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A Computational Study on the Effects of Installing Boat Tails on the Drag Reduction of Trucks

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ABSTRACT

Enhancing vehicle performance, fuel and aerodynamic efficiencies through drag reduction is a crucial concern for the automotive industry, especially for commercial vehicles. This study examined the impact of boat tails on the drag reduction of a locally produced commercial truck with an elevated body box structure. The study included modelling flat and curved boat tails at different radii. For each case, computational fluid dynamic (CFD) analysis has been applied to examine the ideal aerodynamic boat tail for the truck in terms of various radii and angles. The simulation results show that the maximum drag reduction is obtained for the flat boat tail with a length of 0.5 [m] and at an inclination angle of 20 [deg]. Using the flat boat tail, 12.3% reduction in the drag coefficient has been achieved. On the other hand, the maximum drag reduction for the curved boat tail occurred at 10.6 % at radius 100 [mm]. Further, the effects when both optimum modifications are installed at the front and rear ends in two cases. The first case is the optimum front modification together with optimum flat rear end. The second case is the first case is the optimum front modification together with curved rear tail. The two cases resulted in an improvement of the CD (CD = 0.415, 35.5%) for the former case, while the improvement in the second case is (CD = 0.432, 32.8%).

Keywords: *Aerodynamic, CFD, Drag reduction, boat tail.*

I. INTRODUCTION

Drag reduction of heavy vehicles has a significant influence on the reduction of fuel consumption and CO_2 emission. Adapting flow control devices is a primary method of reducing the aerodynamic drag that vehicles experience. Heavy-duty trucks consume about 65% of the fuel used to overcome aerodynamic resistance. Furthermore, approximately 70% of the engine power is typically consumed by the aerodynamic drag produced at 100 km/h, Das *et al* **[1]**. The automotive industry has improved add-on devices to modify the flow around the vehicles hence reducing drag resistance. The total aerodynamic drag for heavy trucks is distributed at the front cab, underbody and back truck box are 45%, 25% and 30%, respectively **[2]**. Several studies showed the effect of the front cab deflector on the drag reduction **[3-5]**.

Kim *et al* **[6]** studied experimentally the effects of a boat tail slant, side angles and with sinusoidal shapes of the rear edges on the drag and side forces reduction. The results showed that the drag reduction reached 15.9%, and that of the side forces reached 22.6% at a yaw angle of 7.0 [deg]. Maine *et al* **[7]** studied the effect of different types of boat tail designs attached to medium-duty trucks. Their results showed that the drag was reduced by 9.6% when using a base flap design. Lee *et al* **[8]** studied experimentally the effect of adding 4 sides boat tail to the back of the truck box at different lower inclined air deflectors. The results showed that the maximum drag reduction was about 9.0% at the lower side tail angle of 45 [deg].

Yang and Ma **[9]** studied the effect of passive add-on devices on drag reduction. A cylinder-shaped device was attached to the top and the bottom of the tail edges. The results showed that the drag was reduced by 7.0% at a cylinder diameter of 140 mm. However, the installed cylinders comparatively have a limited effect on the drag coefficient reduction. Khosravi *et al* **[10]** studied the effect of adding different devices to commercial vehicles such as back vanes and baes flaps. The result showed that the maximum drag reduction was about 4.85% at a flap angle of 25.0 [deg].

Salati *et al* **[11]** studied the effects of rear add-on devices on the drag of a heavy tractor-semitrailer. The rear trailer devices were separated into several parts (airbag geometry, fin, and boat tail. The results obtained showed that drag was reduced by 3.5% when using airbag geometry and reduced by 8.0% when using fin geometry. The maximum drag reduction of 9.0 % was obtained by using base flap with 2.0 [m] length. Hsu and Davis **[12]** studied the effect of adding a hump at the top of Ahmed's body with the combination of a curved boat tail. The simulation results showed that the combination of the hump and the curved boat tail provided a 51.0% drag reduction compared to the baseline Ahmed's body.

In the present study, two types of boat tail shapes are designed and examined to illustrate the effects of slant angle and radius for both shapes. The drag reduction of the truck was evaluated using simulation software. In short, a new design concept to enhance the aerodynamic performance of commercial trucks is provided and supported by the results.

II. MODELING AND SIMULATIONS

A commercial truck is modeled using Ansys Design Modeler software as illustrated in Figure 1. The air enclosure wind tunnel with a blockage ratio (BR) of 2% is constructed for simulation as shown in Figure 2. Table 1 lists the baseline truck and the air enclosure dimensions. Meshing is carried out and the model position of the inlet, outlet, and wall was defined in the meshing process. The truck speed was set at 25 [m/s]. Table 2 contains the details of the boundary condition.

