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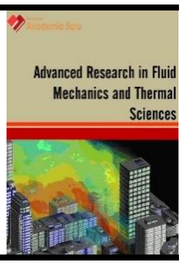

Numerical and Experimental Study on the Effect Of Cab-Extender on the Flow Characteristics of a Tractor-Trailer

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ABSTRACT

The aerodynamic drag on trucks can be reduced by use of active and passive techniques. In this work a passive method of using a cab-extender that is attached to the rear of the tractor is attempted. This cab-extender will help in reducing the drag force that act on the truck by minimizing the gap between the tractor and trailer. In this study, a tractor-trailer model was fabricated and tested in a low speed wind tunnel for its aerodynamics characteristics and the effect of cab-extender was also studied. Later Solid Works CFD package was used to study numerically the effect of this cab-extender on the aerodynamics of the truck and the results were validated against the experimental results. Finally using CFD approach the best angle of the cab-extender was reported for minimum drag.

1. Introduction

Vehicle Aerodynamics has become an important discipline in the transportation field since higher drag means the vehicle will have higher fluid resistance and which directly means an increase in fuel consumption. Bradley [1] found that about 4% of fuel saving could be achieved if the aerodynamic drag encountered by a heavy vehicle is reduced by 20% when operating at 105 km/h. As mentioned by Hsu and Davis [2] it is estimated that with a drag reduction of about 40%, 10,000 USD/year/vehicle can be saved. Even modern day trucks are among the vehicles that are not aerodynamically shaped and it can be classified as bluff bodies which produce high aerodynamic drag. Aerodynamicist is always on the lookout for reduction of this drag.

The aerodynamic drag on trucks can be reduced by use of active and passive techniques. The active techniques which requires energy and involves a control system, whereas passive techniques are simple and cost effective. Altaf *et al.,* [3] has discussed in detail various passive drag reduction techniques for bluff road vehicles. Meanwhile Sudin *et al.*, [4] presented a detailed review paper on various drag reduction techniques for vehicles. Muhammed-Kassim and Fillippone [5] carried out a

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study on fuel saving of various drag reducing retrofits. Harun *et al*., [6] made an experimental study on the effect of front fairing and side skirting on the aerodynamic drags for a range of vehicle operating speeds and yaw angles, and with different combinations.

Altaf *et al*., [7] and also Ha *et al*., [8] carried out a study on the effect of flaps on the drag reduction of vehicles. Fourrié *et al*., [9] used deflectors to reduce the drag on bluff bodies whereas Gilliéron and Kourta [10] used vertical splitter plates to reduce the aerodynamic drag. Falchi *et al*., [11] carriied out both experimental and numerical investigation of flow control on bluff bodies by passive ventilation. Pujals [12] used coherent streamwise streaks for drag reduction of a 3D bluff body. Park *et al.,* [13] studied both experimentally and numerically the drag reduction in flow over a two-dimensional bluff body with small tabs installed on the blunt trailing edge. Recently Lo and Kontis [14] stdudied the effect of vane-type vortex generator on the flow characteristics over a tractor-trailer model. Very recently, Yang *et al*., [15] examined the effect of gap on the drag characteristics of a tractor-trailer using ANSYS-FLUENT. In the present study the effect of cab-extenders on the aerodynamic characteristics of a tractor-trailer is carried out by both experimental and numerically using SolidWork CFD package.

2. Methodology

In the present work the effect of cab-extender on the drag characteristics of a truck has been studied experimentally and computationally.

For the wind tunnel test, a model of the truck was prepared with the scaled dimension of the actual size of the truck. It is to ensure the similarity of the result gained between the actual size and the scaled size. Meanwhile, for the simulation, SolidWorks was used.

A standard truck with tractor-trailer city delivery type was chosen with the dimensions of 11.5 meters long, 3.7 meters in height and 2.5 meters wide. Figure 1 shows the typical truck with and without cab-extender.

