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A study of the influence of bogie cut outs' angles on the aerodynamic performance of a high-speed train

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ABSTRACT

The aerodynamic drag of a high-speed train can contribute significantly to its energy consumption. Hence, the purpose of this paper is to find out a new compound mode of bogie cut outs to achieve drag reduction for a Chinese high-speed train. In this paper, a Detached Eddy Simulation method based on the Realizable k-ε turbulence model was used to investigate the underbody flow features of high-speed trains with different compound modes in the angles of bogie cut outs at $Re = 1.85 \times 10^6$. The time-averaged aerodynamic drag was compared with experimental data from wind tunnel tests. The results show that the DES simulations present high accuracy in predicting this kind of flow underneath the train body, and those numerical results closely agree with the experimental data. The variations of bogie cut outs' angles only cause the changes of flow structures around the bogies and in the wake. As a result, obtain different aerodynamic drag forces. Most of drag of the train is experienced by the streamlined head and all bogie regions. A new compound mode of bogie cut outs is proposed in the present paper, achieving 2.92% drag reduction for a three-car model.

1. Introduction

As trains move forward in the open air they experience a force arising from aerodynamic drag that causes a resistance to their motion. This force increases with the relative velocity of the airflow (Rochard and Schmid, 2000) and can be neglected when trains travel at a low speed. However, with rapid development of high-speed railways all over the world, the regular operation speeds of high-speed trains, being with slender body (length: height ratio≈20 for a three-car grouping model), small aspect ratio (height: width ratio≈1.2) and streamlined nose/tail, have reached 300 km/h, sometimes even up to 350 km/h. This high speed contributes to the aerodynamic drag accounting for 75–80% of the total resistance force (Raghunathan et al., 2002; Gawthorpe, 1978; Schetz, 2001; Tian, 2009; Baker, 2014). As a consequence, the force that not only limits the train speed but also costs lots of energy resources (which will be used to resist this aerodynamic drag to keep this high speed), has become of significant importance in the rail industry.

To solve this issue, the conventional approach is to streamline the nose and tail that has been proved to be the most effective method to achieve the drag reduction for high-speed trains (Tian, 2009; Baker, 2010, 2014). For example, Heine and Matschke (2001) studied 14 different nose shapes, with different design parameters such as height, width, and roof corner radii, of train models at 1:10 scale in a large German automotive wind tunnel. They found that the aerodynamic drag for most configurations is slightly higher than the drag of the ICE2 that is considered as the basic case. The drag was significantly reduced with long and slender noses and with low-rise car bodies. Zhang and Zhou (2013) used wind tunnel tests to research the aerodynamic characteristics of 4 kinds of high-speed trains. They included the CRH2 (a type of high-speed train in China), with different longitudinal slenderness ratios, finding that the aerodynamic drag could be reduced with a longer, more streamlined head. When the length of streamlined head was the same, a larger slenderness ratio was favourable for the drag reduction. Yao et al. (2014) took the aerodynamic lift force of the trailing car and the volume of the streamlined head as the optimization objectives and constructed a Kriging model based on the combination of a cross-validation method and the genetic algorithm (GA) to decrease the number of training samples and improve the optimization efficiency, with no loss of

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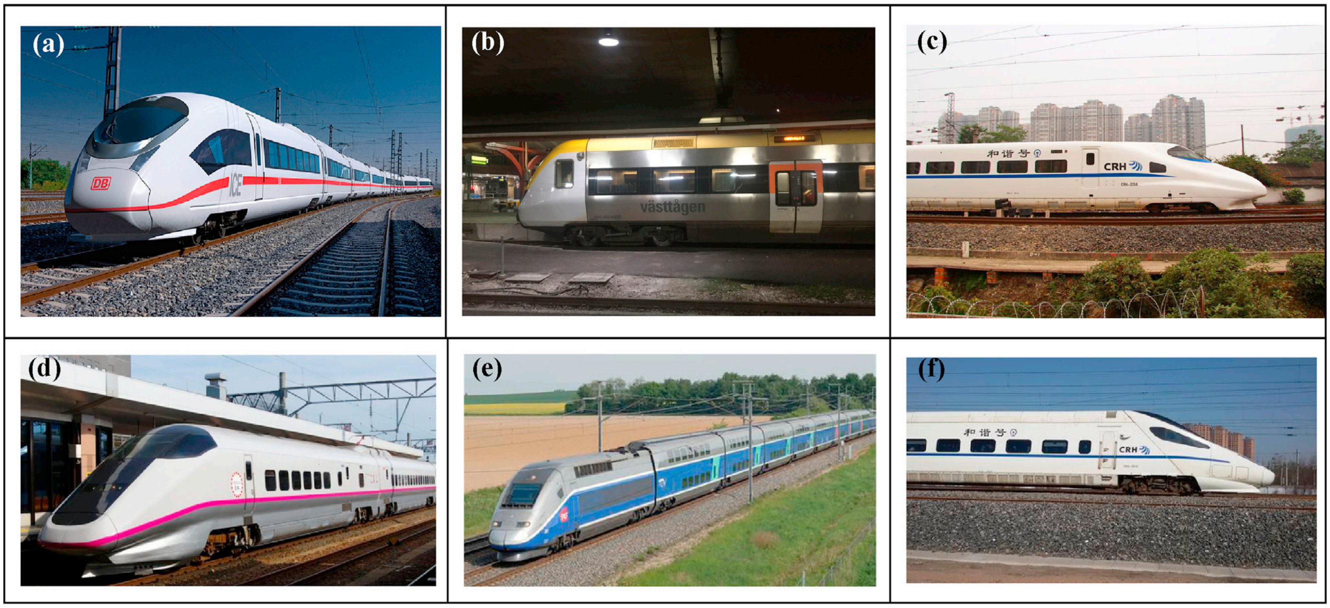

