Influence of Apron and Equipment Cabin on Aerodynamic Characteristics of Intercity Train

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ABSTRACT

The objective of this study was to investigate the influence of apron and equipment cabin on aerodynamic characteristics of intercity train using numerical simulation. Then aerodynamic force of the train in the open air and crosswind, pressure changes of the train and tunnel were obtained. The results show that the intercity train with apron or equipment can reduces drag, which mainly reduces the pressure differential drag more than 7\%. The train with apron has better crosswind stability than with equipment cabin because of the smaller windward area, and obviously it does not better than the original train. And the train with apron also has better performance of passing tunnel than with equipment cabin and the original train.

1. INTRODUCTION

The bottom structure of a train is very complicated, and its complicated structural shape plays an important role in the aerodynamic performance of the train. Reasonable design and arrangement of the bottom structure of the train can effectively reduce the resistance of the train running, thereby improving the overall aerodynamic performance of the train.

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Schulte W et al. carried out wind tunnel experiments and found that the rectifier device installed around the bogie can play a drag reduction effect\cite{1}. Hyeok et al. shows that the more the bogie is coated, the smaller the aerodynamic resistance of the train\cite{2}. IDO, Japanese researchers, conducted wind tunnel tests in 2008, and found that the airflow at the bottom of the train was particularly sensitive to the shape of the bottom. The more the shape of the bottom, the less the flow of the car\cite{3}. Hongqi Tian analyzed the influence of the bottom structure on the aerodynamic performance of the high-speed EMU through the wind tunnel test, and the absolute value of aerodynamic drag and aerodynamic lift of the EMU fitted with the bottom cover was smaller than that of the apron\cite{4}. Zhigang Yang et al. analysis the aerodynamic characteristics of the high-speed train without apron and with apron at different position, the installation of apron can effectively reduce the aerodynamic drag, and the apron mounted at the head or tail car bogie have the best reduction effect\cite{5}. When intercity train running in cross wind environment, the overall aerodynamic performance of the train will usually decrease sharply, then the train will be subject to lateral aerodynamic effects, it even cause train derailment overturned and serious influence on safe operation of the train. Crosswind stability plays a very important role in the numerous problems of train aerodynamics all the time\cite{6,7}. J.Y. Kim et al. adopts the dynamic mesh method to study the pressure change in the subway train during the variable speed operation in 2007\cite{8}.

According to the actual operating environment of intercity train, study on the aerodynamic effect of the train running in the open air, crosswind and tunnel, considered about the demands on the aerodynamic performance of the intercity train, analysis of the influence of apron and equipment cabin on intercity trains.

This paper is organized as follows. In Section 2, the geometry, the numerical method, meshes and boundary conditions are given together with the cases studied. In Section 3, the aerodynamic characteristics of intercity train in each case is compared and analyzed. Finally, conclusions are drawn in Section 4.

2. CFD ANALYSIS

2.1 Computational Model and Boundary Condition

2.1.1 GEOMETRIC MODEL

In this paper, the effect of vehicle under train on aerodynamic effect of intercity train is studied. In order to simplify the calculation process and save calculation time, the model is divided into 4 car groups, and the equipment under the train is symmetrically distributed (shown in Figure 1). Train model length \(L=94.3\text{m}\), width \(W=3\text{m}\), high \(H=3.7\text{m}\), cross sectional area of \(9.56\text{m}^2\). The cross section of the tunnel is shown in Figure 1. The clearance area of the tunnel is \(20\text{ m}^2\), and the ratio of the obstruction (the ratio of the cross section of the train to the tunnel) is 0.45.
2.1.2 COMPUTATIONAL DOMAIN AND BOUNDARY CONDITION

Figure 2(a) is computational domain for intercity train running with the speed of 160km/h in open air. According to the European standard BS EN 14067, the size of computational domain should ensure the full development of the flow field when train is running in open air. The upstream of the flow field shall be no less than 8 times of the characteristic height or 1 time of the characteristic length, and the downstream of the flow field shall be no less than 16 times of the characteristic height or 2 times of the characteristic length. The characteristic height here refers to the distance between the top of the train and the ground. Take the train to the roof height from the ground is $H=4\text{m}$, the characteristic length is $L=100\text{m}$. For ensure the full development of flow field, the computational domain adopted in this paper is more appropriate than the European standard. In addition to considering the full development of the train trailing vortex, the development of vortices on the lee side of the river basin should also be considered when train is running in crosswind. Figure 2(b) shows the computational domain for intercity train is running with the speed of 160km/h in crosswind with the speed of 25km/h. Figure 2(c) shows the computational domain for intercity train is running with the speed of 160km/h in tunnel. The length of the tunnel is 875m.
2.2 Grid Generation for CFD Simulation

