abstract- In this current study the hybrid mesh and the k-ω turbulence model were adopted to investigate the variations of the aerodynamic loads and the flow field of heavy-duty truck while moving on the road with the velocity of 40 km/hr, 50 km/hr, 60 km/hr, 70 km/hr and 80 km/hr. The results showed that, with the variation of the gap between cabin and trailer the forces acting on truck were changes. Drag Force and Lift Force were compared against the different combinations of the cabin and trailer using open source CFD Software OpenFOAM. Geometry was made in CATIA. Meshing was done using unstructured mesh tool of OpenFOAM called as snappyHexMesh. Steady incompressible flow simulations were performed for a modified full scale version of the geometry to evaluate drag reduction.

Keywords: OpenFOAM, Drag force, Lift force, blockMesh, CFD, snappyHexMesh

Introduction

The performance, handling, safety and comfort of an automobile are significantly affected by its aerodynamic properties. Low drag is important for good fuel economy and low emission. Increasing fuel prices and stringent regulations have made this long established relationship now widely acknowledged. But the other aspects of vehicle aerodynamics are no less important for the quality of an automobile, directional stability, wind noise stability, soiling of lights, windows and body, cooling of an engine, gearbox and brakes and finally heating, ventilating and air-conditioning of the passenger compartment. These all depend on the flow filled around and through the vehicle.

In terms of fluid dynamics, road vehicles are bluff bodies in very close proximity to the ground. Their external geometry is extremely complex. There are also internal ducts and recessed cavities and they communicate with the external flow. The flow over a vehicle is fully three-dimensional. Boundary layers are turbulent. Flow separation is common and may be followed by the reattachment. Large turbulent wakes are formed at the rear, and in many cases they interact with longitudinal vortices shade from the after body. As is typical for bluff bodies like Truck, drag is primarily pressure drag. Accordingly, the avoidance of separation or, if this is not possible, its control among the main objective of vehicle aerodynamics.

While a large number of effective drag reduction devices have been developed and are commercially available [1], adoption in the trucking industry has been relatively insignificant due to infrastructure, legislative, maintenance, staffing, and aftermarket barriers which have rendered them cost ineffective to the majority of trucking companies. A good example of such technology is the base flap, which has seen slow adoption in spite of drag reductions in excess of 10%. While there clearly is the potential for substantial drag reduction in the base region of the trailer, any changes to this area of the truck have to be made in light of severe restrictions imposed by existing infrastructure and operational norms. The underbody of the truck offers an area with less potential but with the type of restrictions which are more amenable to engineering solutions. Moreover, drag reduction devices which target consumables like mud flaps are more likely to be tried and adopted, since they must often be changed due to normal wear. The underbody is, however, by no means a blank slate on which the aerodynamicist may impose his/her will; there are practical restrictions in terms of ground clearance and ease of access for maintenance and inspection which have proven to prevent the adoption of extant devices such as side skirts. There are also less obvious issues such as the effect of any drag devices on brake cooling flows, as well as splash and spray.

In this paper mainly concentration is given to numerical investigation of truck without wheel and different combinations of truck based on gap between cabin and trailer at different speed. Here evaluation of coefficient of drag, coefficient of lift, drag force, lift force are done by OpenFOAM Software.

Methodology

The OpenFOAM (Open Field Operation and Manipulation) CFD toolbox is used to analyze the airflow through the bus geometries for both close and open window bus. OpenFOAM has extensive range of features to solve anything complex fluid flow involving chemical reactions, turbulence, and heat transfer to solid dynamics and electromagnetic.

The bus model both open and close is made in CATIA V5. It is then converted into the stereolithogrphy (STL) file. STL file is then linked to snappyHexMesh for generation of mesh. potentialFoam was used to generate initial flow. By giving initial boundary conditions calculations were done by using simpleFoam and finally postprocessing was done by using ParaFoam.

The velocity and pressure distribution over the geometries are visualized and discussed. Through the aerodynamic analysis a contour of pressure and velocity that impacts the truck body is studied. Then accordingly coefficient of drag, coefficient of lift, drag and lift force are calculated. In this case for the flow analysis the tyre portion is not taken into the consideration.

