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Effect of Windshield Configuration and Train Marshalling Length on Train Aerodynamic Performance

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Abstract

The impact of different windshield configurations (internal and external), and train length (3, 6 and 8-car group), on the aerodynamic characteristics of a high-speed train (HST) was investigated. The shear stress transport (SST) k-ω turbulence model was employed to determine the airflow features of the train at $Re=2.3\times10^6$. The result shows that for 3-car group trains, Case 2, Case 3 and Case 4 experience a drag reduction of 1.5%, 1.3% and 2.0% respectively as compared to Case 1. When the marshalling length increase, the aerodynamic drag decreases by 4.2%, 3.7% and 4.7% for the 6-car group trains; while it is 5.0%, 4.7% and 5.2% respectively, for 8-car group trains. Therefore, employing an external windshield for all the inter-carriage gaps except the first gap has the potential to not only reduce the aerodynamic drag of the head and tail cars, but also that of the train for all marshalling length. Though the aerodynamic drag of the head car increases significantly with external windshield, when all the inter-carriage gaps are enclosed with an external windshield, the total aerodynamic drag is reduced significantly. Therefore, to reduce the energy consumption and increase the train speed, fully enclosed external windshield should be employed for all the inter-carriage of the new generation of HSTs.

Keywords: high speed train, windshield, aerodynamic drag, RANS method

1 Introduction

High-speed train is one of the most essential parts of today's transportation system because of its fast speed and high transportation efficiency. The train aerodynamic performance includes the most important parameters for the development of a new high-speed train (HST), and the continuous rise of HSTs operation speed has cause a lot of concern about the train aerodynamic performance. As HST move in open air, it experiences a resistance to it motion due aerodynamic drag force[1]. This force does not only limit the speed of the HST but also increase it energy consumption.

In order to reduce the energy consumption/operation cost, and increase the train travelling speed, a lot of studies have been carrying out to enhance the shape of the HST. HST inter-carriage structure significantly affect the train aerodynamic performance; ensuring that HST surface (i.e., inter-carriage gaps section) is smooth and free of bumps has the possibility to improve the train aerodynamic performance. Kukreja and Jumar [2] noted that vortices are formed around the inter-carriage gap region, and train's drag force could be reduced by effectively enclosing the gaps. Zhang et al. [3]indicated that the aerodynamic drag is reduce by 38.2% when the bogie cavities and inter-carriage gaps are smoothly enclosed.

The length of an HST highly affects it aerodynamic performance, as the flow structure is changed with geometric variation [4]. Tan et al. [5] stated that when the marshalling length of a train increases, the average aerodynamic drag and lift coefficient of the tail cars have a significant negative correlation. Niu et al. [6] indicated that external windshield increases the aerodynamic drag of the head car while that of the tail car decreases. Therefore, in this paper, the internal and external windshield are employed (by making four different configurations) so as to determine the windshield configuration which ensure better aerodynamic performance, and also their influence on the aerodynamic performance as the train length increase.

2 Methods

A simplified train model with a 1:7 scale was employed in this study. The full-scale dimensions of the train model are length L=76.445 m, width W=2.950 m, and height H=3.890 m. The head and tail car length is 25.835 m, and the middle cars are 24.775 m long. The total length of the train is (25.835 m × 2) + (N – 2) × 24.775 m, where N is taken as 3, 6, or 8.

To determine the effect of windshield configurations on the train aerodynamic performance, the internal and external windshield as shown in Figure 1(b) are used. Four train model denoted as Case 1, Case 2, Case 3 and Case 4 in three different groupings (i.e., 3, 6 and 8 car groups) with different windshield configurations are employed as shown in Figure 1(c).

The train model was placed on the center of a computational domain to determine the flow features. The domain is designed according on CEN standard, where the inlet is at least 8H from the nose of the train and the outlet is at least 16H from the rear nose of the train [7].

