Study on Distribution Characteristics of Aerodynamic Drag of a Couple Multiple Units High-Speed Train

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ABSTRACT

Based on unsteady N-S equation of three-dimensional and compressible viscous fluid, the transient pressure on the car surface, both the flow structures and aerodynamic loads are analyzed in detail, the contribution value of all regions of a couple multiple units high-speed train for aerodynamic drag coefficient of the CRH2 whole train is studied. The calculation result shows that by contrasting the results of wind tunnel test with numerical simulation respectively using indirect verification method, the change law of aerodynamic effect shows agreeable accordance with the error under 5%. The aerodynamic drag of head surface area of the front and tail car and the bogie region of each car accounts for 75% of the whole train. The aerodynamic drag coefficient of the later head surface area is twice more than the head surface area in the multiple units region. From the head
car, to middle car, to tail car, the aerodynamic drag coefficient of the front region of bogie firstly reduces, increases afterwards and reduces last, and the aerodynamic drag coefficient of the rear region of bogie firstly increases, reduces afterwards and increases last. From the perspective of the flow field structure, a lot of vortexes are generated in the multiple units region. The flow separation in the multiple units region is significantly.

INTRODUCTION

Since the opening of the Beijing-Tianjin intercity train operation in 2008, as of July 11 this year, the passenger quantity sent by China's high-speed train is more than 5 billion, the average annual increasing rate in passenger traffic increases by more than 30%. There are 8 and 16 two fixed group in high-speed train, in the passenger flow peak, in order to meet the needs of large passenger transport capacity, we can use a couple multiple units high-speed train to improve the transport capacity. In recent years, the couple multiple units high-speed train in the practical application is more and more common, with the train running speed increasing, the aerodynamic problems become more prominent. In order to achieve high-speed train safety, comfort, reduce energy consumption and meet the requirements of environmental protection, the world carried out a large number of train aerodynamics researches. The train's distribution characteristics of aerodynamic drag is related to the train speed increasing, train environmental protection and energy saving capacity, which is the important part of the high-speed train aerodynamic characteristics study. When the speed of the high-speed train speed reaches 300km/h in the open air, the aerodynamic drag accounts for more than 80% of the total resistance, and the aerodynamic drag is closely related to the train shape. In addition, the two groups of eight car couple multiple units high-speed train compared to the 16 high-speed train, the shape of the couple multiple units high-speed train increases a U-shaped groove area in middle, as shown in Figure 1, they are the same length; compared to the eight groups of high-speed train, Not only the couple multiple units high-speed train increases a U-shaped groove area, but also the couple multiple units high-speed train has longer length, so the couple multiple units high-speed train has more complex shape. The different shapes of a couple multiple units high-speed train will bring complicated aerodynamic drag problems. There are many literatures on the study of aerodynamic drag problems of no couple multiple units high-speed
train groups all over the world, and there are few literatures on the research of distribution characteristics of aerodynamic drag of a couple multiple units high-speed train. Therefore, it is necessary to study the aerodynamic drag characteristics of heavy vehicle group, which can provide reference for train drag decreasing design and alleviate the situation of the average energy shortage in China.

Figure 1. A couple multiple units high-speed train  
Figure 2. Boundary layer.

For the problem of aerodynamic drag, domestic and foreign scholars have carried out a number of numerical simulation research. Xifeng Liang[1] used numerical simulation method to study the impact of different types of windshield on aerodynamic drag. Hongqi Tian[2] studied the mechanism of aerodynamic drag formation of high-speed trains and proposed measures such as smooth body surface, optimized windshield and skirt structure to reduce the aerodynamic drag. Shuanbao Yao[3] used the numerical simulation method to analyze the aerodynamic drag distribution of the CRH3 group with 8 vehicles and the aerodynamic drag contribution of the bogie, windshield and pantograph.