Mathematical Formulation

Drag Force (F_D): Aerodynamic drag force is the force acting on the vehicle body resisting its forward motion. This force is an important force to be considered while designing the external body of the vehicle, since it covers about 65% of the total force acting on the complete body. The drag coefficient is dimensionless quantity that describes vehicle aerodynamic resistance and is useful tool for comparing different vehicle shapes .The Aerodynamic drag force is calculated by the following formula:

$$F_D = \frac{1}{2}\rho V^2 C_D A \qquad (1)$$

where

F_D = Drag Force

C_D = Drag Coefficient

A = Frontal Area Of The Vehicle

V = Wind Velocity

ρ = Air Density

Lift Force (F_L)

Lift force causes the vehicle to get lifted in air as applied in the positive direction, whereas it can result in excessive wheel down force if it is applied in negative direction. Engineers try to keep this value to a required limit to avoid excess down force or lift.The formula usually used to define this force is written as:

$$F_L = \frac{1}{2}\rho V^2 C_L A \quad \ldots\ldots\ldots\ldots\ldots (2)$$

where:

F_L = Lift Force

C_L = Lift Coefficient

A = Frontal Area Of The Vehicle

V = Wind Velocity

ρ = Air Density

The cases discussed are as follow:

1. Truck without wheel.
   a) Gap Variation
   b) Cover Gap

Actual dimensions of Bus

Overall length of Truck - 9.9m

Overall width of Truck– 2.3m

Overall height of Truck – 3.2m

Overall gap size between cabin and trailer-1m

Case 1:a)Gap Variation

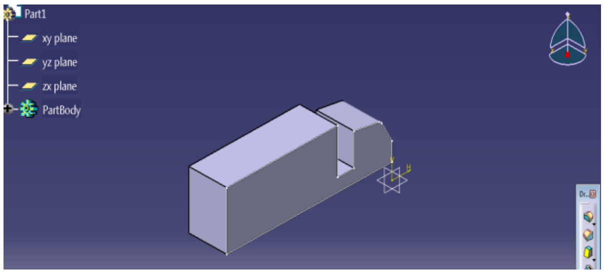

Fig 1 Gap between cabin and trailer is 1000mm

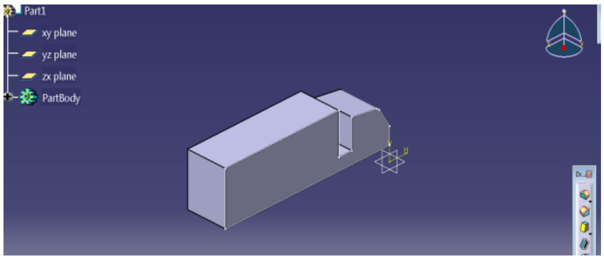

Fig 2 Gap between cabin and trailer is 800mm

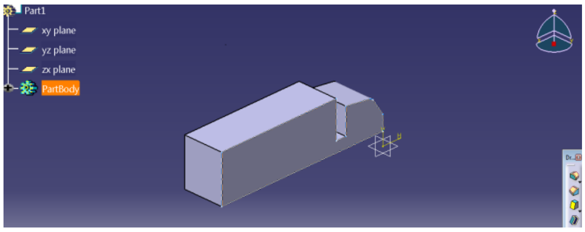

Fig 3 Gap between cabin and trailer is 600mm

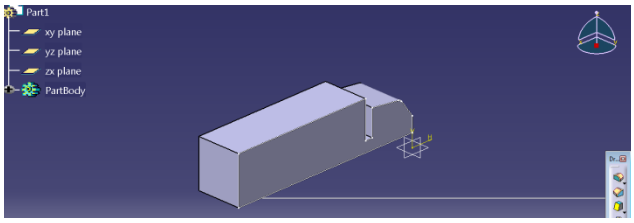

Fig 4 Gap between cabin and trailer is 400mm

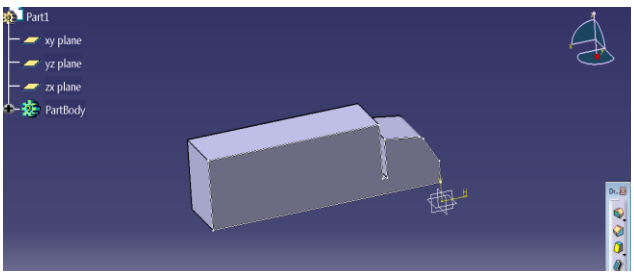

Fig 5 Gap between cabin and trailer is 200mm

Case 1:b)Gap Covered

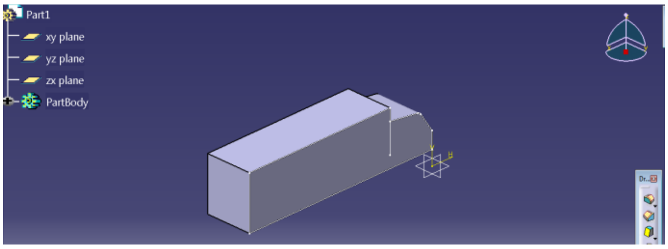

Fig 6: No gap between cabin and trailer

Computational set up

Different cases were considered in order to achieve the given goals. However, the simulation setup is the same for all the cases and hence the procedure is same for all cases. The first step required to begin a new simulation is to input the actual mesh into the file structure of OpenFOAM .The geometry is created in CATIA V5. It is then converted into the stereolithogrphy (STL) file.