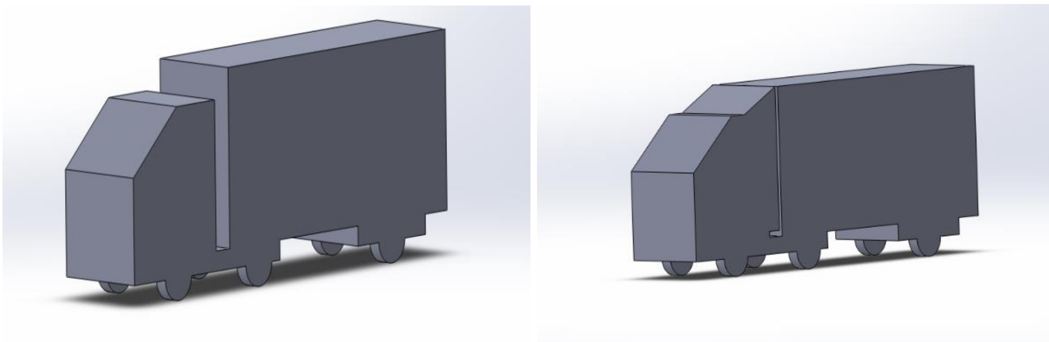

Fig. 1. Model with and without cab-extender

2.1 Experimental Model Development

In preparing an actual model for wind tunnel test, there are some criteria to be followed. The criteria are as follows

- The model should be rigid
- The model should be smooth in surface
- The model should be strong enough to resist the air flow
- There should not have any hole as it will affect the drag

In order to have strong and rigid structure of the model, the material chosen was steel and aluminium. The structure was divided into three components which were head, trailer and the base.

The angle section steel rods were cut according to the scaled dimension and these rods are welded together as shown in Figure 2 to form the skeleton of the truck structure. Then aluminium plates were used to cover up to get the final structure. A special mounting base was attached at the bottom of the truck model to hold it with the external balance of the wind tunnel.

The cab-extender was made by the aluminium plate and placed at the gap between the head and the trailer. Since it was add on, so fastening method should not be permanent as the body structure. Thus the cab-extender was installed by using the tape so it can be removed at any time.

For the finishing, all the edges of the model were covered with tapes to ensure no air will enter the inner space of the truck, as an internal flow can lead to additional drag.

Fig. 2. Model Development

2.2 Wind Tunnel Testing

Wind tunnel tests were conducted in IIUM low speed wind tunnel which is a closed circuit type and it can operate up to a maximum speed of 50 m/s. IIUM wind tunnel has a test section of 2.25m in width, 1.5m in height and 6m in length and it is equipped with a six-component force balance to measure aerodynamic forces and moments. This is a large capacity calibrated balance with an average accuracy of 0.042% of the full scale. A special mounting base was attached at the bottom of the truck model to hold it with the external balance of the wind tunnel (Figure 3). The model used in the experiment was scaled down 1:8 model with the dimensions as given in Table 1. The experiments were carried out for both high and low speeds i.e. at 15 m/s and 45 m/s, respectively.

Table 1
Size of the model for wind tunnel testing

Dimension	Size
Max. Length	1440 mm
Max. Width	315 mm
Max. Height	465 mm
Scale	1:8
Velocity	15,30 & 45 m/s

Fig. 3. Model in Wind Tunnel Testing

2.3 CFD Modelling

Models with different configuration were simulated using CFD commercial package SolidWorks to study the aerodynamic characteristic of the truck model with and without cab-extender. A large computational domain is created to simulate the wind tunnel working section as depicetd in Figure 4. The 3D model was meshed and the physics of the flow were setup. The primary variables of the flow including pressure, temperature and velocity were given and the K-Epsilon turbulence model was selecetd for all tested cases. Boundary conditions were specified on each face of computational domain starting with inlet, pressure outlet, stand and wall. For velocity at inlet, velocity of the incoming flow along the model inlet is specified. The surface of the truck and wall is specified to be a wall with no slip condition applied to it. The computational domain was specified to slip wall boundary condition which means zero shear-stress at that surface. Hence, the fluid is allowed to slip along the surfaces. After the convergence of solution, aerodynamic force and moment coefficients can be obtained.

