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Aerodynamic Simulation Of A Truck Using Platooning Technique

Prasad B.Dhamale[1] and Prof N.P Jadhav[2]

[1]Department Of Mechanical Engineering, Savitribai Phule Pune University, SAE Kondhawa, Pune, India
[2]Department Of Mechanical Engineering, Savitribai Phule Pune University, SAE Kondhawa, Pune, India

Abstract
This paper investigates the aerodynamic influence on a truck in a Platooning with different yaw angles. A Platoon is a group of vehicles that can travel together, safely at high speed. The truck was modeled in a solidworks 14, analyzed for coefficient of drag; hence the drag force & fuel consumption was determined. The truck was then modified by adding boat tail shape at rear side, kept in a platoon & reanalyzed for aerodynamic simulation in ANSYS FLUENT. The results seem promising & reduction in drag force, hence fuel consumption was reduced by 24%.

Keywords:*Platooning, Aerodynamics,, Drag Force, Coefficient Of Drag, Yaw Angle*

1. Introduction

Automotive aerodynamics is the study of the aerodynamics of road vehicles. Its main goals are reducing drag and wind noise, minimizing noise emission, and preventing undesired lift forces and other causes of aerodynamic instability at high speeds. Air is also considered a fluid in this case.

The performance, handling and comfort of an automobile are significantly affected by its aerodynamic properties. A long drag is a decisive prerequisite for good fuel economy. Increasing fuel prices and stringent legal regulations ensures that this long established relationship becomes more widely acknowledged.

Nalanagula S., VaradharajG.T.et al. done the work on trucks from the major commercial vehicles required to transfer goods all around the world. One Large Combination Vehicle (LCV) would consume nearly 23,200 liters of fuel for an annual ride of 100,000 km at highway cruising speeds. With the Euro 6 norms truck manufacturers have to provide reduced emission standards to sustain market and government standards. Again the care of environment has risen as an essential question in front of commercial vehicle manufacturers. Reduced fuel consumption with lower emissions is a need of a time. And Aerodynamic drag is the major culprit in attending this. Up to 65% of fuel is consumed to overcome the aerodynamic drag at highway speeds.

Various aerodynamic designs have been adopted over the period of time to reduce the drag. We can include roof deflector fairings, side skirts, aerodynamic side mirrors, rear side wake region reduction by boat tail design at back portion of commercial vehicles. This proved to be very good options in reducing drag also their efficiency is high [1].

MihelicR., Smith J., Ellis M., et al. in their work presented that the truck Platooning has great potential for reducing transport costs, by lowering fuel consumption due to improved aerodynamics from reduced air resistance, eliminating the need for an attentive driver in the second vehicle, and better usage of truck assets, by optimization of driving times and minimization of idle time. On the societal level, driving safety increases as typically 90% of all accidents are human-induced, and platooning technology prevents human errors, leading to less accidents and damages. Greenhouse gas and air-quality related emissions decrease, and congestion and traffic jams are reduced [3].

Ellis, Gargolof et al.in their study monitored engine cooling fan engagement and showed that when the fan did not engage to meet cooling needs for the trailing vehicle, the fuel savings was between 8.4% and 9.7%. This shows that maintaining enough ram air driven engine cooling now is critical to achieving fuel economy benefits. Fuel economy testing on a public highway with a 36 foot separation distance showed a fuel economy savings of a lead vehicle at 4.5% and trailing vehicle of 10% [4].

In this paper, modeling is done in SOILDWORK 14 & simulations are performed in ANSYS FLUENT. Aerodynamic drag reduction results were analyzed for a truck in Platooning for multiple yaw angles.

The Objectives of this work is to evaluate the fuel saving potential by using Platooning techniques.