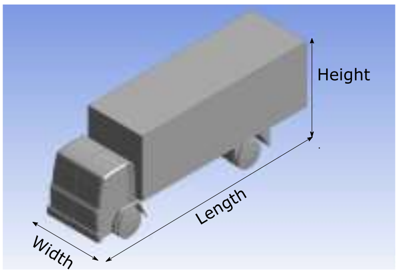

Figure 1: Baseline truck model.

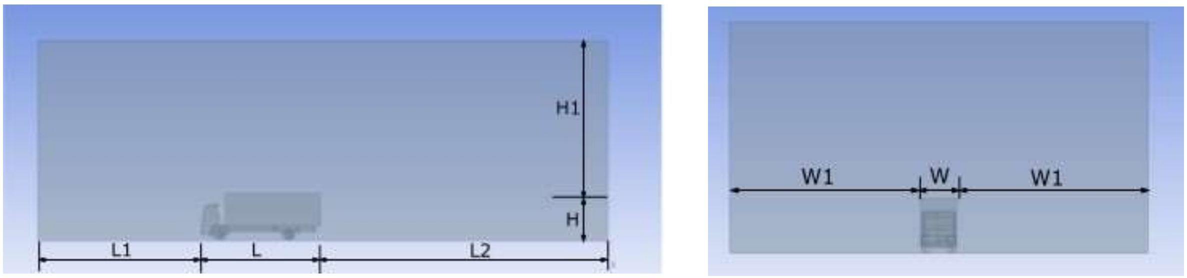

Figure 2: Size of wind tunnel enclosure.

Table 1: Dimensions of base line truck and the air enclosure.

Parameter	Dimension [m]
Truck Height [H]	3.65
Truck Length [L]	9.20
Truck Width [W]	2.40
L1	12.56
L2	22.20
H1	11.85
W1	12.80

Table 2: Details of the boundary conditions

Parameter	Dimension [m]	Value
Inlet	Velocity Inlet	25 [m/s]
Outlet	Pressure Outlet	0 Pa (gauge]
Wall	Wall Boundary	Non-equilibrium wall
Truck Surface	Wall Boundary	No-slip
Reference	Ambient	101.325 [kPa]

In this study, two types of boat tails were used. One flat boar tail in addition to a curved boat tail at five different radii. The curved boat tail radius is designed to be: 60, 70, 80, 90, and 100 [mm] respectively. The flat and curved boat tails are shown in Figures 3 and 4 respectively. Parameter L_1 is the length of the boat tail ranging from 0.1 to 0.5 [m] with a step 0.1[m], L_2 is the thickness, and A is the angle between the boat tail and the horizontal plane from 10 [deg] to 50 [deg] with a step of 10. Furthermore, the parameter R is the radius of the boat tail.

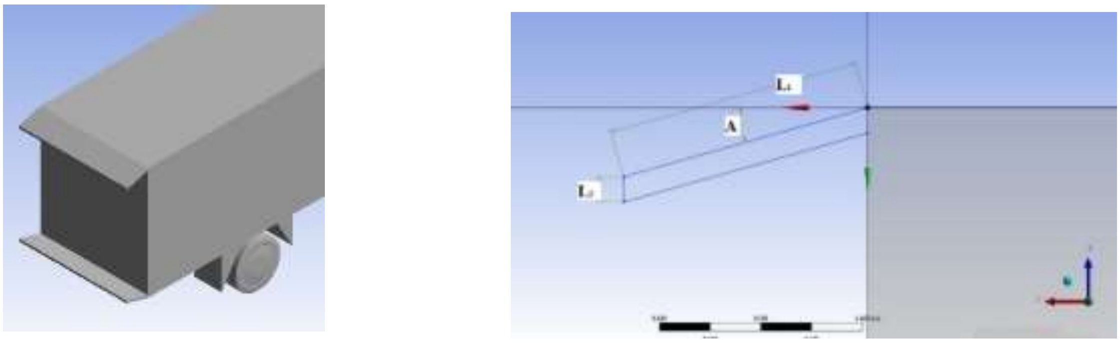

Figure 3: Flat deflector used in the simulation.

