Research on Drag Reduction of Heavy Truck Tail

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Abstract. In order to reduce the aerodynamic drag coefficient of a heavy van truck, three single-variable and one multi-variable composite drag reduction devices were designed based on the rear structure of the heavy van truck. The results show that among the three single-variable drag reduction devices, the inclination angle θ of the linear type drag reduction device has the greatest influence on the aerodynamic resistance coefficient of heavy vans truck, and the model has the best drag reduction effect when the inclination angle θ=20°, the aerodynamic drag coefficient is 0.7693, and the drag reduction rate is 7.64%. The radius R of the arc drag reducing device has the least influence on the aerodynamic drag coefficient. The multivariable composite drag reduction structure also has a good drag reduction effect. The study can provide a reference for the optimal design of the rear structure of related vehicles.

Keywords: Heavy Van Truck; Aerodynamic Resistance Reduction; Rear Drag Reduction; Multivariable; Composite Resistance Reduction.

1. Introduction

In recent years, energy conservation has been advocated in all aspects of production and life. Road freight accounts for a relatively high proportion in the total freight, and heavy trucks occupy an irreplaceable position in road transport. Reducing the aerodynamic resistance of vehicles is very important to save energy and reduce the emission of pollutants.

There are mainly active and passive methods to reduce vehicle aerodynamic resistance [1]. Active drag reduction has a good effect at low speeds, but is less applicable because it requires additional power energy input [2]. Passive drag reduction methods are heavily researched and applied because they do not require additional external energy and are more effective in reducing drag at high speeds. For example, the installation of deflectors can reduce the aerodynamic drag of the vehicle [3]; the addition of pneumatic accessories can improve the air flow between the cab and the cargo area and thus reduce the aerodynamic drag on the vehicle [4]. However, compared with the passive drag reduction methods mentioned above, the aerodynamic drag caused by the cargo compartment accounts for a larger proportion of the aerodynamic drag of the whole vehicle [5], some scholars have established connection channels at the side and rear of the cargo compartment [6], but they cannot be widely used because of the impact on the skeleton structure of the cargo compartment. In addition, the addition of various deflectors can improve the rear airflow and reduce the aerodynamic drag of the truck [7], but because the shape structure of the deflector is too single, the relevant shape and parameters need to be studied in depth.

In summary, the passive drag reduction of vans is mainly the addition of pneumatic accessories to the surface and the optimization of the shape structure. However, the parameters related to the rear of the vehicle, especially for different pneumatic drag reduction accessories, need to be studied in depth. Therefore, this paper takes a heavy-duty van as the research object and designs a suitable pneumatic attachment for the rear of the vehicle. By solving the simulation of different attachment models, the best structure and shape parameters of the pneumatic attachment are found.

2. Original Model and Boundary Conditions

2.1 Model Building and Meshing

A 1/10 model of a heavy-duty van is established and its detail parts such as windows are simplified. Vehicle length l=1397mm, width w=200mm and height h=400mm. A rectangular body of 8l, 7w and 4h around the body is taken as the simulation computational domain. the number of grid cells is chosen to be about 4.67 million after the irrelevance verification.

2.2 Setting of Boundary Conditions

This paper selects steady-state conditions and selects the achievable κ-ε turbulence model for simulation. The entry velocity of 30m/s is used as the inlet condition of the computational domain, and the pressure outlet with a relative atmospheric pressure of 0 is used as the outlet condition of the computational domain, and a non-slip wall is set. The Reynolds number is 2.9×106. The flow field is numerically solved using the SIMPLE algorithm and the second-order upwind formula.

3. Design of Pneumatic Drag Reduction Accessories and Analysis of Drag Reduction Effect

3.1 Design of Linear Tail Drag Reduction Device and Analysis of Drag Reduction Effect

A linear aerodynamic drag reduction device is designed at the rear of the van. Figure 1 is the parameter diagram and effect diagram of the linear drag reduction accessory. Deflectors with the same extension length and inclination degree are installed at the rear of the cargo compartment and closed. In order to obtain the best linear drag reduction device, four types of rear linear drag reduction models with inclination angle θ= 20°, 30°, 40° and 45° were designed.

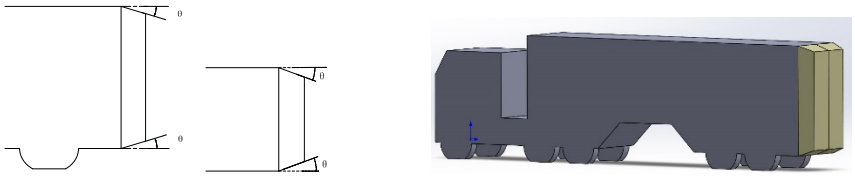


Fig 1. Linear drag reduction device parameter drawing (left) and effect drawing (right)

Table 1 shows the aerodynamic drag coefficients the linear rear drags reduction device (linear model for short). As can be seen from Table 1, the aerodynamic drag coefficient becomes smaller as the inclination angle of deflector installation decreases. The best drag reduction effect is achieved when the inclination angle is equal to 20°, and the aerodynamic drag coefficient of the linear model is 0.7693 with a drag reduction rate of 7.64%. Figure 2 shows the trailing velocity streamlines of the original model and the linear model (θ=20°). As can be seen from the figure, two vortex with opposite spin direction appear in the tail of both the original model and the linear model, but the area of the two vortex in the linear model is greatly reduced, and the tail flow field is significantly improved.

