The Effect on Aerodynamic Performance of Electric Vehicle Caused by Battery Pack Installed in the Chassis

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ABSTRACT

In view of the effect of the power battery pack installed in the classis of the electric vehicle on aerodynamic performance, take the SAE-B model as object. Using the computational fluid dynamics numerical simulation method, the effect of battery pack on the flow field of the vehicle structure and the effect rule on aerodynamic performance of electric vehicles caused by the size of battery pack were studied. Results showed that the battery pack installed in the chassis caused the change of the flow field at the chassis and tail of the vehicle. With the increase of battery pack width, drag coefficient is increased and lift coefficient is reduced. The size of battery pack would change the pneumatic resistance of vehicle. This is a reference for the optimization on aerodynamic performance of electric vehicle and the selection on the size of battery pack.

INTRODUCTION

The aerodynamic performance of automobile has great influence on the power performance, economy, handling stability and ride comfort of the vehicle [1]. In our country, the study on electric cars is still at the early stage. The research about effects on performance caused by the arrangement of power battery pack is rare [2-4]. The research on the impact of aerodynamic performance caused by the arrangement of power battery pack is almost blank. Because of its large size and weight, it is difficult for the electric vehicle power battery pack to find a suitable space on the layout[5]. Currently, many Chinese electric car manufacturers arrange battery pack in the area of automobile chassis. Restricted by the layout of chassis, bulky battery pack is generally lower down to electric vehicle chassis. This change of the structure will cause certain influence on the aerodynamic performance of electric vehicle. In this paper, the
computational fluid dynamics numerical simulation method is used[6]. The effect on aerodynamic performance of electric vehicles caused by the layout of battery pack on the classis were studied, focus on the analysis of the effect of battery pack on the flow structure of the vehicle. And find out the effect rule on aerodynamic performance of electric vehicles caused by the size of battery pack were studied. With the increase of battery pack width, drag coefficient increases and lift coefficient reduced. With the increase of battery pack length, drag coefficient is reduced and lift coefficient is increased. With the increase of battery pack height, drag coefficient increases and lift coefficient reduced. This is a reference for the optimization on aerodynamic performance of electric vehicle and the selection on the size of battery pack.

**NUMERICAL SIMULATIONS**

**Geometric Model Establishment**

According to the structure of most electric vehicles, the geometric model of the research object is the notchback model[7] recommended by SAE increased battery, which is defined as the SAE - B model. The part of battery pack that protrudes from the bottom of the vehicle is simplified to a cuboid. The distance between the cuboid and the left or right sides of the vehicle is 500 mm. The minimum ground clearance of the cuboid is 120 mm. At the same time, the vehicle should meet the collision requirement and the passing ability[7]. The SAE - B model as shown in Figure 1.

**Computational Domain Establishment and Mesh Generation**

In order to simulate that the electric vehicle runs in the actual pavement, ensure that the pneumatic coefficient is not affected by the size of computational domain, the size of computational domain is selected as follow: The space in front of the vehicle is 3 times the length of vehicle, the space over the vehicle is 5 times the height of vehicle, the space beside the vehicle is 5 times the width of vehicle, the space behind the vehicle is 5 times the length of vehicle[8].

The model is meshed in ICEM-CFD, tetrahedral element is the most. In order to improve the precision of simulation and capture the aerodynamic force accurately, the body surface is stretched six layer tri-prism grid which growth ratio is 1.2 and the total thickness is 8 mm. Mover, the mesh of part around the body is densified.

The y+ values are also used to judge the rationality of the meshing, the y+ values distribution on the surface of car as shown in figure 3.

