

Drag reduction of heavy vehicles using boat tails

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Abstract There have been many attempts to improve the fuel efficiency of heavy vehicles. Especially, various flow-control devices have been implemented to reduce aerodynamic drag. Drag reduction of heavy vehicles has enormous effect on the reduction of fuel consumption and CO₂ emission. Most previous studies were conducted using computational simulation for simplified vehicle geometries (GTS, GCM, and Ahmed body). Therefore, the fluid-dynamic mechanism of drag reduction is not fully understood yet. In this study, wind-tunnel experiments for 3 different scale-down heavy vehicle models (5 ton truck, 15 ton truck, 40 feet tractor-trailer) were conducted to evaluate the effect of various boat tails on the drag reduction of those vehicles. Each vehicle model was installed at the test section (1.8 x 1.5 x 4.5 m) of POSTECH closed-type subsonic wind tunnel. Drag force acting on the experimental model was measured by using a 7-component balance. The drag coefficients of the standard vehicle models without any drag-reduction flow-control devices were compared with those attaching various boat tails. In addition, flow visualization experiments were carried out to observe the flow structures modified by the attachment of various boat tails.

Keywords: Drag reduction, Boat tail, Heavy vehicle, Flow visualization

1. Introduction

Many attempts have been made to save the cost of transportation. Especially, drag reduction of heavy vehicles such as trucks or tractor-trailers have enormous influence on the reduction of fuel consumption and CO₂ emission, because freight transport using heavy vehicles occupies majority in the cost of transport[1-2]. For a tractor-trailer driving on a highway, approximately 45% of the aerodynamic drag is resulted from the front part of the vehicle. The other contributions are trailer base (25%) and underbody flow (30%). Numerous aerodynamic flow-control devices such as cab-roof fairing, side skirts, boat tails, and vortex generators have been introduced to reduce the aerodynamic drag force of heavy vehicles[3-5].

Most previous studies have been conducted by numerical simulation for simplified vehicle geometries (GTS, GCM and Ahmed body), due to technological difficulties[6]. However, it is essential to carry out wind tunnel experiments to validate simulation results. In addition, it is still unclear how the unsteady flow around a heavy vehicle influence on the drag force and how to reduce this drag force effectively by adopting pertinent flow-control devices.

The ultimate goal of this study is to find the most efficient configuration of the boat tail to reduce the aerodynamic drag of three representative heavy vehicles, which leads to the maximum reduction of fuel consumption.

2. Experiment setup and method

In this study, we conducted wind tunnel experiments for 3 different scale-down heavy vehicle models (5ton truck, 15ton truck, 40feet tractor-trailer) to evaluate the effects of various boat tails on the drag reduction of those vehicles. Each vehicle model was installed at the test section (1.8 x 1.5 x 4.5 m) of POSTECH closed-type subsonic wind tunnel. The flow uniformity of the wind tunnel is 0.25% and turbulent intensity is less than 0.2%. The drag force and moment acting on a test model were measured using a 7- component balance of which the maximum measurable force is 500N with a resolution less than 0.01N. The scale down ratio of the vehicle models is ranged from 1/8 to 1/6 for retaining the blockage ratio less than 10%[7].

Drag coefficients (C_D) of the standard vehicle models without attaching any drag-reducing flow-control additives, the vehicle models attached with commercial boat tails and with various modified boat tails were compared, and their aerodynamic performance was analyzed for each type of heavy vehicles.

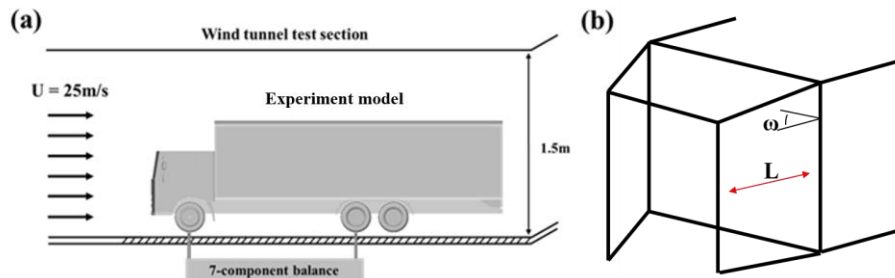


Fig. 1 (a) Schematic diagram of the experimental setup (b) boat tail

3. Results

Drag coefficient was obtained by measuring the drag force exerting on vehicle models in the range of wind speed of 10-55m/s. When Re is sufficiently high, the drag coefficient is independent of Re number. Therefore, the present study was conducted at a wind speed of 25m/s ($Re = 3.0 \times 10^6$) (Fig.2).