Table 1. Aerodynamic drag coefficients and drag reduction rates for different linear models

model	Aerodynamic drag coefficient	Drag reduction rate /(%)
Original model	0.8330	0
Straight line model 1(θ=20°)	0.7693	7.64
Straight line model 2(θ=30°)	0.7854	5.71
Straight line model 3(θ=40°)	0.8141	2.26
Straight line model 4(θ=45°)	0.8183	1.76

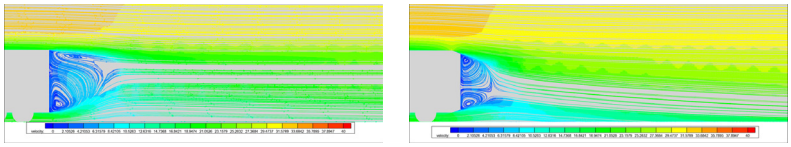


Fig 2. Tail velocity streamlines for the original (left) and linear (right,θ=20°) models

3.2 Design of Circular Tail Drag Reduction Device and Analysis of Drag Reduction Effect

In order to improve the tail vortex, the circular arc tail deflector is designed. The deflector from the body side view of the upper and lower are 1/4 arc, Installation of deflectors with the same extension length and circular parameters around the rear of the cargo compartment, and closing the rear of it, Figure 3 is the parameters of the arc-type pneumatic accessories and effect diagram. In order to obtain the best rear drag reduction device, a total of four tail drag reduction device models with circular radius R=50mm, 60mm, 70mm and 80mm were designed for simulation study.

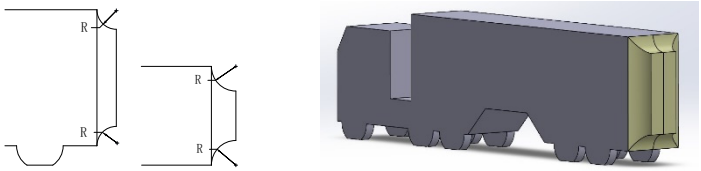


Fig 3. Parameter diagram of arc drag reduction device (left) and effect diagram (right)

Table 2 shows the aerodynamic drag coefficient of the original truck model and the arc tail drag reduction device model (abbreviated as the arc model). It can be seen from the table that the drag reduction effect of the circular arc model is better when the radius of the circular arc model is larger, and the drag reduction effect is the best when the radius of the circular arc model R is 80mm. At this time, the aerodynamic drag coefficient is 0.7906 and the drag reduction rate is 5.09%. Figure 4 compares the turbulent kinetic energy diagram of the above two models. The area of the high turbulent kinetic energy region of the circular model becomes smaller and the value of turbulent kinetic energy decreases, so the energy dissipation is reduced and the aerodynamic drag is lower.

Table 2. Aerodynamic drag coefficients and drag reduction rates of different circular models

Model	Aerodynamic drag coefficient	Drag reduction rate /(%)
Original model	0.8330	0
Arc model 1 (R=50)	0.8319	0.13
Arc model 2 (R=60)	0.8128	2.42
Arc model 3 (R=70)	0.7998	3.98
Arc model 4 (R=80)	0.7906	5.09

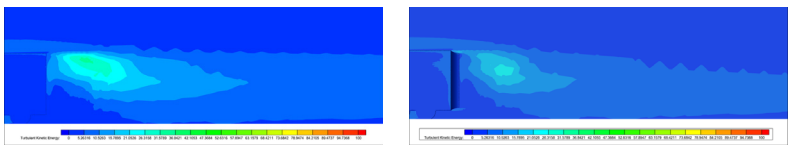


Fig 4. Turbulent kinetic energy clouds of the original (left) and circular arc model (right, R=80mm)

3.3 Design of Cosine Tail Drag Reduction Device and Analysis of Drag Reduction Effect

The airflow from the body converges at the rear of the cargo compartment to create a tail vortex, forming a negative pressure zone at the rear, and a properly designed pneumatic attachment can improve the vortex. The cosine type tail drag reduction structure design is shown in Figure 5. A cosine type drag reduction device of the same extension length and parameters is installed around the rear of the cargo compartment, and its rear end is closed. In order to obtain the best drag reduction effect,

the effect of four different cosine curve (with different parameters ω) type tail drag reduction devices on the aerodynamic drag characteristics of the whole vehicle is studied.