1. CALCULATION MODEL

1.1 Numerical Model

A couple multiple units high-speed train at a certain speed running in the open air, the airflow is free. In this paper, the vehicle speed is 83.33m/s, calculated Mach number \( Ma = 0.245 \), less than 0.3, which can be considered that the air density remains constant, which is incompressible flow problems. As a result, this paper uses the steady and viscous, incompressible N-S equation and RNG k-\( \varepsilon \) with buoyancy correction equation turbulence model to describe a couple multiple units high-speed train running in the open air.
1.2 Calculation Model

CRH2 high-speed train models is selected, which is more common in domestic high-speed rail lines, which is a couple multiple units high-speed train. There are head car, 4 intermediate car and tail car, which length is 151.800m. The length of the first car, the middle car and the tail car are 25.450m, 24.500m and 25.450m respectively, the train width is 3.376m, and the train height is 3.700m. Not consider the bogie, pantograph, windshield, air conditioning shroud and other detailed structure, head car and tail cars are streamlined. Pointwise is used to discretize the calculation area, that is, the unstructured grid is used in the bogie area, and the other regions are structured. While encrypting the lattice density around the train, simulating the surface layer effect, using sparse grid away from the body grid, there is a certain growth factor between dense grid and sparse grid. There are 100 million in six car group space body grid, the first layer of the thickness of the grid is 0.001m, body surface grid scale is 0.05m. The calculation area and the calculation grid are shown in Fig. 2, Fig. 3 and Fig. 4 respectively.

In order to analyze the contribution of each part of the vehicle to the vehicle's pneumatic drag, the train block position is shown in Fig5. Respectively, the first car, the middle car and the rear car is divided into five, which bogie and its surrounding is divided into part of the bogie area, the outside windshield were divided into the first car and tail car, the interior windshield moved to the middle car. For the convenience of comparison, the aerodynamic drag is dimensionless, the aerodynamic drag coefficient \( \text{Cd} = \frac{F_d}{(0.5 \rho U_m U_m S)} \), where: \( \rho \) is the incoming density, 1.225 kg / m\(^3\), \( U_m \) is the vehicle speed, 83.33m/s, \( F_d \) is the aerodynamic drag, \( S \) is Reference area, take 11.2 m\(^2\).
2 RESULTS AND DISCUSSION

2.1 Comparison of Wind Tunnel Experiment and Numerical Calculation

In order to verify the accuracy of numerical methods, we choose the more reliable wind tunnel experiments to compared. Wind tunnel experiment is carried in the length × width × height 15m × 8m × 6m large low-speed wind tunnel, selecting the three groups (head car +middle car + tail car) high-speed train as the research object, the model shrink ratio is 1: 15, synthetic wind speed is 60m / s. Before the formal experiment, by adjusting the wind speed to ensure that the experimental Reynolds number to meet the self-simulation area, that is, the aerodynamic coefficient no longer changes with the flow rate.

The compared aerodynamic drag coefficient results of the high-speed train wind tunnel experiment and numerical calculation is showed at Fig 6.

![Figure 6. Comparison of wind tunnel test and numerical calculation.](image)

The aerodynamic drag coefficient obtained by the numerical calculation method is slightly smaller than that of the wind tunnel experiment. Compared with the wind tunnel experiment and the numerical calculation result, the related error between the two is within 5%, and the coincidence degree is very good. The used method can be used for later studies.

2.2 Analysis of Aerodynamic Coefficient

It can be seen from Fig. 7 that the aerodynamic drag of the front section (tc1 and tc2 area) of the couple multiple units high-speed train and no couple multiple units high-speed train accounts for 75% of the total drag on the head car and the two types of high-speed train bogies (tc1 and tc4 regions) accounted for 58%, the maximum aerodynamic drag coefficient appears in the streamlined head bogie area, therefore, in the train drag reduction optimization, the bogie area should be considered as the focus of the object, and bogie structure should be optimized as much as possible. At the end of the train connection, due to the presence of windshields and gaps, the surface pressure of the train is changed and the
windshield pressure is positive. Therefore, the drag coefficient at the end of the train is small. It is showed in Fig 8. The total drag of the two groups of train is relatively close.

![Figure 7](image1.png)  **Figure 7**  Aerodynamic drag coefficient part of head car.

![Figure 8](image2.png)  **Figure 8**  Pressure distribution of each windshield surface.

It can be seen from Figure 9, two types of bogie area (zc6 and zc9) in middle 1 car aerodynamic drag coefficient accounted for 56% of the entire vehicle, the bogie area drag decreasing design is the focus. The maximum aerodynamic drag coefficient appears in the upper part of the front side of the middle car 1 (zc7), there is flow disorder the windshield between head car and the middle 1 car, resulting in regional aerodynamic drag coefficient in zc7. In the middle 1 car flat cross-section smooth transition, the friction drag is main, so the aerodynamic drag coefficient is relatively small. Also in the upper part of the rear side of the middle 1 car (zc10) aerodynamic drag coefficient is negative, the value is relatively small. The total resistance of the two groups of train is relatively close.

