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Study on the influence of the vehicle rear plan on wake flow field

L L Wu^{1,*}, Y Fu¹, X B Bu¹, X L Zhang¹ and X L Ma¹

¹CAE Performance Division, Vehicle Crash Testing and Reseptanh Department, CATARC Automotive Test Center (Tianjin) Co., Ltd, Tianjin, 300300, China

*wulinlin@catplan.ac.cn

Abstract. The rear plan is one of the key factors that affect the separation of air flow at the vehicle rear.It has important theoretical guidance and engineering significance to study the influence of the rear plan on wake flow field for the early development and design of vehicle shape.Based on a simplified SUV model, the drag coefficients of the models with different rear plans are calculated. The velocity separation, pressure distribution and energy dissipation of air flow at the vehicle rear are compared and analyzed, demonstrating that the rear plan has influence on air separation and the formation of wake vortex at the vehicle rear. It is found that with the decrease of the rear plan, the separation of the air flow at the vehicle rear becomes weaker, the wake vortex gets smaller, and the drag coefficient reduces.

1. Introduction

The drag coefficient is mainly caused by the pressure drag between the front and rear of the vehicle. The negative pressure area formed by the separation of air flow at the vehicle rear is the main source of the pressure drag[1]. The separation of the air flow at the vehicle rear can be effectively controlled by changing the structure of the vehicle rear, thus increasing the pressure of the vehicle rear. It is of great significance to optimize the design of vehicle shape and reduce the drag coefficient.

For the past few years, domestic and foreign scholars have conducted in-depth research on the wake flow flied, and achieved fruitful research results. Riyad and Koike found that increasing the pitch angle of the spoiler properly was conducive to reduce the wake vertex and the drag coefficient[2,3]. Santosh studied the influence of parameters such as the front windshield angle, approach angle, departure angle and the rear windshield angle on the wake flow field and drag coefficient[4]. By simulation, Xu J M and Wei Z C found that the aerodynamic add-on device can effectively increase the pressure of vehicle rear, reduce the pressure drag, and achieve good drag reduction effect[5,6].Lu R M improved the wake flow field and the aerodynamic performance of the vehicle by optimizing the rear windshield angle, departure angle and the height of the rear edge[7]. In the above studies, the influence of some structures of the vehicle rear and aerodynamic add-on devices on the wake flow field have been considered, but the influence of the rear plan on drag coefficient and wake flow field are rarely studied.

In this work, based on the grid deformation technology, the simplified SUV models with different rear plans for CFD simulation calculation are obtained by changing the moving distance of the control points. According to the simulation results, the influence of the rear plan on the drag coefficient and the wake flow field is analyzed.

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2. Establishment of the simulation model

2.1. Geometric model

In order to analyze the influence of the rear plan on the wake flow field, a simplified SUV model is taken as the research object. A simple plane is used to replace the complex structure of the chassis, and the grille only retains its shape. The initial state of the rear plan and the moving direction of the control point are shown in Figure 1.



Because the rear plan is not easy to be measured, the moving range of the control points is used to represent the changing range of the rear plan. L is used to represent the moving distance of the control points with the range from -0.1m to 0.1m. The upper and lower limits of deformation are shown in Figure 2.



2.2. Grid model

The calculation domain is set as 10 times of the model length, 5 times of the model width and 5 times of the model height. At the same time, the wheel deformation is simulated by moving up the bottom of the calculation domain. The maximum grid of the calculation domain surface is 192mm, the maximum grid of the body surface is 12mm, while the minimum grid is 6mm. A three-layers encryption area is set in the calculation domain, while a ten-layers boundary layer with a total thickness of 8mm is set on the body surface. Some encryption areas are also set around of the body surface and in the wake of the vehicle. Finally, 13 million grids are generated, as shown in Figure 3.

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3. CFD simulation calculation

3.1. Governing equation

In the process of driving, the pressure of the surrounding air changes little. During the simulation of the flow field around the vehicle, the surrounding air can be regarded as incompressible fluid[8].