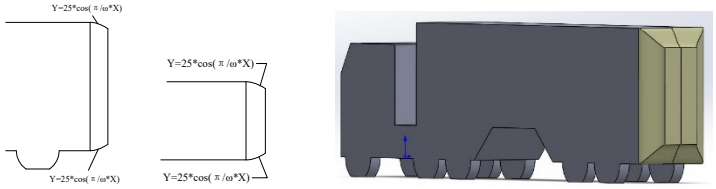


Fig 5. Parameter diagram (left) and effect diagram (right) of cosine type resistance reduction device

Table 3 shows the aerodynamic drag coefficient and drag reduction rate of the original truck model and the cosine curve tail drag reduction device model (Abbreviated cosine model). From the table, we can see that the cosine model 4 is the optimal model, at this time the aerodynamic drag coefficient is 0.7695, and the drag reduction rate of the cosine model is 7.62%. Figure 6 is the pressure diagram of the tail of the original model and the cosine model (ω=125). It can be seen from the diagram that the pressure on the tail of the cosine model is greatly increased and the area of the low-negative pressure area is obviously reduced, so that the aerodynamic resistance of the van becomes smaller.

Table 3. Aerodynamic drag coefficients and drag reduction rates for different cosine models

Model	Aerodynamic drag coefficient	Drag reduction rate /(%)
Original model	0.8330	0
Cosine model 1(ω=50)	0.7966	4.36
Cosine model 2(ω=75)	0.7847	5.79
Cosine model 3(ω=100)	0.7779	6.61
Cosine model 4(ω=125)	0.7695	7.62

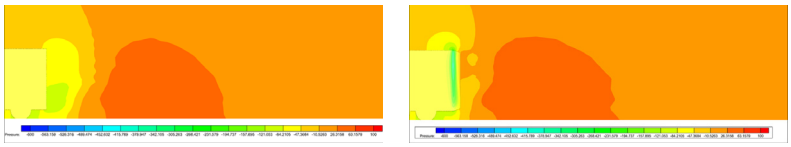


Fig 6. Tail pressure clouds of the original (left) and cosine (right, ω=125) model

3.4 Design of Composite Tail Drag Reduction Device and Analysis of Drag Reduction Effect

The airflow flows through different paths on the upper and lower sides of the cargo box to form different detachment speeds, thus forming a complicated wake vortex. Therefore, different drag reduction accessories are selected for the upper and lower sides, and the inclination angles θ of linear type are selected as 20° and 30°, and the parameters ω of cosine curve type are 100 and 125, and their combinations are shown in Table 4. The composite drag reduction structure has cosine curve type pneumatic accessories on the upper part and left and right sides, and linear pneumatic accessories on the lower part.

Table 4 compares and analyzes the aerodynamic drag coefficients and drag reduction rates of the original model and the composite model. As the cosine curve parameter ω becomes larger, the compound drag reduction effect is enhanced, while the drag reduction effect does not change regularly when the bottom linear inclination angle becomes smaller, which indicates that the compound drag reduction is not a single accumulation of drag reduction effect, and the compound drag reduction effect is affected by various factors. Among them, when the upper cosine curve parameter ω=125 and the lower linear inclination angle θ=20° have the best effect of drag reduction, the composite model aerodynamic drag coefficient is 0.7694 and the drag reduction rate is 7.63%.

Table 4. Aerodynamic drag coefficient and drag reduction rate of the tail composite model

Model	Cosine curve parameters ω	Angle of straight line θ/(°)	Aerodynamic drag coefficient	Drag reduction rate /(%)
Original model			0.8330	0
Composite model 1	125	20	0.7694	7.63
Composite model 2	125	30	0.7711	7.43
Composite model 3	100	20	0.7749	6.97
Composite model 4	100	30	0.7723	7.29

4. Conclusion

(1) The tail drag reduction structure of heavy-duty vans is studied in depth, and the three types of drag reduction schemes with single parameter pneumatic attachment structure are designed to possess good drag reduction effect, and the best drag reduction rates of the three types are 7.64%, 5.09% and 7.62% respectively. The tail drag reduction device improves the tail flow field structure, enhances the tail pressure and reduces the front and rear differential pressure resistance of heavy vans.

(2) The single parameter tail drag reduction structure is investigated, and the linear tail drag reduction device has the greatest effect on the aerodynamic drag coefficient of the whole vehicle, and the circular arc model has the least effect. When the inclination angle of the linear model θ=20°, the aerodynamic drag coefficient is the smallest, and its value is 0.7693. The cosine type tail drag reduction device also has a better drag reduction effect, when the parameter ω=125 in the cosine curve, the aerodynamic drag coefficient is 0.7695.

(3) The cosine type and linear type tail composite drag reduction structure also have good drag reduction effect. When the cosine curve parameter w=125 and the straight line parameter w=20, there is the best drag reduction effect, and the minimum aerodynamic drag coefficient is 0.7694. The compounding of the tail drag reduction structure is not the cumulative effect of a single factor, but the result of the combined action of multiple factors.

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