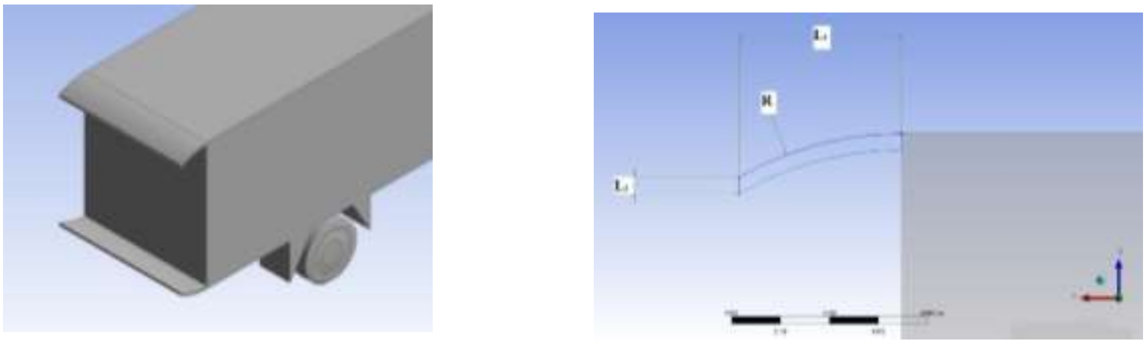

Figure 4: curved deflector used in the simulation.

III. RESULT AND DISCUSSION

The results obtained from the simulation of the drag coefficient (CD] for the baseline truck with the flat boat tail are presented in Figure 5. The results obtained from the simulations are tabulated in Table 3. The baseline truck without any cab deflectors shows the highest value of CD which is around 0.64. The maximum drag reduction is about 12.3 % when the angle of the boat tail was set to 20 [deg] at L_1 0.5 [m] as shown in Figure 5.

Table 3: The drag coefficients for the flat boat tail.

CD					
Length, L_1 [m] / **Slant angle [deg]**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**
10	0.613	0.605	0.594	0.579	0.571
20	0.610	0.599	0.587	0.576	0.565
30	0.619	0.608	0.596	0.587	0.573
40	0.623	0.616	0.606	0.589	0.577
50	0.633	0.621	0.611	0.598	0.583

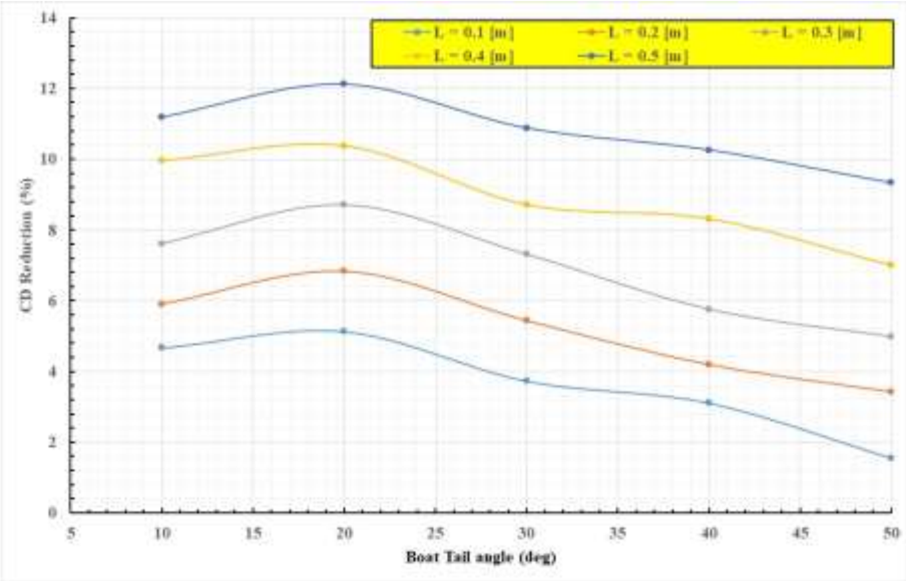

Figure 5: The drag reduction for the flat boat tail at different angles.

Further, the results obtained from the simulation of the drag coefficient, CD for the baseline truck with the curved boat tail are shown in Figure 6. The results obtained from the simulations are tabulated in Table 4. The maximum drag reduction for the curved boat tail is about 10.6 % when the radius was set to 100 [mm] as shown in Figure 6.

Table 4: The drag coefficients for the flat boat tail.

