Study of the Air Conditioning Installation Mode’s Effect on Aerodynamic Performance of High Speed Train

Qi-Chen Hong and Ming-Zhi Yang

ABSTRACT
With the improvement of the train speed, the interaction between train and air increases obviously, creating a series of aerodynamic performance problems that cannot be ignored. This paper focuses on high-speed train drag reduction research, to study whether the installation of air conditioning system will have a greater resistance to the train and the influence of the diversion angle of the air deflector on the aerodynamic characteristics of the train running in different environments. The results indicates as follows: In the open environment, when the roof of the train is installed with air conditioning, the resistance coefficient of the head car, the middle car and the tail car is increased by 27.39%, 20.33% and 18.25% respectively, while the resistance coefficient of the pantograph is reduced by 22.07% and the resistance coefficient of the vehicle up to 19.23%; With the air conditioning shroud diversion angle changed from 90° to 15°, in the open environment, vehicle air resistance decreased by 11.77%, the total resistance of the three air-conditioning decreased by 59.04%; In the crosswind environment, the overturning moment coefficients of air conditioners increased by 14.84%, 17.61% and 4.90% respectively.

KEY WORDS: High speed train; Air conditioning system; Numerical simulation; Aerodynamic characteristics.

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1. INTRODUCTION

As the most important means of transport at home and abroad, high-speed trains possess large transport capacity, low energy consumption, environmental protection and other advantages. With the increase of the train speed, the dynamic environment of the trains turns out to be aerodynamic domination. The aerodynamic problem is becoming the key technology of the high-speed train [1-2]. When the train speed reaches 250-300 km/h, the aerodynamic drag could take 75% of the total resistance. [3] The researchers carried out a large number of train shape optimization design and achieved remarkable results, the current vehicle shape on the optimization of the design to the bottleneck period, people began to explore the partial equipment to optimize the train to reduce the aerodynamic drag. The original structure of the air conditioning shroud is analyzed by numerical calculation, the outer surface pressure and velocity field distributions of the original shroud at 350 km/h were obtained and the shroud was optimized, the optimized shroud reduces the aerodynamic drag of the head vehicle by 2.6% and improves the aerodynamic performance of the vehicle. [4] The design of the pneumatic components of the train which is influenced by the head type, windshield and air conditioning of CRH3 high-speed EMU is optimized. The optimized external windshield can reduce the resistance of the vehicle by 11.4%. The rectification of the air conditioner can only decrease the resistance of the train air conditioner, while the other parts of the resistance changes little. [5] Based on tunnel wind experiment, series of researches were taken to evaluate three different sizes of air conditioning shrouds, and shows that in the roof with optimized air conditioning shroud drag reduction effect is obvious, the whole car resistance can be reduced by 4.59%. [6]

When the train is actually running, the air conditioner acts as a raised part of the outer end of the train, the air flow phenomenon is easy to appear here which will lead to a series of aerodynamic problems such as the step flow effect. This paper aims to investigate the followings: (1) Aerodynamic performance of the train whether to install air conditioning system or not. (2) Aerodynamic performance difference between the trains with different shapes of air conditioning shroud. To achieve these goals, the basic control equation of incompressible flow is used for steady flow field analyses.

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2. COMPUTATIONAL MODEL AND GRID

2.1 Physical model

In this paper, a motor vehicle group which is set as the research object. China's high-speed train is usually used in eight car grouping way, as the middle section of the train does not change, the shortened model does not change the basic characteristics of the train flow field structure. [7] In order to improve the efficiency of calculation, this paper uses three car grouping, which is head car+ middle car+ tail car, as shown in Figure1-1 and Figure1-2. In addition to the pantograph, the other small parts of the train surface omitted, the head car and tail cars are streamlined.

![Figure 1-1. High-speed train calculation model.](image1)

![Figure 1-2. High-speed train calculation model](image2)

2.2 Numerical calculation basic theory

The speed of the train in this paper is 350km/h, the Mach number is smaller than 0.3, in this paper, the basic control equations for incompressible flow are adopted. According to the law of conservation of mass, the mass of flowing fluid micro-unit per unit time and the mass of effluent fluid element are equal, and the mass conservation equation of incompressible fluid motion can be derived. [8-9]:

\[
\frac{\partial u_i}{\partial x_i} = 0
\]  

(1)

According to the law of conservation of momentum: the force acting on the fluid element and the growth rate of the fluid volume of the element are equal, and the momentum conservation equation in three directions can be obtained:

\[
\frac{\partial}{\partial t} (u_i) + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho} \frac{\partial p}{\partial x_i} + \mu \frac{\partial^2 u_i}{\partial x_i \partial x_j} 
\]