Domain specifications

The computational domain is designed to lead to a free flow with negligible blockage, which essentially means a box that consist of a inlet, a outlet, two sides, a roof and ground surface. When the geometry was defined in the creation of the computational mesh, all faces of the domain were assigned names. The names of the inlet and outlet planes (at x = 0 and x = L) are front face and back face of domain as velocity inlet and pressure outlet respectively. The names of the planes at y = L, z=0, and z=L are outer wall as wall. The names of the model are car as a wall.

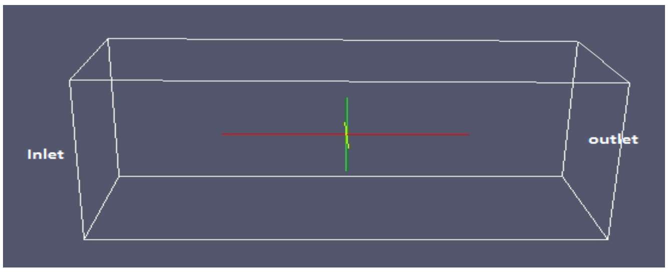

Fig.7 Defining the Domain

Mesh

Mesh is created using snappyhexmesh, OpenFOAM's native meshing tool. Utility snappyHexMesh is used to create high quality hexdominant meshes based on arbitrary geometry. It is controlled by parameters in the le snappyHexMeshDict. It can be executed in parallel. It preserves the feature edges, addition of wall layers. Details of mesh size is given in the following table.

Table 1 Details of mesh size

No.of points	No.of cells	No.of faces	No.ofinternal faces
2185655	1986273	6157320	5963048

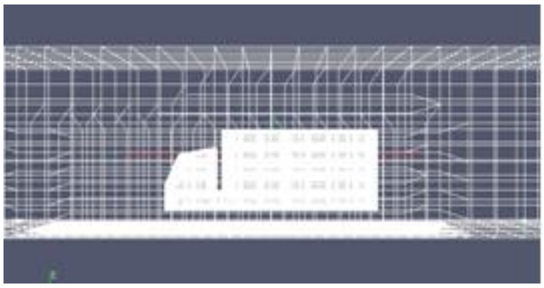

Fig.8 Side view after meshing

Boundary conditions

The tests were taken at different operating speed range such as 40 km/hr, 50 km/hr, 60 km/hr, 70 km/hr,80 km/hr. That means each geometry of truck can pass through these speed range. For example consider case 1 when it pass through 40km/hr, velocity of the inlet boundary condition is set with value 40km/hr (16.16m/s) with temperature of 300K (26.85^{0}C). The outlet boundary condition is set to pressure outlet with gauge pressure of 0 pa. The density of the air is set as 1.125kg/m^3 and the viscosity of the air is 1.7894×10^{-5} kg/(ms).

Turbulence Modeling

All of the simulations took turbulence into account with the k- ω-SST turbulence model. This model was used for its ω proven reliability in separation zones and its ability to blend a good free stream model to a good boundary layer model.

Turbulence Intensity

The turbulence intensity, *I*, is defined as the ratio of the root-mean-square of the velocity fluctuations, u`, to the mean free stream velocity, u.

$I = \frac{u'}{u}$. .... (3)

For internal flows the value of turbulence intensity can be fairly high with values ranging from 1% - 10% being appropriate at the inlet. The turbulence intensity at the core of a fully developed duct flow can be estimated as:

$I = 0.16Re^{-1/8}$ .... (4)

For external flows the value of turbulent intensity at the freestream can be as low as 0.05% depending on the flow characteristics. We are considering turbulence intensity as 0.02%.

About Turbulence Length Scale

The turbulence length scale, *l*, is a physical quantity which represents the size of the large eddies in turbulent flows. Empirical relationship between the physical size of the obstruction (or characteristic length), L, and the size of the eddy, *l*, can be used to get an approximate length scale.

l=0.07L

Turbulent Kinetic Energy(K) and Specific Dissipation Rate (ω)

Required Turbulent Kinetic Energy(K) and Specific Dissipation Rate (ω) can br find out from the following equations and table no.5.2 gives the (K) and (ω) for our selected operating speed range.