In the figure, y+ values are mainly concentrated between 30 and 160. This result conforms to the non-equilibrium wall functions and can realize the application of the turbulence model. This also verifies the rationality of the meshing.
Turbulence Model And Boundary Conditions

The speed of vehicle is far lower than the speed of sound, so the flow field around the vehicle can be regarded as a three-dimensional incompressible viscous isothermal flow field [9]. In the case of especially large strain rate per unit time, the standard model could result in a negative normal stress. In order to make the flow conforms to the physical law of turbulence. The normal stress should be mathematical constraints [10]. In compared with the $k-\varepsilon$ standard model, RNG$k-\varepsilon$ turbulence model consider the turbulent vortex. It has higher reliability and accuracy, less computing time and the required memory of computing. It is suitable for the calculation of complex flow field outside the vehicle. The basic governing equations of turbulent flow calculation are three dimensional incompressible Reynolds Navier-Stokes equations, RANS equations for short. The control equations include the continuity equation (1) and the kinematic equation (2), respectively:

$$\frac{\partial u_i}{\partial x_i} = 0$$  \hspace{1cm} (1)

$$\frac{\partial (u_i u_j)}{\partial x_j} = -\frac{\partial p}{\partial x_j} + \frac{\partial}{\partial x_j} \left( \mu_{\text{eff}} \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right)$$  \hspace{1cm} (2)
In formula (1), (2), vectors $u_i$, $u_j$ are average velocity components, vectors $x_i$, $x_j$ are coordinate components, $p$ is the pressure on micro-unit of fluid, $u_{\text{eff}}$ is effective viscosity coefficient of turbulence.

In the RNG$k - \varepsilon$ model, the large-scale motion and the adjusted viscosity term is used to reflect the influence of small scale motion, and the small scale movement is removed from the control equation systematically. The turbulent kinetic energy $k$ equation and the turbulent kinetic energy dissipation rate $\varepsilon$ equation as shown in formula (3) and (4), respectively:

$$\frac{\partial (pk)}{\partial t} + \frac{\partial (pku_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \alpha_k \mu_{\text{eff}} \frac{\partial k}{\partial x_j} \right] + G_k + \rho \varepsilon$$  

(3)

$$\frac{\partial (\rho \varepsilon)}{\partial t} + \frac{\partial (\rho \varepsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \alpha_{k\varepsilon} \mu_{\text{eff}} \frac{\partial \varepsilon}{\partial x_j} \right] + \frac{C_{1 \varepsilon}}{k} G_k - C_{2 \varepsilon} \frac{\rho \varepsilon^2}{k}$$  

(4)

In formula (3), (4), $\rho$ is fluid density, $k$ is turbulent kinetic energy, $\varepsilon$ is turbulent kinetic energy dissipation rate, $G_k$ is the generation item of turbulent kinetic energy caused by the mean velocity gradient.

The parameters in the above formula $\alpha_k$, $\alpha_{k\varepsilon}$, $C_\mu$, $C_{1 \varepsilon}$, $C_{2 \varepsilon}$, $\eta_0$ and $\beta$ are all empirical constant. The value of each parameter is shown in table I.

According to the above model, the boundary conditions are defined and the wall function is chosen non-equilibrium wall function. The computational domain entry point is set to speed entry $V=39$ m/s, and the turbulent intensity is 0.5%. The exit point is set to the pressure exit, and the relative pressure is zero. The around and the upper surface of the computational domain are set to slip wall. The ground is set to moving wall. The surface of vehicle body is set to no slip wall.

**SIMULATION ANALYSIS**

**Comparative Analysis Of The Two Model**

According to the model and boundary conditions, the SAE model and the SAE-B model are simulated, respectively. The results are shown in table II.

Relative to the SAE model, the drag coefficient of the SAE-B model increased 0.0343 and lift coefficient of the SAE-B model increased 0.0065. So the increased battery structure of the vehicle has a larger effect on the drag coefficient and lift coefficient.

Because the battery pack is arranged in the bottom of the vehicle. The contrast analysis of the flow field structure in the bottom and the rear of the vehicle for the two models are used to find the aerodynamic coefficient change regularity.
The Influence Of Battery Pack For Vehicle Main Floe Field

BASE FLOW FIELD

Boundary conditions of the two models are set, respectively, and simulation is calculated. The motion pattern at the bottom of each model is shown in figure 4.