In order to get better mesh and reduce the number of grids, different parts of train are set with different discrete sizes. The surface of the streamlined head, bogie and bottom structure surface of the train is 0.03m, the mesh size of the body and windshield is 0.08m. In the area closer to the train, the grid is relatively dense, and becomes sparse with distance. According to the experience, the boundary layer of the car body, the bogie and the bottom structure are covered with 35 layers. The grid thickness of the first layer is set to 1mm, which is enough to meet the computational requirements of the turbulence model. The bogie structure is complex and it is difficult to generate structural grids. Therefore, the bogie region is discretized by unstructured grids, and the boundary layer is not painted. The rest of the structure is discretized by structural grid. The grid numbers are more than 50 million after discretization. Figure 3(a)~(d) shows the computational grid for intercity train in open air and crosswind.

The train through the tunnel belongs to unsteady problems, the computational domain partition sliding mesh method to realize the relative motion between the train and the tunnel, the partition of the data exchange between the exchange surface. When the train passes the tunnel, the switching surface is the annular surface between the vehicle and the tunnel. The shape of intercity trains is complicated, and unstructured grids are used to divide them. The outer space of the tunnel and the air domain is divided by a structural grid. The total grid numbers are above 30 million. Figure 3(e) and (f) shows the grid for intercity train pass through tunnel.
2.3 Methodology for CFD Simulation

This paper adopts three-dimensional, incompressible, steady N-S equations and the standard $k-\varepsilon$ turbulence model for structured grids, the calculation of the intercity train running in open air and crosswind of numerical simulation. Unstructured grids are simulated by using three-dimensional, compressible and unsteady N-S equations as well as $k-\varepsilon$ turbulence models for numerical simulations when train passing tunnels.

In the steady flow calculation, the *QUICK* scheme and the structured grid is adopted in steady operation. The *QUICK* scheme is more accurate than the other schemes for the structural mesh aligned with the flow direction. The *Second-Order Upwind* scheme is adopted to simulate the train passing through the tunnel. The *SIMPLEC* algorithm is used to solve the incompressible flow field.

3. RESULTS AND DISCUSSION

3.1 Aerodynamic Characteristics of Intercity Train in Open Air

Figure 4 shows the aerodynamic force coefficient of the different model intercity train in open air. In Figure 4(a), the intercity train with apron and with equipment cabin are both reduce the differential pressure drag, and more effectively in head car. The intercity train with equipment cabin reduces more differential pressure drag than the one with apron about 25.6% than 9.3%. But for frictional drag, Figure 4(b) shows...
the intercity train with apron and equipment cabin are both increased. Figure 4(c) shows the intercity train with apron and with equipment cabin are both reduce the drag than the original train, mainly reduce differential pressure drag. The one with apron reduce 7.48% than the original one and the one with equipment cabin is 10.5%. In short, the drag from big to small also is tail car, head car, middle car.

Figure 4. Aerodynamic face coefficient of the intercity train in open air. (a) Pressure difference drag coefficient; (b) Frictional drag coefficient; (c) Total drag coefficient; (d) Total lift coefficient.

Figure 4(d) shows the total lift coefficient of three intercity train model in open air. The intercity train with apron and with equipment cabin both have a greater impact on head car, and have little influence on the tail car. For head car, the one with equipment cabin reduce about 64% while the one with apron is about 21%.

3.2 Aerodynamic Characteristics of Intercity Train in Crosswind

Figure 5 shows the aerodynamic face coefficient of the different model intercity train in crosswind.
Figure 5. Aerodynamic face coefficient of the intercity train in crosswind.
(a) Lift coefficient; (b) Lateral force coefficient; (c) Overturning moment coefficient.