Turbulent Kinetic Energy (K) $= \frac{3}{2}(UI)^2$ (6)

Specific Dissipation Rate (ω) $= \frac{K^{1/2}}{C\mu^{1/4} \times l}$ (7)

Table 2: values of K and ω

Sr. no.	Speed in km/hr	Speed in m/sec	K	ω
1	40	11.11	0.074	0.709
2	50	13.88	0.115	0.886
3	60	16.66	0.166	1.064
4	70	19.44	0.226	1.241
5	80	22.22	0.296	1.4195

Result And Discussion : Considering Case 1 each model running at different speed as follows:

Table 3 Value Of Drag Coefficient At Different Speed For Case 1(a),(b) Combinations

Distance (mm)	Cd At 40km/hr	Cd At 50km/h	Cd At 60km/hr	Cd At 70km/hr	Cd At 80km/hr
1000	0.9859	1.1545	1.1525	1.1493	1.1497
800	0.9695	1.1337	1.1317	1.1856	1.1366
600	1.1288	1.1292	1.1284	1.1282	1.1304
400	1.1282	1.1253	1.1247	1.1266	1.1194
200	1.1118	1.1104	1.1094	1.1083	1.1063
0	1.0431	1.0430	1.0441	1.0444	1.0440

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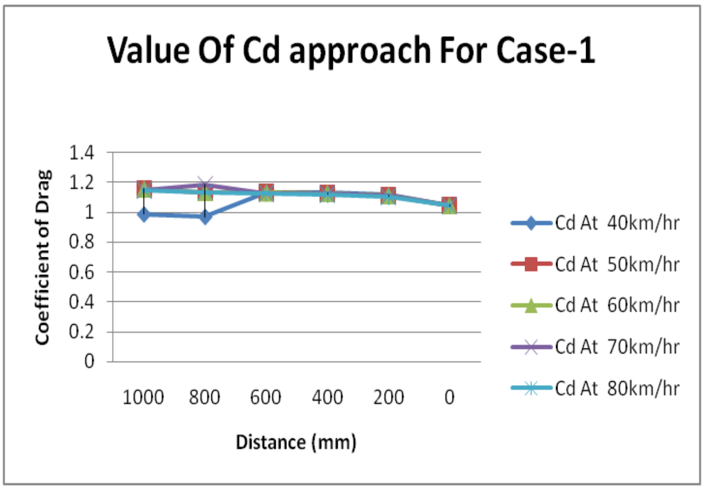

Fig.9 Graph of C_D v/s Speed(km/hr)

Observations:

1. As the distance between cabin and trailer decreases coefficient of drag also decreases.

2. Coefficient of drag remains almost constant at all the speed for each combination but slightly decreases with respect to speed 40km/hr when the gap between cabin and trailer is 1000mm, 800mm.