In figure 4 (a), the bottom of the vehicle is smooth, the air flows smoothly. In figure 4 (b), the air flow at the bottom of the vehicle is complicated, because of the obstruction of battery pack. Around the battery pack, the air separation phenomenon occurred obviously. Because of the obstruction of battery pack, a part of air flows to both sides of the battery pack, and another part of air flows to the bottom of the battery pack. These two parts of airflow converge in battery back-end, and form two distinct vortexes. The energy of the vortex area has dissipated, and forms a negative pressure zone.

<table>
<thead>
<tr>
<th>TABLE I. BASIC PARAMETERS.</th>
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<th>TABLE II. DRAG COEFFICIENT AND LIFT COEFFICIENT OF SAE and SAE-B.</th>
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<td>drag coefficient</td>
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(a) Flow Pattern at wake of Model SAE (b) Flow Pattern at wake of Model SAE-B

Figure 4. Flow Pattern at tail of Model SAE and Model SAE-B.

(a) SAE model (b) SAE-B model

Figure 5. Velocity Vector of Horizontal Section.
In order to understand the effect of battery pack at bottom of the vehicle on air velocity more clearly, the horizontal section velocity vector diagram 10 cm from the ground is shown in figure 5.

According to the contrast of figure 5, the bottom of the SAE model is smooth, the airflow at the bottom of the vehicle accelerate to peak gradually. Then the airflow velocity declines gradually under the effect of the boundary layer. The air flow at the bottom of the SAE-B model is obstructed by the battery pack. The airflow velocity at the frontend of the battery pack drops significantly. The embossment of battery pack reduced the ground clearance of vehicle bottom. The velocity of airflow below the battery pack is accelerated. But compared with the smooth bottom of the vehicle, the velocity of airflow reduced more largely. Use Bernoulli's principle to analyze, the velocity of airflow at the bottom reduced, the upward pressure at the bottom of vehicle rose, so as to make the aerodynamic lift increased.

**WAKE FLOW FIELD**

The velocity vector diagram of longitudinal middle section can be used to analyze how the battery pack affected the flow field at the wake of vehicle. The velocity vector of the two models is shown in figure 6.

Through the velocity vector diagram, when air flows through the wake of the battery pack in SAE-B model, the flow section expanded suddenly, and the airflow separated at the time airflow closed and left the corner. This result in the energy lost, and the average speed of airflow reduce. Finally the airflow velocity at the wake of the vehicle is very slowly, the trend of folding up is weak. It cannot join in the airflow from the top of the surface smoothly, at the wake of the vehicle. It makes vortex intensity at the wake of the vehicle heighten, the pressure at the wake of the vehicle decrease, the pressure drag increase, the airflow is similar to mutation.

**The Relations Of Battery Pack Size and Aerodynamic Coefficients**

In order to study the effect of battery pack size on the aerodynamic performance of electric vehicle, the drag coefficient and the lift coefficient of the aerodynamic performance were analyzed. The geometric center of the battery pack in vehicle on the longitudinal and transverse position remains the same, the
height of the battery pack changes proportionally in vertical, the aerodynamic performance simulated by changing the dimensions of the battery pack size respectively.

![Figure 7. Drag Coefficient and Lift Coefficient of the Different Width of the Battery Pack.](image)

![Figure 8. Drag Coefficient and Lift Coefficient of the Different Length of the Battery Pack.](image)

THE EFFECT OF BATTERY PACK WIDTH ON AERODYNAMIC PNEUMATIC

The length and height size of battery pack remains the same, change the width of the battery pack size $b$. When the specific value of the battery pack width $b$ and vehicle width $B$ is taken 0.375, 0.438, 0.5, 0.563, 0.625, simulated respectively, the variable relationship of drag coefficient and lift coefficient at different battery pack width is shown in figure 7.

Through figure 7, with the increase of the specific value of the battery pack width and vehicle width, the drag coefficient rise almost in linear relationship. The drag coefficient increased about 0.007, when $b/B$ increased 0.063, the total range ability is big. With the increase of the specific value of the battery pack width and vehicle width, lift coefficient tends to decline. At most, the lift coefficient decreased by 0.04, the whole decrease amplitude is large. The reason is that the battery pack is more wide, the windward area of battery pack is more big, the resistance of vehicle is more great, the vortices formation at the back-end of battery pack became big, the drag coefficient rise. The battery pack is more
wide, more air flow through the battery accelerated, pressure at the bottom of the vehicle decreased, so the lift coefficient decreased.