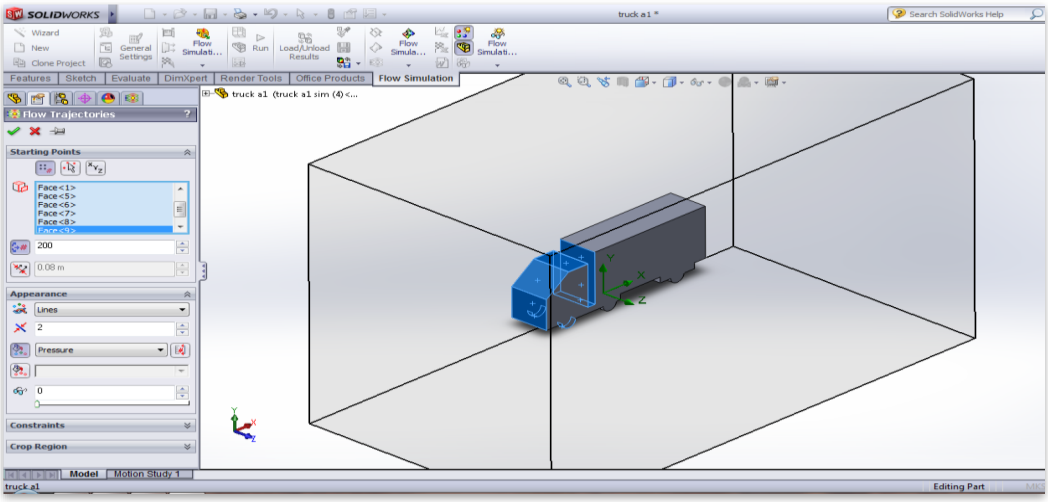

Fig. 4. Model in the CFD control volume of SOLIDWORKS

3. Results and Discussion

3.1 Experimental Validation

The model with and without cab-extender as described above in Table 1 was tested in wind tunnel and the results were recorded. The experiment was done for both high and low sped i.e. at 15 m/s and 45m/s respectively. Later the CFD simulation was carried out for the above cases and the results are recorded. Table 2 and Table 3 shows the results for drag coefficient for both wind tunnel experiment and CFD simulation for 15 m/s and 45 m/s respectively. It can be very clearly seen the results from the simulations agree very well with the experimental results. Moreover in both the cases, when the cab-extender was used, the drag coefficient reduced. Thus, It shows that model with no cab-extender will have greater drag force than the model with cab-extender. The cab-extender used in this study was at 25° angle. It can be seen from Figure 5 that without cab-extender, the flow enters the gap between the tractor and trailer and creates vortices that leads to an increase in drag coefficient, whereas with a cab-extender at an optimum angle (Figure 7) it can be completely avoided.

Table 2
Drag Coefficient of truck with and without cab-extender at 15m/s

Model	Drag Coefficient Experimental	 Simulation
No cab-extender	0.911	0.914
With cab-extender	0.808	0.787

Table 3
Drag Coefficient of truck with and without cab-extender at 45m/s

Model	Drag Coefficient Experimental	 Simulation
No cab-extender	0.863	0.856
With cab-extender	0.764	0.773

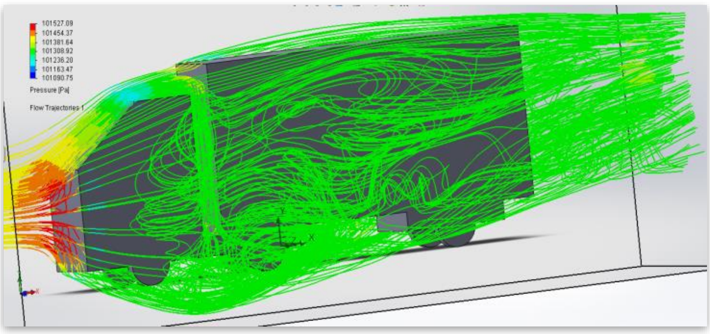

Fig. 5. Flow over the truck without cab-extender

3.2 Numerical Study on the Effect of Cab-Extender Angle on the Drag Characteristics

In this section, the effect of the angle of the cab-extender on the drag coefficient is examined. The CFD simulation was done for three different cab-extender angles 10°, 25° and 38°. The angle of the cab also affects the drag coefficient. Table 4 and Figure 6 shows that if the angle is small (10°), then the cab edge height is lower than that of the trailer, the drag coefficient will be almost the same as the truck with no cab-extender since the air still enters the gap and creates vortices. As shown in Table 4 and explained earlier, the angle at 25° has the least drag coefficient since that is the optimum angle with the height of cab-extender matching with the height of the trailer that does not allow air to enter the gap.