A uniform velocity of 60m/s was applied at the inlet for all case study and based on this velocity and height H=0.5557m, the Reynolds number is calculated as Re=/μ≈2.3×106. The upper wall, back, and front are set at symmetry boundary conditions while the outlet is set with a total pressure of 0 Pa. A moving no-slip wall at 60m/s is employed at the ground.

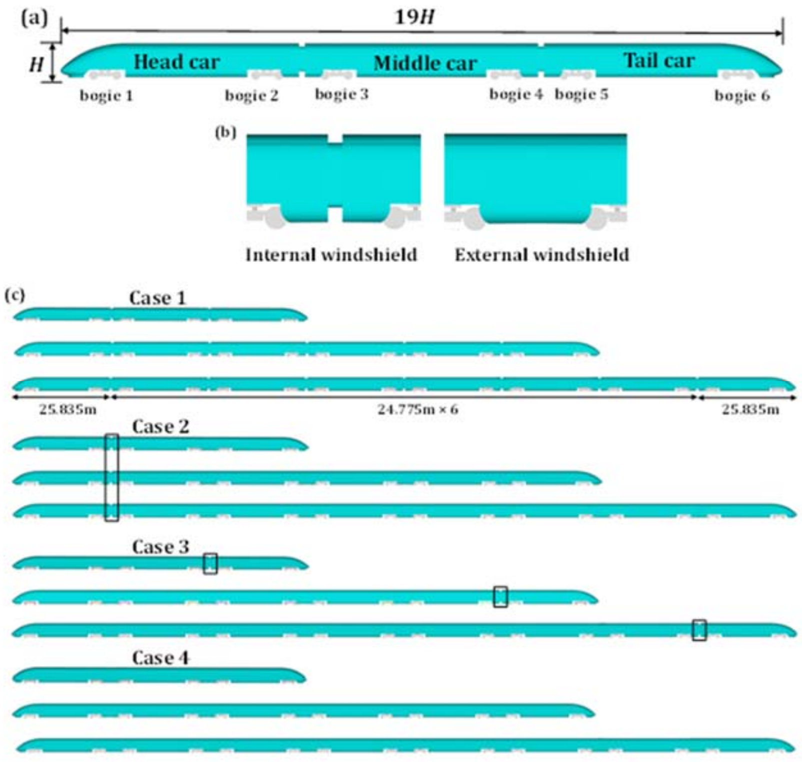

Figure 1: Case 1, Case 2, Case 3 and Case 4 represent HST models in 3, 6 and 8 car groupings for each case

To generate mesh grids, three refinement boxes were placed around the train.15 prism layers were applied on the train surface with an aspect ratio of 35 in spanwise and streamwise directions, whereas for the ground and bogies, 10 layers were added with an aspect ratio of 25. The thickness of the first layer is 0.11mm, which result in y+ for most of the train surfaces being less than 10.

The SST k-ω model (where, k is the turbulence kinetic energy, and ω is the specific dissipation rate) is employed in this study, developed by Menter. [8]. The pressure and velocity field are coupled using SIMPLE-C algorithm. The second-order upwind was selected for solving the turbulence kinetic energy and specific dissipation rate equations. 10e-6 was set as the residual value for the continuity equation to guarantee the flow convergence.

3 Results

Table 1 shows that in each case, as the marshalling length increase, the discrepancy of the aerodynamic drag force coefficients of the head car is small and negligible. When the total train drag is evaluated, as compared to Case 1, a drag reduction of

1.5%, 1.3% and 2.0% is recorded for Case 2, Case 3 and Case 4 respectively for 3-car group trains. When the marshalling length increase, as compared to Case 1, the aerodynamic drag decreases by 4.2%, 3.7% and 4.7% for the 6-car group trains; while it decreases by 5.0%, 4.7% and 5.2% respectively, for 8-car group trains. These indicate that the head car's drag increases significantly with external windshields in all the inter-carriage gaps, whereas the total train drag decreases.