(2)

where \( u_i \) is velocity of the flow field, which represents the velocity component of three coordinate directions of u, v, w; \( x_i \) or \( x_j \) is three coordinates, represents x, y, z three coordinate components; \( \rho \) is the fluid density, which is considered to be 1.225kg/m\(^3\) in incompressible flow; \( \mu \) is aerodynamic viscosity;

2.3 Calculation area and boundary conditions

According to the European standard BSEN 14067, the boundary of the calculation domain should not interfere with the flow field around the vehicle, the upstream of the calculation area is not less than 8 times the characteristic length,
and the calculation area downstream is not less than 16 times the characteristic length. [10-11] The characteristic length is defined as the vertical distance of the top surface of the train from the ground. Since all the working conditions in this paper are running horizontally, the characteristic length is 3.7m. Figure 2-1 shows the size of the calculation field when the train is running in open environment. The calculated domain size is 400m × 120m × 80m; Figure 2-2 shows the size of the calculation field when the train is running in cross wind environment. The calculated domain size is 400m × 160m × 80m. All of the sizes of the calculation domain are in compliance with the European standards.

2.4 Calculation grid

When the train is running, the flow field near the train will change drastically, therefore, in the process of grid discretization, the grid around the train should be localized to ensure the accuracy of the calculation, at the same time, the tail flow field of the train should be encrypted by the presence of the tail vortex. For the area away from the body, the grid is relatively sparse, so that the grid can not only guarantee its quality, but also reduce the total number of grids, which can improve the efficiency of computation. The adjoining layer is set to the surface of the train surface, the thickness of the first layer of the near wall is 1mm, then the wall Reynolds number 30 < y + <100, which meets the calculation requirements of the turbulence model, the number of the total grid is 55 million.

Unlike the train running on the open line, when the train running in the cross wind environment, it will have to consider the flow field caused by the natural wind in addition to considering the flow field around the vehicle body and the rear of the tail car. The rear side of the grid also need to do encryption processing. Under the cross wind condition, the total number of domains in the calculation domain is about 58 million. The grid around the train is illustrated in Figure 3.
3. NUMERICAL METHOD VALIDATION

In order to verify the accuracy of the numerical simulation method, the aerodynamic research and development center in China 8 m by 6 m has carried on the wind tunnel test of wind tunnel. The size of the test model is the same as that of the computational model.

According to CEN standard [12], the aerodynamic force and pressure coefficients are defined as follows:

\[
C_d = \frac{F_x}{(q\infty S)} \quad (3)
\]

\[
C_s = \frac{F_y}{(q\infty S)} \quad (4)
\]

\[
C_l = \frac{F_z}{(q\infty S)} \quad (5)
\]

\[
C_m = \frac{M_x}{(q\infty Sb)} \quad (6)
\]

where \(F_x\), \(F_y\), and \(F_z\) are the mean drag, lateral force and lift, respectively, and \(q\infty\) is dynamic pressure, \(q\infty = 0.5 \rho v^2\); air density, \(\rho\), was considered to be 1.225 kg/m\(^3\). Further, \(C_d\), \(C_s\), \(C_l\) and \(C_m\) are the mean drag coefficient, lateral force coefficient, lift coefficient, and overturning moment factor respectively. Moreover, \(S\) is the cross-sectional area of the train, in this test \(S = 0.19m^2\) (full scale model is 11.2 m\(^2\)), \(b\) for the horizontal reference length, in the test to take 0.203 m (full scale model of 1.6 m), the moment of the overturning moment is the train leeward side wheel and rail contact point.

The numerical calculation model is established according to the wind tunnel test model. The boundary condition is set as the fixed wall, and the other boundary conditions are defined according to the previous description. Figure.4 shows the comparison between the test result and the calculated resistance coefficient. The results show that the numerical calculation is
4.87% difference with the wind tunnel test, and the numerical calculation is accurate and reliable, which satisfies the requirements of engineering application.

Figure 4. Date comparison between wind tunnel test results and numerical results.

4. NUMERICAL RESULTS

4.1 Influence of air conditioning unit on the aerodynamic performance of the train

Figure 5 shows the presence of air-conditioning unit of two trains under the condition of the surface pressure distribution of contrast, by figure 5 - (a) we know that when the roof without air conditioning device, the train near the tip of the nose suffers a large positive pressure. From the tip of the nose up, the speed increases, the pressure gradually reduced. When the roof is equipped with air conditioning device, when the air reaches the air conditioning area and is hampered here, in the air conditioning device near the wind surface forms a larger positive pressure area. In the front of the end area, the air flow velocity increases due to the protrusion of the cross section, resulting in a larger negative pressure zone, after which the air flow flows smoothly at the top of the air conditioner. Thus, due to the presence of air conditioning devices, the flow field at the top of the train caused a greater impact.