R [mm]	60	70	80	90	100
CD	0.612	0.596	0.588	0.583	0.575

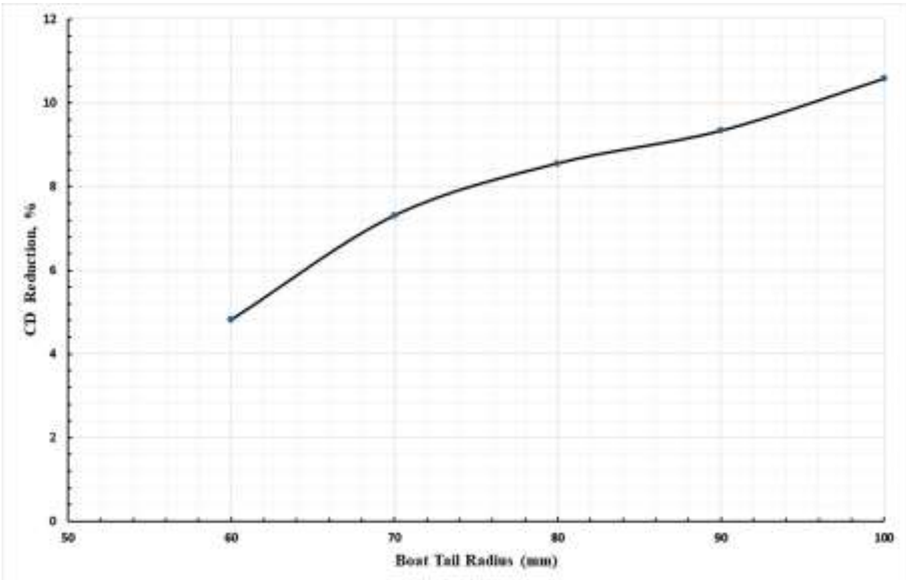

Figure 6: The drag reduction for the curved boat tail at different radii.

The streamlines originate from the edge of the plane and were obtained on a plane that is positioned horizontally across the truck. The velocity streamlines for the baseline truck are shown in Figure 7. The low-velocity streamlines in the back of the container are due to the wake region. The high pressure mainly occurs at the frontal area of the cab and container. When boat tails are attached to the container, it directs more air into the low-pressure region behind the truck. Thus, the turbulence in this region is increased and the vortex region becomes smaller. The wake region on the truck back can be reduced by adding tail boats as shown in Figures 8 and 9.

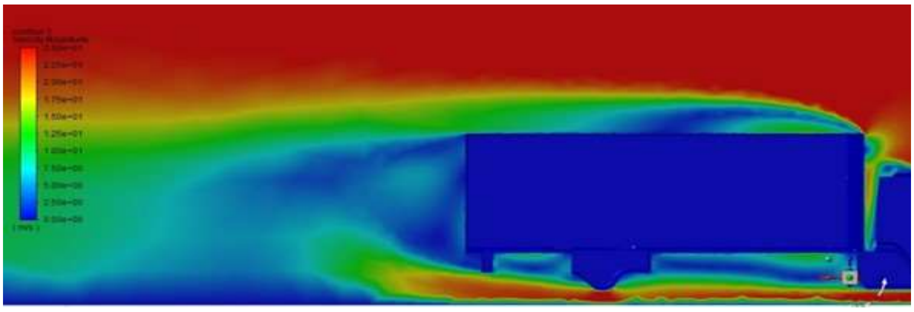

Figure 7: Side view of velocity contours for baseline truck.

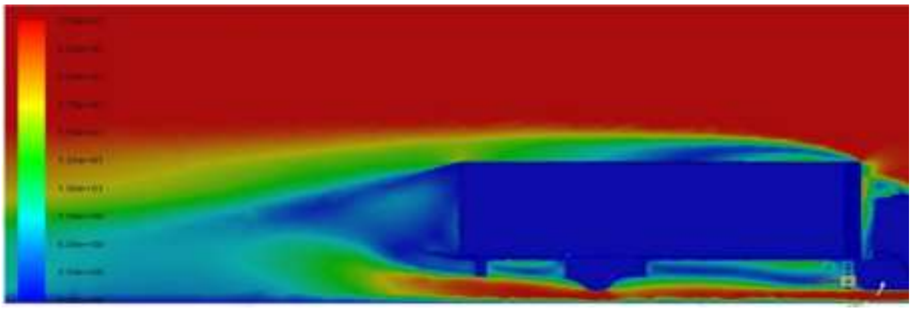

Figure 8: Side view of velocity contours for flat tail boat at angle 20 [deg].