2. Methodology.

The aerodynamic evaluation of platooning employed detailed geometry of the class 8 heavy truck trailer freight.The Computational Fluid Dynamics methodology used was the lattice Boltzmann method as implemented in the commercially available CFD software. Simulations were performed with full scale geometry and evaluated at 65 miles per hour. The Lattice Boltzmann method was chosen to obtain consistency with previous study performed by authors as well as providing an efficient approach to simulate unsteady flow effects. Modelling is done in Solidworks 14.0 software with the following geometry dimensions:

Overall length of the vehicle=6935mm

Width of the vehicle=2318mm

Height of the vehicle=3657mm

Weight of vehicle=15000 lbs

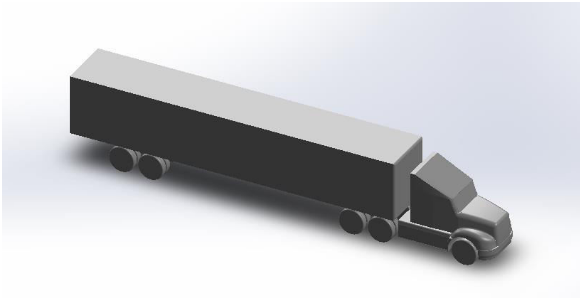

Fig.2.1 CAD model

The single vehicle Simulation geometry Is as shown in figure 2.1. Is the reference setup for evaluation of typical class 8 heavy commercial vehicle aerodynamic performance. The case consists of a single tractor and a single 5.5m trailer spaced with a 22 inch a forementioned trailer gap. Prior to platooning studies the single vehicle aerodynamic analysis has done at two different yaw angles i.e.at 0° and 6°. These analysis is been recorded for the drag reduction evaluation by platooning. The following geometry and operating conditions were considered to simulate the vehicle configuration. These conditions are as follows:

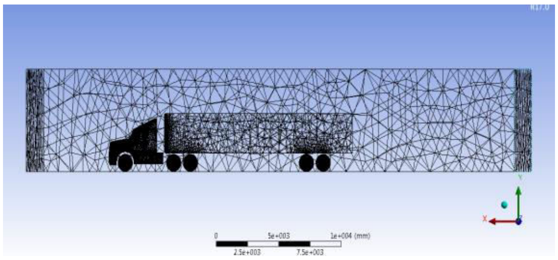

Fig.2.2 Tetrahedron meshing of cad model

Vehicle speed (mph) =65

Yaw angles (degrees) =0, 6, 12,18,24,30

Outlet pressure (atm) =1

Computational domain (m3) =16 x 5 x 6

Space = 3 dimensional

Equation of state = Constant viscosity and viscous k-epsilon Model

Truck surfaces are considered no slip condition (smooth wall condition) since friction causes the infinitesimally thin layer of air molecules immediately adjacent to the body surface to stick to the wall due to viscosity, thus it has zero velocity adjacent to the surface. The side wall of the computational domain is considered to be wall with slip condition

3. Results for the Single Vehicle Configuration

The flow structures around the body were studied along with various pressure, velocity and vorticity distributions at various locations of the vehicle. The frontal pressure is one of the major contributors to the drag.

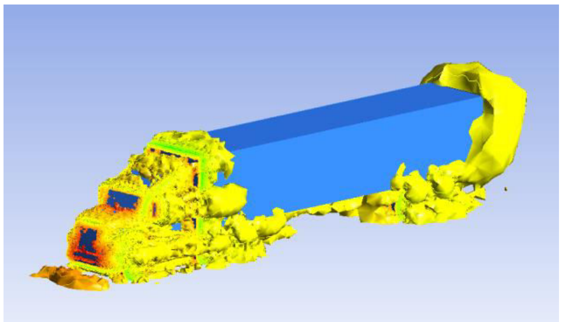

Fig.3.1 Vortices along the vehicle

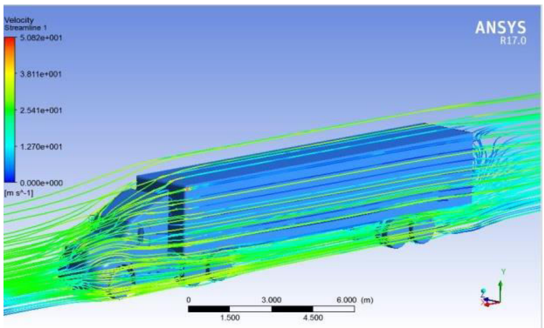

Fig.3.2 Velocity along the vehicle

The higher pressure at the front portion is responsible for the aerodynamic drag in case of single vehicle configuration. At the rear portion the low pressure wake region formed because of flow separation from the corners of the vehicle. Because of this flow separation and low pressure vortices formed at the rear portion of the vehicle. Here generally is the 2D separation takes place which is responsible for the large amount of energy loss over length of the body requiring more fuel consumption to the vehicles increasing carbon and other emissions polluting environment by increasing fuel usage. The main aim of this study is to reduce drag and thereby fuel usage.