Figure 5 (a) shows the lift coefficient of three intercity train models in crosswind, it is obvious that the one with equipment cabin increase 26% than the original one, while the one with apron increase 12%. Figure 5 (b) and (c) show both apron and equipment cabin increased the lateral frontal area, the deterioration of the crosswind stability of trains. But the lateral force coefficient and overturning moment coefficient of the one with apron are more approximating to the original train than the other.

3.3 Aerodynamic Characteristics of Intercity Train in Tunnel

From the line into the tunnel, intercity train running environment mutation, flow space suddenly narrowed, the train surface pressure increased dramatically, while the compression wave generated in the tunnel, compression wave echo attenuation in the tunnel, so after entering the tunnel, the train surface pressure fluctuations still exist.

Figure 6 shows the apron installed decreased the surface positive peak value of 3.76%, negative peak value decreases by 4.46%; while the equipment cabin measured decreased the surface positive peak value of 3.255%, negative peak value increased by 11.77%.

Figure 7 shows that compared with the original model, the installed apron reduces the positive peak value of the tunnel wall surface by 1.62%, and the negative peak absolute value by 6.58%; the installed equipment cabin increased the positive peak value of the measured point on the tunnel wall by 2.40%, and the negative peak absolute value increased by 8.96%.
As the Figure 6 and Figure 7 show, compared with the original model, both the apron and the equipment cabin reduce the pressure on the surface of the train and the tunnel wall, but the change of the pressure is almost the same. The installation of apron has great influence on the negative peak value of the train surface measuring point, and has little influence on the positive peak. The equipment cabin has a greater influence on the negative peak value of the measuring point, and has less influence on the positive peak.

Figure 8 shows the intercity train body surface pressure amplitude variation of the original train model, the intercity train with apron and the intercity train with equipment cabin is basically identical along train longitudinal direction. The pressure amplitude decreases gradually from the head to the tail, and the maximum pressure amplitude is 7.16KPa, 6.87KPa and 7.34Kpa respectively. The maximum amplitude of pressure at the surface measuring point of the intercity train with apron is 5.72% lower than that of the original train model, while the maximum amplitude of pressure at the surface measuring point of the intercity train with equipment cabin is 5.57% higher than that of the original train model.
Figure 8. Pressure amplitude variation at intercity train surface along longitudinal direction of train.

Figure 9. Pressure amplitude variation at tunnel wall surface along longitudinal direction of tunnel.

Figure 9 shows the tunnel wall surface pressure amplitude variation of the original train model, the intercity train with apron and the intercity train with equipment cabin is basically identical along tunnel longitudinal direction. The pressure amplitude decreases gradually from the head to the tail, and the maximum pressure amplitude is 8.27KPa, 8.45KPa and 8.78KPa respectively. At 150 meter away from the entrance of the tunnel, the pressure amplitude of the tunnel wall surface are at its maximum for all of them. The maximum pressure amplitude of the intercity train with apron is 3.66% lower than the original train model, and the maximum amplitude of the intercity train with equipment cabin is 4.83% higher than that of the original train model. The installation of apron improves the performance of train tunnel. The installation of equipment cabin makes the windward area of the train increase and the blocking ratio increases, so the peak value of the pressure peak increases.

CONCLUSIONS

This paper from installation of apron or equipment cabin to study the effects of bottom structure on the aerodynamic characteristics of intercity train, and analysis to
the stability of train in crosswind and characteristics of train pass tunnel. The main conclusions are as follows:

(1) The influence of the drag of the head car is greatly affected by the installation of the apron and equipment cabin, which mainly reduces the pressure differential drag of the intercity train. And the total drag of the intercity train with apron is decreased by 7.48% than the original model, while with equipment cabin decreased is 10.5%. The drag from big to small also is tail car, head car, then middle car.

(2) Compared with the original model, the crosswind stability of intercity train with apron decreases and the performance of passing tunnel improved, but the lateral force and overturning moment increases significantly. The maximum amplitude of the pressure on the surface of the measuring point of the train is reduced by 5.72%, and the maximum amplitude of the pressure at the measuring point of the tunnel wall is reduced by 3.66%.

(3) Compared with the original model, the crosswind stability of intercity train with equipment cabin deteriorated sharply and seriously affects the head car. The lift, lateral force and overturning moment of the head car increased by 26.37%, 61.76% and 54.64% respectively. The maximum increase of peak value of surface pressure of tunnel is about 5.57%, and the maximum increase of peak value of wall pressure is about 4.83%.

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