THE EFFECT OF BATTERY PACK LENGTH ON AERODYNAMIC PERFORMANCE

The height and width size of the battery pack remains the same, the length of the battery pack size \( l \) changes. When the specific value of the battery pack length \( l \) and vehicle length \( L \) is taken 0.286, 0.310, 0.333, 0.357, 0.381, simulate calculation, respectively.

The variable relationship of drag coefficient and lift coefficient at different battery pack length is shown in figure 8.

![Figure 8](image_url)

Figure 8. Drag Coefficient and Lift Coefficient at Different Battery Pack Length.

Through figure 8, with the increase of the specific value of the battery pack length and vehicle length, the drag coefficient tends to descend. The drag coefficient only descends 0.0061, the total descend range is very small, it can be ignored. With the increase of the specific value of the battery pack length and vehicle length, lift coefficient tends to increase. At most, the lift coefficient increased by 0.062, the whole increase amplitude is large. The reason is that the battery pack is longer, the airflow velocity got the wake of battery is more slow, the slower the formation of, the vortex intensity is abate, the pressure drag is reduced, the drag coefficient is descended. The battery pack is longer, the boundary layer on the surface is thicker, the air flow channel is compressed, the airflow velocity drops, pressure increases, the lift coefficient rise.

THE EFFECT OF BATTERY PACK HEIGHT ON AERODYNAMIC PNEUMATIC

The length and width size of the battery pack remains the same, the height of the battery pack size \( h \) changes. When the specific value of the battery pack height \( h \) and the maximum ground clearance of vehicle \( H \) is taken 0.1, 0.2, 0.3, 0.4, 0.5, simulate calculation, respectively.
Under the condition that the chassis structure size has not obvious change, the increase of the height of battery pack size means that the minimum ground clearance of vehicle decrease. The variable relationship of drag coefficient and lift coefficient at different battery pack height is shown in figure 9.

Through figure 9, with the increase of the specific value of the battery pack height and maximum ground clearance of vehicle, the drag coefficient tends to increase, and the total range ability is big. With the increase of the specific value of the battery pack height and maximum ground clearance of vehicle, lift coefficient tends to decrease, the change trend is gradually increased, and the total range ability is big.

The reason is that the battery pack is higher, the windward area of battery pack is more big, the resistance of vehicle is more great, the vortices formation at the back-end of battery pack became big, the drag coefficient rise. The battery pack is higher, the air flow channel is compressed, the airflow velocity is accelerated, the pressure at the bottom of the vehicle is decreased, and the lift coefficient is decreased.

Above analysis uses the SAE-B model as the object. The aerodynamic performance of electric vehicles is studied. The variable relationship of drag coefficient and lift coefficient under the change of battery pack size.

CONCLUSION

In this paper, FLUENT software is used to establish the SAE-B model. The turbulence method which can realize is used to analyze the effect of the battery at the bottom of vehicle on the flow field structure around vehicle. The variable relationship of aerodynamic performance and the change of battery pack size is researched through simulation. Draw the following conclusions.

1) The battery pack had a great effect on flow field structure of the bottom and the wake of the vehicle. The main effects include the airflow velocity at bottom of the vehicle reduced, a large number of vortex generated, the drag coefficient and lift coefficient increased.

2) The different dimension of battery pack causes different effect to the aerodynamic performance. The battery pack is wider, the drag coefficient is greater, and the lift coefficient is smaller. The battery pack is longer, the drag coefficient is smaller, and the lift coefficient is larger. The battery pack is higher, the drag coefficient is greater, and the lift coefficient is smaller.

According to the analysis results above, the layout of the battery pack should not extrude out of the bottom of the vehicle, otherwise it will cause adverse effect to the aerodynamic performance. When the battery pack extrude out of the bottom of the vehicle, it should arrange “long narrow” type, this is beneficial to reduce the aerodynamic drag. The analysis results can provide the reference for aerodynamic performance optimization of electric vehicle and battery layout.
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