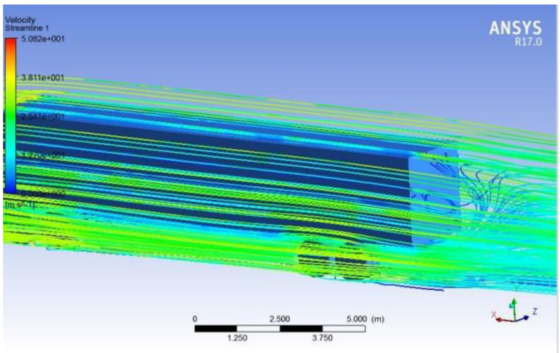

Fig.3.3 effect of low pressure at rear

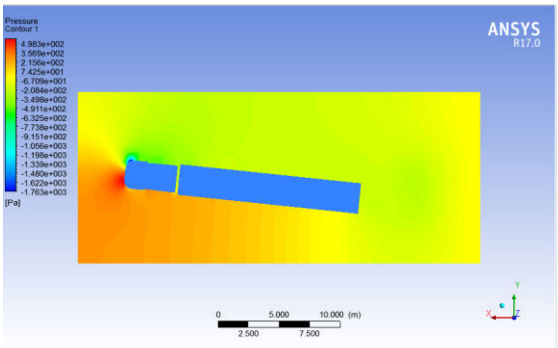

Fig.3.4 Pressure distribution at 6 degree yaw angle

As we increase the angle of yaw the direction of flow causes to act the air pressure act towards the one side of the vehicle. It causes the vehicle to increase drag by increasing the drag on the vehicle wheels. And again vehicle undergoes yawing, pitching and rolling moment.

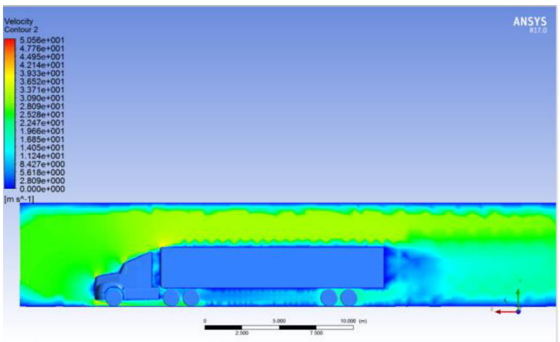

Fig.3.5 Velocity distribution at 6 degree yaw angle

The following table gives values of coefficient of drag for a single vehicle configuration at different yaw angles.

Table 3.1 Coefficient of drag on a single vehicle at different yaw angles

YAW ANGLE (degrees)	Vehicle-1	Vehicle-2	Vehicle-3
0	0.643	0.649	0.653
6	0.650	0.655	0.590
12	0.662	0.664	0.661
18	0.667	0.670	0.674
24	0.670	0.673	0.671
30	0.671	0.673	0.676

This table 3.1 and figure 3.6 shows that as we go on increasing the yaw angle the drag on the vehicle goes on increasing. But after the certain value of yaw angle the drag value increment comes to saturation and further no drag increase took place maintaining nearly constant value. This is due the increasing amount of flow at rear which increases the pressure and by decreasing pressure difference at front and at rear it reduces total drag on the vehicle.

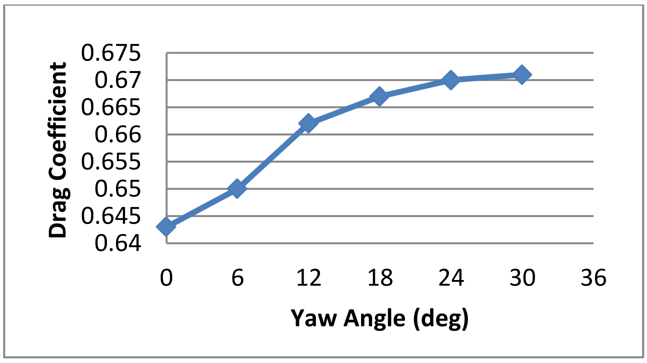

Fig.3.6 Graph showing change in drag with respect to yaw angle

4. Simulation of Vehicle in a Platoon

For the evaluation of the drag reduction capability of the platooning technique the CFD analysis of platoon of three vehicles done. The initial ambient conditions are kept same as that for the single vehicle. Initially the separation distance between the two vehicles is taken as 5 meters and then by varying the yaw angles the effect on the drag reduction analysed.