Case 1	Component								Total
	Head car	M1	M2	M3	M4	M5	M6	Tail car	
3-cars	0.1279	0.0947	-	-	-	-	-	0.1751	0.3977
6-cars	0.1265	0.0932	0.0812	0.0744	0.0769	-	-	0.1542	0.6064
8-cars	0.1264	0.0933	0.0827	0.0740	0.0730	0.0745	0.0722	0.1478	0.7441
Case 2	Component								Total
	Head car	M1	M2	M3	M4	M5	M6	Tail	
3-cars	0.1270	0.1150	-	-	-	-	-	0.1508	0.3928
6-cars	0.1261	0.1160	0.0731	0.0670	0.0661	-	-	0.1325	0.5811
8-cars	0.1265	0.1188	0.0730	0.0670	0.0654	0.0635	0.0642	0.1284	0.7068
Case 3	Component								Total
	Head car	M1	M2	M3	M4	M5	M6	Tail car	
3-cars	0.1526	0.0661	-	-	-	-	-	0.1764	0.3951
6-cars	0.1523	0.0867	0.0740	0.0674	0.0495	-	-	0.1551	0.5850
8-cars	0.1520	0.0866	0.0745	0.0671	0.0654	0.0648	0.0481	0.1507	0.7092
Case 4	Component								Total
	Head car	M1	M2	M3	M4	M5	M6	Tail car	
3-cars	0.1521	0.0870	-	-	-	-	-	0.1509	0.3903
6-cars	0.1520	0.0866	0.0738	0.0672	0.0651	-	-	0.1336	0.5783
8-cars	0.1519	0.0866	0.0740	0.0672	0.0647	0.0638	0.0643	0.1286	0.7011

Table 1: The aerodynamic drag coefficient for 3, 6 and 8 car groupings in Case 1, Case 2, Case 3 and Case 4

4 Conclusions and Contributions

This study reveals that the variation of windshield configuration and train marshalling length significantly impact the airflow surrounding the train, which affects the HST aerodynamic performance.

Differences in the train marshalling has no impact on the drag of the head car, while the drag of the tail car decreases as the train length increase due to boundary layer growth. As the windshield configuration varies, for 3-car group trains, Case 2, Case 3 and Case 4 experience a drag reduction of 1.5%, 1.3% and 2.0% respectively as compared to Case 1. When the marshalling length increase, the aerodynamic drag decreases by 4.2%, 3.7% and 4.7% for the 6-car group trains, while it is 5.0%, 4.7% and 5.2% respectively, for 8-car group trains. Therefore, employing an external windshield for all the inter-carriage gaps except the first has the potential to not only reduce the aerodynamic drag of the head and tail cars, but also that of the train for all marshalling length. Though the drag of the head car increases significantly with external windshield, when all the inter-carriage gaps are enclosed with an external windshield, the total aerodynamic drag is reduced significantly.

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References

[1] J. Zhang, J. Wang, Q. Wang, X. Xiong, G. Gao, A study of the influence of bogie cut outs' angles on the aerodynamic performance of a high-speed train, Journal of Wind Engineering and Industrial Aerodynamics, 175 (2018) 153-168.
[2] N. Kukreja, S. Jumar, Aerodynamic loss in inter-car space of train and its reduction, Int J Latest Trends Eng Tech, 6 (2016) 80-89.
[3] J. Zhang, A. Adamu, X.-c. Su, Z.-h. Guo, G.-j. Gao, Effect of simplifying bogie regions on aerodynamic performance of high-speed train, Journal of Central South University, 29 (2022) 1717-1734.
[4] Z.-k. Sun, T.-t. Wang, F. Wu, Numerical investigation of influence of pantograph parameters and train length on aerodynamic drag of high-speed train, Journal of Central South University, 27 (2020) 1334-1350.
[5] C. Tan, D. Zhou, G. Chen, J. Sheridan, S. Krajnovic, Influences of marshalling length on the flow structure of a maglev train, International Journal of Heat and Fluid Flow, 85 (2020) 108604.
[6] J. Niu, Y. Wang, D. Zhou, Effect of the outer windshield schemes on aerodynamic characteristics around the car-connecting parts and train aerodynamic performance, Mechanical Systems and Signal Processing, 130 (2019) 1-16.