Pressure contour

a)At Speed 50km/hr

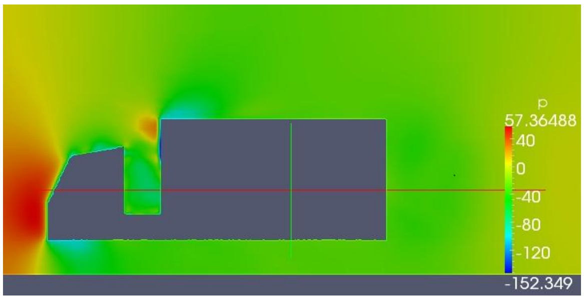

Fig 10 Gap between cabin and trailer is 1000m

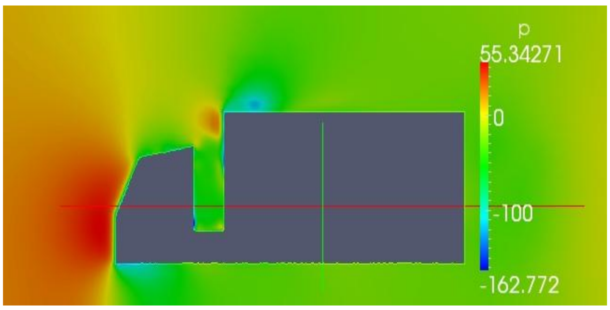

Fig. 11 Gap between cabin and trailer 800mm

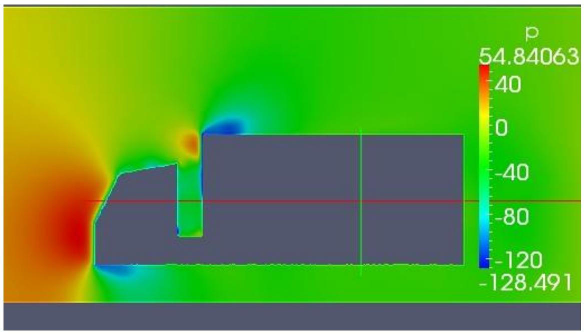

Fig. 12 Gap between cabin and trailer 600mm

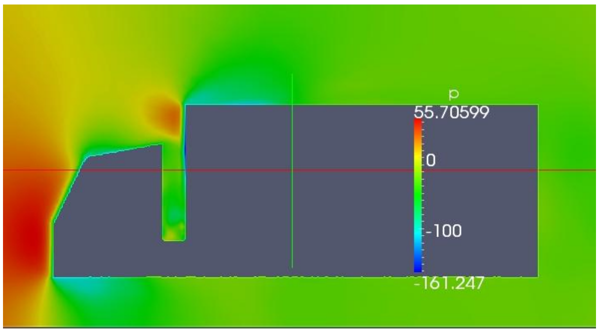

Fig. 13 Gap between cabin and trailer 400mm

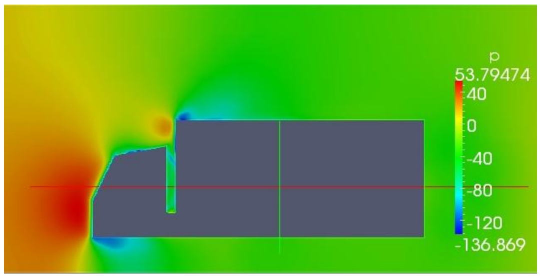

Fig. 14 Gap between cabin and trailer 200mm

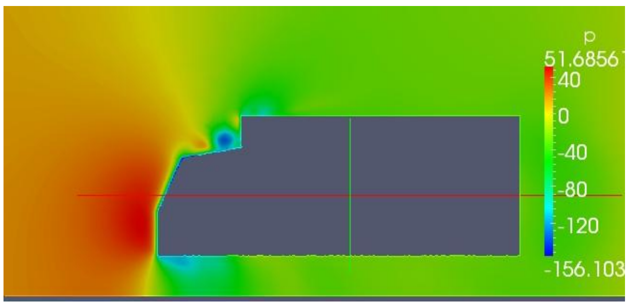

Fig.15 No Gap between cabin and trailer

a)As the gap between cabin and trailer decreases the pressure counter also decreases by some amount.

b)When the gap is covered the coefficient of drag decreases more hence less pressure counter is occurred at this combination of the current model.