Table 1 shows the pneumatic resistance coefficient and the aerodynamic lift
coefficient of each part of the train in the two cases with and without air conditioner. The existence of air-conditioning on the impact of the larger impact on the lift less impact. When the roof has air-conditioning unit, the head car, car, tail car resistance coefficient increased by 27.39%, 20.33%, 18.25%, while the pantograph resistance coefficient decreased by 22.07%, the vehicle's resistance coefficient increased 19.23%. The presence of air conditioning does have a greater contribution to the improvement of train resistance, and the impact of the pantograph has been weakened.

<table>
<thead>
<tr>
<th>Train parts</th>
<th>$C_d$ With Air conditioning</th>
<th>$C_d$ Without Air conditioning</th>
<th>$C_l$ With Air conditioning</th>
<th>$C_l$ Without Air conditioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head car</td>
<td>0.186</td>
<td>0.135</td>
<td>-0.080</td>
<td>-0.086</td>
</tr>
<tr>
<td>Middle car</td>
<td>0.128</td>
<td>0.102</td>
<td>-0.036</td>
<td>-0.017</td>
</tr>
<tr>
<td>Tail car</td>
<td>0.129</td>
<td>0.106</td>
<td>0.035</td>
<td>0.034</td>
</tr>
<tr>
<td>Pantograph</td>
<td>0.032</td>
<td>0.041</td>
<td>0.003</td>
<td>0.005</td>
</tr>
<tr>
<td>Sum</td>
<td>0.475</td>
<td>0.38</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

### 4.2 Air conditioning shroud diversion angle on the aerodynamic performance of the train

From the above analysis we can see that air conditioning as a passenger train essential to the device, its raised shape disrupts the original smooth flow field structure. The traditional air conditioning structure is rectangular, its front and rear are perpendicular to the roof surface. There will be a greater pressure resistance near the area of air conditioning due to the particular structure. In order to reduce the aerodynamic drag, we need to optimize the structure of air conditioning. Air conditioning shroud can effectively improve the flow field structure of the roof area outside. In the design of air conditioning shroud, its design has a great influence on reducing air resistance. This section focuses on the aerodynamic performance of the diversion of different air conditioning shrouds. Diversion angle are $15^\circ$, $30^\circ$, $60^\circ$ and $90^\circ$ respectively, as is illustrated in figure 6.
Figure 6. The structure of the shroud: (a) diversion angle of 15° (b) diversion angle of 30° (c) diversion angle of 60° (d) diversion angle of 90°.

Figure 7 shows the train with the four different shapes of shroud running in the open air, the distribution of the surface pressure coefficient. It can be observed from the figure that under different schemes, the distribution law of the surface pressure coefficient of the longitudinal section of the train is exactly the same, only in the size of the difference, all appear in the around of air conditioning device.

Figure 7. Contrast of pressure coefficient of vertical section of train with different diversion.

From Fig.8-1, it can be observed that with the diversion angle changed from 15° to 90°, the lateral force coefficient of the head car, the middle car and the tail car increased by 0.85%, 6.05% and 6.12% respectively, and the lateral force coefficient of the pantograph was reduced by 1.94%. Figure 8-2 can be observed in the various parts of the train overturned torque coefficient changes, the size of the relationship is first car > car > tail car, with the diversion
angle from 15° to 90°. The overturning moment coefficients of the vehicle, the vehicle and the tail car increased by 1.78%, 3.04% and 4.39%, respectively. The overturning moment coefficient of the pantograph was reduced by 1.47%.

CONCLUSIONS

(1) The aerodynamic performance is quite different of the train in the two cases with and without air conditioning, the presence of air conditioning devices will make the train suffer greater resistance: the first car, middle car, tail car resistance coefficient increased by 27.39%, 20.33%, 18.25%. The total resistance coefficient of three cars increased by 19.23%.

(2) The change of the diversion angle of the air conditioning shroud has a significant effect on the change of the train resistance. When the diversion angle is reduced from 90° to 15°, the resistance coefficient of the three cars decreases by 21.50%, 8.16% and 10.21% respectively. Total drag coefficient is reduced by 11.77%.

(3) Reducing the diversion angle of the air conditioning shroud can effectively reduce the aerodynamic drag of the train. When the diversion angle is reduced from 90° to 15°, the overturning coefficient of the first vehicle, the vehicle and the tail car increased by 1.78%, 3.04% and 4.39% respectively.

REFERENCES