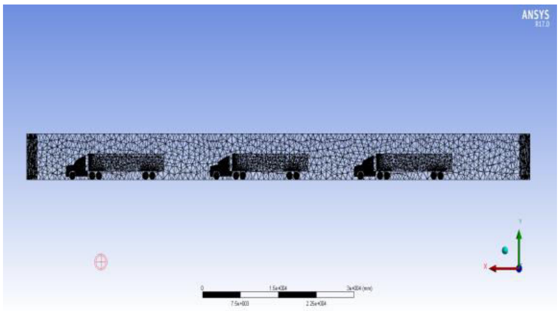

Fig.4.1 Tetrahedron Meshing of a vehicle platoon

Yaw angles (degrees) =0, 6, 12,18,24,30

Outlet pressure (atm) =1

Computational domain (m3) =45 x 5 x 6

Space = 3 dimensional

Equation of state = Constant viscosity and viscous k-epsilon Model

4.2.1 Results for the vehicle platoon configuration

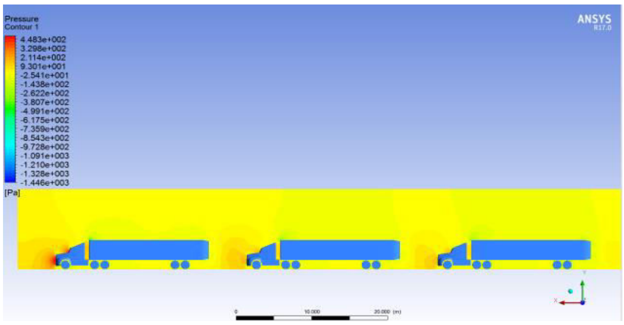

Fig.4.2 Pressure variation on a platoon with zero degree yaw angle

This pressure variation shows that the pressure at the front of the first vehicle very high as compared to the second and third vehicle while on the rear side of first vehicle the pressure increased because of the air forced by the following vehicle on the first vehicle. It reduces the pressure difference at front and rear position of the vehicle reducing the drag on it. Hence we find the reduced drag force on the first vehicle as compared to that of single vehicle.

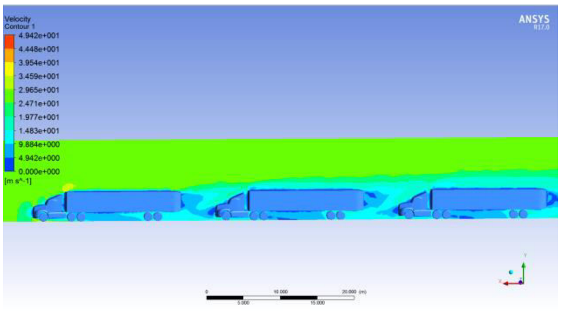

Fig.4.3 Velocity distribution around platoon at zero degree yaw

The figure 4.3 describes how the velocity goes on changing from first to last vehicle reducing the wake region behind vehicle because of platooning.

As the yaw angle goes on increasing pressure on the platoon changes increasing the drag value on the platoon initially up to certain angle after which it comes to saturation at some particular yaw angle as the flow on rear side increases, increasing pressure at rear and thus reducing drag.