Vector Plot for KE

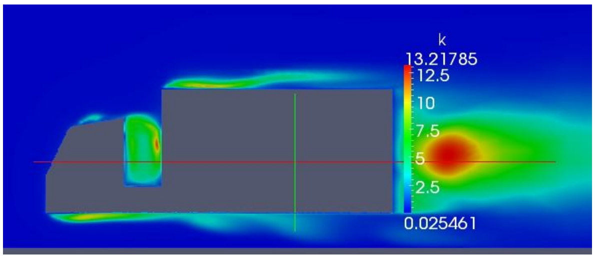

Fig 16 Gap between cabin and trailer is 1m & speed 50km/hr

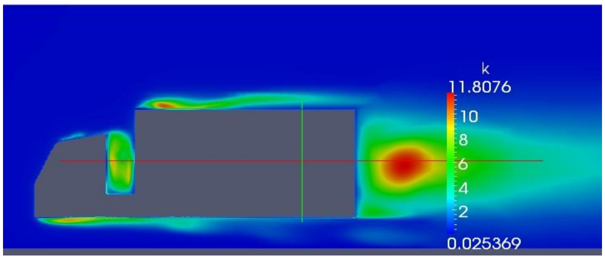

Fig 17 Gap between cabin and trailer is 800mm & speed 50km/hr

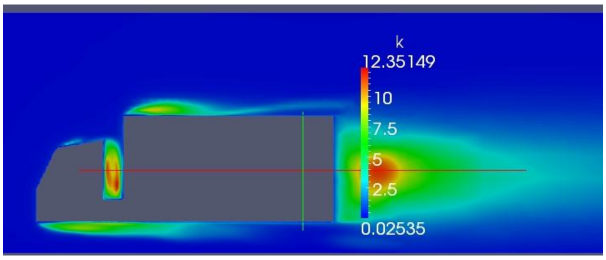

Fig 18 Gap between cabin and trailer is 600mm & speed 50km/hr

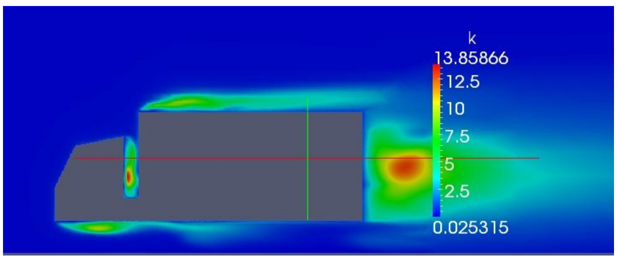

Fig 19 Gap between cabin and trailer is 400 & speed 50km/hr

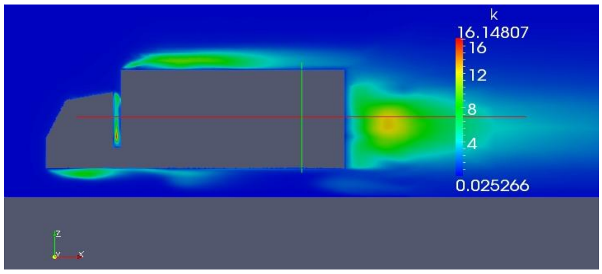

Fig 20 Gap between cabin and trailer is 200 & speed 50km/hr

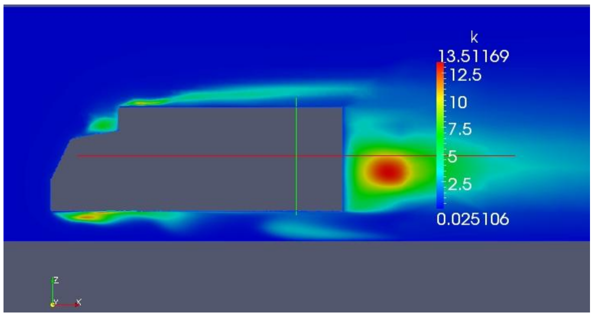

Fig 21 No Gap between cabin and trailer & speed 50km/hr

Pressure contour

a)At Speed 80km/hr

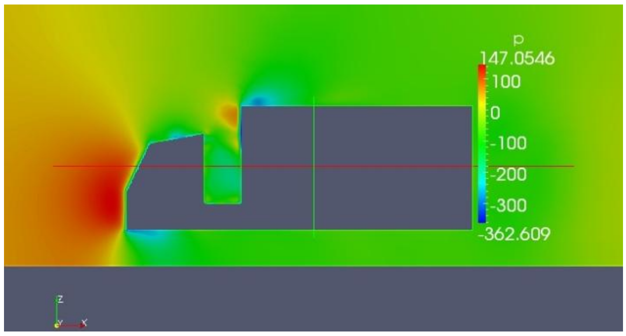

Fig 22 Gap between cabin and trailer is 1000mm & speed 80km/hr

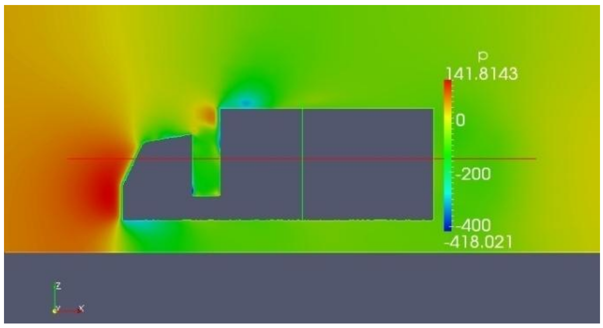

Fig 22Gap between cabin and trailer is 800mm & speed 80km/hr

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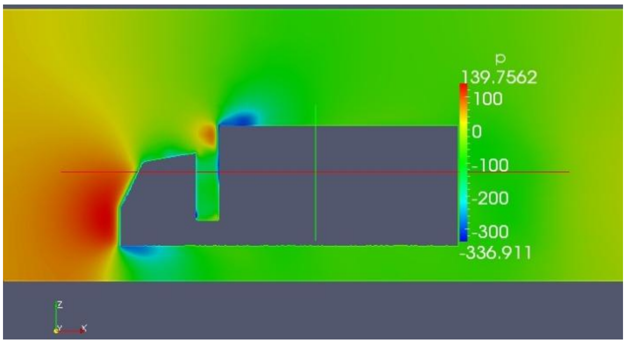