![Figure 9](image3.png)  **Figure 9**  Aerodynamic drag coefficient of each part of middle 1 car.

![Figure 10](image4.png)  **Figure 10**  Surfaces streamlines on the multiple region.
It can be seen from Table 1 that the aerodynamic drag of the middle 2 car bogie area (zc11 and zc14) in the couple multiple units high-speed train accounts for 32% of the total middle 2 car, and the middle 2 car bogie area (zc11 and zc14) accounting for 61% of the total middle 2 car, the reason for the difference in two types of bogie aerodynamic drag coefficient is that reconnection area (zc15) accounted for 46% of the middle 2 car, zc15 aerodynamic drag coefficient accounts. (zc13) aerodynamic drag coefficient is the minimum, the aerodynamic drag coefficient of the rear-end streamlined area (zc15) in the middle 2 car is positive and maximum. The aerodynamic drag coefficient in zc15 is negative. The aerodynamic drag in the later bogie area (zc14) is greater than the previous bogie area (zc11) both two types of high-speed train. The flow field structure of the two types of EMU in the middle 2 car is quite different, so the total drag difference is large.

<table>
<thead>
<tr>
<th>Area</th>
<th>zc11</th>
<th>zc12</th>
<th>zc13</th>
<th>zc14</th>
<th>zc15</th>
<th>Middle 2 car</th>
</tr>
</thead>
<tbody>
<tr>
<td>a couple multiple train</td>
<td>0.0160</td>
<td>0.0157</td>
<td>0.0083</td>
<td>0.0203</td>
<td>0.0524</td>
<td>0.1127</td>
</tr>
<tr>
<td>no couple multiple units</td>
<td>0.0160</td>
<td>0.0140</td>
<td>0.0102</td>
<td>0.0217</td>
<td>-0.0004</td>
<td>0.0615</td>
</tr>
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</table>

It can be seen from Table 2 that the aerodynamic drag of the middle 3 car bogie area (zc17 and zc20) in the couple multiple units high-speed train occupies 25% of the middle 3 car, the proportion is smaller than that of the middle 1 and middle 2 car, and the reconnection area (zc18) aerodynamic drag coefficient accounted for 70%, the head streamlined area has great impact on middle 3 car. The aerodynamic drag in zc17 an zc20 accounts for 67% of the middle 3 car, and the drag reduction design of the bogie area is the focus. The aerodynamic drag coefficient In the middle 3 car horizontal section area (zc19) is the smallest, mainly the frictional drag. The same aerodynamic drag coefficient of the upper part of the tail bogie is negative, the proportion is very small. As the flow field structure in two types of high-speed train in the middle 2 car is quite different, so the total drag difference is large. Figure 10 is the surface of the surface of the reconnection of the surface stream, the air flow through the groove area, the first
declining after the rising, the basic flow separation occurring, because the two streamlined surface connection area is smooth enough, the basic flow along the wall downstream development. The flow separation causes the airflow to become more turbulent, so the rear streamline area aerodynamic drag coefficient is twice the front-end reconnection zone.

<table>
<thead>
<tr>
<th>Area</th>
<th>zc17</th>
<th>zc18</th>
<th>zc19</th>
<th>zc20</th>
<th>zc21</th>
<th>Middle 3 car</th>
</tr>
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<tr>
<td>a couple multiple units</td>
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<td>0.1040</td>
<td>0.0094</td>
<td>0.0142</td>
<td>-0.0026</td>
<td>0.1479</td>
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<tr>
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<td>0.0175</td>
<td>0.0108</td>
<td>0.0095</td>
<td>0.0230</td>
<td>-0.0004</td>
<td>0.0604</td>
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It can be seen from Figure 11 that the aerodynamic drag of the middle 4 car bogie area (zc22 and zc25) in the couple multiple units high-speed train occupies 65% of the total middle 4 car, and the aerodynamic drag of the middle 4 car bogie area (zc22 and zc25) accounts for 69% of the middle 4 car, the same the drag reduction design in bogie area is the focus. The maximum drag coefficient appears in the rear bogie area (zc25). The drag coefficient in horizontal section area smooth transition is the smallest, mainly for the friction drag. Also in the upper part of the rear side of the middle 4 car (zc10) drag coefficient is negative, the value is relatively small. The total drag in middle 4 car of the two types of high-speed train is relatively close, and the flow field of the reconnection zone does not have a significant impact on the middle 4 car.