Table 4
Drag coefficient for different cab-extender angle and speed

Model	Drag Coefficient		
	15 m/s	30 m/s	45 m/s
No cab-extender	0.914	0.868	0.856
Cab-extender 10^0	0.878	0.855	0.844
Cab-extender 25^0	0.787	0.778	0.773
Cab-extender 38^0	0.815	0.800	0.796

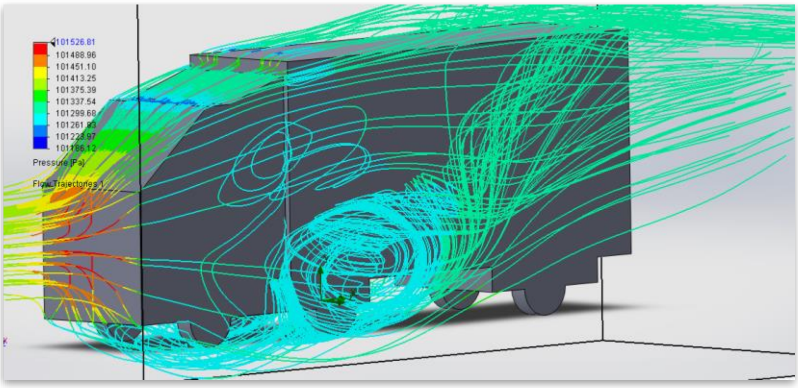

Fig. 6. Flow over the truck with cab-extender at 10°

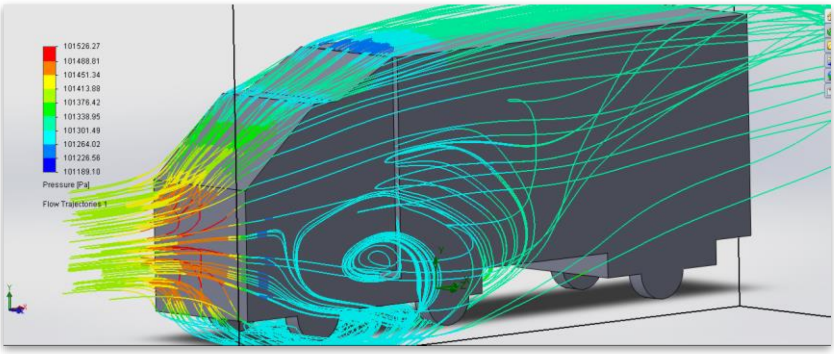

Fig. 7. Flow over the truck with cab-extender at 25°

Meanwhile, for a greater angle 38°, the height of cab-extender exceeds the height of the trailer (Figure 8), then the drag coefficient will be slightly higher than the moderate angle. Figures 5-8 depicts the streamlines of the flow over truck without cab-extender and for all the three angles of cab-extender, from which it can be noted that for 25°, the flow is moving smoothly as compared to other angles and with no air entering the gap thus leading to reduction of drag coefficient. Therefore, it can be concluded that the angle of 25° is the optimum cab-extender angle.

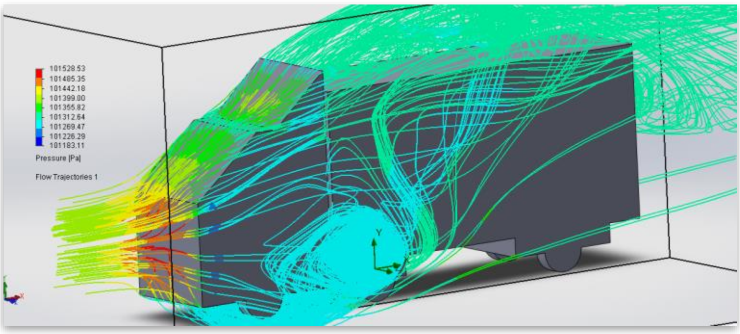

Fig. 8. Flow over the truck with cab-extender at 38°

4. Conclusions

The aerodynamic characteristics of a tractor-trailer with cab-extender have been studied both numerically and experimentally. The results obtained shows that the measured drag coefficient agreed well with CFD prediction. Moreover the results show that in order to reduce drag coefficient, cab-extender should be used so that the air flow will not enter this gap and create vortices.

Cab-extender angle and height has the strong effect on the drag coefficient. Too small angle will lead to the reduction of the cab height (lower than the trailer), thus allowing air to enter the gap. Meanwhile, too large angle will lead to the increase of the cab height, which will exceed the trailer height, thus create higher frontal area. Thus the best angle is to have an angle such that the cab-extender height matches with the trailer, which was 25^0 for this work where the drag coefficient is the lowest.

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