(1) Mass conservation equation

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i} (\rho u_i) = 0 \tag{1}$$

here, ρ is the density, u_i is the velocity component in direction *i*.

(2) Momentum conservation equation

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_i}(\rho u_i u_i) = -\frac{\partial P}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_i} + \rho g_i + F_i$$
(2)

here, P is the static pressure, τ_{ij} is the stress, g_i is the gravity component in the direction i, F_i is the energy item caused by resistance.

(3) Gas state equation

$$PV = \rho RT \tag{3}$$

here, P is the gas pressure, V is the gas volume, R is the gas constant, T is the thermodynamic temperature.

3.2. Turbulence model and boundary condition

Some studies have shown that among the three commonly used turbulence models, the Realizable $k - \varepsilon$ model has the highest calculation accuracy[9]. In this study, the Realizable $k - \varepsilon$ model is selected. The settings of boundary conditions are shown in Table 1.

Position	Type of boundary	Value
Inlet	Velocity Inlet	120 km/h
Outlet	Pressure Outlet	0 Pa
Slip	Slip Wall	/
No-slip	No-slip Wall	120 km/h
Side	Slip Wall	/
Body	No-slip Wall	/

4. Analysis of simulation results

4.1. The influence of the rear plan on drag coefficient

For each 0.02m movement of the control point, one model is taken, and a total of eleven geometric models corresponding to different rear plans are created. Through the simulation, the drag coefficients of the eleven geometric models are obtained, as shown in figure 4. It can be seen from the figure that when the moving distance of the control point increases in the positive direction, the rear plan decreases, the drag coefficient reduces, and the minimum value of the drag coefficient is 0.320. While the moving distance of the control point increases in the negative direction, the rear plan increases, the drag coefficient rises, and the maximum value of the drag coefficient is 0.336.

It can be seen that the drag coefficient decreases with the decrease of the rear plan, which indicates that the drag coefficient is positively related to the rear plan. In addition, the maximum value of the drag coefficients is 16 counts larger than the minimum value, which shows that the rear plan has a great influence on the drag coefficients.



4.2. The influence of the rear plan on wake flow field

The separation of the air flow at the vehicle rear should be pay closed attention to when analyzing the influence of the rear plan on the wake flow field. The simulation results of L=0.0m and $L=\pm 0.1m$ are selected to analyze the influence of the rear plan on the wake flow field.

The cloud diagrams of pressure are shown in Figure 5, from which it is clear that the pressure distribution of the positive pressure area in front of the vehicle is almost the same. The negative pressure area in rear of the vehicle decreases with the decrease of the rear plan, so that the pressure drag of the vehicle decreases with the decrease of the rear plan.



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It can be seen from the cloud diagrams of velocity vector in Figure 6 that with the decrease of the rear plan, the area and intensity of the vortex formed by the separation of the air flow at the side of vehicle rear gradually decrease. The energy loss due to vortex is also reduced, which makes the pressure of the vehicle increase and the pressure drag decrease. In addition, there is no obvious change of the separation of the air flow at the top and bottom of the vehicle rear.



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From the cloud diagrams of turbulent kinetic energy in Figure 7, it can be seen that with the gradual reduction of the rear plan, the separation position of the air flow at the vehicle rear keeps moving backward. The area of turbulent kinetic energy is decreased, while the intensity of turbulent kinetic energy is also reduced. As the consumed energy decreases, the pressure of the vehicle rear increases.



5. Conclusion

Based on the simplified model of a SUV, this paper analyzes the influence of rear plan on the drag coefficient and wake flow field. Specific conclusions can be summarized, including:

(1) The rear plan has a great influence on the drag coefficient, which decreases with the decrease of the rear plan.

(2) The rear plan has a great influence on the pressure of the wake flow field, which increases with the decrease of the rear plan.

(3) The rear plan mainly affects the separation of the air flow at the side of the vehicle rear, but has little effect on the separation of the air flow at the top and bottom of the vehicle rear.

(4) There are many parameters involved in the design of the vehicle shape, and there is a strong correlation among them. Therefore, when the rear plan and other parameters change at the same time, whether the above conclusions are still valid remains to be further verified.

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