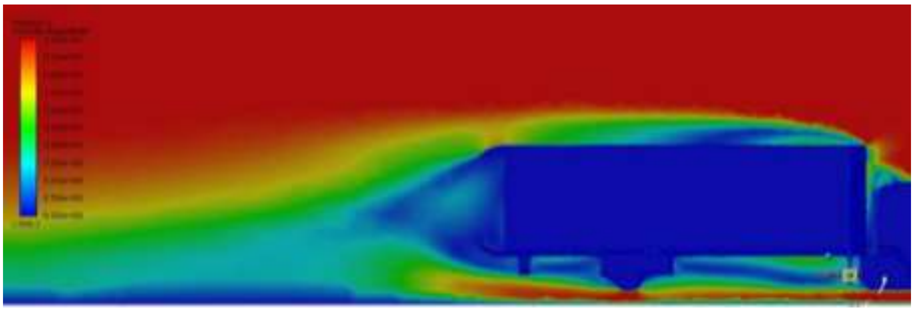

Figure 9: Side view of velocity contours for curved tail boat with 100 [mm] radius.

To highlight the interaction of the cumulative improvement between the modification and the front **[13]** and rear ends, two cases are considered. First case: curved cap roof deflector with R = 1.5 [m] and flat boat tail with length, L = 0.5 [m] and slant angle of 20 [deg], the CD reduced from 0.643 to 0.415. This accounts for 35.5% reduction. Second case: curved cap roof deflector R = 1.5 [m] with curved boat tail R = 0.9 [m], the CD reduced from 0.643 to 0.432 i.e., 32.8% reduction. Figure 10 and Figure 11 show the effects when both optimum modifications are installed at the front end and rear end in the two cases.

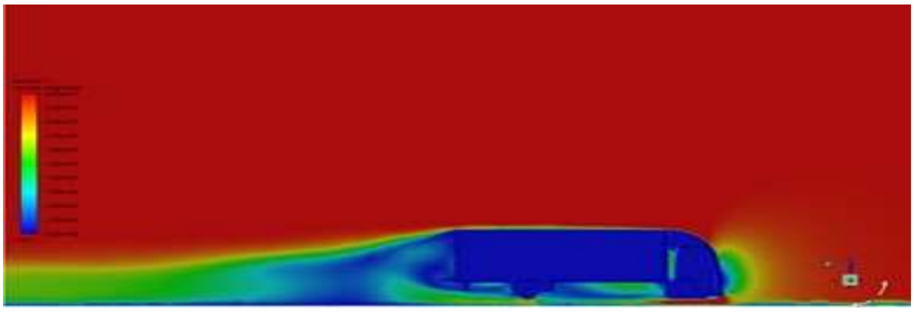

Figure 10: curved cap roof deflector with R = 1.5 [m] and flat boat tail with length, L = 0.5 [m]

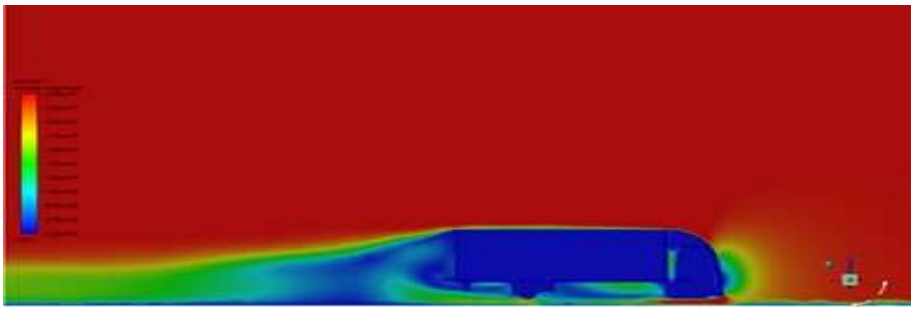

Figure 11: curved cap roof deflector R = 1.5 [m] with curved boat tail R = 0.9[m]

IV. CONCLUSION

In this paper, two types of boat tails are tested. A flat boat tail at different length and angles are mounted at the top and the bottom of the commercial truck. Furthermore, a curved boat tail at five different radii. The simulation shows that the additional boat tail devices influence the drag reduction. The flat boat tail with a length equal to 0.5 [m] at the angle of inclination 20 [deg] has the highest drag reduction value. The drag coefficient decreased considerably by 12.3 % compared to the baseline truck. It is concluded for all the flat boat tails that the highest reduction values at the angle of inclination 20 [deg]. Furthermore with the combination of the cab roof deflector and the flat boat tail the reduction in the drag could reach 35.5%.

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