Fig. 1. High-speed trains with various bogie cut out configurations: (a) Germany, (b) Sweden, (c) CRH2 in China, (d) Japan, (e) France, (f) CRH5 in China.

generality. This resulted in a decrease in the drag of the whole train by 3.34%, in conditions without crosswind. Li et al. (2016) conducted multi-objective optimization of a CRH2 high-speed train head using a free-form deformation method to achieve the mesh deformation process without re-modelling and re-meshing and also discovered that streamlining the head could improve the aerodynamic performance of the high-speed train in the open air.

There are also some other measures that can be used to obtain some drag reduction of high-speed trains, such as ensuring the surface of the train as uniform and free from protuberances as possible (it mostly focuses on the inter-carriage gaps and pantograph region), and fairing, as far as practicable, the under-body, especially in the bogie regions. Liang and Shu (2003) used numerical simulation to investigate the influence of different styles of inter-carriage gaps (small, large and closed types) on the train aerodynamic drag. They found the big and closed windshields could greatly decrease the drag force. Huang et al. (2012) carried out a series of wind tunnel tests to study the effect of two types of inter-carriage gap structures on the aerodynamic drag of each car of the high-speed train model in a 3-car formation. They found the similar results as what Liang and Shu (2003) obtained. Mancini et al. (2001) conducted research on the effects of bogie fairings on the overall aerodynamic drag using reduced- and full-scale tests carried out on a new ETR 500 high-speed train. Reduced scale tests were performed using a 1:7.5 model of the ETR 500 with a locomotive and two trailers. Measurements carried out on the first trailer with and without fairings and with different fairing geometries showed that optimised fairings can decrease drag by up to 20%, while retrofitted fairings can reduce it by more than 10%. Full-scale tests were also carried out on an ETR 500 in operation. This had 2 locomotives and 8 trailer cars, and was considered both with and without bogie fairings. This showed that the measured drag of the ETR 500 with fairings is approximately 10% lower than the drag of the standard configuration without fairings. Zheng et al. (2011) simulated the

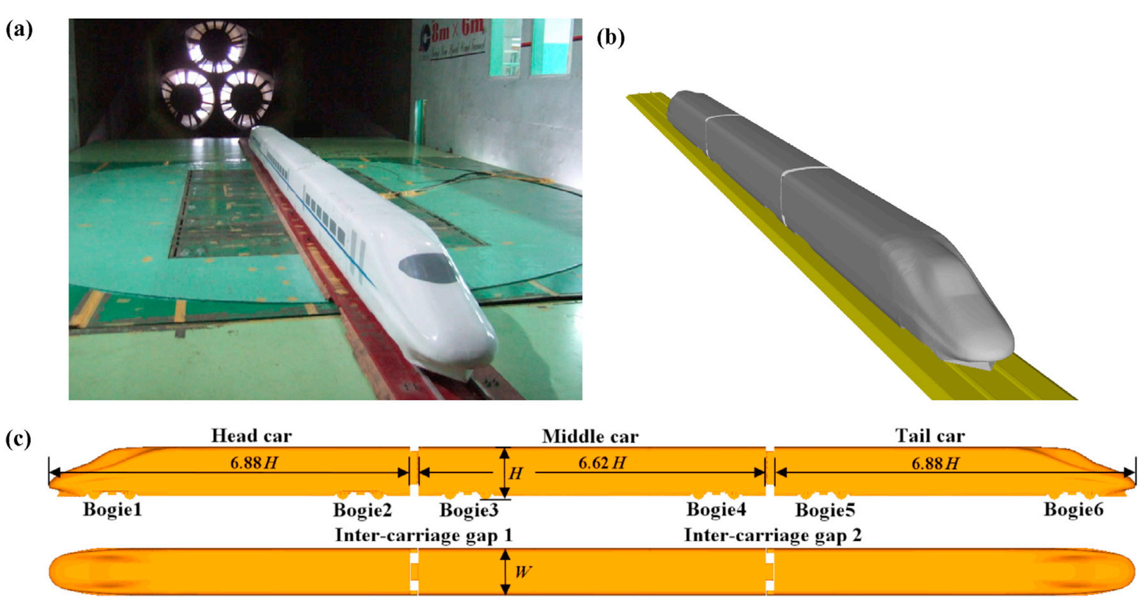

Fig. 2. High-speed train model: (a) 1:8 scaled model used in the wind tunnel tests (Taken from Zhang and Zhou (2013)), (b) 1:8 scaled model used in the numerical simulations, (c) Side view and top view of the model used in the present study.