Fig 23 Gap between cabin and trailer is 600mm & speed 80km/hr

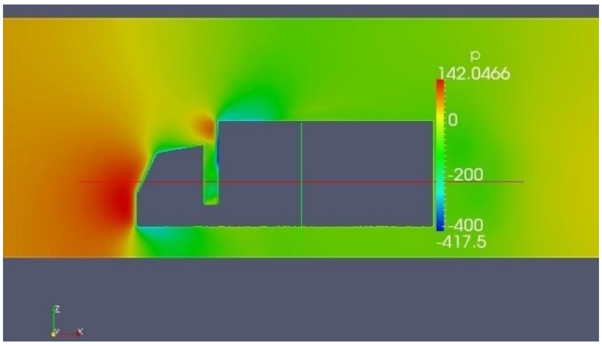

Fig 24 Gap between cabin and trailer is 400mm & speed 80km/hr

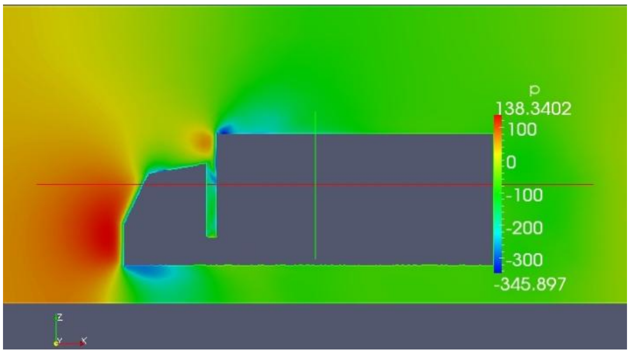

Fig 25 Gap between cabin and trailer is 200mm & speed 80km/hr

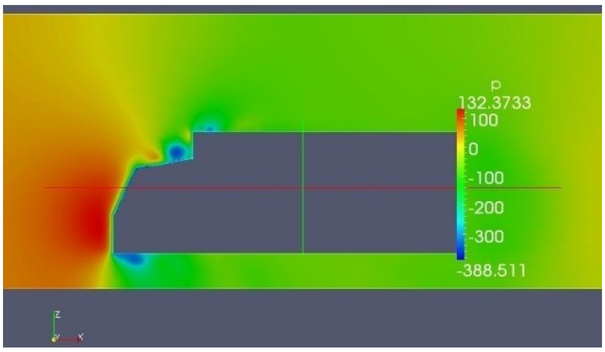

Fig 26 No Gap between cabin and trailer & speed 80km/hr

a)As the gap between cabin and trailer decreases the pressure counter also decreases by some amount.

b)When the gap is covered the coefficient of drag decreases more hence less pressure counter is occurred at this combination of the current model

Vector Plot for KE

It is conclude that from all the velocity contours that air velocity is decreasing as it is approaching the front of the truck, then air velocity increases away from the truck front. The red vectors has maximum kinetic energy while blue vectors has minimum. As the speed increase the magnitude of K.E also increases and intensity of Turbulence is also increases over the truck.