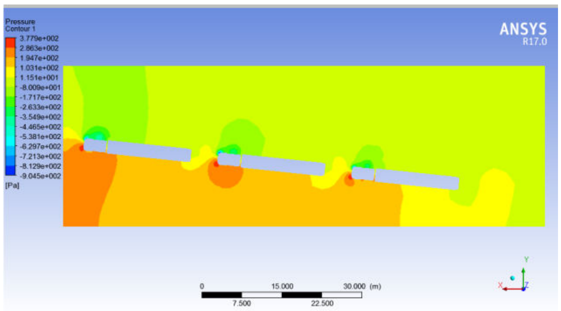

Fig.4.4 Pressure variation on a platoon at 6 degree yaw angle

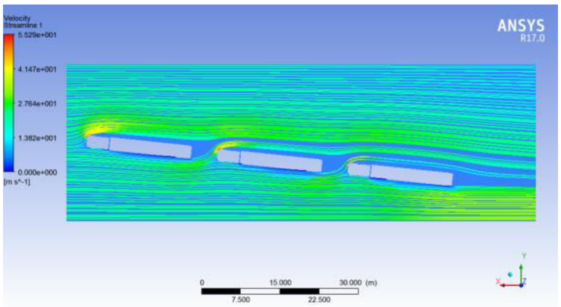

Fig.4.5 Velocity streamlines at 6 degree yaw angle

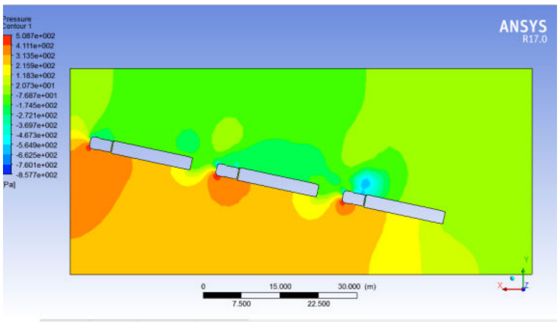

Fig.4.6 Pressure variation on platoon at 12 degree yaw angle

As the yaw angle further goes on increasing the wake area i.e. the low pressure area starts increasing on the other side of the vehicle which is opposite to the flow.

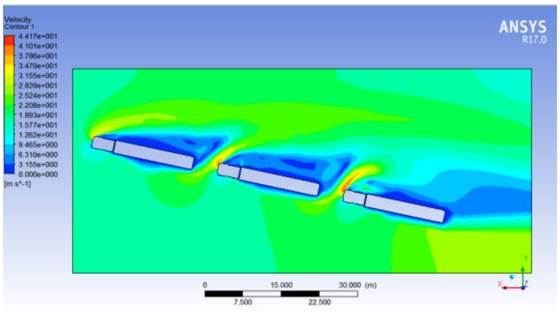

Fig.4.7 Velocity variation around platoon at 12 degree yaw angle

This will try to suck air from the rear of the vehicle reducing the pressure at rear further below increasing the drag on the vehicle. After some specific angle for a particular model the drag will begin to saturate as flow at rear increases stopping drag increment. As the velocity of the vehicle goes on increasing the drag on the vehicle increases with square of the velocity as velocity is the major parameter affecting drag.

5. Result and Discussion

After getting the results from the CFD analysis the total drag reduction ability of the platooning technique is determined. Along with this the effect of boat-tail on the drag reduction with platooning is analysed. From the total change in drag with yaw angle the fuel consumption reduction for the same system analysed. The following table shows the change in the drag coefficient with respect to the changing yaw angle and the changing vehicle speeds. Also the change in the fuel consumption of the total platoon is calculated by the formula given by Argonne national laboratory:

$$\text{Yaw Averaged Drag} = (\text{Sum of Cd of platoon}) / (\text{Sum of Cd of single vehicle})$$

$$\text{YAD}\ \% = (1 - \text{YAD}) * 100\ \%$$

The sum of Cd is Sum of coefficient of drag at different yaw angles for the particular vehicle in the platoon and estimated fuel savings given by:

$$\text{Fuel Savings}\ \% = (\%\ \text{YAD})/2$$

Table 5.1 Effect of yaw angle on drag coefficient at 80 kmph.