The drag coefficient was calculated from the x-directional drag force and projection area as follow;

$$C_D = \frac{F_x}{\frac{1}{2}\rho V_0^2 A} \quad (1)$$

The drag coefficients of the three standard vehicle models (5ton model ($C_D = 0.629$), 15ton model ($C_D = 0.749$), 40ft model ($C_D = 0.792$)) tested in this study are well matched with the results of previous studies.

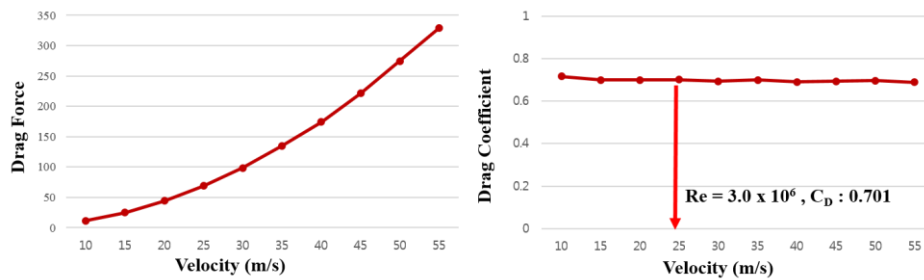


Fig. 2 Variation of drag force and drag coefficient of the 5ton truck model according to wind velocity.

Fig.3 shows the effect of various boat tails on the drag coefficient of heavy vehicle. The experimental results show significant differences depending on the deflection angle (ω) of the boat tail rather than their length. Especially, for $\omega = 55^\circ$, the drag force is increased, due to strong flow disturbance caused by the tail. The drag reduction effect is improved with increasing the deflection angle up to a certain point. Among the modified boat tails tested in this study, the deflection angle of $\omega = 80^\circ$ exhibits the most distinguished improvement in drag reduction (4.24%).

In the previous boat tails, there is a slight step between the trailer and boat tail due to installation problem, it is found to be ineffective due to presence of flow separation. In order to overcome this shortcoming, we attached a gap repair (G) to the upper boat tail. As a result, it reduces the drag about 6.6% by delaying the main separation point. In addition, a new bottom tail was adapted to

control the under body flow. The total drag coefficient reduction was about 7.2% when the gap repair and bottom tail are attached.

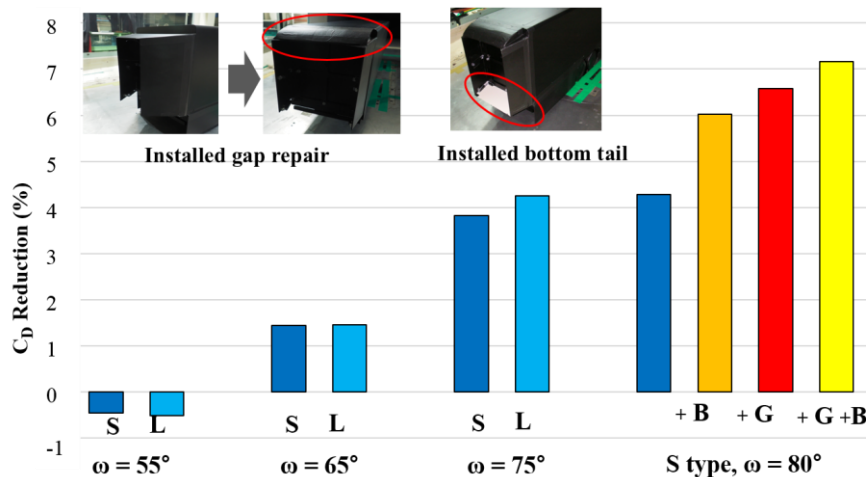


Fig. 3 Drag reduction effect of various boat tails.

4. Conclusion

In this study, the effect of boat tails on the drag reduction of heavy vehicles was investigated experimentally. The deflection angle (ω) of the boat tails has significant influence on the drag reduction, compared to their length. Among the modified boat tails tested in this study, the boat tail with deflection angle of $\omega = 80^\circ$ exhibits the most distinguished improvement in drag reduction (4.24%). The drag coefficient is additional reduced by up to 6.0% and 6.6% by installing a top gap repair and bottom tail as supplementary accessories, respectively.

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