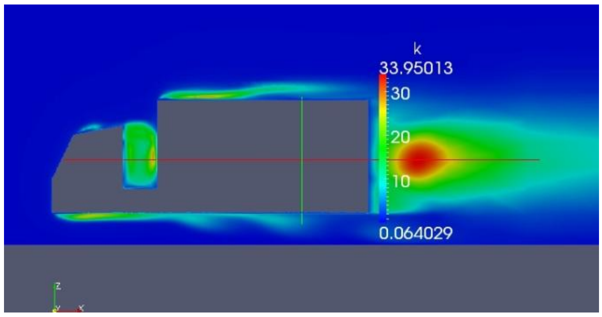

Fig 27 Gap between cabin and trailer is 1000mm & speed 80km/hr

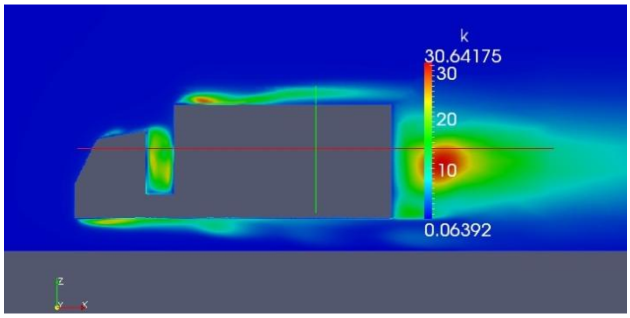

Fig 28 Gap between cabin and trailer is 800mm & speed 80km/hr

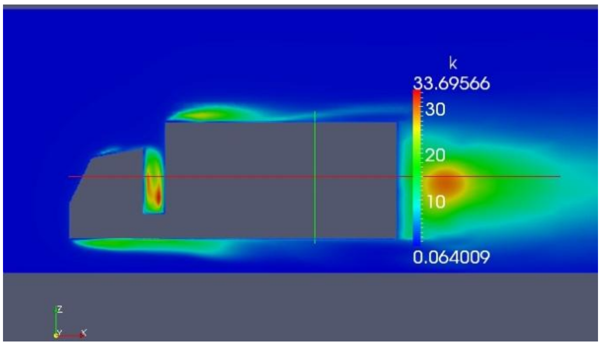

Fig 29Gap between cabin and trailer is 600mm & speed 80km/hr

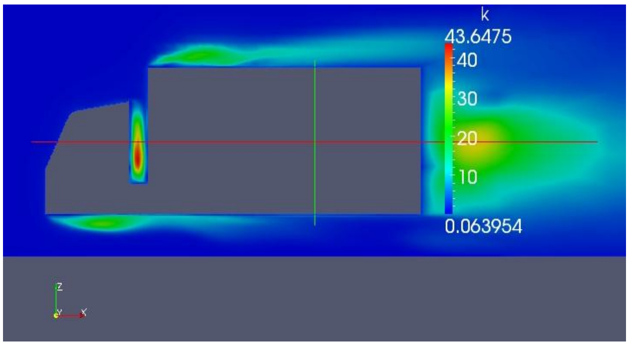

Fig 30Gap between cabin and trailer is 400mm & speed 80km/hr

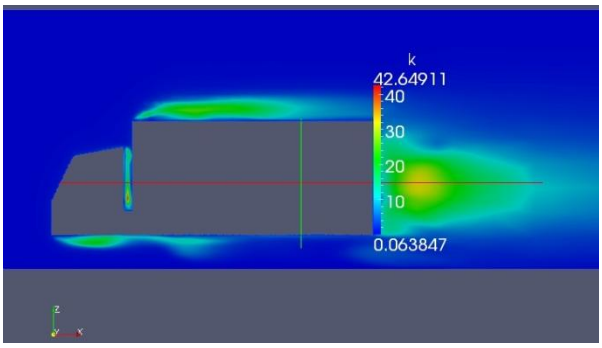

Fig 31Gap between cabin and trailer is 200mm & speed 80km/hr

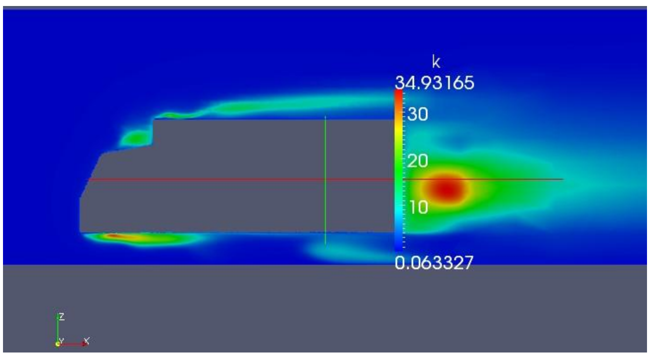

Fig 32 No Gap between cabin and trailer & Speed 80km/hr

Results At Maximum Gap Of 1000mm

Table 4: Results At Maximum Gap Of 1000mm

Speed(km/hr)	Cd	Cl	Fd	Fl	K	P	U
40	0.985999	0.234357	503.8544	119.7586	8.445	36.7653	15.8104
50	1.154564	0.270533	920.8679	215.774	13.2178	57.3648	19.7344
60	1.152566	0.255984	1324.39	294.1464	18.9805	82.7152	23.5675
70	1.149372	0.25095	1798.264	392.6272	25.9541	112.6128	27.4721
80	1.149769	0.247309	2350.169	386.9305	33.9501	147.0546	31.4652

Results At No Gap Between cabin and Trailer

Table 5: Results At Maximum Gap Of 1000mm

Speed(km/hr)	Cd	Cl	Fd	Fl	K	P	U
40	1.043125	0.254027	533.0461	129.81	8.6377	33.1048	16.1112
50	1.043007	0.257217	831.8911	205.1536	13.5216	51.6856	20.1456
60	1.044149	0.256534	1199.811	294.7778	19.481	74.5114	24.2381
70	1.044497	0.253214	1634.181	396.1694	26.5183	101.5915	28.3437
80	1.044029	0.249739	2134.032	390.7324	34.9316	132.3733	32.7339

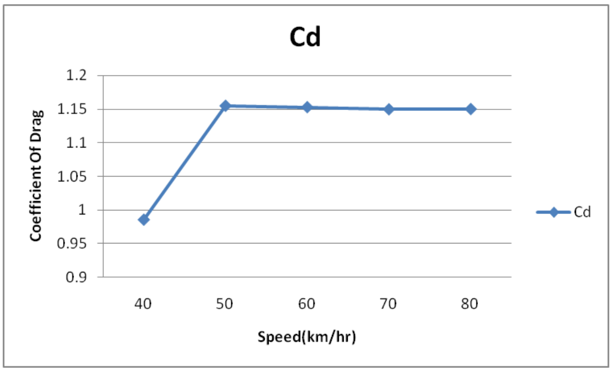

Fig.23 Values of Cd when Gap is 1000mm

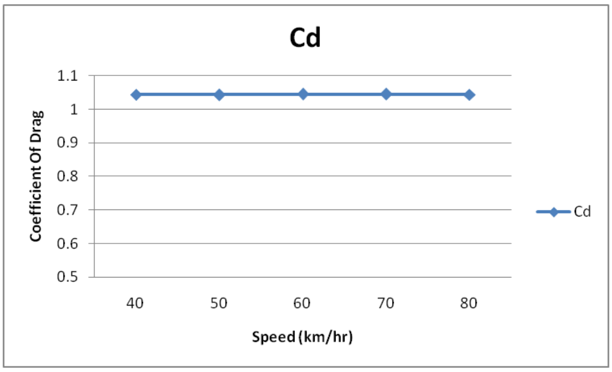

Fig.23 Values of Cd when Gap is 0mm

Conclusion

In case 1 where we have considered the truck model without wheel, we studied different combinations of cabin and truck. The gap between cabin and trailer considered as 1000mm, 800mm, 600mm, 400mm, 200mm, 0mm.If there is a gap between cabin and trailer more drag comes on the truck. From above results we can also conclude that as speed increases drag force on the truck also increases. It could be proved from the above results that as compare to lift more drag force occurs on the vehicle moving on a plane road.

Acknowledgment

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