YAW ANGLE(degrees)	DRAG COEFFICIENT					
	% DRAG REDU	Vehicle-1	% DRAG REDU	Vehicle-2	% DRAG REDU	Vehicle-3
0	9.56	0.5815	20.34	0.5122	24.87	0.4831
6	8.91	0.5921	19.74	0.5217	22.42	0.5043
12	8.20	0.6077	18.96	0.5365	22.43	0.5135
18	8.40	0.611	17.90	0.5476	20.16	0.5325
24	7.81	0.6177	17.28	0.5542	18.63	0.5452
30	7.15	0.623	16.65	0.5593	18.17	0.5491
	Avg=8.34	Sum=3.633	Avg=18.48	Sum=3.2315	21.11	Sum=3.1277

For the first vehicle:

% YAD=1-(3.6639/3.963) = 8.30 %

% fuel Savings = 4.15 %

For the middle vehicle:

% YAD=1-(3.2315/3.963) = 18.45%

% fuel Savings = 9.23 %

For the last vehicle:

% YAD=1-(3.1276/3.963) = 21.07%

% fuel Savings = 10.53 %

Hence total platoon fuel savings = 4.15+9.23+10.53 = 24.32%

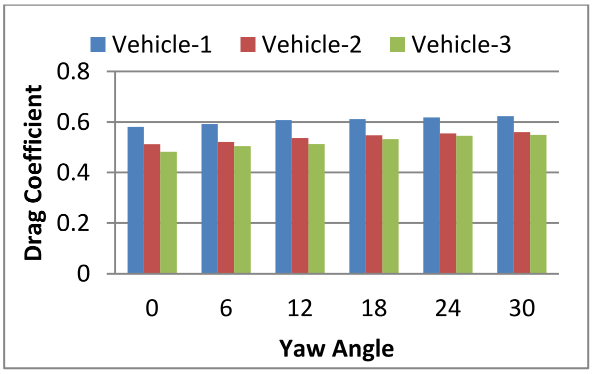

Fig.5.1Effect of yaw angle on drag coefficient at 80 kmph.

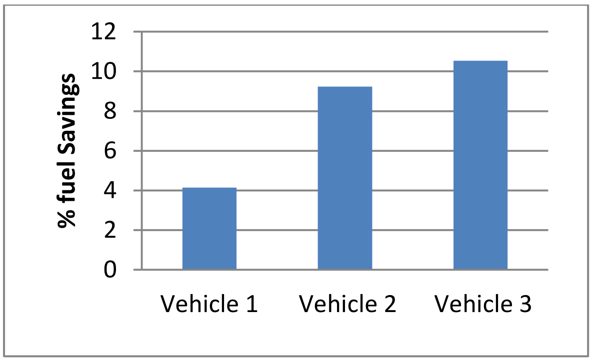

Fig.5.2 Reduction in fuel consumption in platoon vehicles

From this summarized results it can be said that the effect of platooning on the drag reduction for on highway commercial vehicles is very much significant. Along with various add-on devices like Boat-tail the Drag reduced further by 3-4 % while the fuel consumption of the vehicle platoon reduced up to 2% more than Just with platooning. In all the platooning along with the boat-tail reduces drag up to average 20% for overall platoon. Effectively drag reduction found to be higher on the middle vehicle ass compared to the vehicle at front and rear to it. The effective use of platooning thus saves fuel up to 23-26 % for the platoon reducing the emissions because of fuel.

6. Conclusion

Platooning can supplement the aerodynamic drag reduction seen from adding improved aerodynamic devices on individual tractor-trailers, with the more aerodynamic individual tractor-trailers generally having the greater average percentage drag reduction.

The decision to incorporate platooning in to the freight industry is complicated, but this study has provided information to help understand the benefits as well as the challenges of platooning as a fuel savings technology.

Highway infrastructure concerns for closely platooned vehicles may not differ significantly from those for doubles, except that current highway size and weight regulations are generally focused on single vehicle definitions. Addressing infrastructure compatibility for multi-unit platooning should include a fresh review of doubles regulations for equivalent criteria.

Reductions in aerodynamic drag, in concert with reductions in rolling resistance from fewer axles, and combined with increased net freight capability and reduced emissions, are freight hauling performance enhancements that current technology can achieve.

In a future regulatory world, where platooning is considered a viable production technology, the advantages of the double versus single tractor or trailers is an effective and proven alternative.

Truck platooning has great potential for reducing transport costs, by lowering fuel consumption due to improved aerodynamics from reduced air resistance, eliminating the need for an attentive driver in the second vehicle, and better usage of truck assets, by optimization of driving times and minimization of idle time.

On the societal level, driving safety increases as typically 90% of all accidents are human-induced, and platooning technology prevents human errors, leading to less accidents and damages. Greenhouse gas and air-quality related emissions decrease, and congestion and traffic jams are reduced.

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