Figure 11. Aerodynamic drag coefficient of each part of middle 4 car.
Figure 12. Comparison of aerodynamic drag proportion in head and tail car.

We can see from table 6 that the aerodynamic drag coefficient in two types of
high-speed train tail car is relatively close, reconnection area does not have a great impact on the tail car drag coefficient. The aerodynamic drag coefficient in wc27 and wc30 accounted for 30% of the tail in the couple multiple units high-speed train, the aerodynamic drag coefficient in wc27 and wc30 accounted for 31% of the tail in the no couple multiple units high-speed train. The maximum resistance coefficient of the two types of high-speed is in the trailer streamline area (wc31), accounting for 54%, the tail drag reduction design is very important. The cross section of the tail car is smooth and the drag coefficient is relatively small, mainly for the frictional resistance. The upper part of the tail car (wc28) has a minimum drag coefficient.

<table>
<thead>
<tr>
<th>Area</th>
<th>wc27</th>
<th>wc28</th>
<th>wc29</th>
<th>wc30</th>
<th>wc31</th>
<th>Tail car</th>
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</thead>
<tbody>
<tr>
<td>a couple</td>
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<td>0.0122</td>
<td>0.0299</td>
<td>0.0813</td>
<td>0.1515</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>units</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>no couple</td>
<td>0.0213</td>
<td>0.0073</td>
<td>0.0173</td>
<td>0.0261</td>
<td>0.0806</td>
<td>0.1525</td>
</tr>
<tr>
<td>multiple</td>
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We can see from the Fig 12 that the tc1 regional drag coefficient is 0.0492, the zc2 regional drag coefficient is 0.0478, the sum of the two regional drag coefficients is 0.097, the head car drag coefficient is 0.1295, accounting for 75% Other regional drag coefficient is computed like this. So the head car and tail car streamlined area of the proportion of pneumatic drag can reach 70%, so a reasonable streamlined design for the train pneumatic drag is critical.

It can be seen from Fig. 13 that the front bogie drag coefficient in the front, middle and rear bogie is decreasing and the drag coefficient of the rear bogie is gradually increasing. Due to the impact of re-groove area, in the car 2 and 3 fluctuations, but the law is still established.

Figure 13. Comparison of aerodynamic drag proportion in bogie.
2.3 Analysis of Flow Field

As can be seen from Fig. 9 and Fig. 10, when the air is obstructed and the air flows through the head nose cone and the deflector groove, the airflow velocity is about 0 m/s and the pressure is maximum. So the head car and tail car streamlined regional pneumatic drag accounted for a large proportion of the first car or tail car. In Head near the nose cone, the flow rate is low, and the flow velocity is 0, the pressure is the largest. Along the body back, the flow rate increases, the pressure decreases, the place of the first car streamlined end where is near the shoulder area is negative pressure area. When the airflow continues to flow along the vehicle body and flows to the reconnection site, the air flow first decline and then rises, and the surface of the reconnection train is positive and the back pressure is larger than the front end. Therefore, the drag coefficient of the rear end streamlined area is bigger than the front. The pressure distribution of the head and tail cars is relatively complex, and the change of the pressure distribution in the middle section is small.

![Figure 14](image1.png)  
**Figure 14.** Pressure distribution of train surface.

![Figure 15](image2.png)  
**Figure 15.** Transient flow field structure around the multiple region—the second invariant $Q = 40000$ level.

There is the reconnection zone vortex structure diagram in fig 10, taking $Q = 40000$, using pressure rendering. In the reconnection area, a large number of vortices are generated, and the vortex structure is large. These vortices are detached from the rear end to form pulsations, so that the turbulence around the recirculation zone is very complicated.

3 CONCLUSION

(1) The aerodynamic drag coefficient obtained by the numerical calculation method is slightly smaller than that of the wind tunnel experiment. Compared with the wind tunnel experiment and the numerical calculation result, the related error between the two is within 5%, and the coincidence degree is very good. The used method can be used for later studies.

(2) The pneumatic drag of the streamlined area and the bogie area is the main source of the vehicle's pneumatic drag. The aerodynamic drag of the head and rear bogie is negative, which is beneficial to the energy saving and consumption reduction.
REFERENCES


